RABBIT PRODUCTION

10th Edition

Steven D. Lukefahr, James I. McNitt,
Peter R. Cheeke and Nephi M. Patton

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This 10th edition of Rabbit Production is dedicated to the memory of James I. McNitt. In the early 1980s, Jim took a sabbatical leave from the Bunda College of Agriculture in Malawi, Africa, where he was a research scientist, to collaborate with the research team at the Rabbit Research Center at Oregon State University. Since 1982, with the 5th book edition, "Jim" contributed by first writing the chapter on rabbit reproduction. In subsequent editions of the book, he provided his collective knowledge and experiences in rabbit production and research with the other co-authors in updating the contents. Also, since the 7th edition, Jim was the lead co-author, which involved even more work. His broad and practical experiences were invaluable to the quality of the book. But more importantly, he was a wonderful and true colleague, scientist and friend to the rabbit world.

Rabbit Production

10th Edition

Steven D. Lukefahr, Ph.D.

(Regents & Piper Professor), Texas A&M University-Kingsville, USA

James I. McNitt, Ph.D.

(Professor Emeritus), Southern University and A&M College,
Baton Rouge, Louisiana, USA

Peter R. Cheeke, Ph.D.

(Professor Emeritus), Oregon State University, Corvallis, USA

Nephi M. Patton, D.V.M., Ph.D.

(Professor Emeritus), Oregon State University, Corvallis, USA

CABI

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CABI
Nosworthy Way
Wallingford
Oxfordshire OX10 8DE
UK

Tel: +44 (0)1491 832111
E-mail: info@cabi.org
Website: www.cabi.org

CABI
WeWork
One Lincoln St
24th Floor
Boston, MA 02111
USA

Tel: +1 (617)682-9015
E-mail: cabi-nao@cabi.org

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Preface

Rabbit Production is widely recognized as a source of up-to-date information for highly experienced rabbit raisers as well as beginners. The recent advances in scientific knowledge of rabbit production methods have necessitated a revision to offer the most current information to our readers.

We have tried to write in a style that will be useful to people interested in rabbits, regardless of educational background. We hope that after reading this book you will have gained knowledge that will be useful to you in your rabbit raising endeavors. In this edition an effort was made to update the material and to provide more of an international focus on rabbit production practices around the world. One such change is that units of measure appear in both English (pounds, gallons, feet, etc.) and metric (grams, liters, meters, etc.) systems where numeric measures are given for the convenience of all readers. We have also included a conversion table as Appendix 1. In addition, the breeds of rabbit photo gallery has been expanded to include breeds from other countries.

This edition has also placed more emphasis on the important role of rabbits as a food and income resource in developing countries. This role continues to increase, with expanding project interest in Eastern Europe and in Africa, Asia, and Latin America. The ability of rabbits to reproduce and yield high quality meat on low quality diets based on forages and agricultural by-products, as well as their modest housing requirements, makes them well suited for subsistence agriculture to feed the masses.

In many countries, rabbits continue to be valued as a food source, a hobby and as a source of secondary income. With the current market structure, few people make their primary living from rabbits, but the enjoyment of rearing rabbits and the income and satisfaction from providing food or fiber make rabbits an inviting species. Rabbit raising is popular with youth programs and as a small-scale family enterprise because of the small size and the small investment. In addition, rabbits can be reared in many cities and towns where other livestock cannot be kept.

This book is founded on the collective many years of experience of the authors. **S.D. Lukefahr** has operated his own rabbitry and has worked for many years in over 30 developing countries, where he promoted rural or village-level rabbit farming. He has been involved in rabbit-breeding research since 1978, has an extensive publication record, and has made many significant contributions, especially to our knowledge of rabbit breeding and genetics. In 1997, he was awarded the coveted International Animal Agriculture Bouffault Award for his contributions. He served as President of the World Rabbit Science Association from 2004 to 2008 and as General Secretary for Developing Countries from 2008 to 2016. **J.I. McNitt** spent a number of years in Africa as a rabbit specialist and was the leader of a rabbit research program at Southern University and A&M College. The primary goal of the research center was to assist small, limited resource farmers with production problems. As a result, most of his research was aimed at production – housing, feeding, management, etc. He retired in 1998. This book edition is dedicated to his memory. **P.R. Cheeke** has conducted rabbit nutrition research since 1969 and has published extensively in this area. In 1985 he was awarded the prestigious Mignini International Award for excellence in rabbit research. **N.M. Patton** conducted rabbit disease research for 25 years. He was a consultant to a large rabbitry for 10 years, during which time he has experienced most of the problems that rabbit raisers can encounter. In 1993, he was elected President of the World Rabbit Science Association. He retired from Oregon State University in 1996. **G.S. Templeton**, author of the early editions of the book, was Director of the U.S. Rabbit Experiment Station for 23 years. Thus, this book rests on a solid foundation of practical and scientific knowledge of rabbit production.

We thank our friends who have provided much assistance and insight in preparing this edition. Dr. David Harris, who worked with the former Rabbit Research Station at Oregon State University, used his photographic skills to provide many excellent photos and figures that are used in this edition. Leslie Samson, Samson Angoras, has again provided extensive assistance in writing the Angora chapter including updating the contents for this latest edition. Allen Mesick, a rabbit breeder and judge and an active leader for the ARBA, provided several rabbit breeds photos and largely updated the chapter on Rabbit Shows. Dr. Chris Hayhow, a veterinarian and past and present ARBA president, kindly reviewed the chapter on Rabbit Diseases and Health Problems. Dra. Stephane Bertagnoli updated the sections of this chapter on Hemorrhagic Viral Disease and Epizootic Rabbit Enteropathy. In addition, Drs Hervé Garreau, Thierry Gidenne, and Yinghe Qin generously provided photos of rabbit breeds. Dra. Gabriela González-Mariscal extensively reviewed the entire previous edition of the book and made valuable suggestions for updating the material for the new edition. Lastly, the authors wish to express their sincere apprecation to the CABI publishing team (Alexandra Lainsbury, Emma McCann, Lauren Davies, and James Bishop) for their professional assistance.

Appendix

Conversion factors from the metric system to US measures. In most cases, we have used the approximate values because the values in the text are also approximate.

Metric	**To**	**US measure**
Area		
Hectares (ha)	Multiply by 2.47	Acres
Square meters (m^2)	Multiply by 10.9	Square feet (ft^2)
Square meters (m^2)	Multiply by 1.20	Square yards (yd^2)
Length		
Meters (m)	Multiply by 3.28	Feet (ft)
Kilometers (km)	Multiply by 0.622	Miles (mi)
Centimeters (cm)	Multiply by 0.394	Inches (in)
Meters (m)	Multiply by 1.09	Yards (yd)
Volume		
Milliliters (ml)	Multiply by 0.0338	Fluid ounces (fl oz)
Liters (l)	Multiply by 0.264	Gallons (gal)
Liters (l)	Multiply by 1.06	Quarts (qt)
Mass		
Grams (g)	Multiply by 0.0352	Ounces (oz)
Kilograms (kg)	Multiply by 2.2	Pounds (lb)
Ton (metric)*	Multiply by 0.91	Ton
Temperature		
Celsius	9/5C +32	Fahrenheit
Force		
Kilopascals (kPa)	Multiply by 0.145	Pounds per square inch (lb/in^2)

*Note that, unless specified to the contrary, the use of ton in this text refers to the metric ton (1,000 kg or 2200 lb)

1

Introduction

Rabbit production is developing into a significant agricultural enterprise in the United States (Fig. 1.1). This is particularly evident because of the increasing desire of society to know where their food comes from and how it was produced. It is also relatively important in several European countries, such as France, Spain, and Italy, where rabbit is regarded as a gourmet meat, and is expanding in several other countries around the world. In China, the Angora rabbit is raised for its wool, which is exported to other countries for the production of high-quality luxury garments. Rabbit pelts are used in making fur coats and toys. In addition to being raised commercially for meat, wool, and fur, rabbits are also produced in large numbers for laboratory use. They are particularly useful in certain types of medical research. Many people in the United States raise rabbits for show or exhibition purposes and enjoy the challenge of breeding animals that display traits that best exemplify the standards of a particular breed. Others keep rabbits simply as pets. Whatever one's motivation for keeping rabbits, information on nutrition, diseases, breeding, and management is useful for attaining an end product of healthy, well-nourished, productive animals.

History, Taxonomy, and Domestication of the Rabbit

The origin and evolution of rabbits is difficult to trace, because rabbit bones are small and fragile and often are destroyed or rearranged by predators. Fossil records trace the order Lagomorpha back about 45 million years to the late Eocene period. The leporids (rabbits and hares) appear to have originated in the Iberian Peninsula (Spain and Portugal) and southern France.

The modern lagomorphs consist of two families (Leporidae and Ochotonidae) with 11 genera (Table 1.1). They range from the highly successful hares and rabbits of the *Lepus*, *Oryctolagus*, and *Sylvilagus* genera to several endangered genera and species. The *Bunolagus* genus, with one species, the riverine rabbit, is restricted to Karoo floodplain vegetation. Other rare and endangered lagomorphs include the Sumatran hare (*Nesolagus netscheri*) in Indonesia, the Amami rabbit (*Pentalagus furnessi*) in Japan, and the volcano rabbit (*Romerolagus diazi*) in Mexico. Further information on rabbit taxonomy can be obtained from the Internet at https://www.britannica.com/animal/rabbit.

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Fig. 1.1. A productive doe and her litter. Because of their high reproductive capacity and high growth rate, rabbits are among the most productive of domestic livestock. (Courtesy of P.R. Cheeke)

Table 1.1. The modern lagomorphs.

	No. of modern species	Present natural geographical distribution	Examples
Family Leporidae Genera:			
Sylvilagus	17	North America, South America	Brush rabbit, swamp rabbit, cottontail
Oryctolagus	1	Europe, North Africa	European wild rabbit, all domestic species
Caprolagus	1	India	Hispid rabbit (endangered)
Bunolagus	1	South Africa	Riverine rabbit
Poelagus	1	Central Africa	Bunyoro rabbit
Pronolagus	3	Southern Africa	Red rock hare (actually a rabbit)
Pentalagus	1	Amami Islands (Japan)	Amami rabbit (endangered)
Romerolagus	1	Mexico	Volcano rabbit (endangered)
Nesolagus	2	Sumatra (Indonesia)	Sumatran rabbit, Annamite rabbit
Brachylagus	1	North America	Pygmy rabbit
Lepus	32	Eurasia, Africa, North America	Jack rabbit, snowshoe hare, European hare
Family Ochotonidae Genus:			
Ochotona	14	Western North America, Asia	Pika

Source: Smith, A. 2020. *Encyclopaedia Britannica*. https://www.britannica.com/animal/rabbit.

All breeds of domestic rabbits are descendants of the European wild rabbit, *Oryctolagus cuniculus*. Rabbits were originally classified as rodents but are now placed in a separate order, Lagomorpha, primarily because they have two more incisor teeth than rodents (six instead of four). The lagomorphs are divided into two major families: (1) pikas and (2) rabbits and hares.

Pikas, or rock rabbits, are common inhabitants of mountainous areas in North America and Asia (Fig. 1.2). In contrast to other lagomorphs, they are highly vocal, having a loud call or whistle. Pikas inhabit rocky areas of talus or piles of broken rock. They collect grass and other vegetation, which they cut and then allow to cure into hay in the sun. The hay is stored in piles in the rock crevices, to be used

Fig. 1.2. A pika or rock rabbit. Pikas, along with rabbits and hares, are members of the order Lagomorpha. (Courtesy of Justin Johnsen, licensed under the Creative Commons Attribution-Share Alike 3.0 unported license)

Fig. 1.3. A jack rabbit. Jack rabbits are actually hares, close relatives of rabbits. (Courtesy of B.J. Verts)

for winter feed. Pikas differ from rabbits in a number of fairly obvious characteristics, besides their whistling and calling. Both sexes lack the typical external sex organs of other animals and instead have a cloaca into which the fecal, urinary, and reproductive tract discharges are made.

They have much less developed hind legs than rabbits and hares and resemble rodents in their appearance. Pikas are commonly seen or heard in high mountain areas, where they are often observed perched on rocks. A shrill whistle is used as an alarm signal. Unlike rabbits and hares, which are nocturnal, pikas are most active by day.

Hares differ from rabbits in that they are born fully haired, with their eyes open, and can run within a few minutes of birth (Fig. 1.3). They are born in the open without a well-defined nest. They have long legs and take long leaps or bounds when running. Hares have long ears and are wary and alert. They can detect enemies at considerable distances and depend on their speed and endurance for escape. Hares are in the genus Lepus (e.g., *Lepus europaeus* – European hare; *Lepus californicus – black-tailed* jack rabbit). Some of the more common hares in North America are the jack rabbits of the western United States and Canada and of northern Mexico. Jack rabbits can become serious agricultural pests, causing great damage to crops and rangeland. In the past, rabbit drives were used to control them, whereas pesticide baits are now employed. The Arctic hare is found in northern Canada and in Alaska, Greenland, and Asia. The snowshoe hare is found in most of Canada and the northern continental United States. Both the Arctic and snowshoe hares have different coat colors in summer and winter, being brown in summer and white in winter. The populations of snowshoe hares in northern areas fluctuate on about a 10-year cycle. Populations of their predators, such as the snowy owl and Canada lynx, fluctuate in a similar manner. The European hare is an important species for hunting in Europe. During the breeding season, European hares engage in courtship rituals involving dashing about wildly and leaping into the air, thus accounting for the expression “mad as a March hare.” High blood levels of the male hormone testosterone occur during the period of “March madness.”

The two main genera of rabbits are the true rabbits (*Oryctolagus*) and the cottontail rabbits (*Sylvilagus*). *Oryctolagus* encompasses the wild European rabbit and its domesticated descendants, which include all the breeds of domestic rabbits. *Sylvilagus* includes a number of North American cottontails, such as the Eastern, Desert, Brush, Marsh, and Swamp cottontail rabbits. The recent discovery of a new species of *Sylvilagus* in South America may result in the reclassification within the *Sylvilagus* genera.

Cottontails and domestic rabbits cannot be crossed. Laboratory investigations have shown that sperm and eggs of the two genera will fertilize, but the developing embryos die in a few hours, after about four cell divisions. The same is true for crosses of hares and rabbits. The lack of viability of the hybrid embryos is due in part to differences in chromosome numbers among the genera. There are 22 chromosome pairs in *Oryctolagus,* 21 in *Sylvilagus*, and 24 in *Lepus*.

The story of the domestication of rabbits is shrouded in mystery. It is believed that the original site of domestication was the Iberian Peninsula (Spain and Portugal and the south of France). The first recorded rabbit husbandry was in early Roman times, when rabbits were kept in leporaria, or walled rabbit gardens. Rabbits reproduced in these enclosures and were captured and killed for food. In the Middle Ages, sailing vessels distributed rabbits on islands in various sea lanes, to be used as a source of food by sailors. Wherever these releases were made, the rabbits increased greatly in number at the expense of the indigenous animals. As exploration of the world increased, the European wild rabbit was further distributed by sailors. In 1859, a few rabbits were released in Victoria, Australia and, in 30 years, gave rise to several million rabbits. Other releases of a few rabbits in Australia also gave rise to millions of rabbits in the areas of release. The wild rabbit became a serious pest in Australia and New Zealand because of the favorable environment, abundant feed, and absence of predators. The European wild rabbit, although released in North America, was never able to gain a foothold and does not exist on the continent in significant numbers. A feral population of *Oryctolagus* has developed on the San Juan Islands off the coast of the state of Washington.

In the Middle Ages, rabbits were kept in rock enclosures in England and Western Europe. There is also evidence of Pre-Columbian domestication of rabbits and hares by indigenous tribes in Central America involving captive rearing and breeding in small pen enclosures. True domestication is largely believed to have occurred in the sixteenth century in monasteries, although this may have occurred as early as AD 600. By 1700, seven distinct colors and patterns had been selected: non-agouti solid color, brown, albino, dilute (blue), yellow, silver, and Dutch spotting. By 1850, two new colors and the Angora-type hair had been developed. Between 1850 and the present, the remaining colors and fur types have been developed and selected.

Potential of the Rabbit for Meat and Fur Production

The domestic rabbit has the potential to become one of the world's major livestock species. In the future, as the human population exerts increasing pressure on the world's food resources, it is likely that rabbits will assume an increasingly important role as a source of food. However, this does not imply that rabbits will have to be raised mostly on large commercial farms; rather, it is likely that many more people than at present will raise them in small numbers in their backyards. Rabbits also possess various attributes that are advantageous in comparison to other livestock. Rabbits can be successfully raised on diets that are low in grain and high in roughage. Recent research has demonstrated that normal growth and reproductive performance can be achieved on diets containing no grain at all. As competition between humans and livestock for grains intensifies, rabbits will have a competitive advantage over swine and poultry, since these animals cannot be raised on high roughage diets or diets that don't contain grain. Rabbits convert forage into meat more efficiently than ruminant animals, such as cattle and sheep. From a given amount of alfalfa, rabbits can produce about five times as much meat as beef cattle. All these attributes are especially relevant today with rising feed and fuel costs.

The ability of rabbits to efficiently convert forage into meat will be of special significance in developing countries, where population pressures and food shortages are greatest. In many cases, there is abundant local vegetation that cannot be consumed directly by people but that can be fed to rabbits. A few does can be kept by villagers on a backyard scale to produce enough meat to satisfy the needs of a family by using weeds, tropical forages, vegetable tops, and table scraps as feed for the rabbits (Fig. 1.4). Keeping cattle under such circumstances is not feasible because of their larger feed and space requirements, the long time taken to reach slaughter weight, and the problem of using a large amount of meat at once when refrigeration is lacking. Rabbits act as "biological refrigerators" in that the meat from one animal can be consumed without the need for storage. Rabbits will breed year-round, so a continuous supply of meat can be produced with just a few breeding animals. The above scenario is hitting closer to home as more people in the U.S. are growing gardens and raising small livestock in an effort to stretch the food dollar with the economic downturn of the global recession of 2009 and the global Covid-19 pandemic of 2020.

An exciting characteristic of rabbits is their high reproductive potential. This, of course, is well known, being the subject of numerous jokes regarding fertility. Because of their rapid growth rate, short gestation period, and ability to rebreed immediately after kindling (giving birth), rabbits have a reproductive potential that is staggering. Several animals released in Australia resulted in a few years in tens of millions of rabbits. In commercial production, this high reproductive potential is of great importance. Recent research has demonstrated the feasibility of post-partum breeding, so it is possible for a doe to have a litter, be rebred immediately, wean the litter at 28 days, and have another litter 3 days later. This is the normal breeding pattern of wild rabbits during the breeding season. No other type of livestock has this amazing reproductive potential. Such intensive breeding requires a high level of management skill and is not recommended until further research is completed.

There is considerable potential for genetic improvement of rabbits raised commercially. Because the generation time is short, and because the heritability of growth and carcass traits is moderate to high, rapid improvement of these traits through selection can be made. In the United States there has been comparatively little genetic selection of rabbits for such important commercial characteristics as carcass traits, so there is scope for considerable progress in these areas. Compared to other types of livestock production, there has been little commercial development of high performing hybrids, use of well-designed crossbreeding schemes, or other techniques that are routine in the other types of livestock enterprises.

Rabbits lend themselves to both small- and large-scale production (Fig. 1.5). France is one of the world's largest producers and consumers of rabbits. In the 1950s, the size of the average French herd was six does. Thus, the French

Fig. 1.4. A village rabbitry constructed of bamboo, palm thatch, and other locally available material. Rabbit production has considerable potential in developing countries. (Courtesy of S.D. Lukefahr)

Fig. 1.5. A large rabbitry in Hungary producing about 300,000 fryers annually. Rabbits are suited to both large- and small-scale production. (Courtesy of J.I. McNitt)

industry was based upon a large number of small producers. In recent years, however, the average herd size has increased somewhat, but 96% of the producers in France have 1 to 20 does. Only 1% of the producers have over 200 does, but they produce more than 30% of the rabbit meat. In the United States most rabbitries have 50 or fewer does. Many people keep a few does in the backyard to raise meat for the family and to sell the surplus. In times of economic stress, such as the depression of the 1930s, World War II, and the energy crisis of the 1970s, interest in self-sufficiency increases, and backyard rabbit production increases. This trend has also been observed in present times with the global recession. Because they are noiseless, rabbits can be raised in a suburban situation without infringing on the peace of neighbors. Only a small space is needed for raising rabbits, and they adapt themselves to a variety of conditions, being raised successfully in many cities, in small towns, and on farms in every state of the U.S. They appeal to all classes of people with a diversity of backgrounds. Many of these people have had a lifelong yen for raising animals but have been so situated that they could not realize their dreams. Now they are deriving a great deal of pleasure and relaxation from working with rabbits. The amount of capital needed for the equipment and for the animals is reasonable. Caring for rabbits does not involve strenuous physical exertion, so the work can be carried out with much satisfaction by persons with special needs. Rabbit production is especially useful for occupational therapy. The size of the animal makes it exceptionally valuable in youth programs.

Fig. 1.6. Rabbit is a high-quality, nutritious, and attractive meat. (Courtesy of S.D. Lukefahr)

Rabbit meat is a wholesome, tasty product (Fig. 1.6). Compared to most other meats, it is high in protein and low in fat, cholesterol, and sodium. The meat is white, fine-grained, delicately flavored, nutritious, and appetizing. It is also low in caloric content. The size of the carcass, the fine quality of the meat, and the wide range in methods for preparation make rabbit an excellent and economical meat for use in any season of the year. In many areas it is available in the markets either in the cut-up and packaged (fresh or frozen) form or in the whole carcass. While there appears to be a preference shown by consumers for the cut-up and packaged product, chefs and those in charge of the meat purchasing for institutions such as hospitals, clubs, and hotels prefer it in the whole carcass form so they may cut it to suit their own requirements and methods of preparation. Some processors develop cuts such as fillets or nuggets for specialty restaurant markets.

Although the main commercial use of rabbits is meat, the skins are also important. The furs are used in various apparel items, such as fur coats. However, the price paid for the skins by the larger fur buyers is not sufficient to justify many of the assertions that have been made that one could engage in breeding rabbits for their pelts alone and make a satisfactory profit. The returns from both meat and pelts must be combined to derive the maximum profit from the labor and capital invested. The market values vary from time to time, depending on season, fashion dictates, etc.

Rabbit skins are used in many ways, the best quality being employed in making fur garments and fur trimmings, the poorer quality being used by the felting industry and for manufacturing toys, specialty articles, etc. The normal furs are used chiefly for making imitations of high-priced furs, and the fur industry has become so proficient in this line that by plucking, shearing, dyeing, etc., it is able to imitate many of the wild and more expensive furs. These imitations are sold under a variety of trade names and each imitation must be properly labeled. The better-quality garments that are made from the heavily furred rabbit skins are warm and luxurious, and they wear well (Fig. 1.7). Those skins that are not suitable for manufacturing the better-quality products are used for lining men's and boys' clothing, making toys, trimming children's garments and coats, and manufacturing felt hats. At the time the fur is cut from the skins for use by the felting industry, the skins are shredded and glue that is especially strong is extracted. This glue is used principally by furniture makers. Large processing plants use all parts of the rabbit, even the feet for "lucky rabbit's foot" souvenirs.

The Rex rabbit differs from other breeds in having a coat with no conspicuous guard hairs, giving a very attractive fur. In the United States, there has been extensive interest in Rex Rabbit production but it has yet to develop into an integral component of the American rabbit industry.

In Europe, there is extensive use of Angora rabbit wool in the manufacture of luxury garments. The main source of Angora wool production is China, which produces over 90% of the world's supply. In the United States, Angora production is primarily a hobby, since the high labor costs preclude a viable commercial Angora industry.

Fig. 1.7. A woman wearing a rabbit fur hat and carrying a rabbit fur purse. (Courtesy of S.D. and B. Lukefahr)

Production of Pharmaceuticals

Associated with the production of rabbits for meat and fur is the preparation of pharmaceutical products. The brains, blood, and various internal organs are used in producing "biologicals" for medical use and research. For example, rabbit brains are a source of thromboplastin, which is used to control the dosage of anticoagulant given to prevent thrombosis (heart attack), phlebitis, and other abnormal clotting conditions of the human body. The blood is used to prepare complement, used in biomedical programs. Various enzymes for research are derived from rabbit tissues.

Youth Programs

The raising of domestic rabbits lends itself nicely to 4-H Club, Boy and Girl Scout, and FFA projects (Fig. 1.8). The fact that in many cases rabbits can be raised where larger farm animals or even poultry cannot be handled makes them especially useful animals for these groups. In this connection, rabbit breeders can be of material aid to these younger people by providing desirable breeding stock at nominal prices and by counseling with leaders and

Fig. 1.8. Youth members showing their rabbits. (Courtesy of S.D. Lukefahr)

members of the youth groups with respect to methods for raising or caring for their animals. In many areas where the youthful rabbit raisers may need capital for developing their projects, local bankers cooperate with them and arrange to make loans for that purpose. A boy or girl signs a note and is expected to repay the principal plus interest out of the profits from the endeavor. This cooperation by business executives is helpful and gives the young rabbit raiser an insight into business procedure. Many youth projects have resulted in prizes and trophies being awarded at fairs and other exhibitions. Youth programs are an excellent way of teaching the concept of responsibility to young people.

To teach young persons the fundamentals of animal husbandry, youth groups may begin with young rabbits at weaning age. When the young members of a family group want to raise rabbits, it may be best to purchase an adult doe so that their interest may be kept keen by the chronological events, such as the doe making a nest and kindling and then the young people taking care of the litter, selling the products, etc. Many of these small beginnings on the part of young people have developed into sizeable undertakings.

Hobbies and Pets

Because the domestic rabbit is cage-raised, it lends itself more readily than other farm animals to handling by people with special needs and opens up a new field of activity for them. They derive a great deal of satisfaction from producing meat rabbits, spinning Angora wool and making garments, or just raising rabbits as pets.

People may want to raise rabbits because they enjoy working with animals and thus can advantageously combine a hobby with prospects of a supplemental income. There are many ramifications to this type of activity (Fig. 1.9). Some people may develop an interest in attempting to improve a strain of rabbits by studying its characteristics in an effort to produce animals as nearly perfect as possible and derive a great deal of pleasure from showing them.

Complete rabbit rations can be purchased in small quantities at most feed stores, and these pellets are clean, easy to store, and convenient to feed. Caution should be taken in purchasing very young rabbits, such as Easter bunnies, etc., for small children. In too many cases the rabbits are improperly handled or cared for and may be abused and die. A rabbit purchased for a child's pet should be at least six to eight weeks of age, because it has passed its more delicate stage of development and is less likely to be injured while the child is being instructed by the parent as to the proper method for holding and playing with it.

Fig. 1.9. Rabbits make fine pets! (Courtesy of Cherie Wachter, Humane Society of Broward County, Fort Lauderdale, FL)

Laboratory Use

Rabbits have traditionally been used as laboratory animals. Because they are small and do not require a large amount of space in the laboratories and because the feeding and care are relatively inexpensive, this species is well adapted to certain types of research (Fig. 1.10). These include performing nutritional studies, testing new medical products, producing antibodies, developing information concerning inheritance of malformations, and studying diseases. The rabbit is being used more and more in connection with preliminary research tests with the larger types of farm animals, and its blood is used quite extensively in making antisera. Rabbits used in research are treated humanely. In some cases, as with the controversial Draize test for assessing effects of cosmetics on the eye, alternatives to animal testing have been developed and are in use.

Fig. 1.10. Rabbits are widely used in biomedical research. In this picture, a rabbit used in forage evaluation research is weighed. (Courtesy of S.D. Lukefahr)

Factors Limiting Rabbit Production

Despite the promising potential of the rabbit as a meat- and fur-producing animal, a number of factors presently limit the profitability of rabbit enterprises. These are related to problems of nutrition, disease, genetics, and the high labor requirement for intensive rabbit production. Much less research has been conducted on the commercial production of rabbits than on the commercial production of other livestock species. Therefore, many more unsolved problems exist, and less information is available on optimal feeding, breeding, disease prevention, and management systems. In the area of nutrition, for instance, it is only since 1970 that data on specific nutrient requirements for energy, protein, amino acids, vitamins, and minerals have been obtained. In most cases, the existing data have been collected in experiments using small numbers of animals, with diets that are not representative of commercial feeds. Thus, much refining of this information is needed through continued research.

Diseases such as enteritis, snuffles, and viral hemorrhagic disease (VHD) are very important factors that prevent rabbit production from reaching its potential. Enteritis is a complex of several diseases that cause diarrhea, dehydration, and death of young rabbits. Until the early 1980s, very little progress had been made in understanding the causes of enteritis. Significant advances in the identification of types of bacteria and dietary factors involved in development of enteritis have been made since that time, but much remains to be done.

In the breeding and genetics areas, there has not been a sustained effort to develop superior breeding animals for commercial purposes. The commercial rabbit industry in the United States has been based on rabbit raisers who have not been in the business for very long. One large processor has characterized rabbit raisers as “one-third coming into the industry, one-third in, and one-third leaving.” The lack of many long-term commercial producers means that there have not been many sustained breeding and selection programs carried out for a sufficient period to make real progress. Some selection in the past has been for traits with a low heritability, such as conception rate and litter size, whereas moderately to highly heritable traits, such as milk production and growth rate, have not received much attention. Development of superior breeding stock, with the potential for high performance in all productive traits, would do much to ensure the growth of the rabbit industry. Another factor that limits the profit potential of large-scale rabbit production is the high labor intensity of rabbit rising. Under present management situations, there is a great deal of hand labor involved in feeding, mating, cage cleaning, and virtually all other facets of rabbit production. This is in contrast to the extensive automation and low labor requirements for poultry production. Once a rabbitry reaches a size above 600 does and hired labor is required, the labor costs become a major factor. Additionally, rabbits require “tender loving care,” and with large rabbitries employing hired labor, this is not always easy to provide. For successful development of large commercial rabbit enterprises to occur in North America and other areas with high labor costs, management systems employing greater automation must be developed.

In contrast, for backyard production in both developed and developing countries, the labor requirements are more or less irrelevant. A few does and their offspring for family meat production are easy to manage, with the care often provided by the children. Diseases, such as enteritis, snuffles, and sore hocks seem to be much less prevalent under these conditions, probably because of a more varied diet and less stressful conditions than animals experience in a large rabbitry. Because of low labor costs and often abundant forage resources, some developing countries may prove to be ideal sites for large-scale rabbitries.

The future is bright for rabbit production. Increasing interest in research on rabbit production at universities and experiment stations throughout the world will undoubtedly provide answers to many of the problems currently plaguing rabbit producers. The nutritional qualities of rabbit meat have resulted in new marketing potentials for rabbit as a "health food" in our increasingly health- and diet-conscious society.

Sources of Helpful Information

For many years, the United States Department of Agriculture (USDA) maintained the U.S. Rabbit Experiment Station at Fontana, California (Fig. 1.11). This station was the source of much useful information on rabbit production. The station was closed when it appeared that rabbit production was not going to become a major agricultural enterprise in the United States. Rabbit research was at very low ebb in the 1960s and early 1970s. Since that time, interest in the rabbit as a meat animal has been rekindled, due in part to the increasing awareness of the competition between livestock and humans for grain. A major program of rabbit research was established at Oregon State University's Rabbit Research Center. The Research Center published *The Journal of Applied Rabbit Research,* which contained reports of the latest research on commercial rabbit production. This unit has now been closed, but the rabbit research program at Texas A&M University-Kingsville is still functioning by selling improved breeding stock. Most of the land-grant universities, through their extension departments, sponsor 4-H rabbit club activities in their respective states, and several have sponsored rabbit schools. These schools are similar to the forums or courses

Fig. 1.11. The former U.S. Rabbit Experiment Station at Fontana, California, where Dr. George Templeton served as Director for many years. (Courtesy of P.R. Cheeke)

that for many years have been conducted for other types of farm animals. They have been extremely valuable to the rabbit industry, with members of the university faculty and other well-informed representatives of the rabbit industry participating. One of the most valuable features of these rabbit school programs is the time allotted to questions and answers.

Some of the state agricultural universities issue bulletins on rabbit production and assign a member of the extension department to the specific duty of assisting the industry in the state. Advice may also be obtained by contacting agricultural agents and farm advisors. The Internet is a good source of rabbit information and a method to make contact with experienced breeders.

The American Rabbit Breeders Association, Inc. (ARBA), P.O. Box 400, Knox, PA, 16232–044. addresses many aspects of the rabbit industry, but an overwhelming majority of the members are fanciers, so the primary focus of the organization is on the fancy. The ARBA assists rabbit fanciers in many ways by maintaining a registration and recording system, providing memberships to persons interested in breeding and marketing rabbits and allied products, promoting and conducting public and private exhibitions, providing judging systems, licensing official judges and registrars, making and revising official standards and maintaining a website at www.ARBA.net. A magazine, *Domestic Rabbits,* is also published every other month. The association also organizes and assists local, county, and state associations and specialty clubs, maintains information bureaus, and furnishes at cost bulletins, guide books, and other printed matter. It helps in marketing and in securing legislation and publicity. An annual convention and show are held.

Contact with members of local rabbit clubs is an excellent means for beginners to obtain information relating to rabbit production, such as facts on cooperative buying and marketing of products, lists of reliable breeders, ordinances with relation to the industry, etc.

There is increasing interest in rabbits as pets. As described in Chapter 18, the housing, nutritional, and social needs of companion rabbits differ in several key aspects from those of production or show animals. An excellent resource for pet rabbit information is the House Rabbit Society, 148 Broadway, Richmond, CA, 94804-1912. The HRS maintains a website (www.rabbit.org) and publishes the quarterly *House Rabbit Newsletter*.

Some feed manufacturers have spent a great deal of time and money in research work to develop efficient rations for rabbits. They also issue bulletins and sometimes furnish the breeder with hutch cards and other record cards. Many of them have field representatives who make visits to rabbitries and assist the breeders with their rabbit problems. Some large feed companies have their own research and testing facilities.

A wealth of information about rabbits can be found on the Internet. Using a search engine to locate the sites for the World Rabbit Science Association (WRSA), the ARBA, or the HRS will provide much useful information as well as links to other sites.

A Rabbit by Any Other Name

According to the Oxford dictionary, the word *rabbit* is derived from *rabotte,* a word from an old dialect in northern France, or from the Walloon word *robett,* whereas Webster's dictionary attributes the word to the old Middle English *rabet*. It is interesting to see the word for *rabbit* in a variety of languages:

Afrikaans – konyn
Danish – kanin
Dutch – konij
Finnish – kaniini
French – lapin
German – kaninchen
Hungarian – nyul
Indonesian – kelinci
Italian – conigli
Norwegian – kanin
Polish – królik
Portuguese – coelho
Spanish – conejo
Swahili – sungura
Swedish – kanin

Rabbits are well represented in folklore. The Easter Bunny has its origins in ancient pagan rituals. In early Easter or spring celebrations, rabbits and hares were symbols of fertility and new life. Qualities of the rabbit usually depicted in tales and folklore generally relate to gentleness, mischievousness, and being the dupe or victim of deception, such as Brer Rabbit. Other famous rabbits include Walt Disney's Thumper in *Bambi*, Bugs Bunny, and Peter Rabbit in the Beatrix Potter tales.

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2

Rabbit Production Worldwide

Rabbits are raised to some extent in virtually every country. It is in temperate areas that rabbit raising has been most significant in terms of commercial development, probably reflecting the Mediterranean origin of the animal. Presently, the rabbit is becoming increasingly important in tropical areas in less-developed countries. According to figures compiled by the Food and Agriculture Organization (FAO) of the United Nations (UN), China is by far the largest producer followed by the Democratic People's Republic of Korea (North Korea), and Spain (Table 2.1). It would seem that most rabbits in the world are found in China, where they are mostly raised in very large-scale operations. The FAO figures were provided by the countries themselves, but not all countries report data. For example, it is likely that there are many rabbits raised in India; however, this country does not report the figures. Moreover, accurate data on the numbers of rabbits produced are difficult to obtain, because in most countries such records are not kept and because many rabbits are slaughtered for home consumption and thus would not be officially recorded. In general, data on rabbit production and consumption are similar. Rabbit meat production figures by continent are shown in Table 2.2. It is interesting to note that the smallest figure by far is for the Americas. This fact may largely be based on tradition. A plausible explanation is that in some regions there was a plentiful supply of game for the early colonists and explorers. Between this and the later introduction of major livestock species (cattle, chickens, sheep, and swine), a sufficient meat supply became available to meet the demand for animal food products. The following is a brief description of rabbit production in some major areas of the world.

Europe

Western European countries, such as Italy, France, and Spain, have traditionally been major producers and consumers of rabbit meat. Traditionally, many of the peasant farmers of countries such as France kept a small herd of rabbits to produce meat for their own family's consumption. Rabbit meat was an important part of the diet. As intensification of agriculture occurred and the size of farms increased, many of the former peasant farmers who moved to cities retained their enthusiasm for rabbit meat and purchased it at markets (Fig. 2.1). Rabbit farms were established to meet this demand. Thus, in several European countries, such as Italy and France, rabbit meat is a common and significant item of the diet, and a strong market exists for rabbit.

Since about 1950, the rabbit industry in Europe has changed dramatically. In 1950, most rabbits were produced on a backyard scale, with about six does per rabbitry. There

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Table 2.1. Estimates of rabbit meat production in 2018 by leading rabbit-producing countries.

Country	Estimated production (1000s of metric tons of carcass)
China	949
Dem. People's Rep. of Korea	150
Egypt	67
Spain	56
France	44
Italy	24
Russian Federation	18
Ukraine	12
Algeria	9
Sierra Leone	8
Hungary	6
Mexico	4
Peru	4
Rwanda	4
Colombia	3
Greece	3
Poland	3
Gabon	3
Argentina	2
Belarus	1
Botswana	1
Brazil	1
Ecuador	1
Madagascar	1
Rep. of Korea	1
Rep. of Moldova	1
Switzerland	1
All other reporting countries	3
Total world production	1378

Source: FAOSTAT, 2018. FAO Statistics Division. Available at: http://www.fao.org/faostat/en/#data/QL

were a very large number of very small producers. In common with other agricultural endeavors, continuous intensification of production has occurred (Fig. 2.2). While the number of rabbit raisers has decreased, the size of the average rabbitry has continued to increase to a level that the Europeans refer to as "industrial-scale broiler rabbit production."

Modern European rabbit production is the most advanced in the world with the possible exception of China. This is especially true in the area of genetics. There are numerous private genetics companies that sell high-producing hybrid breeding stock to rabbit raisers. Generally, the hybrids involve the New Zealand White and Californian breeds. The size of the European rabbit industry is sufficient to attract the serious and competitive attention of feed manufacturers, veterinary supply companies, equipment suppliers, and so on. Typically, rabbits are raised in hanging wire cages in environmentally-controlled buildings and fed pelleted diets.

Table 2.2. Estimates of rabbit meat production in 2018 by continent.[1]

Continent	Estimated production (1000s of metric tons of carcass)
Africa	93
Americas	16
Asia	1101
Europe	168

[1] Production of domestic rabbit meat in Australia and New Zealand is negligible and there are no rabbits in Antarctica. Source: FAOSTAT, 2018. FAO Statistics Division. Available at: http://www.fao.org/faostat/en/#data/QL

The prospects for the rabbit industry on the Continent would appear bright. The people are sophisticated in their cuisine, and rabbit meat has enjoyed a high demand. However, in recent years the production of rabbit meat in France and Spain has dropped, while in Italy production has dramatically plummeted. Factors that account for this decline include the worsening European economy, pressure from animal rights groups, animal welfare regulations (mostly concerning housing aspects), commercial use of antibiotics to control disease, the organic food movement, etc. Continued sophistication of rabbit production in Europe, with the use of hybrid breeding stock, environmentally controlled buildings, and innovative management, is foreseen.

Of note, at one time rabbit meat was widely consumed throughout Great Britain. Much of it was wild rabbit, harvested by hunters who earned their livelihood by shooting, trapping, or snaring rabbits. To some extent, this helped control the rabbit populations and kept crop losses at manageable levels. Wild rabbits were also raised in large, fenced warrens managed by gamekeepers. This practice was discontinued because of the extensive ecological damage that occurred. In the 1950s, the viral disease myxomatosis was accidentally introduced into Britain, resulting in a spectacular kill of many of the wild rabbits. The repercussions

Fig. 2.1. Rabbits in a supermarket in France. Rabbits are often sold this way in Europe but cut-up, packaged carcasses are also popular. European consumers, like their North American counterparts, are less willing to cut up rabbits and poultry than they were in the past. (Courtesy of J.I. McNitt)

of this on the domestic rabbit industry are still being felt. The sight of blind, deathly sick rabbits dying of "myxo" throughout the British countryside was repugnant to many people. The mention of rabbit brings to their minds the pathetic appearance of the diseased rabbits. Many British people who once enjoyed rabbit meat will no longer eat it. For this reason, and some stigma that rabbit is a "poor person's meat," the British rabbit industry is quite small. This same scenario has occurred in Australia and in other countries resulting from the introduction of viral hemorrhagic disease. In addition, vocal and sometimes violent animal rights extremists are a further impediment to rabbit production in Britain and in other European countries.

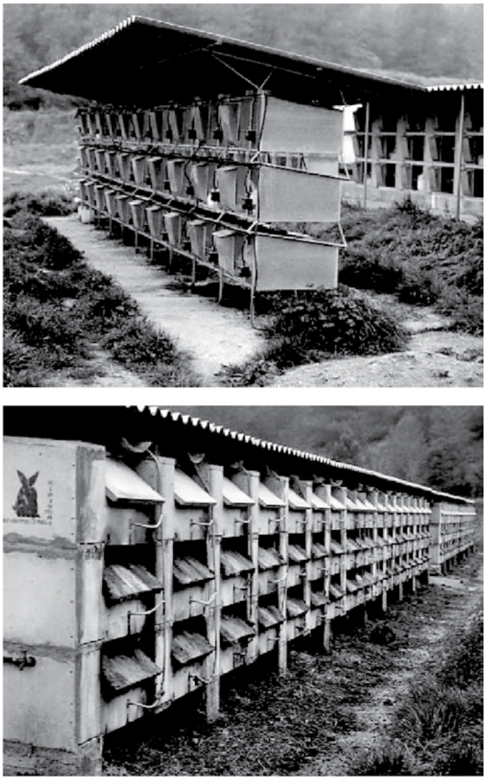

Fig. 2.2. An outdoor rabbitry near Barcelona, Spain, providing good ventilation and protection against rain. Note the dropping boards at the rear of the cages (bottom). The manure can be removed readily by hand or with a tractor. (Courtesy of P.R. Cheeke)

The Americas

Rabbit production continues to be a very minor component of agriculture in North America. Interest in rabbit raising has been highest during periods of economic hardship, such as in the depression of the 1930s and during World War II, when people were most interested in producing their own food. This trend has become evident in present times, not only due to the economy but also because of the coronavirus pandemic. However, and more than ever, people also desire to know where their food comes from and how it is produced.

During the 1920s and 1930s, southern California was the major site of commercial rabbit production. Several large processors operated in the Los Angeles area. After World War II, intensive industrialization of southern California occurred, but after several years rabbit production declined sharply. One of the major rabbit processors operating in California was a company called Pel-Freez. In 1951, Pel-Freez moved to Rogers, Arkansas, and has grown to become the largest rabbit processing plant in the United States. The surrounding area, including neighboring states such as Missouri, has become the major rabbit raising area in North America. Other regions of significant production include the Pacific Coast states of California, Oregon, and Washington and parts of the Midwest. Rabbit production occurs in nearly all areas of the United States but tends to be a small-scale, part-time activity. One of the major problems in most areas is the lack of reliable markets. Again, with the worsening global economy and coronavirus pandemic, there is a renewed interest in small-scale rabbit production combined with gardening so that families can stretch the food dollar.

Rabbit meat is sold mainly in large cities that have high concentrations of immigrants from European countries such as France, Germany, Italy, and Portugal, where eating rabbit is traditional. In the early 1980s, a significant "health food" market for rabbit meat began to develop, because of the low fat, low sodium, and low cholesterol content of the meat and a trend away from red meats in the American diet. The abundance of food of all types in the United States suggests that rabbit meat, to become a more significant component of the diet, will have to displace some existing meat sources. This can be done by making rabbit available at a lower price than other meats, which is unlikely in the near future, or by developing specialty markets based on some unique property of rabbit meat, such as being antibiotic-free. The identification of rabbit as a "healthful" meat is a step in this direction.

In the United States, most commercial rabbitries are part-time endeavors, with breeding herds of 20 to 100 does. There are relatively few rabbitries with 300 to 600 does, and very few with 1000 or more. Economic realities of rabbit production on the American scene indicate that it likely will remain largely a part-time type of enterprise. For commercial meat production, the New Zealand White is by far the major breed, although some Californians are used. The use of rational crossbreeding programs or hybrids is also becoming more popular.

In the 1970s and 1980s, considerable interest in the Rex breed as a fur animal developed in the United States. In some cases, the promotion of Rex fur production was fraudulent or unethical, with promises of unrealistically high prices for the pelts and with very high prices charged by the promoters for the breeding stock. Many people with no knowledge of rabbit raising and little likelihood of success lost their investments. A fur industry based on the very attractive Rex fur may develop in the future.

The situation in Canada for rabbit production is very similar to that in the United States. The major areas of rabbit consumption are Toronto, Montreal, and Vancouver, where there are large European ethnic populations. In Mexico, considerable interest in rabbit production has developed as a means of increasing the protein intake of people with low income. Major breeds used are New Zealand White, Californian, and Chinchilla. In other countries in Central America, rabbit production has been slowly gaining in popularity. In this region, there have been many rabbit projects initiated to assist poor farming communities directly.

In the Caribbean region, there is some small-scale rabbit raising for local meat production, particularly on French-speaking islands such as Guadeloupe and Martinique, and the Dominican Republic. In Haiti, there was a large commercial rabbitry near Port-au-Prince, and rabbit raising is promoted in the hinterlands by a variety of organizations, including various missionary groups. In January 2010, a devastating earthquake shook the heart of Haiti. This came on the heels of decades of economic and political degradation and four violent hurricanes in 2008. Since these disasters and the exodus of many urban residents to rural areas, the Haitian people have taken a keen interest in adding rabbit meat production to help fight against poverty and hunger. There has thus been a strong thrust toward increasing production and, within two years, over 1500 rabbit producers in four regions developed more than 1000 production units. These rabbits have directly benefited nearly 7000 participants. The rabbit is a potential means of improving the nutritional status of people with low income in many of the Caribbean islands by utilizing locally grown forages and agricultural by-products.

In South America, major areas of rabbit production include Argentina, Brazil, Colombia, Ecuador, Peru, and Uruguay, where small-scale production is gaining in popularity and where some large rabbitries have been built. Demand for rabbit meat largely comes from European immigrants, particularly Italians, in the large cities, such as São Paulo and Montevideo, but meat has also been exported to other countries. Potential for growth of rabbit production in South America seems promising, with the abundant forage resources and rapidly increasing human populations. There has been some Angora production, particularly in Argentina, Bolivia, and Chile.

Asia

China is by far the world's major rabbit-producing country. One company in particular, Kangda Foods, has enjoyed tremendous success due largely to their practice of vertical integration. This company supplies the improved breeding stock, the commercial feed and other supplies, and technical support to numerous large-scale producers (Fig. 2.3). Kangda Foods also has its own processing plants with laboratories for assuring quality control and where many meat products have been developed (similar to what Tyson Foods in the United States has done with chicken). For years, rabbit meat from China has been exported to Europe and North America quite extensively. Since the 1980s, major emphasis has been on Angora wool production. China is the source of approximately 80% of the Angora wool used in the textile industry, producing about 4000 metric tons annually. Since the average wool yield for Chinese Angora rabbits is about 200 grams per annum, it appears that about 20 million Angoras are raised in China. Meat is a by-product of the wool production, although about half the rabbit herds in China produce strictly meat rabbits. In rural villages, rabbits in China are not usually fed a pelleted concentrate diet. Instead, they are fed forages, including vegetable tops and water weeds that are often wilted to reduce the moisture content (Fig. 2.4). Various by-products, such as wheat bran, rice bran, or corn bran, are fed as a moist mash supplement. Because of the huge human population and the need to upgrade the diet with high quality protein, and because of rising cereal grain and fuel costs and the Asian Bird Flu epidemic, it is likely that rabbit production will be of increasing importance in China as a means of converting roughages to human food.

Rabbit production is gaining in importance in other Asian countries, such as Indonesia, the

Fig. 2.3. A large-scale rabbit operation with over 30,000 breeding does near Qingdao, China which supplies rabbits to Kangda Foods. (Courtesy of S.D. Lukefahr)

Fig. 2.4. In some areas, rabbits are fed various types of greens including the berseem that this man has harvested for feeding to his rabbits. (Courtesy of S.D. Lukefahr)

Philippines, The Democratic People's Republic of Korea (North Korea), Thailand, and Vietnam. Because of low labor costs, Hong Kong, Taiwan, and South Korea are important markets for rabbit skins and furs for garment manufacture.

A major effort to promote rabbit raising in Indonesia has its basis in the need to increase food production in that densely populated country. Village rabbit raising is a potential means of providing protein to people with low income who consume a nutritionally inadequate rice-based diet. Abundant supplies of rice bran are available that, along with local forages, can provide the feed needed for rabbits. In addition, the selling of young rabbits as pets in large cities such as Jakarta has become a lucrative venture.

In India, meat rabbit production is also becoming more popular. The raising of Angora rabbits for wool is increasing in several northern states in the foothills of the Himalaya Mountains. This is being encouraged as a cottage industry to increase income levels of villagers.

In Vietnam, Asian Bird Flu forced many poultry producers out of business when the government euthanized their birds. Rabbit production filled this void. Farmers also realized that they were no longer dependent on grain but instead could feed their rabbits forage and inexpensive agricultural by-products.

Australia and New Zealand

In Australia and New Zealand, the word "rabbit" is synonymous with "pest." Commercial rabbit raising has been severely limited by regulations forbidding growing of rabbits, because of widespread fear of the results should the animals escape. The reasoning behind this is that wild rabbits have been a major scourge in Australia and New Zealand, causing tremendous damage to crops and pastures and often severe soil erosion of the denuded areas (Fig. 2.5). Often overlooked is the fact that the animal responsible is the European wild rabbit, not the domestic rabbit.

Fig. 2.5. Wild rabbits are major pests in Australia and New Zealand. The ecological damage that high populations of wild rabbits can cause and their high reproductive potential can be appreciated from this image. (Courtesy of the National Archives of Australia)

In 1980, the government of New Zealand, after extensive study, approved legislation permitting the raising of domestic rabbits. Following this, there was a flurry of activity involving importation of Rex rabbits and an attempt to establish a Rex fur industry. This program seems to have faltered. In Australia there are periodic attempts to establish large commercial rabbitries, but so far with limited success. The prospect for increased domestic rabbit production in these countries seems limited.

Africa

Inadequate food production is a critical problem throughout Africa. Rabbit raising could make a significant contribution to human welfare. Since rabbit farming is not a traditional practice throughout Africa, carefully designed training programs are essential. In Ghana, a national program to promote rabbit meat has been quite successful. Billboards, signs on buses and trucks (Fig. 2.6), and radio and television announcements encourage people to raise rabbits and eat rabbit meat. It is claimed that about 5 million rabbits are eaten annually in Ghana. The success of this program has led to similar development schemes in several other African countries. Successful rabbit programs have also been established in Algeria, Benin, Cameroon, Egypt, Nigeria, and Kenya. The emphasis has been on

Fig. 2.6. In Ghana there was once a vigorous campaign to promote rabbit keeping. This is a sign on the side of a bus encouraging the raising of rabbits. (Courtesy of S.D. Lukefahr)

self-sufficient meat production by families living on small farms. However, it is paramount that farmers first receive proper training prior to receiving breeding stock and initiating production. Contrary to popular opinion, rabbits are not easy to raise. It requires both knowledge and skills from experience. As in other tropical areas, rabbit production in Africa seems to have unlimited potential.

Future World Rabbit Production

There is little doubt that rabbits could become important meat animals in many countries, particularly in developing nations with high human population density and a shortage of high-quality grains and plant protein sources. A major purpose of raising livestock is to convert low quality fibrous vegetation to a higher quality human food (eggs, meat, and milk). Rabbits offer a number of advantages over other livestock in this conversion process. Whether the potential of rabbit production is realized depends on several factors, including research to bring actual productivity closer to the potential levels and increased consumer acceptance of rabbit meat. It is virtually a worldwide phenomenon that rabbits are viewed as cute creatures, and many people who readily accept the slaughter of chickens, cattle, and other livestock find the idea of slaughtering and eating rabbits difficult to accept.

Consideration of recent trends in rabbit production suggests that China is now the stronghold of rabbit raising, with a viable industry based on growing domestic consumer demand for rabbit meat, and major export markets. Concerning commercial meat rabbit production in Europe, only time will tell what will be the new normal for the industry. Growth of the North American industry, where rabbits are mostly found in small numbers in backyards or on small farms will likely be modest. Rabbit meat in the United States is in competition with abundant and less expensive other food resources, particularly the highly sophisticated and automated poultry and swine industries. Rabbit raising is labor intensive and well adapted to small-scale backyard self-sufficiency situations, suggesting that it could increase in importance in low-income areas where abundant inexpensive labor is available. Much of the developing world in Africa, Latin America, and Southeast Asia is in that category, and increases in rabbit production in these areas appear likely.

Rabbit Research Worldwide

The development of any livestock industry depends heavily on research to uncover information on nutrition and feeding, the cause and prevention of diseases, optimal breeding and genetics programs, and the solution of a myriad of problems that confront the producer. Compared to the situation with other livestock species, research on rabbits has been very limited. It is useful to review the history of rabbit research and the contemporary situation, with the inevitable risk of omission.

For decades, a serious effort has been made at several universities and research institutions worldwide to "bridge over" advancements from labs to farms. In other words, rabbit researchers investigate in the laboratory a particular problem (e.g., a disease or management issue) that has been detected on the farm. Scientists then develop research projects to find solutions. The new scientific findings or discoveries are of critical importance ("breakthroughs") to improve rabbit production on farms and achieve progress for the rabbit industry.

The U.S. Rabbit Experiment Station was established in Fontana, California, in the late 1920s. Fontana is in southern California, near Los Angeles. In the 1920s, the Los Angeles area was a major site of commercial rabbit production in the United States. The second director of the U.S. Rabbit Experiment Station was George S. Templeton (Fig. 2.7). He started at Fontana in 1933 and retired in 1960. Dr. Templeton directed research on rabbit feeding, nutrition, and management. The Fontana station generated much useful information concerning the scientific production of rabbits. Dr. Templeton's experience and research findings led him to publish in 1955 the book *Domestic Rabbit Production* which, through four editions, came to be the leading source of information in the United States on rabbit production. In 1982, Dr. Templeton's book was revised by Dr. Peter R. Cheeke and Dr. Nephi M. Patton as *Rabbit Production*. Further revisions have been carried out by the current authors in 1987, 1996, 2000, 2012, and 2021. In about 1964, the U.S. Rabbit Experiment Station was closed, following several years of relative inactivity after Dr. Templeton's retirement.

Fig. 2.7. Dr. George Templeton, Director of the U.S. Rabbit Experiment Station in Fontana, California from 1933 to the early 1960s. (Courtesy of P.R. Cheeke)

Very little rabbit research was conducted in the United States from that time until the late 1970s, when the Oregon State University (OSU) Rabbit Research Center was established (Fig. 2.8). The OSU Rabbit Research Center developed programs in nutrition and feeding, rabbit diseases, reproductive physiology, genetics, management, and meat quality. The OSU program focused primarily on commercial meat rabbit production, although much of the research had relevance to other types of rabbit production as well. Other rabbit research programs have been established in the United States at Brigham Young University in Utah, Alabama A&M University, Texas A&M University-Kingsville (Fig. 2.9), and Southern University and A&M College in Louisiana. Several private companies have research and testing centers. Generally, information developed by private companies is proprietary and not made available to the public.

In Europe, France, Italy, and Spain are at the forefront of rabbit research. The Institut National de la Recherche Agronomique (INRA), the French equivalent of the USDA, has a Laboratory of Rabbit Research at Toulouse. Major programs in nutrition and genetics have been conducted. That work has had a major impact on the intensification of the rabbit industry in Europe.

Fig. 2.8. The Oregon State University Rabbit Research Center. (Courtesy of P.R. Cheeke)

Fig. 2.9. The Texas A&M University–Kingsville Rabbit Research and Teaching Program carries out experiments on all aspects of rabbit production, with special emphasis on genetic improvement. (Photo Courtesy of S.D. Lukefahr)

Rabbit research is also conducted in Belgium, Italy, Germany, and Hungary. Spanish scientists have been active in the areas of rabbit genetics and nutrition. The rabbit research program at the Universidad Politechnica de Valencia has an active team of rabbit scientists. Research in Germany has concentrated on Angora wool production. In England, the pioneering research at Cambridge University on genetics and reproductive physiology has been followed by studies on artificial insemination and embryonic development.

Since the 1980s there has been much interest in the rabbit as a meat source in protein-poor developing countries. Rabbit research programs in a number of African, Asian, and Latin American nations, including Brazil, Egypt, Mexico, Nigeria, and Indonesia, have been initiated.

Table 2.3. World rabbit congresses.

	Year	Location
1st	1976	Dijon, France
2nd	1980	Barcelona, Spain
3rd	1984	Rome, Italy
4th	1988	Budapest, Hungary
5th	1992	Corvallis, Oregon
6th	1996	Toulouse, France
7th	2000	Valencia, Spain
8th	2004	Puebla, Mexico
9th	2008	Verona, Italy
10th	2012	Sharm El-Sheikh, Egypt
11th	2016	Qingdao, China
12th	2021	Nantes, France

It is evident from this brief review that there is worldwide interest in the potentials of the rabbit and that a considerable research base has been established.

An organization called the World Rabbit Science Association was formed in the 1970s to promote communication among rabbit scientists. This organization sponsors the World Rabbit Congresses, which are held every four years. As shown in Table 2.3, there have been ten Congresses where rabbit scientists from around the world met to share their research findings.

The American Branch of the World Rabbit Science Association also meets every four years between the meetings of the parent organization. Meetings have been held in Mexico, Cuba, Brazil, and Argentina. These meetings primarily attract scientists from North, Central, and South America and the Caribbean.

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3

Rabbit Breeds

Selecting a Breed

The prospective rabbit raiser should decide on the purpose for which the rabbits will be raised. He or she should then select a breed that will be best suited to this and to his or her personal preferences. No one breed is best for all purposes, but with widely different characteristics among breeds, little difficulty should be encountered in making a selection.

With respect to body conformation, there is considerable variation, from the "racy type" of the Belgian Hare to the compact body shape of the medium-weight meat breeds to the large body frame of the giant breeds. Mature weights range from less than 1.1 kg for the Netherland Dwarf to 6.4 kg for the Flemish Giant.

The different breeds range in length of coat from the short-furred Rex to the Angora, which has an annual growth of 20 to 30 cm of wool. There are also many different coat colors, and the rabbits may be solid black, blue, chocolate, fawn, gray, white, etc., or with spots, or of mixed colors.

For commercial meat production, the New Zealand White is the principal breed and variety. It has a number of desirable traits, including a satisfactory growth rate, acceptable carcass quality, good prolificacy, high milk production, and good mothering ability. In general, it possesses many characteristics desirable for a meat-producing animal. The other major meat breed is the Californian. It tends to finish out at a lighter weight than the New Zealand White but has a higher carcass yield and meat-to-bone ratio. Commercial producers often cross Californian bucks with New Zealand White does to produce a high-quality market animal that combines the best qualities of both breeds. Thus, for commercial meat production, the New Zealand White and the Californian are traditionally the breeds of choice. Other breeds may have potential in certain markets, although careful breed evaluations must be made before they can be widely recommended.

Breeds such as the Altex, Champagne D'Argent, Chinchilla, Dutch, Flemish Giant, Palomino, and Satin have been used to a minor extent, either to produce crossbred meat rabbits or as purebreds. Generally, premium market prices are paid for meat rabbits with white fur, so it is inadvisable to produce colored rabbits commercially.

Other types of commercial production involving breeds include Rex pelts and Angora wool, and Angora wool production is discussed in Chapter 22.

For backyard raising of rabbits as pets and for home meat production, the choice of a breed is not critical, as maximum production and profit are not being sought. Personal preferences as to color and type are greater factors. If children are involved, they will probably be more interested in a variety of colors. For strictly

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pet raising or backyard meat production, there is nothing wrong with indiscriminate crossing. Children may want rabbits of various colors from crosses; this may stimulate their curiosity and result in a lifelong interest in rabbits.

For show purposes, the selection of a breed will be based on personal preferences, availability of good breeding stock, etc. The dwarf breeds require much less feed and space than the medium or giant breeds, which might be a consideration in breed selection.

A significant market sometimes exists for laboratory animals, which are used in biomedical research. Generally, the New Zealand White is used in research, although large numbers of Dutch are also used. The Florida White was developed as a laboratory animal and might be more extensively used if scientists were made aware of its existence. Its feed requirements are considerably less than those of the New Zealand White, which is a significant factor when large numbers of research animals are to be kept for long periods.

Purchasing Breeding Stock

After it has been decided which breed of rabbit one wishes to raise, lists of breeders who have that particular stock for sale can be obtained from reputable and experienced area breeders. Another source is the officers of local, state, and specialty rabbit clubs and from the home office of the American Rabbit Breeders Association. (Most countries have similar organizations.) County extension agents are another source of names of rabbit raisers. Advertisements on websites, in rabbit journals and other periodicals that carry classified ads are good sources of listings. One should, however, avoid the flashy type of advertisement proclaiming that a fortune can be made from raising rabbits, for this is not true, although an experienced, conscientious, industrious person with proper equipment and a well-selected herd should be able to realize a reasonable return.

When an entire herd is being sold, it is wise to inquire carefully into the reasons, as such sales may or may not be excellent opportunities for buying good, healthy breeding stock. It is always best to deal with reputable breeders, and the inexperienced will do well to depend on the advice of one or several established breeders in selecting animals. The source rabbitry should be clean and well managed, with no observable snuffles (respiratory tract infections) or other disease problems. It is never economical to purchase inferior breeding stock, for one good producing doe may make more profit than several inferior ones.

The novice is advised to begin rabbit raising on a small scale, preferably with 1 or 2 bucks and 2 to 10 does, then to expand as experience and the market outlet would indicate. He or she may start with a few junior animals when they are weaned or with mature stock. The former method offers an opportunity to become acquainted with the animals and to gain experience in the business before handling too many rabbits; the latter method may be quicker, but naturally the stock will cost more.

However, when rabbits are to be purchased for raising by a younger member of the family, the additional cost of an adult doe may be justified because youth demands action. Having to supply a nest box and nesting material, preparing for the kindling of the doe, and caring for the litter, followed by marketing the meat, skins, or animals, might help maintain the young person's interest in the undertaking at a time when it might be lagging. Then, on receiving some income from the sale of the products, he or she is ready to go on and plan for another litter. On the other hand, if the stock is purchased at eight weeks of age, or at time of weaning, it seems like a long wait for the young rabbit raiser before the animals are ready to go into production, and he or she may lose interest.

When mature does are moved to a new rabbitry, there are often problems with their first litters, including poor nest making, litters born on the wire (i.e., the doe doesn't use the nest box), abandoning of litters, cannibalism, fetal abnormalities, and resorptions. The same may occur with young does that kindle the first time because of their inexperience in raising a litter. Further, pregnant does should not be purchased, because the move to a new rabbitry may cause a great deal of stress, possibly leading to reproductive failure. Raising rabbits requires both responsibility and patience.

In purchasing stock, use great care to avoid diseases. Newly purchased animals should be quarantined before allowing them to mix with other animals. From a genetics point of view, it is desirable to obtain stock from a number of different sources to get genetic diversity, but from a disease point of view. However, this could be a problem if the rabbits are not checked carefully and quarantined for at least two weeks. Another way to accomplish this is to obtain bucks from different sources and quarantine them before using them in the herd.

When buying stock, ask to see the records. If you are buying commercial stock, find out what selection procedures have been used. Get information on litter sizes and 21- and 56-day litter weights. Generally, the best stock for meat production comes from successful commercial rabbit raisers who keep good records. Many people start with a trio of two does and a buck, which should not be littermates. They should be carefully examined for soundness, good foot pads, normal teeth, good fur quality, and absence of ear mites and other pests and diseases. It is very important to start your rabbitry with the highest quality stock you can obtain. If you have had no rabbit experience, start with no more than 10 to 20 does. Find out whether you really want to raise rabbits. If you find that you do enjoy it, then increase by buying more breeding stock or saving back offspring for breeding. Two hundred breeding does is a minimum economic unit. Rabbitries smaller than this do not make effective use of large quantity purchase discounts for feed, supplies, cages, and other costly equipment. The cost of selling fryers may also be greater for small producers, as they usually have to transport their fryers to pick-up points, while the truck usually comes directly to a large rabbitry. It is advisable to buy no more than 100 does, and then increase by saving your own replacements. A full-time rabbit operation for one person is about 300 does. If breeding stock is being purchased from a small herd, it is advisable to get the bucks from a different source than the does for maximum genetic diversity.

If you are doing any custom breeding, keep one or more bucks in isolation for that purpose. Never use your buck on someone else's does and then return the buck to your herd. Custom breeding is an easy way to introduce rabbit syphilis and other diseases into your herd.

Breeds of Rabbit

Information on breeds of rabbits and the *Standard of Perfection* can be obtained from the American Rabbit Breeders Association (ARBA). The ARBA recognizes about 50 breeds. A list of these breeds and their ideal weights from the *Standard of Perfection 2021–2025* is given in Table 3.1. Most of these breeds are bred and raised for fancy or show exhibition. Pictures and brief descriptions of some of the more common breeds of rabbits are presented in the color plate section.

The major commercial meat types are the New Zealand White and the Californian. The origin of the New Zealand White is unclear, but it definitely was not New Zealand and was most likely the United States. The Red variety appeared first, and the White was developed from a number of crosses of the Red with other breeds. The New Zealand White has attained a position of dominance in commercial rabbit production around the world and is the premier meat rabbit. This is primarily because of its superior reproductive and growth performance and the demand for white-furred rabbits. The Californian was developed for commercial production in California in the 1920s, arising from a Himalayan and Standard Chinchilla cross, which was then crossed with the New Zealand White. The Californian is somewhat smaller than the New Zealand White and finishes out at a lower body weight but tends to have a higher meat-to-bone ratio. In Europe, there is extensive use of hybrids produced by crossing Californian bucks with New Zealand White does.

The Flemish Giant has potential as a sire breed in commercial meat production. Purebred Flemish Giants do not display adequate reproductive performance for commercial production, and their large size results in high maintenance feed requirements and potential sore hock problems. However, when white Flemish Giant bucks are crossed with New Zealand Whites or Californians or with hybrid Californian-New Zealand White does, growth and feed efficiency performance of the fryers is improved, and fryers can be marketed at an earlier age due to more rapid growth. As rabbit production becomes more sophisticated, the high growth rate potential of the giant breeds may be exploited through terminal sire line or breed development (such as the Altex described in Chapter 14) and/or through crossbreeding. Compared to the Flemish Giant, the Altex at maturity typically weighs over 12 pounds (5.4 kg) and has better meat-type conformation.

Table 3.1. Breeds of rabbits recognized in 2020 by the American Rabbit Breeders Association with ideal weights in pounds (kilograms).[1]

			Ideal weight	
Breed	Varieties	Color groups	Senior does	Senior bucks
American	Blue, Ruby Eyed White		11.0 (5.0)	10.0 (4.5)
American Fuzzy Lop		Agouti, Broken, Pointed, Self, Shaded, Wide Band, Tan Pattern	3.75 (1.7)	3.75 (1.7)
American Sable			9.0 (4.1)	8.0 (3.6)
Angora, English		Agouti, Pointed, Self, Shaded, Ticked, Wide Band	6.0 (2.7)	6.5 (3.0)
Angora, French		Agouti, Broken, Pointed, Self, Shaded, Ticked, Wide Band	8.5 (3.9)	8.5 (3.9)
Angora, Giant	Ruby Eyed White		Over 10.0 (4.5)	Over 9.5 (4.3)
Argente Brun			9.5 (4.3)	9.0 (4.1)
Belgian Hare	Rufus, Tan		8.0 (3.6)	8.0 (3.6)
Beveren	Black, Blue, Blue Eyed White		11.0 (5.0)	10.0 (4.5)
Blanc de Hotot			10.0 (4.5)	9.0 (4.1)
Britannia Petite	Black, Black Otter, Blue Eyed White, Broken, Chestnut, Ruby Eyed White, Sable Marten		Under 2.5 (1.1)	Under 2.5 (1.1)
Californian			9.5 (4.3)	9.0 (4.1)
Champagne D'Argent			10.5 (4.8)	10.0 (4.5)
Checkered Giant	Black, Blue		Over 12.0 (5.5)	Over 11.0 (5.0)
Chinchilla, American			11.0 (5.0)	10.0 (4.5)
Chinchilla, Giant			14.5 (6.6)	13.5 (6.1)
Chinchilla, Standard			6.5 (3.0)	6.0 (2.7)
Cinnamon			10.0 (4.5)	9.5 (4.3)
Crème D'Argent			10.0 (4.5)	9.0 (4.1)
Dutch	Black, Blue, Chinchilla, Chocolate, Gray, Steel, Tortoise		4.5 (2.0)	4.5 (2.0)
Dwarf Hotot	Black, Blue, Chocolate		Under 2.5 (1.1)	Under 2.5 (1.1)
Dwarf Papillon	Black, Blue, Chocolate		Under 4.25 (1.9)	Under 4.25 (1.9)
English Spot	Black, Blue, Chocolate, Gold, Gray, Lilac, Tortoise		7.0 (3.2)	6.0 (2.7)
Flemish Giant	Black, Blue, Fawn, Light Gray, Sandy, Steel Gray, Ruby Eyed White		14.0 (6.4)	13.0 (5.9)
Florida White			5.0 (2.3)	5.0 (2.3)
Harlequin	Black, Blue, Chocolate, Lilac	Japanese, Magpie	8.0 (3.6)	7.5 (3.4)

Havana	Black, Blue, Broken, Chocolate, Lilac		5.375 (2.4)	5.375 (2.4)
Himalayan	Black, Blue, Chocolate, Lilac		3.5 (1.6)	3.5 (1.6)
Jersey Wooly		Agouti, Broken, Pointed, Self, Shaded, Tan Pattern	3.0 (1.4)	3.0 (1.4)
Lilac			7.0 (3.2)	6.5 (3.0)
Lionhead	Black, Chocolate, Seal, Siamese Sable, Tortoise, Ruby Eyed White		3.75 (1.7)	3.75 (1.7)
Lop, English		Agouti, Broken, Self, Shaded, Ticked, Wide Band	10.5 (4.8)	9.5 (4.3)
Lop, French		Agouti, Broken, Self, Shaded, Ticked, Wide Band	11.5 (5.2)	11.0 (5.0)
Lop, Holland		Agouti, Broken, Pointed, Self, Shaded, Tan Pattern, Ticked, Wide Band	4.0 (1.8)	4.0 (1.8)
Lop, Mini		Agouti, Broken, Pointed, Self, Shaded, Ticked, Wide Band	6.0 (2.7)	6.0 (2.7)
Mini Rex		Agouti, Broken, Pointed, Self, Shaded, Tan Pattern, Wide Band	4.25 (1.9)	4.0 (1.8)
Mini Satin		Agouti, Broken, Pointed, Self, Shaded, Tan Pattern, Wide Band	4.0 (1.8)	4.0 (1.8)
Netherland Dwarf		Agouti, Broken, Pointed, Self, Shaded, Tan Pattern, Ticked, Wide Band	Under 2.5 (1.1)	Under 2.5 (1.1)
New Zealand	Black, Blue, Broken, Red, Ruby Eyed White		11.0 (5.0)	10.0 (4.5)
Palomino	Golden, Lynx		10.0 (4.5)	9.0 (4.1)
Polish	Black, Blue, Broken, Chocolate, Lilac, Ruby Eyed White, Blue Eyed White		2.5 (1.1)	2.5 (1.1)
Rex		Agouti, Broken, Pointed, Self, Shaded, Tan Pattern, Wide Band	9.0 (4.1)	8.0 (3.6)
Rhinelander	Black, Blue		8.5 (3.9)	8.0 (3.6)
Satin		Agouti, Broken, Pointed, Self, Shaded, Tan Pattern, Wide Band	10.0 (4.5)	9.5 (4.3)
Satin Angora		Agouti, Broken, Pointed, Self, Shaded, Ticked, Wide Band	8.0 (3.6)	8.0 (3.6)
Silver	Black, Brown, Fawn		6.0 (2.7)	6.0 (2.7)
Silver Fox	Black		10.5 (4.8)	9.5 (4.3)
Silver Marten	Black, Blue, Chocolate, Sable		8.5 (3.9)	7.5 (3.4)
Tan	Black, Blue, Chocolate, Lilac		4.75 (2.2)	4.75 (2.2)
Thrianta			5.0 (2.3)	5.0 (2.3)

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[1] For breeds recognizing more than eight distinct varieties, color groups are used to encompass the accepted varieties.

For show purposes, there are a large number of breeds available. The selection of a breed to raise is largely a matter of personal preference and availability of breeding stock. Some fanciers might wish to raise one of the most popular breeds, to compete against a large number of competitors at shows. Other people may wish to specialize in an uncommon or rare breed. The novice should be aware that fancy-bred Californian or New Zealand White does are not suitable for breeding as they generally lack genetic merit for traits required for successful commercial production.

Almost any breed can serve adequately as a pet. There are advantages to small rabbits, such as the Netherland Dwarf, Polish, and Florida White, as pets because their feed and housing requirements are less than those of larger breeds, and they are more easily handled. The appearance of Mini and Holland Lops make them particularly suitable as pets.

There are many breeds of rabbits in other countries that are not raised in the United States. There are also many varieties of the same breeds that differ from country to country. For example, the Champagne d'Argent of France has English Argent and German Argent varieties that differ in color and adult weight from the Champagne D'Argent of the U.S. The English, French, and German Angoras differ somewhat in their wool characteristics. The German Angora has been selected over many years for commercial production and thus has superior wool quality. In many developing countries, there are rabbits referred to as the local breed. These are usually quite small, are multi-colored rather than white, and have short ears, small litters, and a slow growth rate. Such breeds generally thrive under backyard or subsistence conditions involving less favorable environments.

Table 3.2. Prominent European rabbit breeds.

Giant Breeds (adult weight over 5 kg)
Géant Blanc du Bouscat (Bouscat Giant)
Bélier Français (Belier)
Papillon Français (Papillon Giant)
Medium Size Breeds (adult weight 3.5–5.0 kg)
Argenté de Champagne (Champagne d'Argent)
Fauve de Bourgogne (Burgundy Fawn)
Small Breeds (adult weight 2.5–3.5 kg)
Petit Russe (Small Russian)

Some of the more prominent European breeds are listed in Table 3.2. The giant breeds are commonly used in Europe as terminal sire breeds, because of their genes for rapid growth rate of their offspring. The Bouscat Giant is a composite albino breed. It is well known for its prolificacy and rapid growth rate.

The Champagne d'Argent has been raised for a long time in the Champagne region of France. It has been evaluated by French scientists as a commercial breed because of its good fur quality and its productive attributes, including high prolificacy, rapid growth rate, muscularity, and high carcass yields. Another breed, the Fauve de Bourgogne (Burgundy Fawn), is widely distributed in France, Spain, Italy, Belgium, and Switzerland. It originated in the Burgundy region of France. It may have some value as a sire breed in crossbreeding programs.

The Petit Russe (Small Russian) is basically the Himalayan breed. It originated in northern China and then spread through Russia and Poland. The Petit Russe has been studied in France for its potential in crossbreeding systems as one of the breeds contributing to a maternal line. Small breeds such as the Petit Russe tend to show early maturity and excellent maternal traits that can be utilized in crossbreeding programs.

Further Reading

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Breeds of Rabbits

Altex
Owned by Texas A&M University-Kingsville
Photo courtesy of S.D. Lukefahr

American
Owned by Lorena Ferchaud
Photo courtesy of Allen Mesick

American Sable
Photo courtesy of D.J. Harris

Argente Brun
Owned by Jordan Miner
Photo courtesy of Allen Mesick

Breeds of Rabbits

Belgian Hare
Owned by Eric Peterson
Photo courtesy of D.J. Harris

Bélier Français
Owned by J-P. Gollin
Photo courtesy of Hervé Garreau

Beveren
Owned by Kim Calloway
Photo courtesy of Allen Mesick

Blanc D'Hotot
Owned by Julie Wichert
Photo courtesy of D.J. Harris

Breeds of Rabbits

Blanc du Bouscat
Owned by E. Mayeur
Photo courtesy of Hervé Garreau

Blue Vienna
Photo courtesy of D.J. Harris

Britannia Petite
Photo courtesy of D.J. Harris

Californian
Owned by Susie Smith
Photo courtesy of D.J. Harris

Breeds of Rabbits

Champagne D' Argent
Owned by Linda Slinkard
Photo courtesy of D.J. Harris

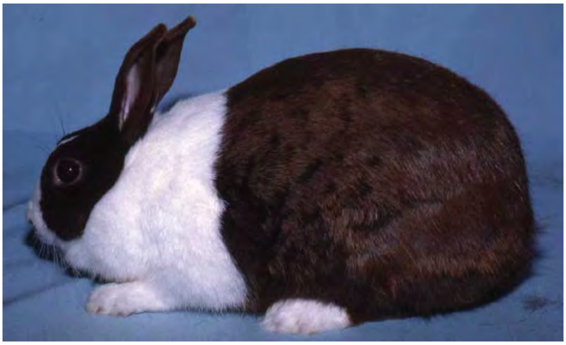
Checkered Giant
Owned by Jill Stahley
Photo courtesy of D.J. Harris

Cinnamon
Owned by Candy Hankins
Photo courtesy of D.J. Harris

Creme d'Argent
Photo courtesy of D.J. Harris

Breeds of Rabbits

Dutch (Chocolate)
Owned by Andrew Crabtree
Photo courtesy of D.J. Harris



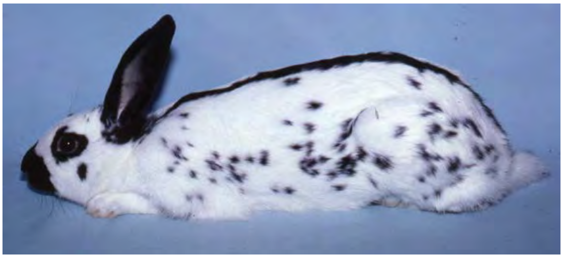
Dwarf Papillon
Owned by Randy Shumaker, Maddie Pratt, and Louis Potter
Photo courtesy of Allen Mesick

English Angora
Owned by Jan Vanden Hout
Photo courtesy of Leslie Samson

English Lop
Owned by Almira and Charles Dickens
Photo courtesy of D.J. Harris

Breeds of Rabbits

English Spot
Owned by Freddie McCown
Photo courtesy of D.J. Harris



Fauve de Bourgogne
Owned by A. Raulain
Photo Courtesy of Hervé Garreau

Flemish Giant
Owned by Amanda Hutcheson
Photo Courtesy of Amanda Hutcheson

Florida White
Owned by the Westhoff Family
Photo Courtesy of Allen Mesick

Breeds of Rabbits

French Angora
Owned by Jan Vanden Hout
Photo courtesy of Leslie Samson

French Lop
Owned by Sharon Campbell
Photo courtesy of D.J. Harris

Fujian White
Owned by Yangshen Lan
Photo courtesy of Yinghe Qin

Fuzzy Lop
Owned by Jan Vanden Hout
Photo courtesy of Leslie Samson

Breeds of Rabbits

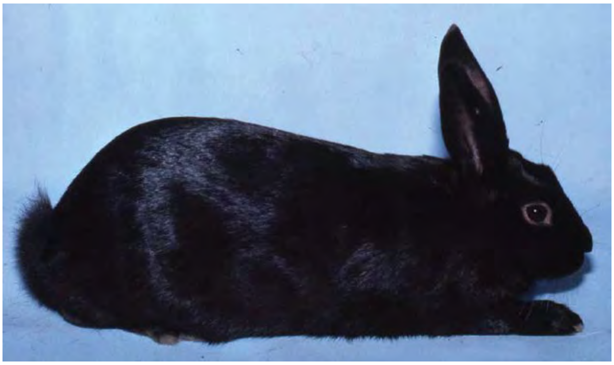
German Angora
Owned by Jan Vanden Hout
Photo courtesy of Leslie Samson

Giant Angora
Owned by Lorraine Mitchell
Photo courtesy of Lorraine Mitchell

Giant Chinchilla
Owned by Dick and Grace Barbee
Photo courtesy of D.J. Harris

Breeds of Rabbits

Harlequin
Owned by Susan Etenburn
Photo courtesy of D.J. Harris

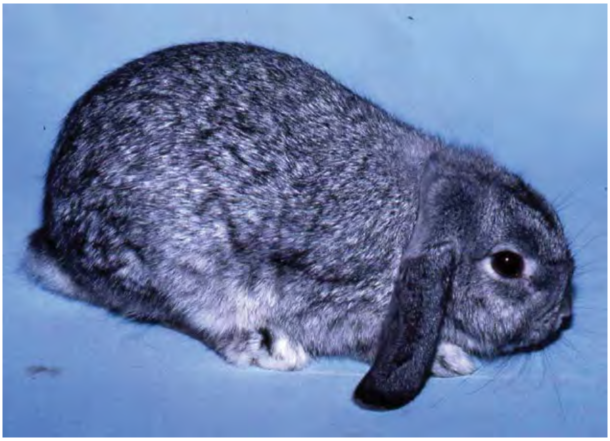


Havana
Owned by Cathy Cook
Photo courtesy of D.J. Harris

Himalayan (Blue)
Owned by Brian Smith
Photo courtesy of D.J. Harris

Breeds of Rabbits

Holland Lop
Owned by Hans Albrecht
Photo courtesy of D.J. Harris



Jersey Wooly
Owned by Jan Vanden Hout
Photo courtesy of Leslie Samson

Lionhead
Owned by Clara Hill
Photo courtesy of Allen Mesick

Breeds of Rabbits

Mini Lop
Photo by D.J. Harris

Minxinan Black
Owned by Xiping Xie
Photo courtesy of Yinghe Qin

Netherland Dwarf
Owned by Linda Johansen
Photo courtesy of D.J. Harris

Breeds of Rabbits

New Zealand White
Owned by Gene Knieling
Photo courtesy of D.J. Harris

Palomino
Photo courtesy of D.J. Harris

Polish
Photo courtesy of D.J. Harris

Breeds of Rabbits

Rex (Red)
Photo courtesy of D.J. Harris

Rhinelander
Owned by Betty Kelly
Photo courtesy of D.J. Harris

Satin (Copper)
Photo courtesy of D.J. Harris

Breeds of Rabbits

Satin Angora
Owned by Jan Vanden Hout
Photo courtesy of Leslie Samson

Silver (Brown)
Photo courtesy of D.J. Harris

Silver Fox
Owned by Kari Staggs
Photo courtesy of D.J. Harris

Silver Marten
Owned by Sharon Etenburn
Photo courtesy of D.J. Harris

Breeds of Rabbits

Standard Chinchilla
Photo courtesy of D.J. Harris

Tan
Owned by Charles Etenburn
Photo courtesy of D.J. Harris

Thrianta
Owned by Danny Long
Photo courtesy of Allen Mesick

4

The Rabbitry and Its Equipment

The type of building and equipment needed will depend on the location of the rabbitry, the climate, the size of the enterprise, and the amount of money to be invested. Every rabbitry presents its individual problems, but whatever the size of the proposed undertaking, the construction and equipment should be planned to save labor in caring for the herd. Neatness in design and convenient arrangement of the equipment for the rabbitry will make for a pleasant environment in which to work and will also create a favorable impression on prospective buyers of breeding stock or rabbitry products.

Before deciding on a location for engaging in rabbit raising and investing too much capital, you should thoroughly consider your own local conditions and such factors as available markets and labor. In a town or city, check to make sure that no local ordinance forbids such an enterprise.

Planning the Rabbitry

The construction of the rabbitry can require either a major outlay of capital or a minor one, depending on the decisions made in the beginning. Many times, a rabbitry is started in whatever building or structure is available. While this usually is the most economical decision, it often does not consider labor in caring for the rabbits, ventilation for controlling respiratory diseases, or room to expand if things go well. However, it does provide a starting place, and, if limitations are recognized, it is a good way to begin. It gives the opportunity to “get one’s feet wet” in the art and science of raising rabbits with a minimal investment. If the rabbitry is thought of as being temporary, a great deal can be learned about one’s abilities and desires to raise rabbits. Then, later, if the experience proves stimulating or profitable, plans for a new rabbitry or expansion of the old rabbitry can be approached with first-hand experience instead of “idealistic” concepts. Rabbit raisers say that one shouldn’t “go” into the rabbit business. You should “grow” into it.

After one to three years of raising rabbits, visiting other rabbitries, talking to many people about their mistakes and yours, and reading extensively on rabbit raising, you will be prepared to design and build your own rabbitry. Consideration must be given to the climate of your area, the prevailing winds, soil drainage, building space available, the size of the rabbitry you desire, and the money available to invest. Design the rabbitry on paper. Then show your plan to knowledgeable rabbit raisers and get their opinions. If possible, discuss the design with an agricultural engineer from the Cooperative Extension Service. Don’t be locked in to one concept. Modify your design if someone who is successful in raising rabbits suggests a logical change.

There are some basic concepts to keep in mind. A long, narrow building with a single tier

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of cages is much easier to ventilate than a wide building or a building with multiple tiers of cages. On the other hand, a long building requires more walking and does not house as many rabbits as a wide building or a building with multiple tiers of cages. Another concept concerns the production of ammonia gas from the excrement of rabbits as it reacts with water. Either this production must be minimized or excellent ventilation must be provided for its removal, or a combination of both. In cold climates, rabbitries are often designed for human comfort and not for the rabbits. The buildings are closed up and sometimes heated. Both of these procedures can be deadly for rabbits unless adequate ventilation is provided to carry away the toxic gases. Rabbits are much more susceptible to heat than cold. The economics of heating or cooling a rabbitry must be taken into consideration. Any increase in utility costs over lights and fans may decrease your profit. Another consideration in design is the ability to expand as needed. A modular design is ideal, because adding new modules is usually a very economical way to expand. Not only does it allow capital to be infused into the rabbitry at a later date, but it also gives one the ability to modify the construction design on the next module to take advantage of experience.

There are other factors to consider before actually beginning construction of your rabbitry. Do local ordinances permit this type of enterprise? Will extra-territorial jurisdictions result in future ordinances against a rabbitry? What kinds of permits are necessary for construction? What types of building materials are most economical? What finances do you have? Is a loan needed?

The Rabbit Building

Modern commercial rabbitries are generally of pole frame construction, with metal or wooden sides and roof. They are of two basic types: those with natural ventilation and those with a controlled environment. A building with natural ventilation in temperate climates may have an open side toward a direction that does not have prevailing winds. In some states, such as Arkansas, rabbitries commonly are open-sided, with a roll-up curtain of plastic, burlap, or canvas that can be dropped down in the winter and rolled up in the summer for better ventilation (Fig. 4.1). With natural ventilation, only one tier of cages should be used, and a long, narrow building is desirable. A central alleyway with a row of cages on each side works well.

Ventilation of rabbitries removes moisture, gases, microorganisms, and heat. Generally, ventilation is required in the summer to remove heat and in the winter to remove moisture. An ideal environment is about 10° to 15°C (50° to 59°F) with about 50% relative humidity. When ventilation is adequate to lower heat or moisture to desired levels, the microorganisms and gases (mainly ammonia) are usually removed adequately also.

There are several characteristics of air important in designing ventilation systems. The higher the air temperature, the greater its capacity to carry moisture as water vapor. Agricultural engineers use charts relating air temperature to water content to determine the air volume necessary in the winter to carry water vapor from the rabbits' breathing, from their urine, and from spilled water (e.g., from leaky drinking valves) out of the building. Another property of air is that hot air rises and cold air sinks. This characteristic is used in locating the air inlets and determining their optimal size.

Natural ventilation systems use wind and animal heat to move air. Advantages of natural ventilation include low cost and freedom from effects of power failures. Disadvantages are the lack of control over air movement, inability to

Fig. 4.1. A Louisiana rabbitry with side flaps that can be closed during inclement weather. (Courtesy of J.I. McNitt)

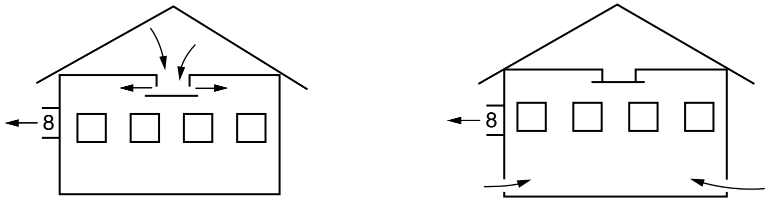
lower the inside temperature of the rabbitry below outside (ambient) temperature, and over-ventilation (drafts). However, drop panels or side flaps mounted on hinges may be lowered during times of inclement weather (Fig. 4.1).

Mechanical ventilation systems are employed in environmentally controlled buildings, using fans to provide the required air flow rate. Advantages include the potential of controlling the air flow rate to required levels for removal of moisture and heat and the ability to use the system to provide heat in cold weather. Disadvantages are the high initial and operating costs and the need for back-up systems in case of power failure.

Mechanical ventilation systems are of two types: positive pressure and negative pressure. In a positive pressure system, fans blow air into the building, creating a build-up of pressure inside. The major disadvantage of this type is that the pressure drives warm, moist air into cracks in the building and into the insulation in the walls and attic. In the winter this may result in excess condensation. Negative pressure systems are those in which the fans blow air out of the building, resulting in the inside air pressure being lower than the outside or atmospheric pressure. Negative pressure systems are more commonly used than the positive pressure type.

Movement of air in mechanically ventilated buildings is controlled by the placement and size of the air inlets. An inlet controls the direction, path, and distribution of fresh air into the rabbitry. In the summer, a lot of turbulence and air volume are needed for cooling purposes. In the winter, less air movement is required for removal of heat. Many rabbitries have insufficient ventilation in the winter, resulting in severe build-up of ammonia. Often this is followed by a high incidence of snuffles and pneumonia in the spring. Ammonia causes severe damage to the cells in the nasal passages, allowing *Pasteurella* bacteria to colonize. High humidity increases the problem because ammonia dissolves in the water molecules in the air. Thus, high humidity means high ammonia. Some ventilation systems use ducts to carry fresh air from outside the rabbitry directly to each cage.

Outlets in mechanical systems should be located on the walls so that air does not have to move more than 12 m (39.4 ft) to get to a fan. Outlets should not be located so they blow into the prevailing wind. In a naturally ventilated building, the air outlets should be at the ridge (highest point of the building) to draw moist, warm air out of the rabbitry even if there is no wind (Fig. 4.2).



WINTER SUMMER

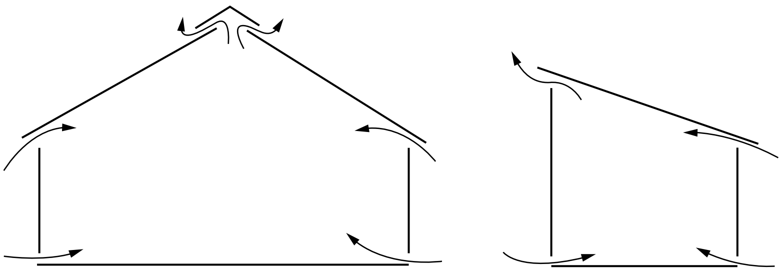


Fig. 4.2. Placement of winter and summer air inlets and outlets for a mechanically ventilated rabbit building (top) and for naturally ventilated buildings (bottom). (Courtesy of James A. Moore)

The economics of commercial meat rabbit production generally does not warrant the construction of environmentally-controlled buildings. The returns generated from sale of meat rabbits may be insufficient to pay the interest on borrowed capital for building construction, to say nothing of utility bills for air conditioning. Therefore, it is recommended that naturally-ventilated buildings be used.

Evaporative cooling systems may be used in hot, dry climates. This type of cooling uses cold water running through mats or coils. Air is drawn through these and cooled. A properly installed sprinkling system on the roof of an enclosed building will help reduce the high temperatures and, when thermostatically controlled, will be a safeguard when sudden weather changes occur. The thermostat should be set so the sprinkler will be turned on when the temperature in the rabbitry reaches about 30°C (86°F). Ideally the volume of water will be just that which will evaporate so there is little, if any, dripping from the eaves. It is the heat used to evaporate the water that produces the cooling, not the cool water flowing over the roof. This system is less effective with roofs that are properly insulated.

In many areas, insulation of the rabbitry is desirable to control environmental temperature. This is important in both hot and cold areas. In hot climates, an insulated building is necessary to complement the action of cooling systems and to minimize radiation of heat from the roof into the rabbitry. Both the walls and the ceiling of an environmentally-controlled building should be insulated. With an open building, insulation of the ceiling will aid in control of high temperatures by reducing radiation from the roof into the rabbitry.

Evaporative systems do not work in areas with high humidity. An alternative that might be used in such areas is bringing in cooled air through tubes or pipes buried in the ground. The outside air is drawn through these tubes and cooled to the surrounding soil temperature (about 10°C or 50°F, depending on the depth). The cooling will result in condensation of the moisture in the air, so it is necessary to slope the pipes to a sump and install a sump pump to remove the moisture.

A solid concrete floor may not be the best type to use in a rabbitry. Concrete floors lead to excessive humidity and ammonia levels, as liquid wastes cannot be readily removed. If solid concrete floors are used, provision must be made for rapid removal of solid and liquid wastes. A better system is to use pits beneath the cages, with concrete alleyways. Concrete alleyways 1 m (3.28 ft) in width between rows of hanging cages are desirable. Beneath the cages, a porous pit of layers of gravel and sand, with a drainage tile to remove liquids, is a good system. Manure is allowed to accumulate and may be removed semi-annually, quarterly, or as required. As long as the sand and gravel layers remain porous, the urine doesn't accumulate, and the humidity of the building will not increase. The pits may be cleaned manually or with scraper devices. Gypsum (magnesium sulfate) spread on the sand immediately after cleaning will help keep the soil porous. This works even better if the gypsum is sprinkled with water after it is applied.

Various devices to automatically remove manure have been developed. They include scrapers on a cable, tractor-driven scrapers, and flushing water systems. Most of them share a common characteristic: they generally don't work very well! Many automatic scraping systems can be seen stacked up outside rabbitries, because they weren't satisfactory. Rabbitries with these systems usually are characterized by high humidity, a strong odor of ammonia, and many sneezing rabbits with snuffles.

It is desirable that a commercial rabbitry be equipped with lights to provide extra hours of light during the late fall and the winter. This has been shown to increase reproductive performance during this period when a decline in reproductive efficiency is often seen, presumably a result of the shortening days, signalling the reproductive system that winter is approaching. The extra lighting should be used to prevent the hours of light from declining. Sixteen hours of light and eight hours of darkness are commonly used in commercial rabbitries. There is evidence that extra light needs to be provided in the morning as well as the evening. There is no evidence that fluorescent lighting provides better results than incandescent, although the former is less expensive to operate. The lights should be controlled by a timer like those used in poultry houses. Electrical outlets for other equipment, such as fans, should not be wired through the timer.

A good policy in a commercial rabbitry is to restrict visitors. Other rabbit raisers may bring diseases with them when they visit your rabbitry. Strangers cause stress to rabbits. A compromise policy is to install a viewing window at one end of the building. Visitors can look inside, but disease organisms and noise are kept out.

A commercial rabbitry should have an office area for recordkeeping, etc. It should be equipped with office supplies, including a calculator. A large rabbitry will find a personal computer a good investment to enhance recordkeeping and economic analysis and to produce daily chore sheets. Other components of the rabbitry include bulk feed tanks and a feed storage room. If the volume of feed used is very substantial, bulk tanks are advisable. Bagged feed is more expensive than bulk, and with increasing costs of labor and materials, the relative difference between the two is likely to continue to rise. A screen may be installed between the bulk bin and the feed cart to remove fines from the feed, if necessary. There is little difference in the amounts of fines between bulk and bagged feed of the same formula. Bulk feed may also be delivered in 800 kg (1764 lbs) nylon bulk feed sacks. They are filled from the top at the feed mill and delivered on pallets. They are removed from the truck with a fork lift or pallet jack. The rabbit raiser empties a sack by dipping from the top with a bucket or by opening a funnel on the bottom. With this system, no expensive bulk tanks are required and, because of reduced condensation, caked feed is seldom seen.

Under certain circumstances, radically different approaches to the housing of rabbits may have merit. For example, it is possible to construct a rabbitry underground in certain locations. The advantages are that control of temperature in a range desirable for rabbit production may be more feasible than with above-ground rabbitries in some climates.

In hot, arid areas raising rabbits in combination indoor/outdoor units has proven effective (Fig. 4.3). The indoor units are constructed of concrete and are connected by a large tube or directly to an outside cage area constructed of wire with slatted floors. In hot areas, the rabbits stay inside during the day and come out into the cages at night to eat.

Fig. 4.3. A combination indoor/outdoor rabbit unit with the indoor part constructed of concrete; the outdoor unit is constructed of wire with slatted floors. (Courtesy of consortium "Green Rabbit Leprino of Viterbo," Italy)

The rabbits are trained to defecate and urinate in the outdoor cages making the units easy to keep clean. Plants that provide forage (e.g. Leucaena and Mulberry) can be grown in the areas over the tubes, which helps keep the units cool. Such units also have application in tropical countries, where they can be constructed of clay or other local building materials. A similar housing duplex system involves a rear unit that is embedded into an earthen dirt bank, while the front unit is typically constructed of standard rabbit wire where feeders and waterers are placed (Fig. 4.4).

Other innovations include using a flushing manure removal system, with solid:liquid separation and fermentation of the solids in a methane generator. A recent innovation involves the utilization of equipment that converts methane gas to electricity, which could be used to provide power for the rabbitry. Some rabbit raisers have combined their waste disposal systems with aquaculture (fish ponds) or greenhouse irrigation. Rabbits have been kept in greenhouses, with their body heat contributing to the heating of the greenhouses. In the near future, the development of vertical, greenhouse farming systems will likely become popular, even in large cities. The purpose is to mass-produce food using solar energy panels, recycled water and nutrients, and the integration of vegetables and small livestock (e.g., chickens, rabbits, and tilapia fish). For example, the wastes from hydroponically-grown vegetables and forages provides feed for rabbits, while manure and urine wastes are used as fertilizer.

Hutches and Cages

A hutch is a small unit of solid construction used for housing a few animals on a backyard scale. A hutch generally is of wood and chicken-wire construction and may have a wire-mesh floor or a solid floor bedded with straw (Fig. 4.5). Inexpensive hutches are satisfactory for the backyard rabbit raiser with a few does. They can be constructed easily, using inexpensive

Fig. 4.4. A duplex indoor/outdoor rabbit unit that has been introduced to rabbit projects in the tropics. (Courtesy of Alessandro Finzi)

Fig. 4.5. A small-scale, backyard rabbit production enterprise. (Courtesy of D.J. Harris)

materials that may be on hand. Hutches are also used in developing countries and are constructed of local building materials, such as wooden planks or bamboo (Fig. 4.6). Rabbits are very adaptable and can be raised in many types of hutches, provided that there is adequate ventilation and provision for manure removal and that the rabbits can be kept dry.

Modern commercial rabbitries do not use hutches. They use wire cages, which are usually suspended from supports on the ceiling. These cages provide good ventilation and waste disposal and place the rabbits at a convenient height for the rabbit raiser to work with them. A variety of different types of wire cages are used successfully. The Quonset-style cage is one of the best, because it requires less wire than a rectangular cage, all corners of the cage can be reached easily, and the door doesn't fall down when one is reaching inside the cage. Quonset-style cages suspended back-to-back provide a ready-made hay feeder (Fig. 4.7) that is useful when hay is fed for enteritis control or to prevent fur chewing or boredom. This area can also be used for feeding greens to the rabbits. Usually, either 14- or 16-gauge wire is used (Fig. 4.8); 12-gauge wire is ideal but is generally too expensive for routine use (Fig. 4.9).

Fig. 4.6. A rabbitry in Malawi (East Africa) constructed of inexpensive local materials. Rabbits are quite suitable for small-scale production in developing countries. (Courtesy of J.I. McNitt)

Another style of cage, which has been referred to as the European-style cage, has two compartments. The young can be kept in one compartment and the doe in the other. Before weaning, the young have access to both compartments; at weaning, the door separating the compartments is closed. It is believed that this system produces less stress to the litter than when the doe is totally removed.

The dimensions of the cage will vary, depending upon the rabbit breed, the management system used, and the personal preferences of the rabbit raiser. For medium breeds and commercial production, a cage 76 cm deep × 76 cm wide × 35.5 cm tall (30 × 30 × 14 in) is satisfactory. A cage 76 cm deep × 91 cm wide (30 × 36 in) should be used for giant breeds of rabbits. The height should be about 46 cm (18 in). For the sides and top, 2.5 × 5.0 cm (1 × 2 in) mesh is used, and for the floor, the mesh should be 1.25 × 2.5 cm (1/2 × 1 in). A type of wire called "baby-saver" is available; it decreases in mesh size from top to bottom so that kits don't fall out the sides of the cage or crawl through to another doe's cage. The door should be of adequate size to allow easy access to all parts of the cage and permit introduction of a nest box.

Fig. 4.7. A Quonset-style hanging wire cage. This style of cage can be readily used for feeding hay. (Courtesy of D.J. Harris)

Wire for cage construction can be purchased from rabbit supply houses or wire manufacturing companies. Ask other rabbit raisers, check current issues of rabbit magazines or search on the Internet to find suppliers. It is best to buy locally to minimize shipping charges (assuming good quality of products). Commercial raisers should build their own cages, using hog rings or J clips to hold them together. Hog rings are preferred because they do not hold water and cause rusting and they

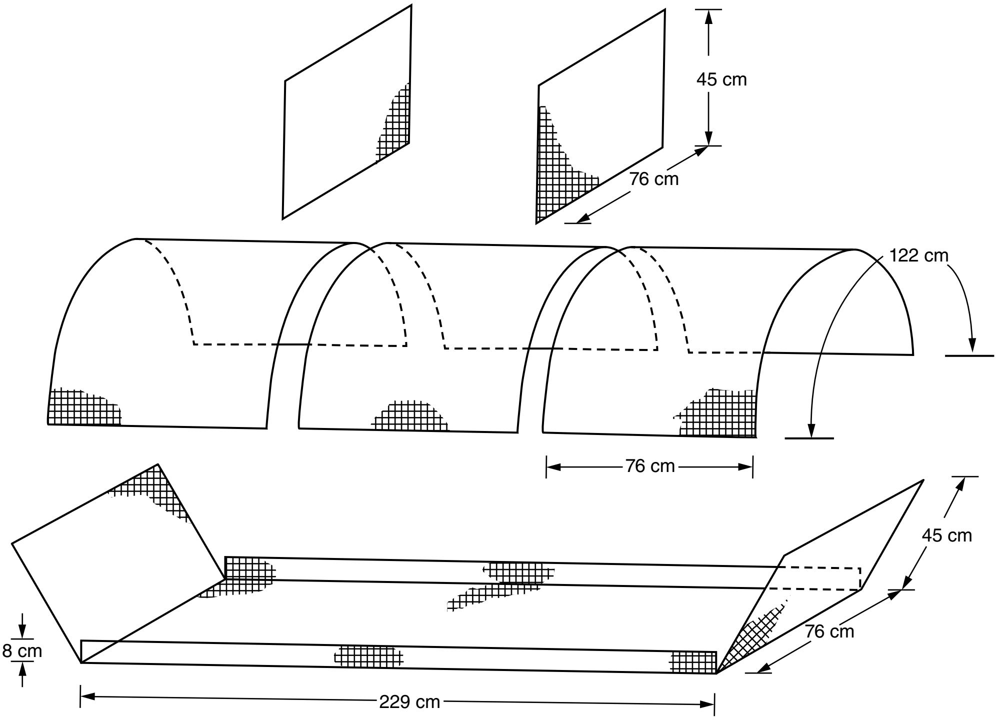


Fig. 4.8. Components of a Quonset cage. (Courtesy of Helene Hedian)

are more effective when joining three or more wires. If only a few cages are needed for a backyard rabbitry, they can be purchased from another producer, or kits of pre-cut cages can be purchased, requiring only to be clipped together. If large numbers of cages are to be built, a power-driven J-clip tool and a power wire shear can be purchased or rented.

Bucks should be kept in 76 × 76 cm (30 × 30 in) cages. For junior does prior to breeding, a 30 × 76 cm (12 × 30 in) cage is adequate, or two or three junior does can be housed together in a larger cage. If the latter is done, they should be separated three weeks before intended breeding to prevent pseudopregnancy. Hanging wire cages should be suspended at a height convenient to the rabbit raiser so that he or she can readily reach into all parts of the cages. In general, cages should be single tiered. If forced-air ventilation is used, then a double-tiered arrangement (Fig. 4.10) may be considered. However, snuffles and other respiratory ailments are often a problem with double- and triple-tiered cages. Adequate ventilation to prevent build-up of humidity and ammonia is extremely critical. Also, with double or triple tiers, it is

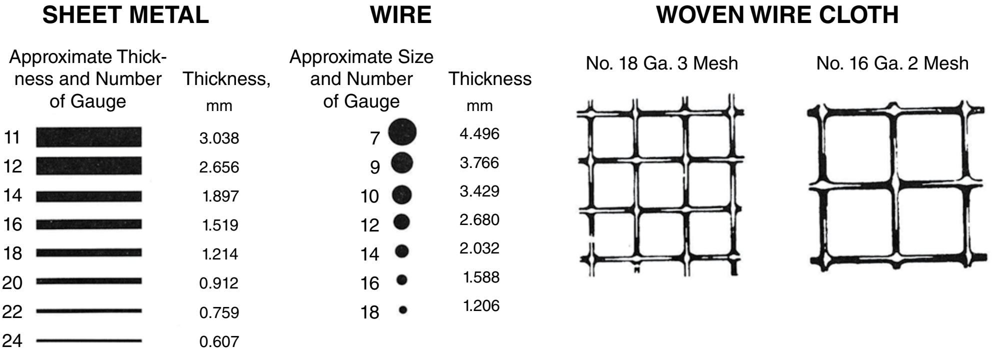


Fig. 4.9. The sizes and identification of sheet metal, wire, and woven wire cloth. (Courtesy of the OSU Rabbit Research Center)

Fig. 4.10. A two-tier arrangement of cages. (Courtesy of Bass Equipment Company)

difficult to readily observe animals or nest boxes on the top and bottom tiers, not to mention difficult to sanitize cages that are more cumbersome to reach. With double or triple tiers, various types of waste-disposal systems have been used, including automatic scrapers (Fig. 4.11) and deflection boards to direct feces and urine into a collection area.

Large cages are sometimes used to save on labor and cage construction costs. These units each house numerous fryer rabbits from weaning to marketing. Feed is provided in large feed hoppers. This system reduces some of the high labor requirements that exist when litters are kept individually in cages. A fairly high stocking density is needed to keep the animals from running and playing, which increases energy expenditure and feed requirements. In order to meet animal welfare standards, the USDA recommends for fryers raised in groups and weighing between 3 to 5 lbs a minimum space area of 1 ft^2 per rabbit (30.5 cm × 30.5 cm or 0.0929 m^2). Fighting is not usually a problem. Junior does, from weaning to four months, can also be kept in group cages. Another alternative group system involves raising fryers in moveable or portable pasture pens. Each day the bottomless pen is moved to a fresh portion of pasture. This system is further described in Chapter 20, "Rabbits for Family and Small Farm Development".

In addition, a new method of raising does is a group housing system (Fig. 4.12). In Europe, there has been mounting pressure from both the government and from animal rights groups to raise livestock under more natural conditions. However, does are highly territorial. In the wild, does burrow and make an isolated den for raising her litter. In several studies that involve raising does together in large open pens, researchers have documented a high incidence of aggression of does attacking one another and killing the kits from other does. In the case of rabbits, raising does together in groups is not natural. The adoption of this system for commercial production in Canada and the United States is not very likely in the foreseeable future.

Feeding Equipment

Feeders

Various types of feed hoppers are commercially available. The most popular is the J feeder (Fig. 4.13). Hoppers should have sufficient

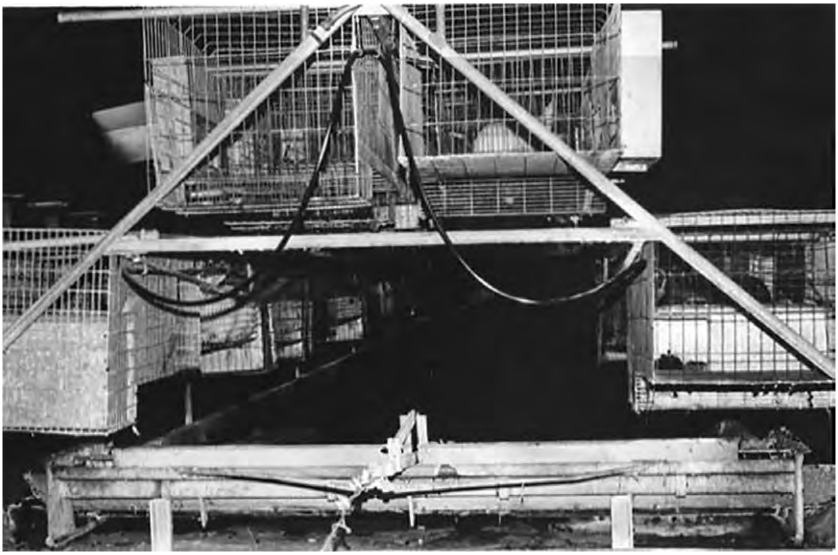


Fig. 4.11. A two-tier caging arrangement with an automatic manure scraper powered by a small electric motor. (Courtesy of OSU Rabbit Research Center)

Fig. 4.12. A doe group housing system in Europe. (Courtesy of Arantxa Villagrá García)

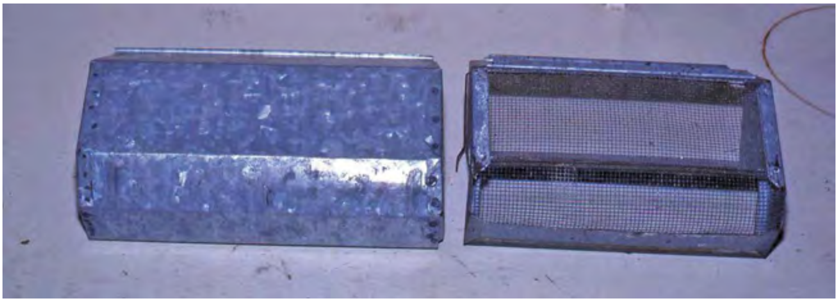


Fig. 4.13. An example of a J feeder, with a mesh bottom to allow fines to sift out of the feed (right) and a feeder with a solid bottom (left). (Courtesy of D.J. Harris)

capacity to hold at least a one-day feed supply and should be designed so feed is not scratched out (scrabbled) and wasted. If scrabbling is a problem, a scrabble guard can be made by inserting a piece of 2.5 × 5.0 cm (6 × 12 in) cage wire into the feeder above the feed. Wires placed 5.0 to 7.5 cm (12 × 19 in) apart over the opening may be needed to prevent young rabbits from getting into the hopper. Some feeders have screen mesh or slotted bottoms that allow fines to fall through. This assures the rabbits of good quality pellets. The presence of fines may reduce feed intake and growth performance. Crocks may be used in small rabbitries, but they require a lot of labor for cleaning, because they are often soiled with feces and urine. Wastage is often a problem.

Feeders should be regularly checked for problems. Rough edges can cause hair loss on the faces of rabbits or cuts that become infected and develop into abscesses. Rabbits may chew small holes in the mesh bottoms of feeders. These holes generally occur where the mesh screen joins the metal and are difficult to see. Feed is observed under the cage, and it is assumed that the rabbits are scratching it out, but the real problem may be a hole in the feeder. As a result, slotted hoppers may be preferred in large rabbitries. Although more expensive, stainless steel feeders should be considered, as they look better and last considerably longer than galvanized feeders. Automatic feeding systems are used in some large-scale rabbit operations; however, these are quite expensive and require careful maintenance. Feeders should also be checked for wetness (the rabbits may soil the feed, water may drip into the feeders, or the pellets may absorb moisture from the air) and for stale, moldy, or caked feed. Feeders should be cleaned and sanitized on a regular basis. Feed crocks on the inside of the cage should be sanitized more frequently than feed hoppers on the outside of the cage.

Hay mangers

Hay feeding may be considered desirable by some rabbit raisers. There is evidence that it may help reduce the incidence of some types of enteritis. Use of home-grown hay may reduce feed costs. Various types of V-shaped hay feeders that attach to the outside of the cage may be built. If Quonset-style cages are used, the hay can be fed directly on the tops of the cages (Fig. 4.7).

Watering Equipment

All rabbit raisers with more than about six does should consider installing an automatic watering system. A properly designed and installed automatic watering system will provide a dependable supply of water. Most rabbits readily learn to use the automatic valves (Fig. 4.14). An automatic watering system is adequate for use throughout the year in rabbitries that are protected so the exposed water pipes will not freeze. However, where there is more exposure, it may be necessary to drain the pipes during short cold spells. In some colder areas, such a system can be used all year if it is allowed to drip to prevent the supply pipes from freezing or if heating cables are installed inside the pipes to prevent freezing. Even in regions where it would be necessary to discontinue using the system during the winter months, the amount of labor saved for the remainder of the year will likely justify installation.

Fig. 4.14. A rabbit drinking from an automatic waterer. (Courtesy of J.I. McNitt)

You may locate necessary materials for installation by referring to advertisements in rabbit magazines or online, or you may purchase them from rabbit and poultry supply houses. A system generally will consist of a pressure tank equipped with a float valve; 1.25 cm (0.5 in) supply pipe; one watering valve for each cage; and gate valves or faucets for eliminating air bubbles, draining the pipes, and cutting off the water supply. The pressure tank may be the standard tank used for this purpose or a half-barrel. A tank with a capacity of 1 liter (33.8 fluid ounces) or less is desirable for warm areas because the small volume of water will be consumed readily and the tank will fill at short intervals and assist in keeping the water in the supply pipes cool; the half-barrel will supply several hundred cages and is especially useful in case the water supply contains sediment. By installing the supply pipe outlet several centimeters or inches from the bottom of the barrel, there will be enough water volume so this sediment will gravitate to the bottom of the barrel and not clog the watering valves. A trap for catching sediment may be installed between the tank and the supply pipe that furnishes water to the cages.

The pressure tank should be about 30 to 60 cm (12 to 24 in) above the highest cage or 30 cm (12 in) above the highest point of the supply pipe, in case it is necessary to raise the supply pipe to clear feeding alleys, etc. If the pipe has to be raised, it is a good plan to install a vent pipe at the highest point, with the open end of the pipe at least a foot above the surface of the water in the tank, to prevent air bubbles from accumulating in the supply pipe. A convenient method for determining the proper height of the tank is to fasten a rubber hose to the outlet from the tank and to the supply pipe, then to raise and lower the tank until the proper tension is obtained on the water valves. About 14 kPa (2 lb/square inch) at the valves is suitable. If there is too much pressure, the rabbit cannot trip a valve with its tongue; if there is too little pressure, the valves will not close properly and may drip. Several days are usually required for the valves to become seated and stop dripping. If they begin to drip after they have been in use for some time, it may be due to minerals contained in the water collecting on the metal and preventing them from seating properly. You can correct this by soaking the valves in a 5% solution of muriatic acid. Generally, you can fix a dripping valve by removing and cleaning it. If not, it should be replaced, because water dripping in the rabbitry contributes to excess humidity.

The supply pipe should be on the outside of the cage so that any dripping will not wet the rabbits and so that the water line cannot be chewed on. The valves should be 15 to 23 cm (6 to 9 in) from the cage floor for the medium weight and heavy breeds and 13 to 18 cm (5 to 7 in) for the small breeds or does with litters. One valve for each cage is adequate. After an automatic watering system is installed, it should be thoroughly flushed several times to remove any particulate matter that may cause the valves to leak. It is advisable to flush and sanitize the water lines monthly, quarterly, or as needed. After sanitizing, the lines should be flushed with clean water.

Nest Boxes

Nest boxes can be constructed from a variety of materials, including wood, metal, wire with disposable cardboard inserts, plastic, and clay pots. They may be open on top or have partial covers to provide protection in cold weather.

Wooden boxes without lids are used quite extensively as nest boxes throughout the year in those areas where winter temperatures are above freezing. They may be simple plywood boxes with a plywood floor that has holes drilled in it. An alternative is to use 3 mm hardware cloth for the floor (Fig. 4.15). A more protected box can be constructed. Cut one end of the box down to about 15 cm (6 in). Nail a board across the top of the box at the back. Cut off the two projecting corners of the sides, slanting from the edge of the top board to the edge of the 15 cm (6 in) board. The doe is able to get away from her litter and is often seen on top of the nest box. Some growers protect the edges of the boards with tin to prevent chewing. Satisfactory results have been obtained with nest boxes as small as 38 × 23 × 18 cm (15 × 9 × 7 in). Advantages of a smaller nest box are that the doe makes a more compact nest, the materials cost less, the box takes up less space in the cage, and the doe is less likely to use it as a resting area or as a latrine.

Fig. 4.15. A wooden nest box with a wire screen bottom. (Courtesy of J.I. McNitt)

Injury of a young litter by the doe jumping into the box may be prevented by a slight change in the nest box. A 15 × 15 cm (6 × 6 in) door should be made in one end, approximately 15 cm (6 in) from the floor. Before the young are old enough to get out of the box, the end with the opening is turned away from the cage wall so the doe can get into the box without jumping over the side. When the young are about large enough to get out of the box, in order to keep them in it a few more days, the box is turned so its opening is against the wall. By this time the doe is not likely to injure the young when she jumps over the side into the box.

A drop nest box (Figs 4.16 and 4.17) has a number of advantages. The nest box is below the floor of the cage. This allows does to mimic the nesting behavior of wild rabbits in holes or depressions. A major advantage is that if the young rabbits do climb out of the nest box or are carried out attached to a teat, they fall back into it as they are crawling around the cage. This reduces deaths from exposure of kits, because rabbits, unlike many other species, will not retrieve and return their young to the nest. The use of drop nest boxes may also reduce the problem of does kindling on the wire. The disadvantage of a drop nest box is that a doe will sometimes use it as a latrine.

The wire component of the drop nest box is made of 2.5 × 5.0 cm (1 × 2 in) wire sides with a 1.25 × 2.54 cm (1/2 × 1 in) wire floor. It is essentially a wire basket that is J-clipped to the bottom of the cage after a section of the floor (41 × 25 cm; 16 × 10 in) is removed. This wire basket (41 × 25 × 20 cm; 16 × 10 × 8 in) is permanently attached to the cage. A plywood insert (39 × 24 × 20 cm; 15 × 9 × 8 in) with a screen bottom is built. The plywood insert is added to the cage whenever a nest box is desired. The insert is filled with nesting material prior to adding it to the cage. The doe will then add her fur to make the nest (Fig. 4.17). The plywood insert is removed 18 to 21 days after the kits are born and is emptied, washed, disinfected, and stored for the next use. To prevent the doe from using the nest box as a latrine, the wire basket can be built only 10 cm (4 in) deep. Then the insert (which is 20 cm (8 in) tall) will be elevated 10 cm (4 in) above the cage floor and will help prevent the doe from fouling the nest. More chewing of the edges may be seen with the elevated nest such that the advantage of the kits falling back into the nest is lost.

Another style of nest box is located outside the cage. It is attached to the front of the cage (Fig. 4.18). The litter is very accessible for inspection by the rabbit raiser, who can remove dead kits, etc., without opening the cage or disturbing the doe. The nest box can be equipped with a door so that the doe can be locked out of it. This prevents her from jumping into the box frequently and trampling the kits. Suitable inside dimensions of the nest box for most breeds are 41 × 25 × 41 cm (16 × 10 × 16 in). The front-loading nest box should have a lid (Fig. 4.18) to prevent the doe from jumping out.

A system that has been successfully employed in research studies to measure milk production is to lock the doe out of the nest box for all but one five-minute period per day. Since kits generally nurse only once each day, this is an adequate exposure to the doe. When the door is opened, the doe usually jumps in,

Fig. 4.16. A "drop" or "subterranean" nest box. (Courtesy of D.J. Harris)

Fig. 4.17. A doe making a nest in a drop nest box. (Courtesy of OSU Rabbit Research Center)

Fig. 4.18. A modern commercial rabbitry with front-loading nest boxes. (Courtesy of D.J. Harris)

Fig. 4.19. A well-filled drop nest box. (Courtesy of OSU Rabbit Research Center)

nurses the litter, and then leaves. The difference between the pre- and post-nursing total litter weights provides a measure of daily milk production. The use of this technique may reduce losses of kits due to trampling. It should be emphasized that if the does are stressed by visitors, unusual noises, etc., they may not jump into the nest boxes in the allotted time. This system requires a high level of management skill.

Various types of bedding can be used in nest boxes, including straw, hay, dry grass, wood shavings, newspaper, sawdust, and shredded sugarcane products. The doe will supplement the bedding with pulled hair to make a nest (Fig. 4.19). Does may eat the straw or hay used in the nest box; this is not necessarily a problem, as the ingested fiber may be helpful in preventing enteric diseases. Another innovation is the use of disposable nest box liners constructed of cardboard. These are removed and burned after use by one litter, which may have value in sanitation and disease control. Regardless of the type of nest box used, it should have adequate drainage.

Winter nest boxes

You can insulate the nest box for winter use by lining it on the inside with one or two layers of corrugated cardboard or several thicknesses of paper and then completely filling it with straw so the doe will have to burrow into it to make a nest. You can also make a nest box for use in low temperatures by placing the standard-size nest box inside a larger box so there will be a space of 7 to 8 cm (2-3/4 to 3 in) on all sides except for the entrance and the top. Fill the 7–8 cm space with closely packed straw or other suitable insulating material. A wooden lid covered on the underside with two thicknesses of cardboard or several thicknesses of paper will supply the necessary top insulation. Make three holes 2 cm in diameter in the end of the lid opposite the opening into the nest box to prevent moisture condensation within the box and to provide ventilation.

Put corrugated cardboard or newspapers on the bottom of the inner box to keep the newborn litter from coming in contact with the cold boards, and then pack the nest box with clean straw so the doe will have to burrow into it to make a hollow for her nest. If the doe allows the litter to nurse and there is adequate dry fur for the litter to fluff to make a nest, the young can survive temperatures as low as −26 to −29°C (−14.8 to −20.2°F) in this type of nest box.

An electric heating pad covered with a moisture-resistant material has also been used with success. It is placed under the nest box and run at a very low setting. Care must be taken not to overheat the litter. Lastly, in hot climates it is common to use commercially made aluminium nest boxes with removable plywood boards for the bottoms.

Identification Equipment

An adjustable tattoo box enables one person to mark a rabbit for identification. The box should be 51 cm long × 20 cm high × 20 cm wide (20 × 8 × 8 in) with a movable 2.5 × 15 × 46 cm (1 × 6 × 18 in) floorboard that may be raised or lowered to accommodate the size of the rabbit. A small board that slides into slots spaced

2.5 cm (1 in) apart is placed at the back of the rabbit to keep it confined in the front end of the box. A top with an opening to allow the rabbit's ear to protrude is fastened to the box at the back end with a 7.7 × 6 cm (3 × 2-1/4 in) T hinge and at the front end with a door hook (Fig. 4.20). This type of restrainer can also be used to hold a rabbit for the collection of a blood sample (Fig. 4.21). Be sure that the rabbit is held securely in the box so that it doesn't struggle. A rabbit that struggles and fights will often dislocate the vertebrae in its back and be left with posterior paralysis. Alternatives to the tattoo box include a towel or a cat bag made of canvas. The rabbit is wrapped securely in the towel or canvas bag so that it does not struggle when it is tattooed or treated.

Feed and Utility Carts

A cart equipped for hauling feed, rabbits, nest boxes, and other equipment is a great convenience and a time and labor saver. A cart with three 30 to 45 cm (12 to 18 in) bicycle-type wheels will provide maneuverability over obstacles on the floor as well as mobility for getting around cages and through the aisles. The cart can be purchased or built at home. Feeding from such a cart greatly reduces the labor of feeding as compared to carrying buckets of feed up and down the aisles. It is also possible to carry more than one type of feed at a time so rabbits can more easily be fed to their requirements. A special bed on the cart for holding rabbits can be used for taking does to the buck's cage for breeding and for transporting rabbits out of the rabbitry.

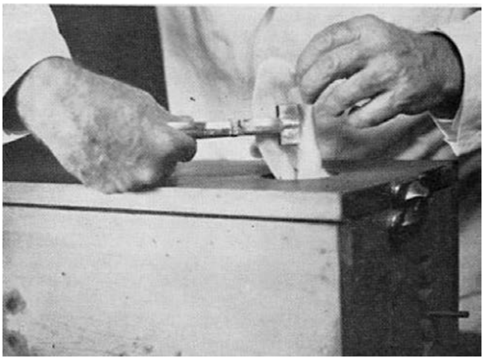


Fig. 4.20. An adjustable tattoo box.

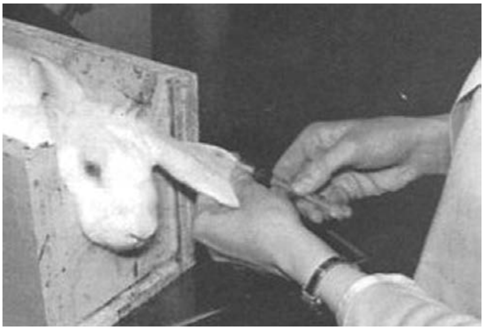


Fig. 4.21. Restraining a rabbit for collection of a blood sample from the ear. (Courtesy of OSU Rabbit Research Center)

Other Equipment

Other equipment needed in the rabbitry may include nail clippers for nail trimming, wire brushes for cage cleaning, and a propane torch or a vacuum cleaner for removing hair from cages. A very useful item is a fish landing net to catch rabbits that may escape.

Further Reading

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5

Rabbit Management

Rabbits vary considerably in temperament and respond readily to kind treatment. If they are handled properly they will be gentle and easy to manage, and these characteristics should be considered in selecting breeding stock. A doe that is fairly aggressive for a few days following kindling should not be condemned if she is gentle at other times. Aggressiveness indicates that she is alert and ready to protect her newborn litter. Some of the does that are the best mothers show this trait. However, if she continues to be aggressive, culling the animal should be considered.

When entering the rabbitry, practice caution so as not to startle the animals. A familiar voice speaking to them will give warning and prevent them from becoming frightened. A background noise, such as the sound from a radio or a fan, is very helpful in keeping rabbits calm.

It should be emphasized that good management is the key to successful rabbit raising. The quality of the stock, the quality of the feed, and the sophistication of the cages, equipment, and building will do nothing to overcome the detrimental effects of poor management. Rabbit production involves a high degree of management skill compared to other livestock endeavors. Cleanliness, ventilation, and close observation of the animals are very important. Close observation is extremely crucial, since early detection may allow correction of problems before they become serious or uncorrectable.

Handling Rabbits

Rabbits should never be lifted only by their ears or legs, for they may be permanently injured. You may lift and carry a small rabbit or fryer comfortably without damaging the pelt or bruising the carcass by grasping the loin gently but firmly, with the heel of the hand toward the tail of the animal. With a medium or heavy weight rabbit, grasp a fold of skin over the shoulder with one hand and place the other hand under the rump to support the weight of the animal (Fig. 5.1).

For carrying, grasp a fold of skin over the shoulder and lift, holding the rabbit against your body with its head under one arm, the forearm being extended along the side of the animal and the hand under its rump for support. This prevents struggling, and the rabbit may be carried comfortably (Fig. 5.2). The aim is not to totally confine the rabbit: rather the rabbit should be held so it feels safe. Gentle handling of rabbits should result in fewer scratching or biting attempts.

Number of Bucks

Traditionally, 1 buck for every 10 does has been used. This underutilizes the buck and increases costs of operation. Research has

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Fig. 5.1. The proper method for lifting medium- or heavy-weight rabbits. (Courtesy of J.I. McNitt)

Fig. 5.2. The proper method for carrying medium- or heavy-weight rabbits. (Courtesy of J.I. McNitt)

demonstrated that the sperm count does not decrease below the level for optimum fertilization even when the buck is used daily for extended periods of time or used three or four times a day for a few days. The buck's only purpose in a rabbitry is breeding. If he is not used often, he may become fat and lazy. If 1 buck is kept for 10 does and your rebreeding interval is 35 days, the buck is only used 10 times in 66 days (35 + 31 days gestation). This means it works about once a week. One buck could service 66 does if it were used daily. With a shorter breeding interval, more bucks are needed. Many commercial rabbit raisers are now keeping 1 buck for 25 to 30 does.

The bucks should not be overfed. They should be on restricted feed, but when they are working hard and during cold weather, they should be fed more. The greatest causes of decreased libido (sexual desire) in bucks are being overweight and high ambient temperatures.

Age to Breed

Individual rabbits vary somewhat in the rapidity with which they develop, so both development and age must be taken into consideration in determining the proper time to start them in production. Sexually, the smaller breeds mature much earlier than the heavier breeds. The small Polish usually are ready to start production at 4 months of age, the medium weight New Zealand, Californian, etc., at 4½ to 5½ months, and the heavy Flemish Giant at 6 to 7 months.

For best results, junior bucks and does should be fed in such a manner that they will make normal growth, develop strong, healthy bodies, and be firm in flesh when they are to be mated for the first time, without being excessively fat. Bucks should be put into service about a month later than does, as they are slower to mature sexually.

A method of determining sexual maturity in does is to examine the vulva. Does that are ready to breed, regardless of age, are those that have a moist, swollen, reddish-pink vulva. Does that show this condition should readily accept the buck when placed in his cage. When does are not ready to mate, the vulva is small and whitish in color with very little moisture observed.

Breeding Schedule

For production of show rabbits, it may be advisable not to attempt to produce more than two or three litters a year, with the time of matings arranged so that the offspring will be of the proper age and development for the desired show classification.

For commercial meat rabbit production, the objective should be to produce and raise as many marketable fryers per doe per year as possible without overstressing the doe. It takes about 35 offspring per doe per year to meet expenses, or the equivalent of about five litters per year. Fryers may be kept with the doe until marketing at eight weeks, but the trend now is for earlier weaning and earlier breed-back, to attempt to increase productivity. Many producers now breed back at 14 or 21 days. In intensive production systems, does may even be bred within 24 hours of kindling. It is remarkable that does will rebreed immediately after giving birth; in fact, their receptivity is very good at that time. Under post-partum breeding systems, litters must be weaned at 28 days, so the does can be given nest boxes in preparation for kindling three days later. No other type of livestock has such a potential for high reproducibility as the rabbit. However, this system may increase the percentage of does that are culled annually. Intensive breeding increases nutritional requirements, so a high-quality feed is needed. Intensive breeding is not recommended for new rabbit raisers. Probably a 35- or 42-day breed-back should be first selected if satisfactory results are obtained. This can be shortened to a period that suits the producer and his or her management skills. With early breed-back, more cages are needed than when does and litters are kept together until marketing of the fryers. This increase in caging costs may be more than compensated for by increased production. Research studies on the "best" weaning age have given mixed results. Work at Oregon State University suggested that highest profits were obtained when all cages were filled with producing does rebred 42 days after kindling. Kits were left with the does until market age; therefore, no cages were used for finishing fryers. Other studies have shown that greatest profits were obtained when does were rebred 14 days after kindling.

Various breed-back schedules, such as 7, 14, 21, 28, 35, and 42 days, are used. Generally, does are on a seven-day schedule basis, simply for ease of recordkeeping. A system that may produce greater profits and longevity of the does is to breed "depending on condition," taking into account the number of offspring in a litter and the condition of the doe. If a doe has a small litter (less than four for medium breeds), she might be bred back in seven days if she is in good condition. However, if she has a large litter, is milking heavily, and is beginning to lose flesh, she should not be bred back until the young are weaned. It is generally agreed that breeding back at 21 or 28 days results in reduced conception.

One of the best methods to judge the body condition of a doe is to use the sense of touch. It is difficult to tell the body condition of a doe by visual examination because of the fur. Put your hands on the doe's back and feel the back-bone and the hipbones. If these bones are prominent, the doe is in poor condition. If she is bred in this condition, she might conceive, but the next litter may be born weak or small in number or weight, or she may abort or resorb the litter. The best thing to do if the doe is in poor condition is to delay breeding until her condition improves. In commercial herds it may be best to cull the doe.

The opposite problem can occur with junior does, which can very easily become overweight, especially if they are on full feed. If they become fat (again, you can tell by feeling the body with your hands), they will not breed. They should be put on restricted feed until they reach normal condition. This can take several weeks to several months. It may be more economical to cull fat junior does and replace them with does in proper condition.

The Mating Process

The doe gives evidence of being receptive by behaving restlessly; by rubbing the chin (chinning) on the cage, water crock, feed troughs, etc., and by making an effort to join other rabbits in nearby cages. The appearance of the vulva, whether it is pale or reddish in color, is generally indicative of the receptivity of the doe. A doe with a dry, pale vulva is less likely to be receptive than one with a pinkish-red, moist vulva.

The doe may object to another rabbit being placed in her cage and quite often will attack and even injure the intruder, so she should always be taken to the buck's cage for mating. If the doe is ready for service and the buck is active, mating should occur almost immediately (Fig. 5.3). When it is completed, the buck usually falls over on his side (Fig. 5.4). The buck's ejaculation occasionally misses the vagina. If there is evidence of this, the doe should be bred again before being returned to her cage. Studies have shown that allowing the buck to breed the doe two or three times when first placed in the buck's cage will possibly increase the conception rate and perhaps the litter size. This may be due to the additional stimulation causing a stronger ovulatory response.

Sometimes a doe will squat in the corner of the cage and will not accept service; in this case, restraining her for mating may expedite and ensure service. This procedure makes many matings possible that would not occur otherwise. Restraining her, however, does not necessarily mean she will conceive. The conception rate from an assisted mating may be much lower than from unrestrained mating.

Fig. 5.3. An example of natural mating. (Courtesy of D.J. Harris)

Fig. 5.4. When mating is completed, the buck usually falls over on his side. (Courtesy of J.I. McNitt)

Figure 5.5 shows the proper method for restraining the doe. Either the right or left hand is used to hold a fold of skin over the doe's shoulders; the other hand is placed under her body and between her hind legs. The thumb is placed on one side of the vulva, the index finger on the other, and the skin is pushed gently backward while avoiding any pinching of the vagina. This procedure throws her tail up and over her back. The weight of the doe's body is supported by the hand, and the rear quarters are elevated, but only to the normal height for mating. Bucks accustomed to being handled will not object to this assistance by the attendant, and many does will respond and accept service naturally when the buck mounts. Assisted mating of rabbits should only be used as a last resort.

The buck and the doe should not be left together unattended for more than a few minutes, as the buck may become injured. If mating doesn't occur within a few minutes, it is advisable to put the doe in with another buck. Sometimes she will refuse service with one buck but will readily accept it with another. If she still won't breed, she is probably nonreceptive for that day and should be rescheduled for the next day or the day after.

Gestation Period

The gestation period, or the time from mating of the doe to kindling of the litter, averages 31 days. About 98% of normal litters will be kindled between 30 and 33 days after breeding but a small percentage may kindle as

Fig. 5.5. Restraining a doe for mating. (Courtesy of D.J. Harris)

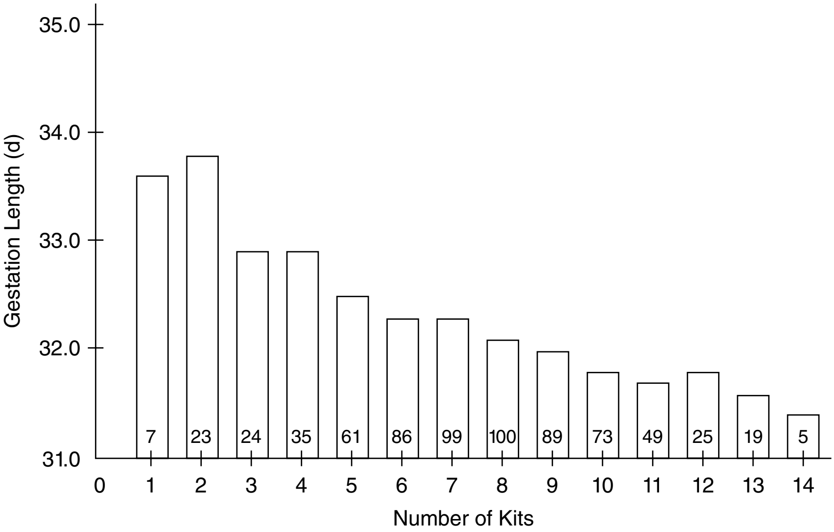


Fig. 5.6. Relationship between number of kits born and gestation length. Figures within the bars show the number of litters of that size included. (Source: McNitt, J.I. and Moody, G.L., 1991. Gestation lengths of four medium breeds of rabbits in Louisiana. *J. Appl. Rabbit Res*. 14: 80–82)

early as 29 days or as late as 35 days. Gestation lengths are generally longer with smaller litters (Fig. 5.6). In cases of prolonged gestation, the litter may contain only a few individuals with one or more abnormally large kits. Often the young may be born dead.

Factors Preventing Conception

There are many factors that influence conception rate. Sterility, extreme age, poor physical condition, pseudopregnancy, poor genetic quality, sore hocks, injuries, retained fetuses, and disease are among the most important factors. Pay special attention to the physical condition of the doe. If she is too thin, you are probably underfeeding, or if she's too fat, you're overfeeding. Both conditions have negative effects on reproduction. Intensive breeding (on a 14-day or less remating schedule) can cause a doe to lose weight and condition, thus reducing her ability to conceive.

Sterility

In its natural environment the wild rabbit breeds during the spring and early summer and is barren during the fall and winter. During this barren period the doe's ovaries become somewhat shriveled and inactive and fail to produce normal egg cells; bucks may fail to produce sperm, or the sperm may lack motility or be abnormally developed. In creating the domestic rabbit, humans have shortened the barren period somewhat. Its duration and intensity vary considerably. Some does and bucks are fertile throughout the year and for successive years. Others are not fertile for extended periods. When does are out of production for an extended time, it is more difficult to get them to conceive; but if the herd has received proper care, a large percentage of both does and bucks should be over the barren period in a short time. In extreme cases, however, the period may last four to five months. Usually, such a prolonged period occurs in an area where excessive temperatures have prevailed, especially when unseasonably or excessively high temperatures occur and continue for some time or when the high temperatures are associated with drought conditions. Indications are that sperm production of the bucks is more likely to be impaired by these high temperatures than ovulation in the does, but both sexes can be affected.

Another cause for prolonged sterile periods may be that the ration has not been properly balanced or that the proper amount of feed wasn't used to keep the rabbits in desired breeding condition. While an animal is molting, the development of a new coat may tax its vitality, and conception may be delayed. Occasionally an animal is permanently infertile and should be culled.

Because there is so much variation among does and bucks in regard to the regularity of breeding, the rabbit breeder may well give considerable attention to overcoming this factor through proper selection of breeding stock. Breeding stock should be selected from parents that produce regularly. Attempts to increase production during the sterile period using vitamins and other feed supplements have not been effective.

During the late autumn and early winter, when the percentage of does that conceive is below that of the spring and summer, the birth weight of the young may be below normal, litters may contain fewer individuals, and the does may neglect their young or the young may be too weak to nurse. A decrease in conception in the winter may be caused by inadequate feeding. In the cold of winter in unheated rabbitries, the rabbits use more of their daily ration to produce heat to keep warm. Therefore, less energy is available for reproductive processes. To offset this increased body heat demand, the daily feed allotment to does should be increased by about 25 to 50% in the winter.

One of the most important factors that influences seasonal fertility is the lighting program. In the wild, the rabbit is a seasonal breeder; this pattern is possibly regulated both by temperature and by light. During the fall, as day length decreases, a light-sensitive gland, the pineal gland, detects the decrease in light and decreases the secretion of certain reproductive hormones by the pituitary gland at the base of the rabbit's brain. By maintaining a longer day length in the rabbitry through the use of artificial lights, you may be able to prevent this winter decline in reproduction. A lighting period of 16 hours per day seems adequate in most regions; the length of the lighting period should be as long as the longest day in your region. This is the principle used in the poultry industry to keep birds laying in the winter. Hand switching of the lights is too unreliable and irregular to give good results. An electric timer should be used to regulate the day length. Note that in the winter, extra hours of light will be required in the morning as well as in the evening. A great deal more research is needed to elucidate the role of environmental factors such as temperature and light in controlling rabbit production.

Young does and bucks may be sexually immature, while other does and bucks may be too old, having passed their period of usefulness. The proper age for rabbits to be put into production was discussed earlier, and the animals may be retained in the breeding herd as long as they maintain good physical condition and produce satisfactory litters. This may be until they are 2½ to 3 years old. There is wide variation, and some individuals may reproduce satisfactorily for 4 years or more. However, in some commercial herds, up to 100% of the does may be replaced each year.

A high culling rate may be desirable to continually upgrade the herd. If proper selection procedures are used, each buck and doe that is culled can be replaced by a younger animal of higher genetic quality.

Physical condition

Rabbits that are abnormally fat or thin may have impaired fertility or they may become sterile. The ration should be adjusted and breeding delayed until they are in the proper physical condition. For those that are too fat, the pelleted diet should be restricted and a limited quantity of a good-quality hay fed. For those that are too thin, the complete pellets or a grain and hay ration should be fed in increased amounts.

Pseudopregnancy

Pseudopregnancy can result from a sterile mating, or from stimulation caused by one doe riding another, or by a doe riding the young in her own litter. This condition lasts for about 17 days. During this time the doe may not conceive. If does have been kept in groups, they should be separated and put into individual cages at least 18 days before being mated. Pseudopregnancy is discussed further in Chapter 11.

Sore hocks or injuries

Sore hocks or injuries may affect the vitality of does and bucks. Rabbits should be examined carefully before being mated, and if any signs of these conditions are found, the affected animals should be isolated and held in quarantine until completely recovered or be culled from the herd. Because susceptibility to sore hocks is genetic and damage to the feet is permanent, affected animals in commercial herds should be culled. Bucks with sore hocks may refuse to breed, because the weight is shifted to the hind feet during mounting, which makes mating a painful experience.

Retained fetus

In some cases, a doe may fail to deliver the entire litter, and the fluids of the retained fetuses will be resorbed and mummified fetuses produced remain in the uterus, usually causing permanent infertility. These cases can be diagnosed accurately by palpation. Because the doe will seldom conceive again, she should be culled from the herd. As is discussed in Chapter 11, the development of mummified fetuses is one of the dangers of using test-mating as a means of pregnancy diagnosis.

Determining Pregnancy

Test-mating does by returning them to the buck's cage to determine pregnancy is not a dependable practice. Some does will accept service again after they have conceived, and others will not accept service even though they have not conceived. Noting the development of the abdominal region and the gain in flesh by the doe as the period of gestation advances is not always accurate and will delay a definite diagnosis until late in the period.

Palpating the abdomen with the thumb and index finger to feel the development of the young in the uterus is an accurate and quick method for determining pregnancy. To make this test, restrain the doe by holding a fold of skin over the shoulders in either the right or left hand, with your free hand placed under the body slightly in front of the pelvis (Fig. 5.7). To make the test accurate, you must relax the doe so the abdominal muscles will not be tense. Generally, you can hold the doe in the air or place the doe on top of the cage for palpation, although the latter method is more secure. If it is necessary to use a table or cart, cover the top with a feed sack or carpeting to prevent the doe from slipping.

You must be acquainted with the relative size and location of the uterus and the embryos as pregnancy advances. Figure 5.8 shows the position of the uterus (the digestive tract has been removed) and illustrates the size of the uterus of a non-pregnant doe (left) and of a doe at the end of 10 days of pregnancy (right). It should be noted that the uterus has expanded to accommodate developing embryos; as the period of gestation advances, the embryos grow larger and the uterus is pushed forward as shown in Fig. 5.9.

There is little danger in palpating, provided it is done at the proper stage of fetal development and the proper technique is followed, but you must use caution and not put too much pressure on the tissues, in order to prevent injury to the developing embryos. The test will be more accurate and there will be less danger of injury if the examination is made

Fig. 5.7. Palpating a doe for pregnancy. (Courtesy of J.I. McNitt)

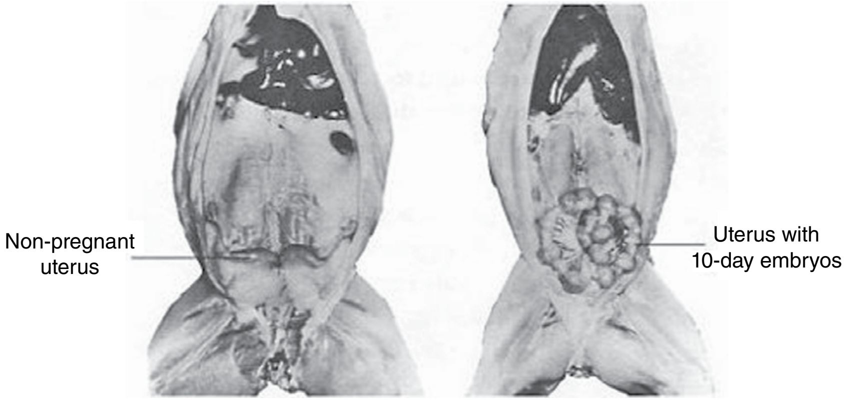


Fig. 5.8. Specimens showing the relative location and size of the uterus of a non-pregnant doe (left) and of a doe that is 10 days' pregnant (right). (Courtesy of USDA)

Fig. 5.9. Specimens showing the relative location and size of the uterus and developing embryos at the end of 14 days (left) and 25 days (right) of pregnancy. (Courtesy of USDA)

about two weeks following mating. Between the tenth and twelfth days of pregnancy, the embryos are each about the size of a small marble and are distributed in the uterus as indicated in Fig. 5.9 (left). With the thumb placed on one side of the uterus and the index finger placed on the other side, apply sufficient pressure to note the marble-shaped bodies, or embryos, by allowing the thumb and finger to slide over them gently. If the technique has been perfected and no developing embryos are found, the doe should be returned to the buck's cage for another service. Sometimes does will not rebreed 10 to 12 days after the original breeding because of pseudopregnancy. The vulvas of these does should be checked daily and the does bred when the color of their vulvas turns red or pink (usually about 18 days after the original service). Non-pregnant does should be kept on a ration that is suitable in quantity and quality for dry does until they are known to have conceived or are culled.

After a few days, the inexperienced person should re-palpate the does that were diagnosed as non-pregnant. If a mistake was made at the first handling and a doe is now found to be pregnant, she should be placed immediately on a management regime that is suitable for pregnant does.

Day 12 of gestation is probably the best stage to learn to palpate. After the fourteenth day it is more difficult to distinguish between the developing young and fecal balls in the digestive organs when palpating (Fig. 5.9, right).

After the technique has been developed, however, it is possible to determine pregnancy by the tenth day. You can avoid confusion by remembering that, with the animal in the proper position for palpating (Fig. 5.7), the uterus lies at the bottom of the abdominal cavity, with the large intestine above it and nearer the backbone of the animal. Palpation should not be done earlier than 10 days following mating. The reason is that the embryos become attached to the uterus (implantation) around day 7 and this bond is quite fragile.

As you gain proficiency in the practice and become better acquainted with the anatomy of the organs in the abdominal cavity, it is possible to identify retained or mummified fetuses and the presence of abscesses or cysts in the reproductive tract. When any of these conditions are detected, the doe should be culled.

It is a good idea to re-palpate does at the time the nest box is added to the cage (usually 28 to 29 days after breeding). The reason for the second palpation is that occasionally does will conceive normally but later will resorb the embryos. If the fetuses die before 19 days of gestation they are resorbed, whereas if they die after 19 days of gestation they are aborted.

Palpation for pregnancy is a must for commercial rabbit raisers. The profit of an operation depends on the production of live litters on schedule. Palpation at 10 to 12 days of gestation saves 21 to 22 days of feed and labor, because if the doe is found to be non-pregnant, she can be rebred immediately. Palpation requires some skill and much patience to learn.

Kindling

The nest box should be placed in the cage 28 or 29 days after the doe has been bred. It should contain bedding of hay, straw, shavings, or similar material. The doe will make a nest of these (Fig 5.10), after which she will pull fur (Fig 5.11) from the hip area, the dewlap, and around the mammary glands to complete the nest (Fig. 4.17). Care should be taken when inserting the nest box to ensure that it is not

Fig. 5.10. A doe making a material nest. (Courtesy of USDA)

placed in the doe's latrine area or where the waterer may drip into it.

A doe will usually consume less feed than normal for two or three days before birth. A small amount of green feed each day may tempt her appetite and have a beneficial effect on the digestive system. She should be made as comfortable as possible and should be undisturbed at the time of kindling. A majority of the litters will be kindled during the night. Both the anterior or breech presentation are normal, and as a rule there are no complications at delivery if the fetuses are normal in size. Occasionally there may be only a few kits in the litter, and in these cases one or more may be abnormally large and kindling may be delayed a day or two.

As each kit is delivered, the doe licks it and may nurse it immediately. When the entire litter is kindled, she pulls more fur from her body and covers the litter.

A normal litter that is clean and has full stomachs and a comfortable nest has made a good start in life. If a doe has not kindled by day 32 to 34 of pregnancy, one method that may be used by experienced breeders is to inject the hormone oxytocin to induce labor. Kindling usually occurs within five minutes after the intramuscular injection of 2 units of oxytocin (1 unit for dwarf breeds). If the doe has not built a nest, some excess fur can be taken from other nest boxes to make one. Does induced by oxytocin rarely kindle in the nest box, so the kits should be picked up as soon as they are born and placed in the box. The doe will usually accept the litter.

Fig. 5.11. A doe pulling fur and making a nest for the forthcoming litter. (Courtesy of J.I. McNitt)

Care of Young Litters

Following kindling, the litter should be inspected and any dead or deformed young removed. If this inspection is done quietly after the doe has left the nest box, the doe will not be disturbed and there is no danger of her injuring the young. It is a myth that if one touches the litter that it will be abandoned by the doe. Perhaps this is true of wild rabbits. Examine the kits to make sure they have nursed, as will be shown by full stomachs. A full stomach appears as a white band (the so-called milk line) seen beneath the surface of the abdominal skin (Fig. 5.12). If a doe does not feed her litter or has not produced enough milk, the litter should be fostered to other lactating does. Does that repeat this abnormal behavior with the next litter should be culled.

Occasionally the kits will become separated and will form two groups within the nest box. With small kits, there is danger that only

Fig. 5.12. One-day-old kits. The one on the left is a “starve out” which has not nursed, whereas the one on the right has a full stomach. Kits that have nursed have a visible “milk line” in their stomachs. (Courtesy of H. Ch. Loliger)

one group will be fed. When this happens and one group of kits does not appear to be cared for, rearrange the bedding into one nest, with the depth of the nest and the fur covering regulated to keep the young comfortable. A large litter sometimes becomes split, but the doe cares equally well for both groups. If this is the case, no intervention is required. Make sure that there is bedding under the young and that there is good drainage from the nest box. If there are too many in the litter, transfer some to other litters (fostering), or if there are too few, bring in young from other litters. Fostering should be done a day or two following kindling and between litters that do not vary more than one to three days in age. Some does will accept kits of varying ages. The goal should be to form nursing groups of similarly-sized kits with no more kits than available nipples.

Sometimes a doe fails to pull enough fur to cover her litter during cold weather. When you discover this, add fur from another litter or pluck fur from the doe's body to cover the young before they are chilled. The fur is easily plucked at kindling time. If the temperatures are high and the doe pulls an excessive amount of fur, adjust the covering to the quantity needed to keep the newborn litter comfortable and save the surplus fur for an emergency when more may be needed for other litters. Inspect the litter periodically to make sure that the nest remains warm and dry and that dead kits are promptly removed.

Nest Box Management

To be satisfactory, a nest box should provide seclusion for the doe during kindling and protection and comfort for the litter afterwards. There are many types, and no one nest box is suitable for use in all rabbitries and in all seasons. Different kinds are discussed in Chapter 4, "The Rabbitry and Its Equipment."

The bedding material should be pliable, absorbent, and of the type the doe can mix with the fur she pulls from her body, with the choice depending upon availability and upon type of nest desired. Straw, hay, wood shavings, leaves, cottonseed hulls, etc., can be used so long as it is not too coarse. If the does are being fed a ration consisting only of pellets, they may eat any palatable material used for bedding. Soft wood shavings or unpalatable bagasse may be used. During the warm season, less bedding is needed. When low temperatures prevail, the nest box should be filled more completely with bedding material.

Shredded paper is a poor absorbent, excelsior is harsh and does not mix readily with the fur, and both of these materials may cause suffering or death of the kits by becoming wrapped around their legs or necks. Shredded redwood bark and peat moss stain the coats, and the dust from them irritates the respiratory tracts of the young rabbits.

It has often been said that "the litter is made in the nest box," and during the time the young rabbits spend there, their weight should increase seven- to eight-fold. A very important aspect of this is the milking ability of the doe, which can be assessed by the 21-day total weight of the litter.

Kits will begin to develop hair within about 4 days after birth, and the eyes will open at about 10 days. The nest box may be removed when the litter is 15 to 21 days old, but the time for taking it out should be determined by the weather conditions. If it is necessary to keep it in the cage longer, it should be thoroughly inspected periodically and any soiled bedding replaced with clean material. The longer the nest box is left in, the more likely that eye infections and other disease problems will develop, so the nest box should be removed as early as possible.

Does usually nurse their litters once per day, usually in the early morning hours. One management practice used quite extensively in Europe is to remove the nest box and put the litter in with the doe for only about five minutes per day. She usually jumps in and feeds the kits. Removal of the nest box reduces mortality caused by the doe jumping in several times a day and trampling some of the litter. With the use of a front-loading nest box (Fig. 4.18), the opening can be closed to keep the doe out except for a once-per-day nursing.

After the nest boxes are removed, they should be thoroughly washed and disinfected. They should be stored where wild rodents cannot get to them, as the smell of rodent urine may cause does to refuse to use the nest boxes.

Fostering Young

Frequently, does give birth to a larger number of young than they can nurse. It is good herd management to foster a doe's excess kits to another doe with a smaller litter. Some studies demonstrate that does have optimal performance if they raise between 6 and 9 kits in the litter. In raising Angoras or rabbits for the meat market, there is a distinct advantage in reducing the size of a large litter to the number that the doe can develop uniformly. In the case of show rabbits, it is especially important to reduce the litter even to four or five so that the young can have an opportunity to develop to the maximum of their inherited possibilities.

In order to distribute the transferred young for fostering, it is advisable when planning the breeding program to mate several does each breeding day so that several will kindle at about the same time. Each newborn litter should be inspected as soon as possible after the doe has quieted down following kindling, and a notation made of the number to be removed from or added to each litter. When all the does due at that time have kindled, the surplus young should be removed and permanently marked with a tattoo, ear punch, etc., so that the transferred young in each litter can be identified at weaning. If all the kits are to be marketed as fryers, identification may not be necessary.

When transferring the young, it is not necessary to use any method for destroying the scent of the human hand or the scent of the dam of the young being transferred. Does do not make any distinction of young, even if they are of different colors or sizes (Fig. 5.13). Fostering is more successful if the largest kits are moved to the new doe and the smallest left with their mother.

When selecting litters for fostering, it is advisable to watch carefully for any evidence of infection among the litters or does, as the transfer procedure could be a means for spreading disease. Under no circumstances should kits be fostered from a doe with mastitis to another doe, because the young can carry the bacteria and may infect the mammary glands of the foster mother.

Fig. 5.13. A Palomino doe nursing kits of a different breed. Does readily accept fostered kits even if they are of different sizes and breeds. (Courtesy of J.I. McNitt)

Causes of Losses in Young Litters

Disease accounts for only a small percentage of the mortality that occurs the first week following kindling. Most losses during this time are due to improper equipment or incorrect feeding and management methods. Some cases may be due to the doe failing to kindle the litter inside the nest box or failing to produce milk. In the latter case, you can diagnose this by feeling the doe's mammary tissue to determine whether it is producing milk (Fig. 11.6). If it is not nursing the litter, the milk glands will be undeveloped and the young will be shriveled and wrinkled. If she is nursing the kits, the udder will be well developed, and when the teats are stripped, there will be evidence of milk. The well-nourished young will be plump, and the milk line may be detected through the abdominal wall, depending on how recently they have nursed. If the doe has not produced any milk, it may be because the ration she received during the gestation period was inadequate in quantity or quality.

For a variety of reasons, does having a first litter often do not use the nest box and have their litter on the floor of the cage. Does should not be culled at this point, but if a doe has her second litter “on the wire”, culling should be considered. The use of drop nest boxes helps to reduce the problem.

At kindling you will obtain better results by making it possible for the doe to be secluded and undisturbed. Many losses of new litters are caused by the presence of strangers in the rabbitry when the doe is due to kindle or by the presence of strange cats or dogs or the natural enemies of the rabbit, such as opossums, rats, and snakes. These predators sometimes cause trouble in the city as well as in the country. Even if they cannot gain access to the cage, they may be so close that the doe can detect their presence, and instead of going into the nest box to kindle, she may kindle on the cage floor. If she has already kindled when she discovers the presence of predators, she may jump into the nest box in an attempt to protect her litter, and because she is frightened, she may stamp with her hind feet and crush her young. The predators seek more food when nursing their own young and, consequently, cause more trouble in the rabbitry in the spring. Evidently, they can locate the cage where a doe is kindling or where a litter has just been delivered by the scent of blood. The losses are more likely to occur at night, and the presence of the intruders may not be detected by the caretaker. The rabbits, however, generally give warning by stamping their back feet, and if this warning is heard, an immediate inspection of the rabbitry should be made.

Feeding the Doe after Kindling

Does reduce their feed intake prior to kindling. This may in part be due to a reduced gut capacity caused by the presence of the fetuses in the body cavity. Following kindling, as lactation begins, their feed intake increases markedly. It is desirable to gradually increase the amount of feed offered to a doe for the first week or so following kindling until full feed intake is reached. Sometimes a young first- or second-litter doe will suddenly die when the litter is one to four days of age (young doe syndrome). This may be due to a stomach hairball, which can reduce feed intake to zero. Ketosis (pregnancy toxemia) is another cause owing to insufficient energy. Sometimes apparently healthy litters will suddenly die at five or six days of age. This may be due to milk enterotoxemia, caused by overfeeding the doe following kindling. Be sure not to overreact and underfeed the doe, as this may reduce milk production excessively.

If an intensive breed-back system (7 to 21 days) is used, consideration should be given to keeping a doe on full feed once she goes into production. With the advent of high-fiber medium-energy diets, dropping the doe back to a restricted diet during the last part of gestation after weaning the first litter may be unnecessary. In fact, the energy demands of almost continuous gestation and lactation may necessitate continuous full feeding.

Weaning

Litters may be weaned as early as 28 days of age. Milk production is declining by then, and the young are consuming solid feed well. Feed is used more efficiently if it is eaten directly by the fryers rather than eaten by the doe and converted to milk. There is some stress at weaning, which may cause the fryers to go off feed and lose weight for a few days.

Be sure that the weaned rabbits know how to drink. If, after the first day of weaning, they have not eaten much, it may be a water problem. Put in a water crock; if they rush to it to drink, then you know they haven’t learned to drink from the automatic waterers. Put a toothpick in the valve or loosen the valve to make it drip slightly. This should quickly teach them to drink. Another method is to put in one or two older fryers to teach the newly weaned litter how to use the water valve. Weaning at an older age reduces this problem.

Determination of Sex

The sex of the young rabbits may be determined accurately a day or two following kindling. Sexing at that time is necessary when one sex may be needed to supply a market for either does or bucks for breeding purposes, when rabbits are being produced for laboratory work, or when Angora bucks are to be kept as “woollers,” in order that any surplus to be crossfostered to other litters will be the undesired sex.

The external organs of both sexes of the newborn rabbits have very similar appearances, and a special technique is required for identification of sex at an early age. To prevent the continual wiggling of the little rabbit, restrain it firmly but gently. Place it on its back in the palm of your hand, with its head extended toward the heel of the hand. Use the index finger to press the tail back and down. Press down on the sexual organs gently but with enough pressure to expose the reddish mucous membrane that, in the case of the buck, can be made to protrude sufficiently to form a circle; in the case of the doe, it will protrude and form a slit that will have a slight depression at the end next to the anus. In addition, the distance between the penis and the anus is greater than the distance between the vulva and the anus.

Until the technique of sexing rabbits has been perfected (Fig. 5.14), it may be a good plan to sex the young at weaning and then practice with several at about three weeks of age. In the older rabbits, the vulva will have a definite slit appearance. The penis will develop a more tubular appearance. This will make it easier to determine the sex of the three-week-old rabbit. Constant irritation of the tender parts may be detrimental, so sexing should not be practiced on the same rabbit at short intervals.

Tattooing and Ear Tags

An efficient, permanent system for identification is a necessity. Tattooing figures or letters, or a combination of the two, in the rabbit’s ear does not disfigure it, is permanent, and is easily accomplished. When young are being fostered, a hand tattoo needle is satisfactory for making one or more dots in each kit’s ear so the transferred young can be identified. It is also used by many breeders for the regular tattooing work in the rabbitry; others prefer the plier

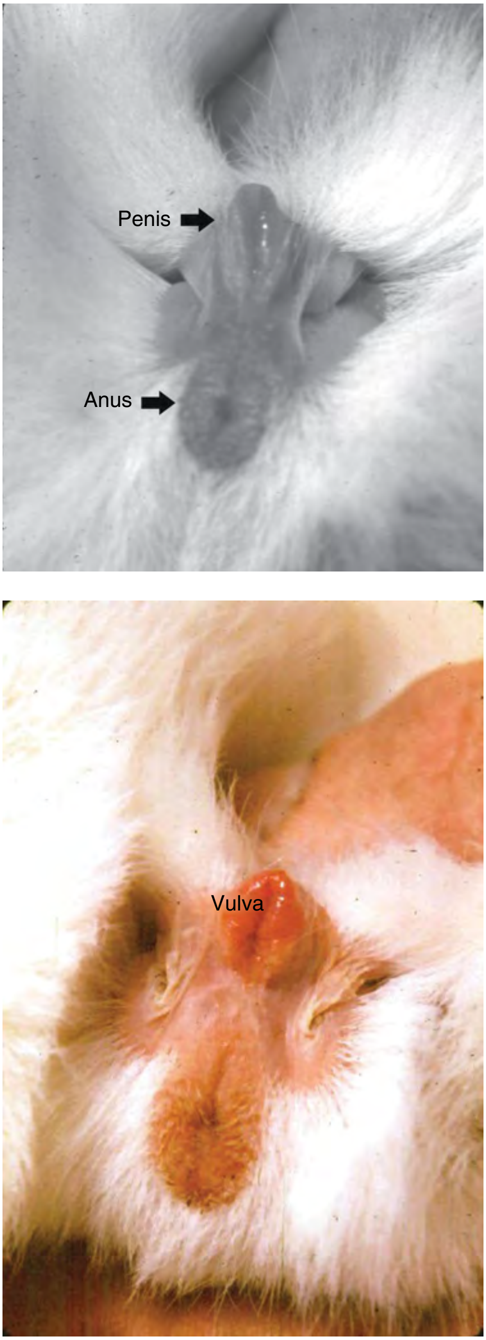


Fig. 5.14. External genitalia of the male (upper) and female (lower) rabbit. (Courtesy of D.J. Harris)

or tongs with removable figures and letters. After the inside of the ear is thoroughly cleaned with alcohol, either instrument may be used to perforate the inner surface of the ear. Tattoo ink or India ink should be rubbed into the perforations immediately (Fig. 5.15). The registration number for purebred stock is usually tattooed in the right ear and the rabbit's individual mark or number in the left ear. A tattoo box that has movable parts so it can be adjusted to different sized rabbits (Fig. 4.20) holds the animal steady so one person can do the tattooing.

Rabbits can also be identified by the use of ear tags. These are produced as wing bands for chickens and are available from poultry supply houses. They are easily inserted using a simple tool (Fig. 5.16). Ear tags are sometimes lost, so identification is not as permanent as with tattoos. One method to make ear tags less vulnerable to loss is to fold the ear and insert the tag halfway across the fold. When the ear is straightened out, the tag will be in the middle of the ear and have less chance of snagging on something and tearing out. For temporary identification, marking the ears with a felt-tipped pen is useful.

Fig. 5.15. A permanent identification mark tattooed in a rabbit's ear (Courtesy of J.I. McNitt)

Fig. 5.16. An ear tag for easy identification. (Courtesy of J.I. McNitt)

Care of the Herd in Hot Weather

Rabbits must be protected from rain and sun. Good circulation of air throughout the rabbitry is a must, but strong drafts and winds should be avoided. It is essential that the animals have a supply of water available at all times. Temperature, humidity, and air currents all have a direct bearing, and are an individual problem to each rabbitry. Adequate shade should be provided.

Rabbits suffer more from heat than cold; it is necessary to give the herd special attention during periods of high temperatures. They are more uncomfortable in high temperatures the first few hot days in the season. Does that are well advanced in pregnancy and newborn litters are the most susceptible to injury. The does give evidence of suffering by excessive moisture around the mouth and nose and occasionally bleeding from the nostrils, rapid respiration, and restlessness; newborn litters by extreme restlessness. Rabbits that show symptoms of suffering should be removed to a quiet, well-ventilated place. Considerable relief can be given by placing a wet cloth in an animal's cage for it to lie on. In the case of the doe that has advanced to the stage where bleeding is occurring and quick action is necessary, placing cracked ice between the folds of a wet cloth and placing it in the cage so she can lie on it is quite effective and may save a doe about to kindle. Immersing the entire animal in cold water for three seconds is another emergency measure to save a heat-stressed rabbit. On extremely hot days, another method is to dowse each adult rabbit about 3 to 4 times a day with tepid water from a hose. This can be done from the front or top of the cage without removing the rabbit from the cage. It takes about 4 hours for a rabbit to reach a critical physiological state of being severely heat stressed, so the regular dowsing can prevent this from occurring. Many rabbit breeders freeze two-liter soda bottles filled with water and place them in the cages when it gets very hot.

Sprinkling the roof and floor of the rabbitry may give relief, except in areas of high humidity. If a roof sprinkler is thermostatically controlled, it will take care of quick weather changes and is especially useful if the caretaker is not available for regulating the sprinkler. If it is extremely hot, sprinkling the rabbits is another possibility, especially the does that will kindle in the next day or two. Be careful not to wet any feed in the feeders. Heavily pregnant does do not seem to be able to dissipate the heat as well as other rabbits, and giving them a cool dip or sprinkling with a hose may be the only way to save their lives.

Fur Chewing

When there are several rabbits in a cage and the habit of fur chewing develops, the eyelashes and whiskers are chewed first, then the fur on the head and next on the body. Rabbits that are alone in a cage chew the fur on their sides or back of their rumps and are capable of reaching fur on the sides of their body where it would seem impossible. If rabbits can reach the coat of another rabbit in an adjoining cage, they may chew its fur. Sometimes does chew the fur on their own young. In cases in which rabbits are chewing their own fur or the fur of other rabbits, the coats have an uneven appearance (Fig. 5.17).

Fur chewing is most likely due to a faulty ration or to the rabbits not receiving the proper amount of feed and is usually associated with a ration that does not contain enough fiber. Keeping good quality hay or straw available at all times and feeding small quantities of green

Fig. 5.17. Examples of fur chewing. The dark patches are areas of exposed skin. These rabbits were fed a diet containing sunflower leaves, which contain tannins that react with protein to cause a protein deficiency. (Courtesy of OSU Rabbit Research Center)

feed daily will assist materially in preventing the fur chewing habit from developing. If the feeding of hay does not solve the problem, increasing the protein content of the ration might help. The addition of 2-½ kg of magnesium oxide per ton of feed sometimes aids in the control of fur chewing.

Occasionally rabbits will pull fur from their cage mates because of boredom. This vice is overcome by putting a round can or a wooden block in the cage. The rabbits spend hours chewing and playing with these objects and seem to forget about the fur chewing. Hanging a small block of wood in the cage will also work and will also provide the additional benefit of reducing fighting. This method of prevention does not work if there is a dietary deficiency. In addition, offering a limited amount of greens or hay may also be helpful.

Other Causes of Hair Loss

Hair loss only on the face may be caused by improperly cut wire for feeder installation or rough places on the feeder itself. Such rough spots scratch the rabbit's face, and a bacterial infection (usually *Staphylococcus*) sets in, causing hair loss on the face. Changing the feeder or smoothing the rough spots with emery cloth will alleviate the problem.

Sanitation

Sanitation is very important in controlling disease. Ideally, cages should be cleaned daily. Any manure hanging on the bottoms of cages should be removed with a wire brush. This helps control enteritis and hepatic coccidiosis. A wire brush mounted on a long handle is a handy tool. A battery-driven electric drill with a wire brush head can be mounted on a handle and used for cleaning the bottoms of cages. A plastic toilet-bowl brush will be less damaging to the galvanizing on the wire but will need more frequent replacement. Cages may be brushed or sprayed with a bleach solution (30 ml of bleach per liter of water). Disinfectants are effective only on the surface, so cages must be thoroughly cleaned to remove attached dirt prior to disinfecting. Rabbits excrete large amounts of calcium carbonate in their urine; calcium deposits may build up (Fig. 5.18). Calcium carbonate is soluble in acid, so a mildly acidic solution (e.g., vinegar) will aid in removing these deposits.

Hair should not be allowed to build up on cages and elsewhere in the rabbitry (Fig. 5.19). Hair can be removed from cages by burning with a propane torch. Be careful with a torch, as it can be a fire hazard. Do not use a torch to burn hair or cobwebs off the ceiling or walls. Instead, a vacuum cleaner may also be used for removing hair.

Flies in the rabbitry are a nuisance. It is conceivable that they could be vectors in the spread of diseases such as pasteurellosis, but this hasn't been proven. In an urban or suburban area, the rabbit raiser can be the target of legal action if the rabbitry is the neighborhood source of flies. Flies can be controlled by using screens to keep them out of the rabbitry and using baits and spraying programs to eliminate them if they do gain entrance. Such management procedures as the repair of leaky water valves are important to keep the manure habitat as dry as possible. (This also helps minimize ammonia production.) Insecticides can be of the organophosphate type, such as malathion, or of the natural type, such as pyrethrum products (obtained from the pyrethrum flower). Spray contact with the rabbits should be minimized, especially with organophosphates. A good rule of thumb is to use only spray products that are safe for use around lactating dairy

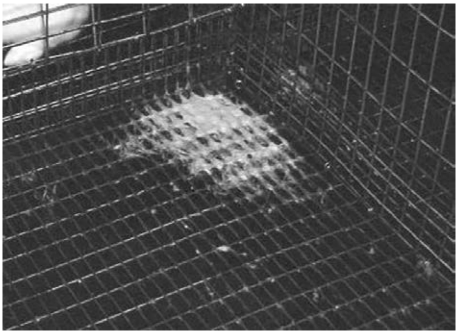


Fig. 5.18. An example of a deposit of calcium carbonate in a rabbit cage. Rabbits excrete large amounts of calcium in their urine. (Courtesy of OSU Rabbit Research Center)

Fig. 5.19. Accumulation of hair on cage bottoms. (Courtesy of D.J. Harris)

cattle. Another method of fly control is the use of natural fly predators, such as beetles and wasps, that can be purchased from commercial sources. The naturally-occurring black soldier fly, *Hermetia illucens*, is also beneficial for fly control in the rabbitry. The females, about the size of wasps, live on nectar from flowers and only enter the rabbitry to lay eggs. They fly close to the ground, lay their eggs in the manure pack, and leave. The larvae are about 2 cm long and are a dirty gray color. They out-compete the filth fly larvae (primarily houseflies and stable flies) for food and will reduce the numbers that hatch. They also will reduce the volume and water content of the manure pack. They are very active and will result in the manure pack moving into the aisles each night. Shoveling the material back under the cages each day is a small price to pay for good fly control.

Growing earthworms in the manure pack will also help keep filth fly populations under control by stirring and drying the manure. However, moisture requirements for worms are much higher than are generally advisable for rabbits, so growing worms under the rabbits may result in increased incidence of pasteurellosis and other respiratory diseases.

A white fungus is often observed on the manure beneath the cages (Fig. 5.20). It is probably harmless, although it is possible that spores released by mature fungi could contribute to respiratory disease of the rabbits. It can be controlled if desired by applying a fungicide to the manure.

Shedding or Molting

The rabbit's coat is prime when the hairs have a good sheen, are tight, and have attained their maximum length. The skin is white and the hair flows back into place evenly when the coat is rubbed from the rump to the shoulders.

Unprimeness is indicated by a dull, uneven coat and loose hair. The hair does not flow

Fig. 5.20. A white fungus is often observed growing on rabbit manure beneath the cages. (Courtesy of P.R. Cheeke)

back evenly when the coat is rubbed from the rump to the shoulders. Patches of new fibers can be seen, and these new fibers will appear in a growth pattern that varies from animal to animal. The skin of these new hair growth areas is dark and easily detected on rabbits with colored coats.

The pattern of shedding in rabbits has not been definitely established. There is a juvenile molt that begins when a rabbit is about two months old and lasts until it is four to six months of age. Heavy feeding of the young tends to cause the molt at an earlier age. In addition, there is the annual molt with mature rabbits. This molt varies in time of appearance in different geographical areas. Rabbits may be thrown into molt by disease, going “off feed,” the sudden occurrence of unseasonably high temperatures, or other stresses. Evidence of molting in the herd is the accumulation of loose hair on the wire sides and in the corners of the cages and the droppings being bound together by embedded fibers.

Shedding first occurs on the sides of the rump and the thighs, followed by the back, then increasingly in areas down over the sides. There is a pronounced degree of similarity in the size and location of the ingrowing new coat areas on both the right and left sides of the rabbit.

A high-quality diet and high feed intake promote molting. The growth rate of hair is more rapid with a high nutrient intake, so the rate of turnover of hair is greater. Restricted feeding of adult show animals reduces the amount of hair shedding and keeps the fur in prime condition for a longer period. Some rabbit raisers claim that molting adversely affects reproductive performance, but this belief is not well substantiated. In fact, little attention is paid to molting in commercial meat rabbit operations.

Environmental Effects on Rabbit Performance

Temperature

Rabbits are very susceptible to heat stress because they have few functional sweat glands and have difficulty in eliminating body heat when the environmental temperature is high. Heat-stressed animals stretch out to maximize body surface area for heat elimination. Animals respond differently to a sudden acute exposure to high temperature than to chronic exposure when reared under high environmental temperatures. In the tropics, rabbits can be successfully raised under conditions in which the temperature is consistently 32° to 35°C (90° to 95°F), whereas rabbits adapted to the cool conditions of the Pacific Northwest of the United States may die of heat stress when the temperature on rare occasions exceeds 32°C (90°F). Animals routinely kept under high temperatures develop metabolic mechanisms to adapt to heat stress. In areas of high temperature, such as the tropics, rabbits consume large quantities of water and consume less feed than in temperate climates. It is also observed that rabbits tend to be smaller and have proportionately longer bodies with thin fur coats and long ears. Such characteristics relate to aspects of heat tolerance. Their productivity is reduced because of the lower feed intake. Provision of adequate water is critical under these conditions. Rabbits that begin to pant or develop extreme wetness around the nose and mouth are in severe heat stress, and immediate corrective action should be taken.

An ideal environmental temperature is 10° to 15°C (50° to 59°F). This is known as the rabbit’s “comfort zone.” At higher or lower temperatures than this, the animal has to expend energy to maintain its body temperature. Rabbits are much more tolerant of low temperatures than high temperatures. A major consideration under low temperatures is that feed consumption is increased so the animal can maintain its body temperature. Thus, the lower the environmental temperature, the poorer the feed conversion, because a greater quantity of feed energy is being used to maintain body temperature. When limited feeding is practiced, provision must be made for extra feed in cold weather. It is significant that, because of the increased feed intake, water consumption also increases as the temperature drops. Restricted availability of water under cold conditions (e.g., from frozen water lines) will reduce performance more than restriction at the comfort zone, because rabbits will not eat if they don't have sufficient water.

An interesting response to cold temperature occurs in some breeds such as the Californian, Siamese Satin, and Sable. If the newborn kits are exposed to cold temperature, or if fur on an adult is chewed or shaved and then the rabbit is exposed to cold, the fur will temporarily grow in black in areas where it is normally white (Fig. 5.21). This occurs because the cold stimulates the formation of melanin pigment in the hair follicles, which causes the hair to be black.

Fig. 5.21. The Californian rabbit on the right had a patch of hair shaved off its rump and was then kept in a cold environment for a few days. The hair grew back in as pigmented fur. (Courtesy of OSU Rabbit Research Center)

Fluctuations in temperature may trigger outbreaks of enteritis. Enteritis outbreaks are sometimes noted following the start of a cold snap. One possibility to account for this is that a sudden drop in temperature triggers an increase in feed intake. This could cause carbohydrate overload, leading to a proliferation of pathogens in the gut, with the production of lethal toxins. Restricting feed or providing coarse hay at the beginning of a cold spell may reduce the incidence of enteritis.

Light

Optimal lighting conditions for rabbit production have not been established. It is believed that the winter decline in fertility that is often observed in some regions of the world may be due, at least in part, to decreasing day length. Use of lights to maintain a total day length equal to the longest day at the particular latitude is recommended. In most regions in the United States, that is in the range of 14 to 16 hours. As discussed in Chapter 4, commercial rabbitries should have lights on a timer and use supplementary lighting both in the morning and the evening to help maintain normal breeding during the fall and winter. It is possible that the spectrum of the light source may also have an influence on animal performance.

Hypnosis

You can readily "hypnotize" a rabbit (put it to sleep) by laying it on its back and gently stroking the chest, abdomen, and sides of the head. When asleep a rabbit is in a trance-like state (Fig. 5.22). Hypnosis may have some value as a means of restraining animals for minor surgery; probably it is mainly used to get the attention of 4-H Club members touring the rabbitry!

Breeding Herd Replacements

An extremely important part of herd management is providing adequate replacements for the breeding herd. In commercial rabbitries it is common to replace 100 to 125% of the

Fig. 5.22. A rabbit that has been hypnotized. (Courtesy of D.J. Harris)

breeding does each year. This does not mean that every doe in the herd is replaced yearly, but it does mean that if you have a 100-doe breeding herd, you will add to this herd 100 to 125 junior does per year. Some cages will have had two or three does during the same year, whereas other cages will have the same doe for two years. In fact, if you are not replacing a sizeable portion of the breeding herd annually, you are probably not improving the quality and health of the herd as rapidly as you should. Snuffles, sore hocks, malocclusion, mastitis, poor reproductive performance, and many other reasons will result in breeding animals being removed from the herd. As a general rule, save one replacement doe per month for every 12 does in production, and one replacement buck for every five bucks in service. The continual replacement of old bucks with young bucks is extremely important. Since each buck is bred to many does, his influence on the genetic quality of the herd is much greater than that of an individual doe. Young bucks tend to have greater libido and will work harder than old bucks. The criteria used in selection of young stock are covered in Chapter 15, "Genetic Selection for Herd Improvement." Proper selection of breeding stock has a great impact on the success of a rabbitry and on the potential for profit.

Herd Records

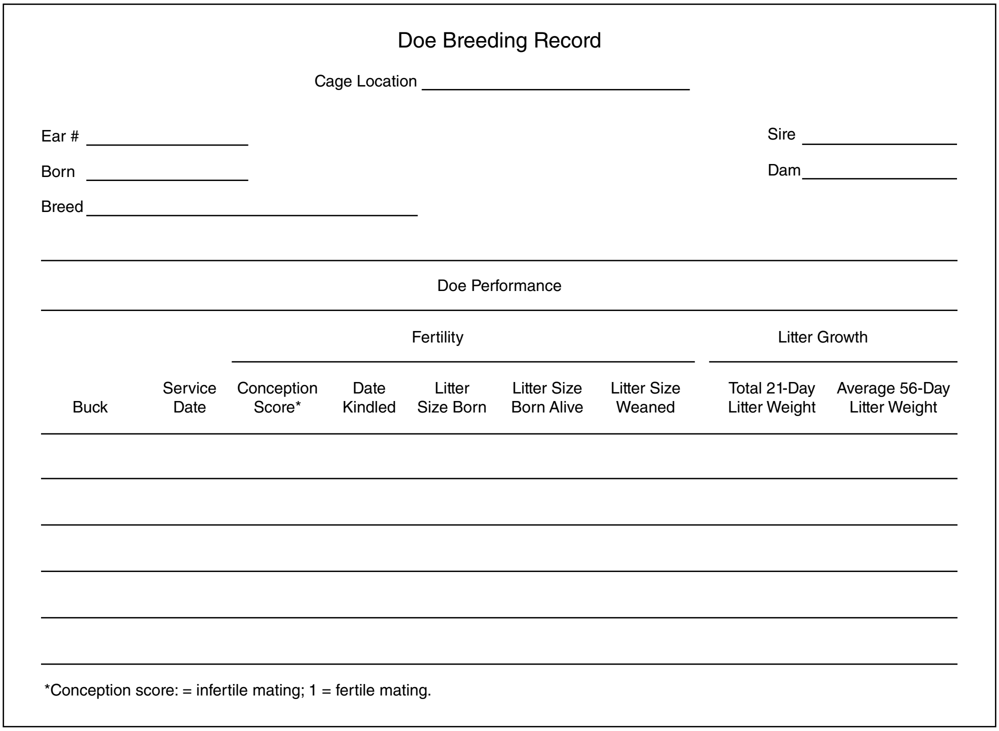
Herd records pay big dividends when selecting breeding stock and culling. A useful and uncomplicated system of records for the commercial breeder and also the breeder of purebred animals involves the use of cage cards for the does, a card for keeping each buck's breeding record, and an extended pedigree record or other permanent record. An elaborate system of bookkeeping is not necessary, but a simple record of income and expense enables the rabbit raiser to determine profit or loss.

Cage cards (such as the one in Fig. 5.23) for making a notation of the date of breeding, buck and doe identification numbers, date of kindling, number of young born and retained, litter number, date and number weaned, and weaned weight of the litter are readily available from feed companies and other commercial sources. Some rabbit raisers may wish to include a record of the weight of the litter at three weeks of age to indicate the doe's milk production. The records that show whether the doe conceives regularly throughout the year, whether she is prolific, and whether she has the ability to properly nurse and care for the litter are especially useful in determining which does are profitable.

Some breeders object to cage cards because during periods of high humidity the cards become limp and fall out of the holders, and the records become illegible. Often the cards become torn, dirty, or lost, making it necessary to keep duplicate records. Cellophane covers will protect them, or information can be transferred to permanent records more frequently. Fifteen centimeter (6 in) pieces of 10-gauge wire bent into a "U" shape and snapped into the channels of the card holders will also help hold the cards in place. These are particularly useful in open rabbitries where birds are a continual problem. Birds have a tendency to peck at the cage cards until they pull them out of the card holders.

The buck record card (Fig. 5.24) is extremely important. It furnishes information as to whether a buck has settled his does throughout the year and information on the relative growth performance and survival rates of his offspring.

Permanent records that contain both pedigree and production information should be maintained for each breeding animal. Information should be transferred to the permanent records when the cage cards are full or at regular shorter intervals. Some rabbit raisers may wish



Doe Breeding Record

Cage Location ____________________

Ear # ____________ Sire ____________

Born ____________ Dam ____________

Breed ________________________

Doe Performance

		Fertility					Litter Growth	
Buck	Service Date	Conception Score*	Date Kindled	Litter Size Born	Litter Size Born Alive	Litter Size Weaned	Total 21-Day Litter Weight	Average 56-Day Litter Weight

*Conception score: = infertile mating; 1 = fertile mating.

Fig. 5.23. A typical doe cage record card. (Courtesy of OSU Rabbit Research Center)

to store herd records on computer media. Commercial computer programs are available for this purpose. In the commercial industry there is a dire need to develop computer programs that can provide a genetic evaluation of all breeding animals for economically important traits, such as those used in major livestock industries. The genetic evaluation procedure uses both pedigree and performance information to compute genetic scores for each animal called expected progeny differences (EPDs). Using EPDs as selection criteria can often result in rapid genetic improvement in the herd. This topic is discussed in more detail in Chapter 15, "Genetic Selection for Herd Improvement."

An extended pedigree includes at least three generations for each buck and doe in the breeding herd and can be supplemented with notes and comments about performance, show winnings, and desirable and undesirable characteristics for each of the ancestors in the pedigree entered on the pedigree blank form. This information is valuable when planning matings for herd improvement. In fact, having an extended pedigree available is the only way to obtain a complete picture of all the factors involved, for it is impossible to remember all essential details. Extended pedigrees are also necessary for use in making applications for the registration of rabbits.

A chore sheet is necessary for good rabbitry management. This is a card, sheet, or computer printout that lists the various chores for the day. It contains such items as does to be bred, nest boxes to insert, does to palpate, litters to weigh, litters to wean, litters from which to select replacements, rabbits to treat for disease, does or bucks to cull, and does to check for new litters. The chore sheet is vital, for it prevents mistakes, such as failing to put in a nest box. It is very discouraging to come into the rabbitry and find a dead litter on the wire because of the failure to put in a nest box.

There are many different methods for arranging chore sheets. Some rabbit raisers will have a daily chore sheet that is kept up daily from the permanent records. Others will set up a weekly chore sheet with each day's chores

Buck Breeding Record

Cage Location ____________________

Ear # ____________ Sire ____________

Born ____________ Dam ____________

Breed ________________________

Buck Performance

		Fertility				Mortality	Litter Growth	
Doe	Cage Location	Date of Service	Conception Score*	Number Born	Number Born Alive	Number of Kits That Died from 1 to 56 Days	Litter Size at 56 Days	Average Litter Weight at 56 Days of Age

*Conception score: = infertile mating; 1 = fertile mating.

Fig. 5.24. A typical buck cage record card. (Courtesy of OSU Rabbit Research Center)

listed. A weekly diary is useful to keep track of necessary chores. Alternatively, a circular calendar can be constructed for this function. One of the advantages of a computer with a good program is that it can print out daily chore sheets on which you merely fill in the blanks and then enter the new information at the end of the day or week as you desire.

6

Economics and Financial Management

Successful commercial rabbit production, like any other agricultural enterprise, requires careful financial planning and bookkeeping. In the United States, commercial meat rabbit raising has rarely been a profitable activity as assessed by normal business standards, which include a salary for the operator and consideration of all expenses. In fact, most rabbit raisers do not consider their labor when calculating expenses, and many still do not show a profit. Often the rabbitry building is one previously used for other purposes, and its value may not be included. Even with free labor and buildings, it is difficult to make money with rabbits. It should be clearly understood by anyone planning to go into commercial rabbit production on a large scale that the record of this business is very poor. The economics of rabbit production in North America make this a high-risk venture. Too often, a prospective rabbit raiser calculates how much money could be made with one doe per year, multiplies that by 10,000 does, and thinks he or she has found an easy way to become a millionaire! It is not the intent of this discussion to discourage rabbit raising but rather to ensure that prospective rabbit raisers enter the business fully aware of the financial limitations and to emphasize the procedures that might aid in attaining financial success.

Financing

There are various ways of financing a rabbit enterprise. The usual sources of capital include the owner's money, money borrowed from a lending agency, and outside equity-money that others invest in exchange for a share of the ownership. In developing countries, there are governmental and non-governmental agencies that typically fund projects that involve groups of people from poor communities.

Most rabbit raisers begin in a small way using their own funds. Many people do not expand beyond this stage. They may regard the rabbitry as a hobby and may be prepared to lose money because they enjoy rabbit raising; it is a means of relaxation, a family activity, etc. They may be perfectly satisfied to contribute their own (or their families') labor at no cost and may use an old building for which they expect no compensation. Their main concern may be to attempt to make enough money from the sale of rabbits to pay for purchased feed.

These attitudes are not suitable for someone planning to raise rabbits as a business. Unless one is independently wealthy, it will probably be necessary to borrow money or obtain equity capital from an outside investor to establish the enterprise. This will require preparation of a loan application, plans for the business, and projections of income and

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expenses. The application process will vary by country and institution. The lender, usually a bank, requires sufficient information in the loan application to ensure that the loan will be a good risk (i.e., that it will be repaid). A lender usually considers the following five factors when evaluating a loan application:

1. Purpose of the loan.
The applicant must be able to provide a detailed explanation of why the loan is needed and how it will be used.
2. Reputation and managerial ability.
The loan applicant must demonstrate that he or she is a good risk by providing evidence of good character, honesty, reliability, and good skills in managing both rabbits and money. The prospective borrower should be well prepared when visiting a banker, rather than merely showing up without adequate facts and figures.
3. Financial statement.
The lender needs to know the applicant's financial status. This requires a statement of current assets (livestock, feed, machinery, cash on hand, etc.), fixed assets (land, buildings, etc.), and liabilities. If the loan is needed for expansion of an existing rabbitry, a balance sheet and cash flow statement for the past several years may be needed. If the current rabbitry has not been a financial success, it is unlikely to be profitable on a larger scale.
4. Repayment capacity.
The lender needs to know whether the rabbitry will generate sufficient returns to meet other expenses (feed, supplies, etc.) as well as interest and principal payments on the loan.
5. Collateral.
The applicant needs to provide collateral to cover the loan in case the business fails or does not do as well as projected. This may include most of the farm assets. Thus, the decision to expand and seek borrowed capital should not be made without considerable forethought and planning.

Expenses

Buildings

It is best to start in a small way and expand the business as you gain experience. Beginning with a large building constructed with borrowed money is usually disastrous. By the time you have finally solved most of the production problems and got the herd producing well, you may be so far behind in payments on the loan that recovery is impossible. Also, you should raise rabbits for a sufficient length of time to be absolutely certain that you like doing so before expanding to the point that you have committed your life savings to the business. The best type of rabbit building is a modular type of structure that can be expanded as needed. It should be as simple as possible, using standard cuts of building materials rather than special cuts. Doing the work yourself will save about 50% on the construction cost. Typically, the cost of the building is US$50 to $100 per cage ("per hole" in rabbit-raiser parlance).

Equipment

Construction of your own cages will roughly save about 50% of the cost (assuming that your own labor is free) over buying pre-assembled cages. Wire in rolls can be purchased directly from the manufacturer. The current cost of a 11.8 × 11.8 cm (30 × 30 in) cage that is uncut in rolls to pre-cut and ready to assemble is roughly $28.00 to $45.00. If the producer does not hire labor to construct or assemble cages, the purchase of wire rolls is a good investment. Feeders are normally purchased rather than built by the rabbit raiser and cost $4.00 to $6.00 each. Components of water systems are purchased and assembled by the operator, at a total cost of about $7.00 per hole. The cost of the cage and its equipment will thus be an additional $39.00 to $52.00 above the cost of the building, for a total investment of at least $89.00 per hole. Purchase of used caging and equipment may reduce costs. However, bear in mind that in humid environments any metal equipment can rust very rapidly. New cages may need to be replaced after only 5 years of use. The purchase of galvanized wire and feeders is a sound investment.

Breeding stock

Unless you are expanding an existing herd, breeding stock must be purchased. Good commercial rabbits should cost about $2.00 per week of age up to $50. As noted elsewhere, it is probably best to buy 8- to 12-week-old animals and raise them to breeding age in your rabbitry. This way, they can adapt to their new environment before they produce. In addition, it may be more cost effective to purchase fewer animals initially and then gradually expand by producing most of the replacements needed to establish the enterprise. Most breeders do not maintain large numbers of replacement animals, so you may have to buy from several sources.

Feed

Feed is the largest single operating cost, making up 75% or more of the total operating expenses. Feed cost is, however, an area where large savings can be made by shrewd buying. The bottom line on feed costs is the cost per kilogram or pound of fryer produced, not the cost per ton of feed. This figure (cost/gain) should be determined on a frequent basis. Buying feed in bulk will save several dollars per ton. A large order of several tons per month (actually a small order when compared to other livestock enterprises) should give the grower some bargaining power for a volume discount.

Labor

Very few rabbitries can afford to hire much outside labor. Even at the minimum wage, hired labor is not economically feasible in most rabbitries, as the example given later will dramatically illustrate.

Miscellaneous expenses

There are many miscellaneous items that will be needed, which can add up to a significant part of the total operating expenses and depreciable costs. Utility costs for operation of lights, fans, and heating or cooling devices; drugs and veterinary expenses; transportation costs for getting rabbits to market; insurance; record cards; small hand tools; cage-building tools; feed buckets; carts; wheelbarrows and shovels; a telephone; magazine and online subscriptions; books; a computer and software – all are examples of the types of costs that need to be included in budget planning. These costs can “nickel and dime” an operation into bankruptcy if they are not built into the projected cost picture.

Income

The major source of income in commercial rabbit production is the sale of animals, including fryers, stewers, laboratory animals, breeding stock, and perhaps pet stock. Other sources of income might include the sale of manure, earthworms, and pelts. Usually, the sale of fryers is the major income-generating activity. The price received for fryers is generally higher in winter than in summer and varies from $2.20–3.20 per kilogram ($1.00-1.45 per pound). Either way, the price is relatively low compared to total expenses. A growing trend is to “cut out the middle-man” by selling either live or custom-dressed rabbits at venues such as farmers markets and restaurants. Because of the Covid-19 pandemic, some states now have rather lax meat inspection laws, especially if the producers do not sell more than 1000 meat rabbits annually.

It is possible to realize a profit in rabbit production, but skilled management is required. Very few beginning rabbit raisers make a profit in the first year or so, which may explain why few growers remain in the business for as long as three years. Rabbit raising is often called “the 18-month industry.” That is about how long it takes for the average new raiser to get discouraged and quit.

With good management it is possible to earn about $20 to $30 per doe per year. However, it is better to calculate this on a per cage basis because, with culling and mortalities, more than one doe may occupy the cage during the year.

Cash Flow

The example in Table 6.1 illustrates the cash flow of a typical small commercial rabbitry of 100 breeding does. At least 160 cages will be needed for does, bucks, fryers, and replacements.

Table 6.1. Sample yearly cash flow for a 100-doe rabbitry.

Expenses			Total cost	Annual cost
	Depreciable	Building (15-year depreciation)	$12,000	$800
		Cages and equipment (5-year depreciation)	6,240	1,248
		Initial herd (2-year depreciation)	2,600	1,300
Total			$20,840	$3,348
	Non-depreciable			
		Feed		$15,360
		Utilities		360
		Insurance		120
		Miscellaneous		300
Total				$16,140
Total Annual Expenses				$19,488
Income	Fryers	3,500@$5.50		$19,250
	Stewers	100@$6.00		600
Total income				$19,850
Net profit				$362

A 100-doe rabbitry will use about 1 metric ton (2205 pounds) of feed per month at an assumed cost of $640 per ton. The utility bill is estimated at $30 per month. Insurance is $10 per month. The building will cost about $12,000 (if built by the owner), and cages and equipment will cost about $6240 (160 holes cost about $39 each, including feeders and water lines and installation). One hundred junior does and four bucks will cost about $25 each if purchased at a young age ($2600 total). Fryers will be sold at $2.75/kg ($1.25/lb) when they reach 1.8 to 2.3 kg (4 to 5 lbs). Stewers will weigh about 4.5 kg (10 lbs) and bring $1.32/kg (0.60/lb). The average well-managed 100-doe commercial rabbitry produces 35 fryers per doe per year and culls about 100 stewers. In other developed countries, such as China, France, Italy, and Spain, fryer production rates per doe are considerably higher due to the use of many intensive practices (e.g., artificial insemination, intense genetic selection, advanced diets, and sophisticated health and reproductive management protocols).

Fixed costs, such as those of the building, equipment, and purchased breeding stock, can be depreciated (amortized) over time. In this example, the building will be depreciated over 15 years, the cages over 5 years, and the breeding stock over 2 years. Variable or operating costs, such as feed, utilities, insurance, and miscellaneous expenses, are deductible in the year in which they occur. Insurance costs would depend on many factors such as location, and liability values as well as deductibles.

It is assumed that 100 replacement does will be needed each year. On average, at least 100% of the does in a breeding herd are replaced each year. Some may last as long as two or three years, and others may die or be culled as early as their first litter. In many cases, the replacement rate is even more than 100%. Calculating the cost of replacements is complicated. If replacements are saved, there will be fewer fryers for sale, as the junior stock must be caged and fed. In this example, about four replacements per month should be kept. Some of the junior does will die prior to reaching maturity, so at least one additional rabbit per month should be saved. This will average out to about the same amount as you would pay to buy a junior replacement doe ($25). The costs of raising or purchasing replacements are not included in this example.

The expense and income projections for this typical 100-doe rabbitry are shown in Table 6.1. The operation shows a total net profit of $362 per year, or $3.62 per doe.

This is with free labor! It takes about 3 hours per day to operate a 100-doe rabbitry, or 1095 hours per year. This provides a return of only $0.33 per hour. This does not include the labor costs of constructing the rabbitry building, making and installing cages, and setting up the rabbitry.

This example should make it obvious that the profit potential of commercial rabbit production is marginal at best. It is not the authors' intent to be gloomy and pessimistic but rather to be realistic. Many prospective rabbit raisers think they have discovered that rabbit raising is a way of getting rich quickly. It just is not so. After all, if it were a way of getting rich quickly, lots of other people would be in the business too. However, with good management and the ability to decrease production costs and(or) increase prices, a marginal profit can be generated. For someone who loves to raise rabbits and who likes to be their own boss, the business can be quite satisfying.

In the above simplified example, several areas for potential savings can be seen. Feed made up 95% of the total operating costs. Thus, major reductions in costs can be accomplished by finding ways of reducing the outlay for feed. Buying bulk feed, working closely with a feed company nutritionist to get a feed that produces the cheapest gains, avoiding feed wastage, and keeping the feed:gain ratio as low as possible are ways of reducing expenses. Home production of rations is generally not cost-effective because of the wide variety of components needed, the necessity of buying some of these items and the rabbits' selectivity with unpelleted feed.

The major fixed costs are those of the building and breeding stock. Where the climate permits, building costs can be reduced by using a simple A-frame construction with open sides. The numbers of replacement does needed can be reduced by using good management, healthy stock, and careful disease control.

The other way of increasing profits, besides reducing costs, is to increase income. This can be accomplished by getting a greater return per fryer or by selling more fryers. Obtaining superior breeding stock and(or) utilizing effective breeding and selection practices is paramount to achieving increased production rates. Another way to increase the price received for fryers over the going rate is to butcher them yourself and sell the meat locally. This may increase profit if you consider your labor to be free. Not everyone wants to slaughter his or her own animals; and health codes and restrictions are often stringent, so this is often not a viable possibility. As previously stated, selling live or custom-dressed fryers at farmers' markets may be an option.

Increasing the size of the herd to increase income is not feasible beyond certain limits, due to the time requirement of about 10 hours per doe per year. For a 400-doe rabbitry this is equivalent to 4000 hours per year, representing almost 11 hours per day, 365 days per year. As size increases, there is little, if any, reduction in the labor required per doe so the herd size should not be increased above the number that can be adequately cared for in the time available. The major way of increasing income is to increase the number of fryers marketed per doe cage per year. In the United States, most growers are marketing in the range of 30 to 35 fryers per doe per year. In Europe, some producers average over 50 fryers per doe. Increasing the number of fryers marketed per doe can be accomplished by good management to ensure that does get bred back on a regular basis, by genetic selection and use of superior breeding stock, by reduction of the breed-back interval, by disease control, and by proper feeding and nutrition. If both doe and buck replacements are selected only from the top 20% of the herd, quick progress in increasing productivity should be made. Each animal that dies or is culled should be replaced with an animal that is superior to it.

Typically, 25 to 40% of all rabbits born die before reaching market age. Mortality can be reduced by simple management practices, such as balancing litters by fostering, culling diseased does, wire brushing cage bottoms daily (to reduce coccidiosis and diarrhea), reducing weaning stress (moving the doe rather than the litter and observing closely to make sure that the kits have learned to drink), palpating to determine pregnancy, and adjusting feed intake of does to keep them in good flesh.

The sale of breeding stock is more profitable than the sale of fryers. Of course, most commercial producers must sell mainly fryers, because a viable industry does not exist if producers are just selling breeding stock to each other. For the grower with superior stock (which requires an extensive knowledge of genetics), however, the sale of breeding animals can be lucrative. Additional, but minor, income can be generated by selling by-products, such as rabbit manure and worms.

In summary, rabbit raising can be an enjoyable activity and can sometimes provide a small profit. It should not be viewed as a way to quick riches. Thus, anyone contemplating building a large-scale commercial rabbitry of several thousand does should look at these figures very carefully!

Further Reading

Lukefahr, S.D., P.R. Cheeke, J.I. McNitt, and N.M. Patton. 2004. Limitations of intensive meat rabbit production in North America: A review. *Can. J. Anim. Sci.* 84: 349–360.

7

Principles of Rabbit Nutrition

The rabbit is classified as an herbivorous non-ruminant. It has a simple, non-compartmentalized stomach, like the human and the pig, and an enlarged cecum and colon (hindgut), like the horse and the guinea pig. The hindgut is an area of bacterial growth, somewhat analogous to the rumen of cattle and sheep, which has an influence on digestive processes, nutrient requirements, and the types of feedstuffs rabbits can utilize.

Nutrient Categories

The nutrients that rabbits require in their feed can be grouped into the following categories:

- protein
- carbohydrates
- fats
- minerals; and
- vitamins.

Each of the known nutrients can be placed in one of these categories. While more than 50 nutrients have been identified, it is fortunate that in feed formulation only a few require critical attention.

Protein

Protein is a fundamental component of animal tissue. It is a major component of muscle tissue, cell membranes, certain hormones, and all enzymes. Proteins are made up of basic units called amino acids. While over 300 different amino acids are known in the plant world, only about 20 are important in animal tissues. Each animal, and each tissue of an animal, has proteins of a characteristic structure. This structure is determined by the amino acids that the protein contains and by the order in which they are joined together. Typically, an individual protein molecule will be made up of hundreds or thousands of amino acids joined together in a particular sequence, which is determined by the animal's DNA and RNA structures. Some proteins are particularly rich in certain amino acids; for example, hair is very high in cystine, a sulfur-containing amino acid.

Certain animals require particular amino acids in their diets. Monogastric animals, such as pigs and chickens, and non-ruminant herbivores, such as rabbits, require these amino acids in their feed. Ruminants, such as cattle and sheep, do not need amino acids in their diet because the bacteria in the rumen manufacture them and the animals eventually "eat" or digest the bacteria. The amino acids that are needed in the diet are called essential amino acids. They cannot be manufactured by an animal. The names of the essential amino acids are shown below.

- arginine
- histidine

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- isoleucine
- leucine
- tryptophan
- lysine
- methionine
- phenylalanine
- threonine; and
- valine.

Of these, lysine and methionine are the ones most likely to be deficient in rabbit feeds. This is because grains tend to be low in these amino acids. In the formulation of rabbit rations, it is not sufficient to consider just the amount of protein in the feed. The content of the essential amino acids also needs to be adequate.

Cereal grains are poor sources of protein and are used in human and animal nutrition primarily as sources of energy. Protein supplements are required because of the low protein content and quality of the grains. The major protein supplement used in rabbit feeds is soybean meal, although cottonseed meal, canola meal, linseed meal, and sunflower meal are also used. Alfalfa meal and other forages are also good sources of protein.

Carbohydrates

Carbohydrates are made of carbon, hydrogen, and oxygen. They are synthesized by plants from carbon dioxide and water, using solar energy. This process is called photosynthesis. The solar energy trapped by plants is used by animals when the carbohydrates are metabolized, producing carbon dioxide and water as waste products.

The simplest carbohydrate is glucose. Most other carbohydrates are made up solely or partially of glucose. The most important carbohydrates in rabbit feed are starch and cellulose. Both are made up entirely of glucose. They differ chemically in how the glucose molecules are joined together. Starch is found in cereal grains and tubers (potatoes, cassava, etc.). Starch is readily digested by animals and is the major dietary energy source for most non-ruminants (pigs, chickens, humans). Cellulose is the structural component of plants, being a major component of plant fiber. No animals produce the enzyme cellulase, which digests cellulose. Therefore, the only animals that can use cellulose as an energy source are those that have bacteria in their gut that accomplish the digestion. Cattle and sheep have a rich bacterial population in the stomach (rumen) that digests cellulose. These animals can eat hay, straw, and other roughages and use them as an energy source because the bacteria digest them. Rabbits, having a bacterial population in the hindgut (cecum and colon), are able to digest cellulose to a minor extent.

The primary function of carbohydrates in rabbit diets is to provide energy, which is expressed in calories, and indigestible fiber, which helps maintain the integrity of the digestive tract. High levels of grain may cause carbohydrate overload of the hindgut, leading to enteritis. On the other hand, the indigestible carbohydrate (fiber) may have beneficial effects in preventing enteritis. These aspects will be discussed in the section on carbohydrate digestion.

Fats

Like carbohydrates, fats function primarily as sources of energy. They contain, on an equal weight basis, about 2.25 times as much energy as carbohydrates. Thus, they are used in the formulation of high-energy diets.

Fat is often added to rabbit rations at levels of 2 to 5% of the diet. Added fat increases the palatability of feeds, reduces fines, and acts as a lubricant in the pelleting process. It also facilitates absorption of fat-soluble vitamins in the gut. A level of 2 to 5% dietary fat seems to help in promoting a shiny, lustrous hair coat, which is useful in show rabbits. A supplement of corn oil once or twice a week will do the same thing.

Technically, fats are called triglycerides. They are a combination of glycerol and three fatty acids. Fatty acids that have attached all the hydrogen possible are called saturated fatty acids. Those that are capable of holding more hydrogen are called unsaturated fatty acids. Unsaturated fatty acids can be converted to the saturated form by the addition of hydrogen (hydrogenation). This happens in the rumen of cattle and sheep, so beef and lamb fat tend to be high in saturated fatty acids. Hydrogenation does not occur in the rabbit gut, so rabbit meat fat is not of the saturated type.

Cholesterol is a complex substance that is often considered with fats. It has been implicated in human health, as it is a constituent of the deposits that form in atherosclerosis (fat deposition in the arteries). Rabbits develop atherosclerosis very readily, so they have been widely used as laboratory animals in the study of this disease. Because alfalfa contains substances (saponins) that reduce tissue cholesterol and because most rabbit diets contain alfalfa, rabbit meat tends to be low in cholesterol.

Minerals

Mineral elements are components of the ash content of feeds. The mineral needs of rabbits are easily satisfied by use of a calcium–phosphorus supplement and of trace mineralized salt to provide the trace elements. Trace elements are those that are needed in traces, or very small quantities. Copper, manganese, and iodine are examples. Alfalfa is an excellent source of calcium, phosphorus, and trace elements.

Minerals function in several ways. They may be part of the structure of the body. Calcium and phosphorus have structural roles as the major components of bone. Minerals may regulate the properties of biological fluids, such as blood and cell protoplasm. Sodium and potassium function in this way. Many trace elements are "cofactors" for enzyme systems; that is, the presence of the minerals is necessary for the enzymes to have activity. Copper, selenium, and zinc are examples of this group. Iodine is a part of the thyroid hormone. Sulfur functions as a component of amino acids (methionine and cystine) and of some vitamins (thiamine and biotin). Iron is a component of a protein that carries oxygen in the blood (hemoglobin). Cobalt is a part of vitamin B_{12}. Phosphorus is a component of a molecule (ATP) that transfers energy in cellular metabolism. Thus, minerals have many diverse roles in animal nutrition.

Trace mineral deficiencies should not be a problem in rabbit production. The use of trace mineralized salt at a level of 0.5% of the diet will ensure that requirements are met. In addition, alfalfa meal is generally a good source of mineral elements.

The functions and the deficiency and/or toxicity symptoms of minerals in rabbits will be briefly described.

Calcium and phosphorus

These elements are important in the structure of bone and teeth. Rabbits are quite unusual in their metabolism of calcium. They absorb it very efficiently and excrete the excess in the urine. This accounts for the chalky white deposits seen in many rabbitries (Fig. 5.18). Legumes, such as alfalfa, are rich sources of calcium. Grains are very low in calcium but quite high in phosphorus. A combination of grain and alfalfa is thus complementary and generally meets calcium and phosphorus requirements.

Vitamin D functions in most animals in regulating calcium absorption and bone mineralization. The significance of vitamin D in regulating calcium absorption in rabbits is unclear. Rabbits seem to be highly efficient in calcium uptake and continue to absorb it in large quantities after the metabolic requirement is satisfied. In other species, the amount of calcium absorbed is controlled by a metabolite of vitamin D, and calcium is absorbed only as needed.

Deficiencies of calcium, phosphorus, or vitamin D produce rickets in young animals and osteomalacia in adults. Young rabbits with rickets exhibit enlarged joints, crooked legs, arched backs, and beaded ribs. Adults may experience demineralization of the bones until their skeletons become paper thin and fragile and broken backs occur readily. Vitamin D toxicity results in calcification of internal organs such as the liver, kidneys, heart and blood vessels.

Rabbit diets generally have more than sufficient calcium, because alfalfa, a major ingredient in most commercial rabbit feeds, is rich in calcium. Because rabbits absorb calcium efficiently, they often have an excess that is excreted in the urine. It is common for walkways in rabbit barns to have white urine stains, attributable to the calcium carbonate being excreted in the urine. This is often accompanied by a red pigmentation of the urine (see "Red Urine" in Chapter 10). Urinary tract blockages caused by excessive dietary calcium are often a problem with pet rabbits (see Chapter 18).

Magnesium

Magnesium functions as a component of bone, as a cofactor in enzyme systems, and in transmission of nerve impulses. A magnesium deficiency causes convulsions, hyperirritability, and death. In certain areas, magnesium deficiency in cattle (grass tetany) is common. However, magnesium deficiency is probably unlikely to occur in rabbits, since legumes (alfalfa, clover) are excellent sources of the element. High dietary levels of calcium increase the magnesium requirement, so it is conceivable that high alfalfa diets could benefit from magnesium supplementation. There have been reports that rabbits chewing fur may respond to supplementation with 2.5 kg of magnesium oxide added per ton of feed. Excess magnesium added as magnesium sulfate (Epsom salts) can cause severe diarrhea.

Potassium, sodium, and chlorine

These elements function in maintaining proper ionic relationships (acid–base balance) in the blood and other body fluids. Because potassium occurs abundantly in legumes, such as alfalfa, and because grains are good sources also, a deficiency is unlikely in rabbits. Provision of salt at a level of 0.5% of the diet satisfies the sodium and chlorine needs. European researchers have suggested that these elements in diets should be provided so that the sum of potassium and sodium, minus chlorine, is about 25 milliequivalents per 100 grams of feed. When enteritis occurs in rabbits, these elements are drawn into the gut, causing a disturbance of fluid balance in the body. The result is dehydration, which may be lethal. Potassium, sodium, and chloride are electrolytes (charged molecules in solution); administration of electrolyte solutions in the drinking water or by injection to animals with enteritis is sometimes beneficial.

Sulfur

Sulfur is a component of the sulfur amino acids and the vitamins thiamine and biotin. Thus, it is required only as a component of these nutrients. Inorganic sulfate is used in formation of connective tissue. In poultry, responses to feeding inorganic sulfate (e.g., sodium sulfate) have been noted. It is not known if such responses occur in rabbits.

Iron

Iron is a component of several organic molecules that function in energy metabolism. Hemoglobin, a blood pigment in the red blood cells, contains iron. Hemoglobin functions in oxygen transport in the blood. A deficiency of iron results in decreased hemoglobin formation and in anemia. Iron deficiency in rabbits is unlikely, because most commercial rabbit diets contain adequate iron.

Copper

This element is closely involved with iron metabolism. A copper deficiency impairs iron utilization, causing anemia. Copper is also a cofactor for several enzymes. A peculiarity of copper deficiency is that a graying of black fur occurs. This is due to the role of copper in the synthesis of melanin, a pigment in hair and fur. Copper sulfate is sometimes used as a feed additive for rabbits, at dietary levels of 125 to 250 parts per million (ppm). It may, under some conditions, improve growth and feed efficiency and reduce enteritis.

Cobalt

No specific metabolic requirement for cobalt is known. Its only nutritional role is as a part of the structure of vitamin B_{12}. This vitamin is synthesized in the hindgut of the rabbit by bacteria. When rabbits eat their cecal contents (cecotropes), they satisfy their vitamin B_{12} requirement. In fact, a large excess of the vitamin is obtained in this way. Cecotropes are also known as soft feces or night feces.

Manganese

Manganese deficiency in rabbits causes a malformation of the skeletal system (Fig. 7.1), including crooked legs, brittle bones, and decreased weight, density, length, and ash content of the bones. This is due to the metabolic role of manganese in the formation of the organic matrix of bone. A deficiency in rabbits fed practical diets is unlikely.

Fig. 7.1. Manganese deficiency, showing crooked front legs due to impaired bone formation. (Courtesy of S.E. Smith)

Zinc

Does fed zinc-deficient diets have been shown to have impaired fertility. Loss of hair and dermatitis are also observed (Figs 7.2 and 7.3). Zinc functions is a cofactor of numerous enzymes and is involved in DNA metabolism. Zinc is bound by phytic acid in soybean meal and grains, thus reducing its availability to some animals, such as swine and poultry. It is likely that in rabbits the zinc–phytate complex is destroyed by bacterial activity in the gut. Zinc deficiencies in commercial rabbit production have not been reported.

Iodine

Iodine is a constituent of the thyroid hormone thyroxin. In an iodine deficiency, the thyroid gland in the neck enlarges in an attempt to synthesize more thyroxin. This enlargement is called a goiter. Iodine-deficient reproducing animals produce weak or dead offspring that have readily observed goiters. Rabbit rations should always be supplemented with iodized salt.

Fig. 7.2. Zinc deficiency, showing loss of hair and crusting of the skin (dermatitis) on the ears. (Courtesy of C.E. Joseph and the *Journal of Nutrition*, American Institute of Nutrition)

Fig. 7.3. A zinc-deficient rabbit (left) contrasted with a zinc-adequate control. Stunted growth, altered posture, and abnormal fur are characteristics of zinc deficiency. (Courtesy of C.E. Joseph and the *Journal of Nutrition*, American Institute of Nutrition)

Selenium

For many years, selenium was known only for its toxic properties. Feeds grown in areas that have soils with a high selenium content (the Great Plains states of the U.S.) may sometimes contain sufficient selenium to be toxic to livestock. Toxicity symptoms include loss of hair and blindness. In 1958, Oregon State University researchers discovered that white muscle disease (stiff lamb disease, nutritional muscular dystrophy) in sheep could be prevented by supplementary selenium. Subsequent work has demonstrated that selenium functions as a part of an enzyme, glutathione peroxidase, that is involved in the removal or detoxification of peroxides, such as hydrogen peroxide, which are formed in tissues during normal metabolic processes. Vitamin E functions by preventing peroxide formation; thus, vitamin E and selenium are very closely related in nutrition. The rabbit is interesting in that it apparently depends completely on vitamin E for protection against peroxide damage. No selenium deficiency symptom has ever been demonstrated in rabbits, so it appears that selenium is not a required nutrient for rabbits, or the requirement is very low.

Vitamins

The discovery and identification of vitamins occurred almost entirely in the twentieth century. Although there were hints of the existence of factors that could prevent disorders such as beriberi and scurvy in humans, it was not until the period following 1900 that chemical techniques became sufficiently sophisticated to allow the identification of these substances. The term "vitamin" came from the fact that one of the first vitamins to be studied was a chemical type called an "amine." The compound was called "a vital amine"; this was later shortened to "vitamine," and then to "vitamin." A substance found in butter was called "fat-soluble A," and the substance found to protect against beriberi was called "water-soluble B." Later these were called "vitamin A" and "vitamin B." It was soon discovered that "vitamin B" was actually made up of several vitamins, so it was called "the vitamin B complex." These designations continue to this day; the fat-soluble vitamins are vitamins A, D, E, and K, while there are numerous members of the water-soluble vitamin B complex group, and vitamin C. The last vitamin to be discovered was vitamin B_{12}, in 1948. Thus, the Golden Age of the discovery of vitamins was 1900 to 1948.

Although vitamins are newcomers to our knowledge of nutrition, they have become legends in their own time. People ascribe tremendous results to gulping large quantities of vitamins. A great commercial industry has developed, with an unlikely alliance between the large drug companies and the "health food" movement. The drug companies manufacture vitamins, and the "health food" industry promotes and sells them at "megavitamin" dose levels. Most reputable nutritionists are somewhat appalled at this development, because the extensive scientific studies of the effects of vitamins do not support this massive overdosing.

This background is highly relevant to a discussion of rabbit nutrition. Because, in popular opinion, the thing to do at the first sign of illness is to take some vitamins, you should be aware that the dietary vitamin needs of rabbits are in most cases quite low. Large amounts of money have been spent unnecessarily to feed rabbits vitamins for which they have no need. The vitamins are simply excreted in the urine or may even be toxic to the rabbits (e.g., vitamin A).

Definition of a vitamin

Vitamins are defined as having the following properties.

1. They are organic compounds. The term "organic" is used in the original chemical terminology rather than in the current popular jargon. An organic compound is one composed primarily of carbon and hydrogen. This is in contrast to inorganic substances, such as the minerals.
2. They are components of natural food but are distinct from the other organic compounds - the carbohydrates, fats, and protein.
3. They are essential for normal growth and maintenance of tissue and have a specific, essential role in metabolism.
4. When they are absent from the diet or not properly absorbed, specific deficiency symptoms result.
5. They cannot be synthesized by animals, so they must be obtained from the diet.
6. They are required in very small quantities.

There are some exceptions to the fifth generalization listed. Vitamin D can be synthesized if there is exposure to sunlight. Most species, including rabbits, can manufacture their own vitamin C. Niacin, a B vitamin, can be made in tissues from the amino acid tryptophan.

Units of vitamin measurement

Vitamins are required in very small quantities. Even a megadose of a vitamin in a diet is, by weight, a very small amount. To facilitate the expression of vitamin requirements, the term "International Unit," or "IU," is often used, particularly for vitamins A, D, and E. There are several different chemical compounds that are active for each of these vitamins, so it is convenient to consider them as a group and express their activity in IU. Definitions for the International Units of vitamins A, D, and E are as follows:

Vitamin	International Unit
Vitamin A	1 IU = 0.3 μg retinol or 0.344 μg retinol acetate
Vitamin D	1 IU = 0.025 μg vitamin D3
Vitamin E	1 IU = 1 mg dl-α-tocopherol acetate

The activities of other vitamins are expressed on a weight basis, usually as milligrams (mg) or, in the case of vitamin B_{12}, as micrograms (μg).

Fat-soluble vitamins

There are four members of this group: vitamins A, D, E, and K. It should be noted that vitamin K exists in water-soluble form also, so it has some properties of the water-soluble vitamin group as well. The fat-soluble vitamins are not excreted readily, so they are stored in the body for extensive periods of time. Thus, they do not need to be fed continuously, and it takes a prolonged feeding period on a deficient diet for deficiencies to develop. With the exception of vitamin K, fat-soluble vitamins are not synthesized by bacteria in the gut.

VITAMIN A. Vitamin A is not found as such in plants; rather it occurs in plants as β-carotene, a substance that animals can convert to vitamin A. This vitamin is required for the growth and maintenance of all body tissues, particularly the epithelial tissues, such as the skin, the digestive tract, and the reproductive tract. It is an essential component of compounds that function in vision. Symptoms of vitamin A deficiency in rabbits are retarded growth, nervous system effects such as incoordination and paralysis, blindness, and hydrocephalus (enlarged head) of fetuses born to vitamin A-deficient does. An interesting deficiency symptom in rabbits is that the ears or the tips of the ears droop. Vitamin A is required for cartilage formation, so in a deficiency, the ear cartilage is defective and cannot support the weight of the ear. Rabbit rations low in alfalfa meal should be supplemented with vitamin A (alfalfa is the richest plant source of vitamin A activity). Vitamin A activity of feeds can be reduced by feed processing (e.g., pelleting) and feed storage.

Vitamin A is stored in the liver. The liver vitamin A level is a good indicator of an animal's vitamin A status. Except in cases of severe deficiency or toxicity, the blood vitamin A levels do not correlate well with vitamin A status. Thus, when a deficiency or toxicity of vitamin A is suspected, liver rather than blood is the tissue that should be analyzed for vitamin A content.

The vitamin A requirement of does in production is approximately 10,000 IU of vitamin A per kilogram of feed. The toxic level of the vitamin in livestock is generally considered about 500 times the minimum requirement, with non-toxic levels up to about 1 million to 1.5 million IU per kilogram of diet. However, studies at the Oregon State University Rabbit Research Center showed that a level of 100,000 IU per kilogram of diet, which is only 10 times the vitamin A requirement, can cause reproductive problems in does, including abortion; fetal resorption; small, weak litters with a high mortality in the first week; and kits with hydrocephalus (Figs 7.4 and 15.2). These signs are also characteristic of vitamin A deficiency. Because of the metabolic mode of action of vitamin A, many of the toxicity symptoms are the same as deficiency symptoms. It is possible that some outbreaks of abortion, weak litters, and hydrocephalus in rabbit herds could be caused by vitamin A toxicity. Diets containing a high level of alfalfa meal have several times the amount of vitamin A required, and the addition of a vitamin mixture rich in vitamin A could push the level to a toxic situation. Hydrocephalus may also be of genetic origin, so cases of the disorder can occur when vitamin A status is normal.

The vitamin A activity of several forms of alfalfa meal, compared with some other sources of vitamin A, is shown in Table 7.1. From these values, it is evident that a ration with 50% dehydrated alfalfa might contain 165,000 IU of vitamin A per kilogram, which could be a toxic level. The conversion of carotene to vitamin A in animals is regulated so that toxic amounts of vitamin A are not produced. However, additional supplementation with

Fig. 7.4. A kit with hydrocephalus (left) bred from a doe receiving a toxic level of vitamin A in the diet, contrasted with a normal kit. (Courtesy of OSU Rabbit Research Center)

synthetic vitamin A to a carotene-rich diet could readily produce vitamin A toxicity.

The actual vitamin A activity of alfalfa meal is influenced by drying and processing conditions; therefore, it can fluctuate widely and differ considerably from the value shown in Table 7.1.

Vitamin A activity of alfalfa and other green plants is associated with various carotenoid pigments, of which β-carotene is the most important. The conversion of β-carotene (the form of vitamin A in plants) to vitamin A occurs in animals with considerable variation between species in the efficiency of conversion and the site. In cattle, for example, significant amounts of carotene are absorbed and are stored in the liver and body fat. Some breeds, such as the Guernsey and the Jersey, are inefficient at converting carotene to vitamin A, resulting in their milk fat and body fat having the yellow color of carotene. In rabbits, carotene is efficiently converted to vitamin A in the intestine so that very little carotene is absorbed.

Table 7.1. Vitamin A Activity of Feeds.

Feedstuff	IU of Vitamin A activity per kg
Alfalfa leaf meal, dehydrated	150,000–530,000
Alfalfa meal, dehydrated	150,000–330,000
Alfalfa meal, sun-cured	50,000–150,000
Dried grass meal	150,000
Carrots	120,000
Yellow corn	8,000
Other grains	0

Xanthophylls are another type of carotenoid pigment in plants. They do not have vitamin A activity but can cause pigmentation of the fat of some animals. The yellow shanks of broiler chickens and the yellow color of egg yolk are a result of xanthophyll deposition. Feeds high in xanthophylls include green plants (e.g., alfalfa) and marigold petals (used as pigmenting agents in poultry diets). Rabbits normally do not have pigmented fat. Some rabbits have a genetic lack of an enzyme that hydrolyzes xanthophylls and therefore may develop yellow body fat.

VITAMIN D. The principal function of vitamin D is to regulate calcium absorption. In most species, the amount of calcium absorbed in the intestine is controlled by a "calcium-binding protein" that transports calcium through the intestinal wall to the blood. The activity of this calcium-binding protein, and thus the amount of calcium absorbed, is regulated by vitamin D. This does not seem to be the case in rabbits, as they absorb calcium efficiently regardless of their need for it. Thus, the role of vitamin D in the metabolism of the rabbit is obscure.

Vitamin D can be synthesized by the skin of animals exposed to sunlight. Sunlight also converts pro-vitamin D in plants to vitamin D during hay curing, so sun-cured hays (e.g., alfalfa meal) are good sources of vitamin D activity. For animals kept under confinement conditions, the vitamin should be added to the diet. Vitamin D toxicity is probably of more significance than deficiencies in rabbit production. Several cases of vitamin D toxicity have occurred when excessive levels of the vitamin were inadvertently added to rabbit feeds. Toxicity symptoms are loss of appetite, impaired movement, and calcification of soft tissues, such as kidneys and arteries.

VITAMIN E. This vitamin is also called α-tocopherol. Vitamin E is very closely linked to the mineral element selenium in its metabolism and function.

Both nutrients function by preventing tissue destruction by toxic peroxides formed during metabolism. Vitamin E acts as an antioxidant to prevent peroxides from being formed. Selenium is a part of the enzyme glutathione peroxidase, which converts toxic peroxides into harmless substances such as water. In a deficiency of either vitamin E or selenium, tissue breakdown due to peroxide damage occurs. This results in destruction of muscle tissue (nutritional muscular dystrophy), infertility, resorption of fetuses, and a variety of other effects that vary according to the species of animal involved. Rabbits seem to depend entirely on vitamin E for protection against peroxides. As mentioned earlier, attempts to demonstrate a selenium deficiency in rabbits have not been successful. Alfalfa and grains are quite good sources of vitamin E, but it is recommended that rabbit diets be routinely supplemented with vitamin E, as there are losses in feed processing.

VITAMIN K. Vitamin K has a very specific metabolic function; it is essential for blood clotting. In a vitamin K deficiency, a blood protein, prothrombin, is not activated to allow it to participate in the clotting process. While vitamin K deficiency is not often encountered in animals, there are some classic examples of induced deficiencies. Sweet clover poisoning of cattle is caused by feeding molding sweet clover hay; it causes profuse bleeding and hemorrhage. Sweet clover contains coumarin, which is converted by molds to a potent antagonist of vitamin K called dicumarol. Dicumarol is very similar in structure to vitamin K but cannot substitute for it in prothrombin synthesis. The result is an induced vitamin K deficiency. Another example is the rat poison warfarin. This induces a vitamin K deficiency, causing death by internal bleeding. The sulfa drugs, such as sulfaquinoxaline, are vitamin K antagonists that increase the vitamin K requirements. Finally, some of the mold toxins (mycotoxins) in moldy hay and grain can act as vitamin K antagonists. Symptoms of vitamin K deficiency are abortion and placental hemorrhage in does and prolonged bleeding following a minor injury. A vitamin K deficiency in rabbits is unlikely, because the vitamin is synthesized in the gut by bacteria and obtained by the rabbit when it eats its cecotropes (cecotrophy).

Water-soluble vitamins

The members of the vitamin B complex are all synthesized by bacteria in the cecum and the colon of the rabbit. When the rabbit eats its night feces (cecotropes), these bacterially synthesized vitamins are consumed and absorbed. Numerous studies have shown that rabbits do not respond to supplementation with B vitamins, because the bacteria supply more than adequate quantities via cecotrophy. In addition, the grains and forages used in rabbit diets are good sources of these vitamins. Therefore, only a very brief description of each of these vitamins will be given, as there is little likelihood of deficiencies being encountered in rabbit production.

THIAMINE (VITAMIN B_1). Thiamine is a cofactor for certain enzymes involved in carbohydrate and fat metabolism. A deficiency causes loss of appetite, accumulation of pyruvic acid in the blood, and muscle paralysis.

RIBOFLAVIN (VITAMIN B_2). Riboflavin is a component of several compounds that function in the complete oxidation of glucose within cells. These compounds are involved in the chemical transfer of the energy of glucose to specific biochemical reactions in metabolism. Riboflavin deficiency causes reduced growth and a lowered feed efficiency.

NIACIN. The classic condition of niacin deficiency is pellagra, a disease that until the 1940s was responsible for thousands of human deaths each year in the southern part of the United States. Niacin can be synthesized from the amino acid tryptophan. Since corn is very low in both these nutrients, niacin deficiency has been a problem in humans and in animals for which corn is a major dietary ingredient. Again, niacin is synthesized by gut bacteria, so a deficiency in rabbits is unlikely. Niacin functions metabolically in a manner similar to riboflavin. It is a component of cofactors that are involved in oxidation of carbohydrates within cells.

PYRIDOXINE (VITAMIN B_6). This vitamin functions in protein metabolism. It is a cofactor for several reactions involved in amino acid metabolism.

A classic deficiency symptom is convulsions. A deficiency in rabbits is extremely improbable, because of this vitamin's abundance in forage and grains and the intestinal synthesis by bacteria.

PANTOTHENIC ACID. This vitamin also is essential for energy metabolism. It has a role in the oxidative breakdown of sugars and fatty acids to carbon dioxide and water. No deficiency of pantothenic acid in rabbits has ever been produced.

BIOTIN. Biotin deficiency causes loss of normal hair pigmentation. This has occurred in mink because of the feeding of raw eggs, which contain a biotin antagonist called avidin. Biotin has a metabolic function in fatty acid metabolism. Again, because of the intestinal synthesis of B vitamins in rabbits, no dietary supplementation is normally needed, although biotin deficiency has been experimentally induced in rabbits by feeding raw egg whites. Deficiency signs included dermatitis and loss of hair.

CHOLINE. This compound can be synthesized by animals, so it is questionable that it should even be called a vitamin. Experimentally, choline deficiency has been produced in rabbits, causing poor growth, anemia, muscular dystrophy, and death. The abundant distribution of choline in feeds and body and intestinal synthesis provide adequately for the choline needs of rabbits.

FOLIC ACID. Folic acid (folacin) functions in the interconversion of amino acids and in nucleic acid synthesis. Nucleic acids are components of DNA and RNA. Its function is closely related to that of vitamin B_{12}. Folic acid deficiency causes anemia. Deficiencies in rabbits are unknown.

VITAMIN B_{12}. Like folic acid, vitamin B_{12} functions in the synthesis of nucleic acids. Anemia is the primary deficiency symptom. Vitamin B_{12} contains cobalt and is synthesized by the gut bacteria as long as cobalt is present. Even when very low levels of cobalt have been experimentally fed to rabbits, it has been impossible to produce a vitamin B_{12} deficiency. The bacteria in the hindgut of horses and rabbits are extremely efficient at using cobalt for vitamin B_{12} synthesis. Horses thrive on pastures so low in cobalt that cattle and sheep dependent on such pastures will die of vitamin B_{12} deficiency. Thus, a cobalt deficiency is actually a metabolic deficiency of vitamin B_{12}.

VITAMIN C. Only a few species require dietary vitamin C; these include humans, monkeys, guinea pigs, and certain fish. Rabbits synthesize vitamin C from glucose in their tissues, so they have no dietary requirement for this nutrient.

Water

Although normally provided separately from the feed, water is often referred to as a nutrient. Rabbits should have free access to fresh, pure water. With herds larger than a few does, an automatic watering system should be installed. It saves labor and eliminates contamination of the water. If crocks are used, they should be regularly cleaned to maintain sanitary conditions. The amount of water consumed varies with age of rabbits, type of ration, season, and stage of production. In both cold and hot weather, water consumption is increased. During warm weather, a doe and her litter will drink about four liters in 24 hours. In cold weather, rabbits eat more feed and, as a consequence, increase their water intake also.

The use of heating cables in water lines in cold weather areas is advisable to prevent freezing and maintain a continuous supply of water to the animals.

Digestive Processes in the Rabbit

Rabbits are monogastric herbivores. They have a simple stomach and an enlarged hindgut (cecum and colon) (Fig. 7.5). It has commonly been assumed that the enlarged hindgut is an area functionally similar to the rumen of cattle. This is not correct, but there are some similarities. In ruminants, there is no requirement for dietary essential amino acids, because bacteria make them in the rumen. In rabbits, the bacterial protein synthesized in the hindgut makes

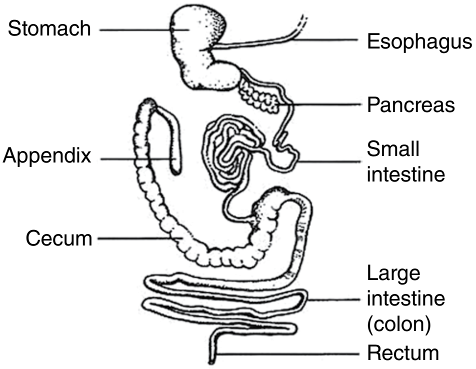


Fig. 7.5. A schematic of the major sections of the gastrointestinal tract of the rabbit. (Courtesy of OSU Rabbit Research Center)

very little contribution to their protein needs, so they are dependent on dietary essential amino acids. Cattle can digest fibrous feeds, because the rumen bacteria produce cellulase, which breaks down cellulose. Rabbits do not digest fiber efficiently. In fact, fiber digestibility in the rabbit is lower than in most other species, even the simple monogastrics, such as rats and swine. The reasons for this will be discussed in the fiber portion of the section on carbohydrate digestion. Ruminants and rabbits do share one characteristic related to their gut bacteria: the bacteria in both the rumen and the hindgut synthesize adequate quantities of the B vitamins. Both rabbits and ruminant animals have dietary requirements for only vitamins A, D, and E; the others are synthesized in adequate amounts by bacteria in the gut.

Digestion and digestibility

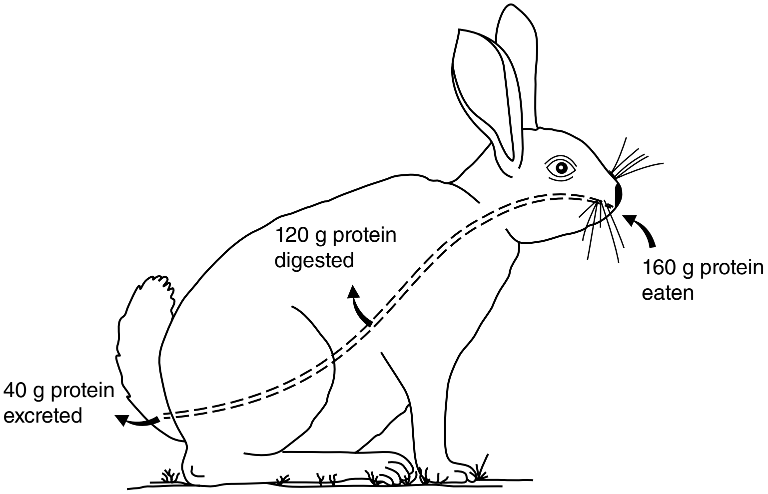
Digestion is the preparation of feed nutrients for absorption. Absorption is the transport of the products of digestion from the digestive tract into the blood. During digestion, large molecules, such as proteins and starch, are split apart by digestive enzymes into the basic units of which they are made (amino acids and glucose, for proteins and starch respectively). In rabbits, most of the digestion occurs in the small intestine and is accomplished by digestive enzymes that are secreted into the digestive tract (Fig. 7.5). Most of these enzymes are produced in the pancreas and secreted through the pancreatic duct into the small intestine. There is also some fermentation (digestion by bacteria) in the cecum and the colon. This is much less important to digestion in the rabbit than once believed.

Determination of digestibility is a technique used to measure how much of a particular feed an animal can digest. To make the determination, it is necessary to measure both the feed intake and the feces excreted. The difference between these is the amount of nutrient absorbed. This is shown diagrammatically in Fig. 7.6.

Animals are kept in metabolism cages, which are designed so that the feces and urine can be separated and collected (Fig. 7.7). Determination of the digestibility of feeds is very important, because it provides an estimate of their nutritional value. If a certain feed ingredient contains 80% protein, but only 30% of it is digestible, then that feedstuff has the equivalent of only 24% protein, because 70% of the protein it contains is simply excreted in the feces. While the digestibility of many feeds has been determined for cattle, sheep, and swine, there has been comparatively little research on this subject with rabbits.

Protein digestion

Protein is digested primarily in the small intestine by several enzymes secreted from the pancreas. Trypsin and chymotrypsin are two of the principal protein-digesting enzymes. The digestion process consists of breaking the bonds that join amino acids together in the protein. Thus, the dietary protein is broken into the individual amino acids of which it is composed. These are then absorbed into the blood. Protein not digested in this manner passes through the small intestine to the hindgut, where it is subjected to the action of bacterial enzymes. Bacteria in the hindgut synthesize amino acids, which they incorporate into their own proteins. This bacterial protein could be available to the rabbit when it eats its cecal contents (cecotrophy). However, research on nitrogen and protein metabolism in rabbits has demonstrated that the bacterial protein, consumed via cecotrophy, makes a very small contribution to the animal's protein and amino acid needs.



$$\% \text{ digestibility} = \frac{120}{160} \times 100 = 75\%$$

Procedure:

The rabbit is kept in a metabolism cage. Feed is consumed, and the feces excreted are weighed. Samples of the feed and feces are analyzed for their protein content.

Data collected:

Feed contains 16% protein
Feces contain 10% protein
Feed consumed = 1000 grams (g)
Feces excreted = 400 g

Calculations:

Protein consumed = 1000 g feed × 16% protein
= 1000 g × .16 = 160 g

Protein excreted = 400 g feces × 10% protein
= 400 g × .10 = 40 g

Protein digested = protein consumed – protein excreted
= 160 g – 40 g = 120 g

$$\text{Protein digestibility} = \frac{\text{protein digested}}{\text{protein consumed}} \times 100$$

$$= \frac{120 \text{ g}}{160 \text{ g}} \times 100 = 75\%$$

Fig. 7.6. An example of the calculation of protein digestibility. (Courtesy of OSU Rabbit Research Center)

The rabbit is dependent on good quality dietary protein to meet its essential amino acid needs.

In cattle and other ruminants, the bacteria in the rumen synthesize protein from sources of nitrogen such as urea. This type of feed source is called non-protein nitrogen (NPN). In addition, the rumen bacteria convert low-quality proteins, deficient in essential amino acids, to higher-quality bacterial protein. This is economically advantageous, because low-quality

Fig. 7.7. Metabolism cages, which allow separate collection of feces and urine. These are used for such purposes as the measurement of nutrient digestibility. (Courtesy of D.J. Harris)

proteins and NPN sources are cheaper than high-quality proteins. Because rabbits have a similar bacterial population in the hindgut, it has been hypothesized that rabbits might efficiently use low-quality proteins and NPN sources such as urea. Numerous studies have demonstrated that they cannot. Urea is of almost no value to rabbits as a nitrogen source for protein synthesis.

In comparison to other monogastric animals, rabbits digest the protein in forages very efficiently. Pigs fed alfalfa meal will digest less than 50% of the protein in the alfalfa. Rabbits, on the other hand, will digest 75 to 80% of the alfalfa protein, in spite of the fact that they don't digest the fiber fraction any more efficiently than swine do. This is probably due to cecotrophy. As a result of more than one passage through the digestive tract, more efficient extraction and digestion of the forage protein occurs. This is one of the main reasons why large quantities of alfalfa and other forages are fed to rabbits and serve as a major source of protein. In the future, as grain becomes less available for animal feeding and we rely more on forages for livestock feed, the ability of the rabbit to use forage protein efficiently will become very important.

Carbohydrate digestion

Dietary carbohydrates are of two types: the readily digestible sources, such as starch and sucrose, and the relatively indigestible types, such as cellulose and hemicellulose. Starch is the major carbohydrate in grain, whereas cellulose and hemicellulose are major components of the fiber fraction of forages.

Starch is digested in the small intestine of the rabbit by an enzyme called amylase, which is secreted by the pancreas. Amylase splits starch into the glucose molecules of which it is composed. Glucose is then absorbed into the blood and used by the rabbit as an energy source. Because feed passes through the small intestine of the rabbit so rapidly, significant amounts of undigested starch may reach the hindgut. Here it is fermented by bacteria. High levels of grain fed to rabbits may cause carbohydrate overload of the hindgut. The abundant starch allows bacterial populations to "explode." If certain toxin-producing organisms are present, the result can be enterotoxemia and death. Thus, type and amount of dietary carbohydrate can influence the development of a major disease problem in rabbits.

The fiber fraction of feeds is poorly digested by rabbits. This is illustrated in Table 7.2. If rabbits digest fiber so poorly, how do they make efficient use of fibrous feeds? This apparent contradiction can be explained by recognizing that fiber makes up only 20 to 25% of forages. Thus, forage like alfalfa meal is 75 to 80% non-fiber. The rabbit efficiently digests the non-fiber fraction, such as the protein and soluble carbohydrates, and excretes the fiber fraction. European studies have suggested that there is a separation of large and small particles in the cecum. The small particles are retained for further digestion, whereas the large particles (i.e., fiber) are rapidly excreted. The ability of the rabbit to utilize high dietary levels of alfalfa and other forages is due to a high intake of these low-energy feeds, with rapid excretion of the fiber and efficient digestion of the non-fiber components.

While fiber is not useful as an energy source for rabbits, it is a very important component of rabbit feeds. Numerous studies have shown that low fiber diets promote increased enteritis. Fiber may have a specific protective effect by having a scabrous action on the intestinal lining and maintaining it in a healthy condition. Increasing the fiber levels reduces the soluble carbohydrate level, which may aid in reducing carbohydrate overload of the hindgut. Provision of dietary fiber will also help prevent fur chewing.

Fat digestion

Fats are digested in the small intestine by the pancreatic enzyme lipase. Bile is also required to emulsify fat (break it into small droplets) in the aqueous medium of the gut contents. Popular opinion seems to be that high dietary fat might be indigestible; this is not correct. Fat is readily digestible, and fat levels as high as 25% of the diet have been fed to rabbits with no ill effect. In practical feeds, levels of 3 to 5% are used; higher levels may reduce pellet quality, causing crumbling of the pellets.

Table 7.2. Digestibility of the alfalfa hay fiber by various animals.

Animal	% Fiber Digestibility
Cattle	44
Sheep	45
Goats	41
Horses	41
Pigs	22
Rabbits	14

Adapted from Maynard, L.A. *et al*. 1979. *Animal Nutrition* (7th ed.) McGraw-Hill Book Co. New York, p.31.

Digestion of minerals and vitamins

These nutrients do not require digestion, as they are already in a form that can be directly absorbed. Thus, digestion is a process that applies only to the major nutrient categories of proteins, carbohydrates, and fats.

Cecotrophy

Cecotrophy is defined as the act of consuming cecal contents. Unsavory as this may sound, it is a normal behavioral pattern for many types of animals, including rabbits. The principal nutritional consequence of cecotrophy in rabbits is that this is a means of providing the B vitamin requirements. All the members of the B complex group are synthesized by bacteria in the rabbit hindgut and are made available to the animal after it consumes its soft feces. As a result, rabbits do not require B vitamins in their diet. Another consequence of cecotrophy is that it provides a small amount of bacterial protein. However, it is doubtful that this is of practical significance.

Rabbits excrete two types of feces. The hard feces or day feces, which are produced in the large intestine, are the fecal pellets commonly seen. The feces that are consumed via cecotrophy are the night or soft feces, produced in the cecum. These are consumed directly from the anus. They are excreted in grape-like clusters, surrounded by a gelatinous membrane. They may often be found intact in the anterior portion of the stomach in necropsied animals. Since the cecotropes are consumed directly from the anus, raising rabbits on wire does not inhibit cecotrophy. In fact, prevention of cecotrophy for experimental purposes is quite difficult and involves equipping rabbits with a collar to prevent them from reaching the anus (Fig. 7.8). The term "night feces" is a misnomer, because these soft pellets

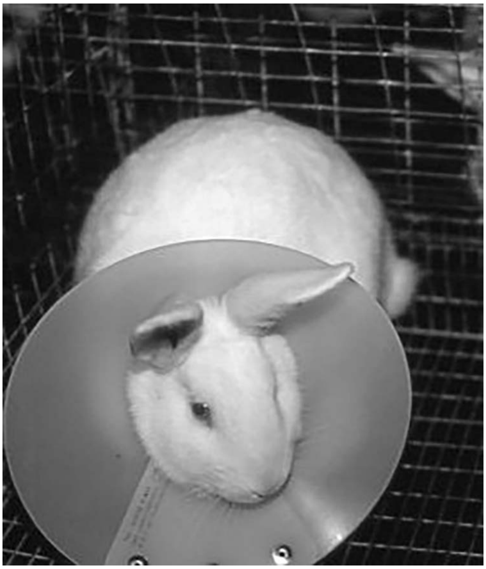


Fig. 7.8. A rabbit equipped with a collar, to prevent cecotrophy. This technique is used experimentally to study the nutritional effects of cecotrophy. (Courtesy of P.R. Cheeke)

are often seen during the day as well, and they are not true feces.

The major differences between the composition of hard feces and cecotropes is that the hard feces have a much higher content of crude fiber and are lower in crude protein. The cecotropes contain over twice the protein content as hard feces, and about half as much fiber. The cecotropes also have a very high concentration of B-complex vitamins.

Feed Analysis

A complete analysis of a feed for all known nutrients would be extremely expensive. Nutritionists have devised a system for analysis of feeds that gives a general idea of their overall feeding value. This is called the proximate analysis. For particular feedstuffs or when certain nutritional problems are encountered, more sophisticated analyses may be conducted for amino acids, minerals, vitamins, or other specific nutrients. In ration formulation, "book values" are generally used. Such values are tabulated in the National Research Council (NRC) publications on nutrient requirements of animals. It is generally not feasible to get complete analyses on specific feedstuffs that are being used by feed manufacturers in preparing feeds.

The components measured in the proximate analysis scheme are:

- crude protein
- fat (ether extract)
- crude fiber
- ash
- nitrogen-free extract (NFE); and
- water.

Crude protein is actually based on a measurement of nitrogen content. It is assumed that all the nitrogen in a feed is associated with protein. Crude protein is defined as nitrogen content times the factor 6.25. This is somewhat imprecise, since not all the nitrogen is from protein and this measurement gives no indication of amino acid content of protein sources. The fat or ether extract is that portion of the feed that is soluble in ether. Crude fiber is a measurement of the plant cell wall components. The crude fiber determination has been largely replaced by measurement of acid detergent fiber (ADF). The ADF is a more specific measure of the cellulose and lignin content of forage. Most laboratories now routinely measure ADF instead of crude fiber. Unfortunately, feed tags (by law) express fiber as crude fiber. For alfalfa-based rabbit diets, crude fiber is generally 7 to 9 units less than ADF, so if the analyzed ADF value is 23%, for example, the crude fiber is about 15%. Ash is obtained by burning a feed sample in a laboratory furnace and weighing the incombustible residue. This corresponds to the total mineral content. The nitrogen-free extract (NFE) is the difference between 100% and the sum of all the other proximate components. NFE is composed primarily of soluble carbohydrates, such as starch.

The energy content of feeds is obtained by burning a feed sample in an instrument called a bomb calorimeter (Fig. 7.9). Energy in the U.S. is measured in units called calories, a measurement of heat. A calorie is the amount of heat required to raise the temperature of one gram of water by 1°C. In the bomb calorimeter, a known amount of feed is burned in a "bomb," which is surrounded by a known weight of water. The water takes up the heat,

Fig. 7.9. A bomb calorimeter used in the determination of the calorie content of feeds. The bomb (the container in which the feed sample is burned) is in the technician's right hand. The feed sample is put into a cup in her left hand and then inserted into the bomb. (Courtesy of OSU Rabbit Research Center)

and the temperature rises. From the weight of the sample, weight of the water, and rise in temperature of the water, the total heat energy (calories) can be determined. Popular usage of the term "calorie" is incorrect. A calorie is too small a unit to be useful in nutrition. We use kilocalories (kcal). One kilocalorie is equal to 1000 calories. When people talk about how many calories they have eaten today, they are actually talking about the number of kilocalories rather than calories. In most countries other than the U.S., feed energy is expressed as joules, which is the unit of energy measurement in the metric system. The conversion factor is 1 calorie = 4.184 joules.

The total energy content of a feed is called the gross energy. Gross energy is not useful for expressing energy content of feeds, since anything that burns will have high gross energy content. That does not mean that an animal can "burn" it. Therefore, feed energy is expressed as digestible energy (DE). This is determined by feeding an animal a test feed and collecting the feces excreted. The gross energy content of both the feed and the feces is measured in a bomb calorimeter. The feed gross energy then is corrected for the amount of indigestible energy excreted in the feces to estimate digestible energy. As a rule of thumb, the DE content is 4 kilocalories per gram for protein and carbohydrate and 9 kilocalories per gram for fat.

Total digestible nutrients

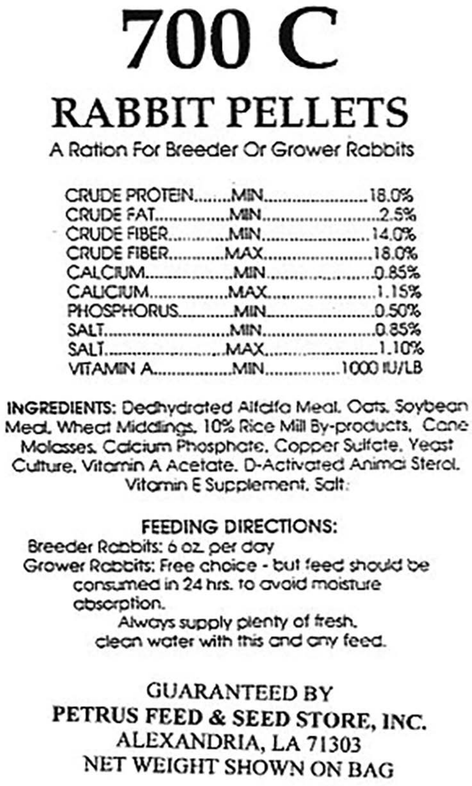
Total digestible nutrients (TDN) are an indirect method of estimating DE. It is calculated by adding up the digestible components of a feed that can yield energy. The caloric content of a feed is due to its protein, fat, and carbohydrate content. Minerals and vitamins do not provide energy. TDN is calculated by the following formula:

$$\begin{aligned}\%\text{TDN} = {} & \%\text{ digestible crude protein}\\ & + \%\text{ digestible crude fiber}\\ & + \%\text{ digestible NFE}\\ & \times 2.25\text{ (digestible fat).}\end{aligned}$$

The fat content is multiplied by 2.25 because fats have about 2¼ times the energy content of protein and carbohydrate.

Information on a feed tag

By law, a feed tag must provide certain information, varying somewhat by state or province. A typical tag is shown in Fig. 7.10. Crude protein is usually listed as "minimum" or "min." In other words, the feed manufacturer can provide more protein than listed on the tag. The manufacturer is not likely to consciously do so, as protein is expensive. Similarly, the crude fiber is listed as "maximum" or "max." Again, this is to protect the buyer. Fiber sources are generally cheaper than grains. By stating a maximum fiber level, the manufacturer assures the buyer that cheap, low-quality fibrous feedstuffs haven't been added to dilute the feed. If the feed has less than the maximum fiber content listed, it means that higher cost ingredients have been used. As a result, rabbit feeds generally have protein contents very similar to the tag values, whereas crude fiber levels are often lower than listed. This regulation has caused misunderstanding by some rabbit raisers, who may want their feed to contain a particular fiber level. They would prefer that the tag read "minimum" for crude fiber. However, this is not required by feed regulations.



700 C

RABBIT PELLETS

A Ration For Breeder Or Grower Rabbits

CRUDE PROTEIN	MIN	18.0%
CRUDE FAT	MIN	2.5%
CRUDE FIBER	MIN	14.0%
CRUDE FIBER	MAX	18.0%
CALCIUM	MIN	0.85%
CALICIUM	MAX	1.15%
PHOSPHORUS	MIN	0.50%
SALT	MIN	0.85%
SALT	MAX	1.10%
VITAMIN A	MIN	1000 IU/LB

INGREDIENTS: Dedhydrated Alfalfa Meal. Oats. Soybean Meal. Wheat Middlings. 10% Rice Mill By-products. Cane Molasses. Calcium Phosphate. Copper Sulfate. Yeast Culture. Vitamin A Acetate. D-Activated Animal Sterol. Vitamin E Supplement. Salt.

FEEDING DIRECTIONS:

Breeder Rabbits: 6 oz. per day

Grower Rabbits: Free choice - but feed should be consumed in 24 hrs. to avoid moisture absorption.

Always supply plenty of fresh, clean water with this and any feed.

GUARANTEED BY
PETRUS FEED & SEED STORE, INC.
ALEXANDRIA, LA 71303
NET WEIGHT SHOWN ON BAG

Fig. 7.10. A typical feed tag. The information on a tag is useful, but only limited inferences can be drawn as to the value of the feed, using both the guaranteed analysis and a list of ingredients. (Courtesy of Joel Petrus)

It is impossible to look at a feed tag and say conclusively that the feed is good or bad. The information provided is insufficient to allow a judgment to be made. Crude protein is not a measurement of protein at all, but a measure of nitrogen. There is no indication on the tag of the quality of the protein (its content of essential amino acids). There is no indication of the digestibility of the protein. A crude protein analysis does not distinguish between soybean meal and shoe leather. There is no information on a feed tag about the energy content of the feed or about the specific level of minerals and vitamins.

Relationships between Feed Manufacturers and Rabbit Raisers

Misunderstandings sometimes occur between rabbit raisers and feed manufacturers. There are probably several reasons for this. One is that compared to other domestic livestock, rabbits are picky, finicky animals. Pigs or feedlot steers will eat almost anything a feed mill can concoct. Rabbits, on the other hand, are quite discriminating. A subtle change in the feed, even to a new batch of the same feedstuff, may cause them to go off feed or to scratch large amounts of feed out of the feeder. Enteritis outbreaks seem to be associated with the feed. All the factors involved in enteritis haven't been identified, but certainly the feed seems to be one of them. When an outbreak occurs, the rabbit raiser blames the feed, while the feed mill may be unable to identify any problem with it. Greater understanding by both sides is needed. Feed manufacturers should appreciate that rabbits are unique animals and, for reasons that have yet to be identified, they develop conditions such as enteritis on certain feeds. Rabbit raisers should recognize that a feed mill is not a "fly-by-night" operation and that feed manufacturers want to produce a high-quality product. The basic underlying problem is that we still don't know exactly how to feed rabbits. Much more research is needed to identify all the subtle factors that seem to influence how rabbits respond to commercial feeds. It is very frustrating to both sides for a rabbit raiser to lose large numbers of animals when a certain feed is used but the feed manufacturer cannot find anything wrong with it. It is hoped that this situation will change in the future as more is learned about the nutritional needs and peculiarities of rabbits.

Another complaint often voiced by rabbit raisers is that when they get a new batch of feed, it doesn't look exactly the same as the last batch. There are several reasons for this. One is that different batches of the same ingredients are not exactly the same. One batch of alfalfa meal may be greener than another purchased at a different time. Thus, a feed could have exactly the same formula but, when prepared at two different times, not have exactly the same appearance. A formula that is not changed is called a closed formula. Many commercial diets are of an open formula type. That is, they are changed periodically to adjust for changes in ingredient costs. The advantage of a closed formula is that the variability in the feed is reduced. The disadvantage is that if one or more ingredients increase in price relative to alternative ingredients, the cost savings that would be possible by switching ingredients cannot be realized. As long as drastic changes are not made, substitution of one feed ingredient for another, while maintaining adequate nutrient levels, should not cause problems. The alternative is to not take advantage of changes in ingredient prices. Rabbit raisers often object to changes in ration composition as a result of least-cost formulation by the feed mill but at the same time object to price increases if the mill doesn't adjust for changing commodity prices. You can't have it both ways!

Fig. 7.11. An example of a pelleted diet with excessive fines (left) compared with good-quality pellets (right). (Courtesy of P.R. Cheeke)

A feed problem that rabbit raisers often complain about is the occurrence of fines in pelleted feed (Fig. 7.11). Minimizing fines can be accomplished by the selection of feed ingredients and by the use of pellet binders. Wheat contains a type of protein, gluten, which has sticky or gluey properties, particularly when steam is used in the pelleting process. Thus wheat products, such as ground wheat, wheat bran, wheat middlings, etc., can be included in the formula to improve pellet quality and reduce fines. Almond hulls, available in some areas (especially California), also have good pellet-binding activity. Pellet binders are discussed in Chapter 8.

Further Reading

Cheeke, P.R. 1987. *Rabbit Feeding and Nutrition*. Academic Press, San Diego.

Cheeke, P.R. 1999. *Applied Animal Nutrition: Feeds and Feeding* (2nd ed.). Prentice Hall, Upper Saddle River, NJ.

de Blas, C., and J. Wiseman. 2020. The Nutrition of the Rabbit (3rd ed.) CAB International, Wallingford, U.K.

National Research Council. 1977. *Nutrient Requirements of Rabbits*. National Academy of Sciences, Washington, DC.

8

Feeds and Feeding

Nutrient Requirements of Rabbits

Since rabbits are kept under confinement conditions, they are totally dependent on the feed provided. Generally, they are fed nothing but a pelleted feed. That feed must contain all the nutrients they need, in adequate amounts and in proper balance, and must be palatable and well accepted by the rabbits. This diet must not only be satisfactory for the short term but must be adequate for reproduction and longevity. Breeding does should theoretically be able to produce 12 or more litters. In order that a feed may give satisfactory results, it is necessary that nutrient requirements be met. Information on these requirements is obtained from the National Research Council publication *Nutrient Requirements of Rabbits*. More recent tabulations of the nutrient requirements of rabbits have been published by European rabbit scientists (see Tables 8.1 and 8.2).

The National Research Council (NRC) is a branch of the National Academy of Sciences. The NRC establishes committees charged with the responsibility of reviewing the world's scientific literature to find, examine, and evaluate information on the nutritional needs of each of the major types of livestock. These committees are made up of scientists with recognized expertise in the nutrition of the particular animals under consideration. After each committee has agreed upon its recommendations, a report is issued in which the nutritional requirements are published. The reports are used extensively in the feed industry by animal nutritionists as the standards for the nutrient requirements for animals. Among the animals for which requirements have been established are rabbits, dairy cattle, beef cattle, poultry, warm water fishes, trout, salmon and catfish, horses, cats, swine, laboratory animals, sheep, mink, and foxes and dogs. A publication on each of these species is available from the NRC for a small fee.

Compared with those of many other species, the nutrient requirements of rabbits have not been well established. Only a limited amount of research has been conducted. In many cases, the work has used small numbers of animals and diets that do not resemble practical commercial diets. Thus, the data available are imprecise and will require considerable "fine tuning" with more research. Nevertheless, the present requirement figures are a much better guideline than nothing at all, which is the alternative.

The NRC nutrient requirements for rabbits were last published in 1977, so they are out of date. Because of the perceived minor importance of rabbits, the NRC has discontinued revision of the rabbit nutrient requirement publication. An updated version of the NRC requirements has been published by de-Blas and Wiseman (2020) (Tables 8.1 and 8.2).

DOI: 10.1079/9781789249811.0008

Table 8.1. Nutrient requirements of intensively reared rabbits, as concentration kg^{-1} corrected to a dry matter content of 900 g kg^{-1}. (Modified with permission from deBlas, C. and Wiseman, J. 2020. *The Nutrition of the Rabbit* (3rd edn), CAB International, Wallingford, U.K.)

Nutrient	Unit	Breeding does	Fattening rabbits	Mixed feed
Digestible energy	MJ	10.7	10.2	10.2
Metabolizable energy	MJ	10.2	9.8	9.8
NDF[a]	g	320 (310–335)[b]	340 (330–350)	335 (320–340)
ADF	g	175 (165–185)	190 (180–200)	180 (160–180)
Crude fibre	g	145 (140–150)	F155 (150–160)	150 (145–155)
ADL	g	*55*[c]	*50*	*55*
Soluble NDF	g	Free	*115*	*80*
Starch	g	170 (160–180)	150 (140–160)	160 (150–170)
Ether extract	g	45	Free	Free
Crude protein	g	175 (165–185)	150 (142–160)	159 (154–162)
Digestible protein[d]	g	128 (115–140)	104 (100–110)	111 (108–113)
Lysine[e]				
Total	g	8.1	7.3	7.8
Digestible	g	6.4	5.7	6.1
Sulfur amino acids[f]				
Total	g	6.3	5.2	5.9
Digestible	g	4.8	4.0	4.5
Threonine[g]				
Total	g	6.7	6.2	6.5
Digestible	g	4.6	4.3	4.5
Calcium	g	10.5	6.0	10.0
Phosphorus	g	6.0	4.0	5.7
Sodium	g	2.3	2.2	2.2
Chloride	g	2.9	2.8	2.8

ADF, Acid detergent fibre; ADL, acid detergent lignin; NDF, neutral detergent fibre; free = no nutritional limit.

[a] The proportion of long fiber particles (>0.3 mm) should be >0.22 for breeding does and >0.205 for fattening rabbits.

[b] Values in parentheses indicate the range of minimal and maximal values recommended.

[c] Values in italics are provisional estimates.

[d] The digestibility of crude protein and essential amino acids is expressed as fecal apparent digestibility.

[e] Total amino acid requirements have been calculated for a contribution of synthetic amino acid of 0.15.

[f] Methionine should provide a minimum of 35% of the total sulfur amino acid requirements.

[g] Maximal levels of 5.0 and 7.2 g kg^{-1} of digestible and total threonine, respectively, are recommended for breeding does.

There are breed differences in nutritional requirements, largely associated with variations in body size and relative capacity of the digestive tract. Small breeds, such as the Netherland Dwarf, have a lower capacity to utilize low-energy, high-fiber diets than do larger breeds. This is of particular significance under cold weather conditions, which increase energy requirements. On high-fiber diets, rabbits of the dwarf breeds, particularly lactating does, may not be able to consume sufficient feed to meet their energy requirements. They will become emaciated and may die of malnutrition. As more research on this aspect of rabbit nutrition is conducted, it may become common to use higher energy diets for the small breeds.

Composition of Feeds

Besides knowing the nutrient requirements of rabbits, you must have knowledge of the nutrient content of feedstuffs, in order to be able to combine them to provide a nutritionally adequate diet. Also important is information on any other characteristics of the feed ingredients that might affect their use, such as the presence of toxins, palatability, pelleting ability, or nutrient imbalance.

Feeds can be classified into several groups.

1. Roughages: bulky feeds that are high in fiber and low in digestible energy, e.g., alfalfa meal, hay, pasture, silage, green chop, straw and chaff, corn cobs, cottonseed hulls, bagasse, wood.

Table 8.2. Trace element and vitamin requirements of intensively-reared rabbits, as concentration (kg^{-1}) corrected to a dry matter content of 900 g kg^{-1}. (Modified with permission from deBlas, C., and Wiseman, J. 2020. *The Nutrition of the Rabbit* (3rd edn), CAB International, Wallingford, U.K.)

Nutrient	Unit	Breeding does	Fattening rabbits	Mixed feed
Cobalt	mg	0.3	0.3	0.3
Copper	mg	10	6	10
Iron	mg	50	30	45
Iodine	mg	1.1	0.4	1.0
Manganese	mg	15	8	12
Selenium	mg	0.05	0.05	0.05
Zinc	mg	60	35	60
Vitamin A	mIU[a]	10	6	10
Vitamin D	mIU[a]	0.9	0.9	0.9
Vitamin E	IU	50	15	40
Vitamin K_3	mg	2	1	2
Vitamin B_1	mg	1	0.8	1
Vitamin B_2	mg	5	3	5
Vitamin B_6	mg	1.5	0.5	1.5
Vitamin B_{12}	µg	12	9	12
Folic acid	mg	1.5	0.1	1.5
Niacin	mg	35	35	35
Pantothenic acid	mg	15	8	15
Biotin	µg	100	10	100
Choline	mg	200	100	200

[a] m = 1000

2. Concentrates (feeds high in energy or protein):
  - energy sources: cereal grains (corn, wheat, barley, milo, oats, rye, buckwheat, triticale), milling by-products (wheat bran, mill run, wheat shorts, etc.), beet and citrus pulp, molasses, fats and oils, brewers and distillers grains, roots and tubers (potatoes, cassava);
  - protein sources: concentrates that have over 20% crude protein, e.g., soybean meal, rapeseed (canola) meal, cottonseed meal, meat meal, fish meal, milk by-products.

3. Mineral supplements: limestone, dicalcium phosphate, salt, trace mineral mixtures.

4. Vitamin supplements.

5. Non-nutritive additives: antibiotics, antioxidants, bacterial preparations, colors and flavors, emulsifying agents, enzymes, hormones, chemotherapeutics (drugs), pellet binders.

Some of the major feedstuffs in these categories will be discussed, with emphasis on any peculiarities related to their use by rabbits. Data on their composition will be given, listing only nutrients that are significant in rabbit feed formulation.

Roughages

The roughages discussed here are those that are usually fed in the dry state, either as hay or incorporated into a pelleted diet.

Clovers

Most clovers are somewhat similar to alfalfa in feeding value for rabbits. Because they are legumes, they are good sources of protein. Clover is highly palatable in both the green and dried forms. Good-quality clover hay can be used as a substitute for alfalfa meal in rabbit rations as long as contents of protein, TDN (total digestible nutrients), and calcium are checked. Analyses for some typical clovers are shown in Table 8.3.

Grasses

Grasses are generally somewhat lower in nutritional value than legumes, such as alfalfa and clover. They tend to be lower in protein, calcium, and vitamin activity. Tropical grasses are of lower feeding value than temperate zone grasses, because of a lower protein and higher fiber content. Most grasses, when incorporated into complete rabbit diets as a source of roughage, are quite palatable. They generally contain 0.2 to 0.4% calcium and 0.2 to 0.3% phosphorus. The composition of some common temperate and tropical grasses is shown in Table 8.4.

Green feeds and succulents

For backyard rabbit raising, feeding of green feeds can be advantageous. If palatable greens are fed free choice, the amount of pelleted feed used can be reduced by about 50% with no adverse effects on performance. Most greens are very high in water content, so large amounts have to be consumed to make a useful contribution to rabbits' nutritional needs. Because of the

Table 8.3. Composition of clovers.

	Dry matter (%)	DE (kcal/kg)	TDN (%)	Crude protein (%)	Crude fiber (%)	Calcium (%)	Phosphorus (%)
Fresh red clover	22.7	600	14	4.2	5.0	0.41	0.06
Red clover hay	87.0	2170	49	14.1	25.5	1.30	0.22
Fresh white clover	17.6	500	10	5.0	2.8	0.25	0.09
White clover hay	90.7	2200	51	17.0	22.0	1.72	0.29
Fresh crimson clover	17.6	500	10	3.0	4.9	0.24	0.05
Crimson clover hay	88.8	2190	50	14.8	24.6	1.22	0.24

Table 8.4. Composition of common temperate zone and tropical grasses on an "as fed" basis.

	Dry matter (%)	Crude protein (%)	Crude fiber (%)	TDN (%)
Bahiagrass fresh	30.3	2.5	9.5	15
Bahiagrass, hay	90.8	4.3	30.5	50
Bermuda grass, fresh	35.0	3.6	9.8	20
Bermuda grass, hay	91.2	7.2	26.8	44
Brome grass, fresh	30.0	4.2	8.8	18
Brome grass, hay	91.4	8.9	29.1	45
Coastal Bermuda, fresh	28.8	4.3	8.2	18
Coastal Bermuda, hay	88.4	17.1	26.9	50
Dallis grass, fresh	25.0	3.0	7.2	15
Dallis grass, hay	90.9	6.5	29.1	50
Guinea grass, fresh	24.2	1.4	10.1	10
Guinea grass, hay	89.3	6.3	28.1	40
Johnson grass, fresh	24.8	3.6	7.4	14
Johnson grass, hay	89.0	7.1	30.1	45
Kentucky bluegrass, fresh	29.0	4.5	7.5	17
Kentucky bluegrass, hay	88.9	9.1	26.7	54
Napier grass, fresh	14.9	1.6	4.7	7
Napier grass, hay	89.1	8.2	34.0	45
Orchard grass, fresh	24.2	2.8	7.9	14
Orchard grass, hay	88.6	9.8	30.3	45
Pangola grass, fresh	20.0	2.2	6.0	12
Pangola grass, hay	87.5	8.4	24.0	40
Ryegrass, fresh	26.1	2.9	6.6	15
Ryegrass, hay	86.1	8.3	24.9	55
Sudan grass, fresh	14.3	3.0	3.5	8
Sudan grass, hay	90.7	10.6	28.3	45
Tall fescue, fresh	25.0	4.4	5.9	15
Tall fescue, hay	84.7	5.2	30.7	40

large quantity of fresh material required and the problems associated with collecting and feeding bulky materials, it is generally not feasible to use greens except on a backyard scale. Greens can sometimes be useful in stimulating appetite in animals that have gone off feed. Green feeds should not be left in piles that become heated before being fed, as digestive disturbances may result. If fed on the cage floor they quickly become fouled with feces and urine, so greens should be fed either on top of the cage or in a feeder designed for this purpose. Rabbits are highly selective when fed green feeds. They tend to choose succulent leaves, flowers, etc., and reject coarser plant parts. Feeding greens to rabbits is important in tropical areas, where concentrates are expensive but where tropical forages are abundant and can be readily harvested by hand. Labor costs for such work are generally much less than in Europe and North America. Under these conditions, it is possible to base a rabbit enterprise on the feeding of forage and by-product feeds (Fig. 8.1).

Examples of some common succulent feeds are clover; grasses; comfrey (Fig 8.2); vegetables and vegetable tops (carrots, lettuce, cabbage, celery, etc.); amaranthus; kale; rape; various roots and tubers, such as carrots, potatoes, and turnips; and various weeds, such as dandelions. The composition of some of these feeds is shown in Table 8.5. Note that most of them are 80 to 90% water, so they are of rather limited nutritional value.

Alfalfa

In Europe alfalfa is called lucerne. Alfalfa meal is a very desirable feed for rabbits and, in much of the United States, is the largest single component of commercial rabbit feeds (Table 8.6). Besides its value as a feed, alfalfa has other desirable attributes in the entire agricultural scene. It produces more protein per acre than any other crop – for example, two to four times as much as soybeans. It is a legume, so it doesn't require nitrogen fertilization. It is a perennial, so the energy costs associated with its production are less than for many annual crops. It improves the soil, adding organic matter and reducing erosion. Alfalfa meal is not consumed directly by humans, so its use by livestock is complementary, rather than competitive, in relation to human food needs.

The protein in alfalfa meal is well digested by rabbits, so a major part of the total protein requirement can be met with alfalfa. It is a good source of phosphorus and is an excellent source of calcium and potassium. It provides indigestible fiber, which helps prevent enteritis. It is the richest common plant source of vitamin A

Fig. 8.1. Feeding green forage (coastal Bermuda grass) in a rabbitry in Haiti. This large commercial rabbitry used green feed and wheat milling by-products as the basis of the feeding program. Low labor costs made harvesting and feeding of grass economical in this situation. (Courtesy of P.R. Cheeke)

activity; dehydrated alfalfa meal may have over 60 times as much carotene as yellow corn and over four times as much as carrots. Alfalfa is palatable to rabbits at moderate dietary levels. Thus, it has many qualities that will ensure its continuing use as a rabbit feed. As competition between humans and as competition between humans and animals for grains continues, alfalfa will become an increasingly important rabbit feed. Studies at the Oregon State University Rabbit Research Center demonstrated good results with diets in which alfalfa replaced all of the grain.

Fig. 8.2. Comfrey, a large-leaved succulent plant often used as a source of greens for rabbits. (Courtesy of P.R. Cheeke)

Concentrates

Grains

Grains are plant seeds, including corn, wheat, barley, sorghum, millet, rice, triticale, oats, rye, buckwheat, and *amaranthus* (Fig. 8.3). Cereal grains (cereals) are the seeds of cultivated grasses (e.g., wheat is the domesticated version of wild wheat grass). Grains are a major source of energy for both humans and livestock. Some cereal grains, such as wheat and rice, are grown primarily for human consumption, whereas others, such as sorghum (milo), are grown in the United States principally for livestock feed. The main factor that determines (or should determine) which grain is used in a feed is its cost and, in particular, the cost per unit of energy.

In many areas, grains are sold on the basis of bushel weight, which is the weight of a particular volume of grain. Grains such as corn and wheat are quite dense, while oats are

Table 8.5. Composition of greens and succulents on an "as fed" basis.

	Water (%)	Protein (%)	Fiber (%)
Apples	82.1	0.5	1.3
Bananas	75.7	1.1	0.5
Bean leaves	71.2	5.2	3.3
Beet, mangel	89.0	1.3	0.8
Beet, sugar	80.0	1.4	1.2
Cabbage	90.4	2.0	1.0
Carrot roots	87.1	1.3	1.2
Cassava, tubers	68.0	1.2	1.5
Cauliflower leaves	90.0	2.7	1.0
Celery	94.1	0.9	0.6
Comfrey	86.8	2.6	1.8
Dandelions	86.3	3.2	1.5
Kale	88.4	2.4	1.6
Kudzu	73.6	4.6	8.1
Lettuce	94.6	1.2	0.6
Pea vines	87.8	2.7	3.2
Potatoes	80.0	2.1	0.5
Raisins	13.0	3.4	4.4
Rape	83.1	3.0	2.5
Rutabagas	88.0	0.8	1.2
Sweet potatoes	69.0	1.7	1.3
Turnips	91.0	1.1	1.0

Table 8.6. Composition of alfalfa on an "as fed" basis.

Nutrient	Fresh Alfalfa	Dehydrated Alfalfa Meal	Sun-cured Alfalfa Meal	Alfalfa Hay
Dry matter (%)	24	92	91	89
DE (kcal/kg)	620	2350	2200	2200
TDN (%)	14	53	50	50
Crude protein (%)	4.9	17.4	17.6	17.7
Lysine (%)	0.26	1.01	1.0	1.0
Methionine + cystine (%)	0.14	0.55	0.54	0.54
Crude fiber (%)	6.5	23.9	27.3	24.9
Fat (%)	0.8	2.7	2.1	2.4
NFE (%)	10.1	38.1	34.1	37.3
Ash (%)	2.2	9.8	9.6	8.1
Calcium (%)	0.45	1.32	1.3	1.33
Phosphorus (%)	0.08	0.28	0.28	0.28
Vitamin A equivalent (IU/g)	56.4	146.6	63.6	64.0

Fig. 8.3. *Amaranthus* has a large seed head, containing a grain that may have potential as an animal feed. (Courtesy of D.J. Harris)

fluffy. As a result, a bushel of oats weighs much less than a bushel of wheat or corn.

Corn, wheat, and milo are high energy grains, while barley and oats tend to be lower in energy because of their fibrous hull. The protein content is variable, depending upon the species, variety, cultural and environmental conditions, etc. Adverse growing conditions, such as drought, usually result in an increase in percent protein. This is because the grain is shriveled, having less than normal starch content, so the protein makes up a higher percentage of the total weight. Corn and milo usually have about 9% protein, while wheat and barley tend to have somewhat higher levels. Where large amounts of grain are to be used, a protein analysis is certainly advisable as an aid in ration formulation.

Oats and corn tend to be highest in fat content of the common grains, while oats and barley are highest in fiber content. All grains are essentially devoid of calcium, but they are moderately good sources of phosphorus. For non-ruminant animals, the phosphorus is of low availability, being bound as phytic acid phosphate. The availability of grain phosphorus for rabbits is quite high because of production of bacterial phytase in the hindgut. Phytase is an enzyme that digests phytic acid, releasing the bound phosphate. All grains except yellow corn are lacking in vitamin A activity.

Triticale, a synthetic grain, has a feeding value similar to that of wheat. Rye generally gives results inferior to those of other grains; it contains factors such as pectins that may impair nutrient digestibility. Amaranthus grain is of experimental interest because of its high lysine content. However, it contains unidentified toxic factors and has given very poor results in feeding trials with rabbits. Buckwheat is not commonly used as a livestock feed but probably would be satisfactory for rabbits, based on results with swine and poultry.

Corn is generally used as a standard of comparison for grains. Since grains are used primarily as sources of energy and because corn is generally the highest energy grain, other cereals will usually be ranked somewhat lower. With a value of 100 assigned to corn, grains rank as shown in Table 8.7.

One potential problem with the use of grain in rabbit diets is the possibility of carbohydrate overload of the hindgut, resulting in enteritis. Work at the OSU Rabbit Research Center indicated that high levels of grain may result in the stimulation of bacterial growth in the cecum, leading to the production of bacterial toxins causing enteritis. High energy grains, such as corn, may be more likely to cause this effect than low energy grains, such as oats. Corn has a waxy endosperm, which may reduce its digestibility in the small intestine, increasing the likelihood of carbohydrate overload of the hindgut.

The composition of some of the important grains used in rabbit feeding is shown in Table 8.8.

Table 8.7. Relative values of selected cereals as TDN source.

Corn	100
Barley	90
Oats	78
Rye	93
Sorghum (milo)	88
Red winter wheat	101
White winter wheat	95
Red spring wheat	95

Other energy sources

Other concentrates that function as energy sources include wheat milling by-products (wheat bran, shorts, mill run), beet and citrus pulp, bakery waste, molasses, brewers' and distillers' grains, etc. Wheat bran and other wheat by-products are quite palatable to rabbits at moderate levels, are comparatively good sources of both energy and protein, and are rich in phosphorus. They can be used at levels of 20 to 30% of the complete diet with good success. Wheat contains a type of protein called gluten. Some humans are intolerant of gluten. However, there is no evidence that animals, including rabbits, have gluten intolerance. Molasses has a total sugar content of about 50 to 60%. It has a fairly high mineral content (8 to 10%), composed of sodium and potassium salts. Molasses is highly palatable and is used to increase the acceptability of feed by rabbits through its taste, reduction in fines, and improved pellet quality. Levels of 3 to 10% of the diet are generally used. At higher levels, it may cause diarrhea due to the high mineral content. Dried beet pulp is the residue remaining after extraction of sugar from sugar beets. It is quite palatable to rabbits. Although it is fairly high in fiber, the fiber is of a quite digestible type because it is low in lignin. Citrus by-products, such as dried citrus pulp, are somewhat unpalatable and probably shouldn't be fed at levels higher than 10% of the diet. The composition of some of these products is shown in Table 8.9.

Table 8.8. Nutrient composition of selected grains.

Grain	DE (kcal/kg)	TDN (%)	Crude protein (%)	Crude fiber (%)	Lysine (%)	Sulfur amino acids (%)
Yellow corn	3790	83	9.3	2.0	0.20	0.26
Barley	3330	75	9.5	6.2	0.27	0.34
Red wheat	3680	84	12.8	2.4	0.38	0.48
White wheat	3680	79	9.8	2.7	0.32	0.44
Oats	2950	65	12.1	10.6	0.34	0.33
Milo	3330	75	10.7	2.2	0.27	0.27
Amaranthus	NA[1]	NA	16.0	5.0	0.83	0.77
Buckwheat	2990	68	11.1	10.3	0.62	0.39
Triticale	NA	78	15.0	4.0	0.52	0.50
Rye	3330	76	12.0	2.2	0.42	0.35

[1] Not available.

Table 8.9. Composition of selected energy sources

	DE (kcal/kg)	TDN (%)	Crude protein (%)	Crude fiber (%)	Lysine (%)	Sulfur amino acids (%)
Wheat bran	2610	57	15.1	10.3	0.58	0.52
Wheat mill run	2700	62	15.6	8.1	0.60	0.48
Beet pulp	3080	70	8.6	18.3	0.59	0.21
Dried citrus pulp	2050	47	6.4	11.6	NA[1]	NA[1]
Molasses	2460	55	3.9	NA[1]	NA[1]	NA[1]
Brewers' dried grains	1900	43	25.3	15.3	0.9	1.0
Distillers' dried grain	3500	81	27.2	9.1	0.6	0.9
Rice bran	3160	72	1.27	11.6	0.57	0.42

[1] Not available.

Fats and oils also can serve as energy sources. Fats are palatable to rabbits, and levels as high as 25% fat in the diet have been successfully fed. Under practical conditions, added fat levels of 3 to 5% are used. Fats help reduce fines in feed, increase palatability, and act as a lubricant during pelleting. Vegetable oils provide essential fatty acids, which may aid in promoting good fur quality. Examples of common vegetable oils are corn oil, soybean oil, canola oil, cottonseed oil, and safflower oil.

Protein supplements

Protein supplements commonly used in rabbit feeds include soybean meal, cottonseed meal, sunflower meal, rapeseed (canola) meal, safflower meal, linseed (flax) meal, and peanut meal. In addition, alfalfa meal might be regarded as a protein supplement since at the levels at which it is commonly used it supplies a significant part of the total dietary protein. Protein supplements are normally considered to contain at least 20% crude protein.

Soybean meal is the protein supplement of choice for rabbit rations. It is highly palatable and has a high digestibility and a good amino acid balance. Two types are commonly available: regular soybean meal, with 46% crude protein, and dehulled meal, with 49% crude protein. Either one can be used, depending on which is cheaper per unit of protein. Soybean meal is the residue remaining after the oil has been extracted by solvents. The meal is heated to destroy a number of inhibitors. It should be noted that raw soybeans to be used in animal feeding should be heat-treated. Soybeans contain trypsin inhibitors, hemagglutinins, and several other toxic factors that are destroyed by heat. A common procedure for detoxifying soybeans is the extrusion process, in which the beans are put through a die in the extruder. The friction generated in the die heats the material sufficiently to destroy the inhibitors.

Cottonseed meal can be used in limited quantities in rabbit diets. Cottonseed meal is lower in essential amino acids, such as lysine and methionine, than is soybean meal, so it is a poorer quality protein than soybean meal. It usually contains about 41% crude protein. Cottonseed meal should be used with caution in rabbit feeding. It has been successfully fed for prolonged periods at 5% of the diet; the upper safe limit has not been determined. It contains a toxic substance called gossypol. Gossypol causes tissue damage, especially to the heart. It also has been shown to cause infertility in males of some species, even at low levels in the diet. Therefore, it may not be advisable to include cottonseed meal at high levels in the diet of bucks. Gossypol can be detoxified by the addition of iron salts, such as ferrous sulfate. The effectiveness of this treatment for rabbits has not been determined. Cottonseed oil contains a toxic fatty acid called sterculic acid. This is present at low levels in expeller-produced cottonseed meal. Expeller-produced meal is the residue from mechanical removal of the oil as opposed to residue from extraction of the oil with solvents.

Sunflower meal is the residue remaining after oil has been extracted from sunflower seeds. Sunflowers are a major crop in the former

Soviet Union and northern Europe. Since about 1975, sunflower production has expanded rapidly in the United States, especially in North and South Dakota and other northern states.

Sunflower meal contains about 32% crude protein and about 24% crude fiber. The dehulled meal contains about 47% crude protein and about 11% crude fiber. The protein tends to be low in lysine and sulfur-containing amino acids. For this reason, sunflower meal shouldn't be used as the sole protein supplement. It can be used at levels up to 10% of the total diet.

Rapeseed (canola) meal is of particular interest to rabbit producers in Canada and the northern United States. Rapeseed is now the second most important crop, after wheat, in western Canada. It is grown primarily for its oil, which has applications in both food and industry. The meal remaining after oil extraction is used in animal feeding. Rapeseed contains glucosinolates, which are compounds that inhibit the function of the thyroid gland. Glucosinolates interfere with the synthesis of the thyroid hormone. As a result, the gland enlarges in an effort to produce more hormones. This enlarged gland is called a goiter. Plant breeders have very effectively selected for low glucosinolate varieties of rapeseed. As a result, the rapeseed meal now available is of a low glucosinolate type and does not cause problems with livestock. To avoid the negative implications of the word "rape," Canadian producers are now referring to the low glucosinolate meal as canola meal. This can be used as a complete replacement for soybean meal in rabbit diets. Canola meal contains about 40 to 44% crude protein.

Safflower meal contains about 22% protein and 32% fiber; dehulled meal has about 40% protein and 10% fiber. Safflowers are grown as an oil seed crop in the western and southwestern United States. The meal is high in fiber and low in protein. Safflower meal is similar in composition to alfalfa; it can be used as a complete replacement for alfalfa meal in diets for does and fryers. Palatability tests have demonstrated that safflower meal may be even more palatable to rabbits than alfalfa meal.

Linseed meal is produced from flaxseed, which is grown primarily for its drying oils used in paint manufacture. Linseed meal is now quite a minor protein supplement. It contains about 36% crude protein; the protein is low in lysine. Linseed meal contains mucilaginous gums that may have a laxative effect and that may also have a favorable effect on the hair coat. It is possible that feeding a supplement of linseed meal to show rabbits could enhance the sheen and general appearance of the fur.

Peanut meal contains 45 to 55% crude protein. It is a common protein supplement in Europe, being imported from Africa and South America. It can be used satisfactorily as a replacement for soybean meal. Peanut meal is somewhat notorious in the feed trade for being the source of the original reported outbreak of aflatoxin poisoning. This problem is discussed in further detail in Chapter 9.

Several other plant proteins are sometimes available for animal feeding. They include crambe meal, mustard meal, sesame meal, palm kernel meal, and coconut oil meal. They are not commonly used in the United States. A number of types of beans, such as kidney, pinto, and fava beans, are fairly good sources of protein and might have some potential in rabbit feeding. Grain lupines are also potential protein sources.

Proteins of animal origin include meat meal, meat and bone meal, blood meal, feather meal, and fish meal. For reasons of cost, protein quality, and palatability, these protein supplements are used only to a very limited extent in rabbit feeding, if at all.

Synthetic amino acids are sometimes used in rabbit diets. Synthetic lysine and methionine are the two most commonly used. Methionine hydroxy analog (MHA) can serve as a methionine source.

Non-nutritive Feed Additives

Examples of non-nutritive feed additives are antibiotics, flavoring agents, enzymes, bacterial preparations, antioxidants, worming agents, coccidiostats, hormones, and other drugs. Very few antibiotics and drugs are approved by the Food and Drug Administration (FDA) for feeding to rabbits. Each new feed additive has to be cleared for each species of livestock to which it will be fed. This FDA clearance involves extensive testing for safety and efficacy. "Efficacy" means that the additive must give the response claimed by the manufacturer. If an additive is to be sold as a growth promotant, then the FDA must be provided data confirming that it does stimulate growth. Because of the great expense necessary to generate the data needed for FDA clearance, it is unlikely under present regulations that new drugs will be cleared for rabbits unless the industry expands greatly. The cost of getting clearance would exceed the profit that the manufacturer could expect from the sale of the product. In the United States, the only drugs approved as of 2013 for addition to rabbit feed were 11 mg of oxytetracycline per kg of feed and 0.025% sulfaquinoxaline in the diet.

Antibiotics

Antibiotics have been naturally present in animal feed for many centuries. Contrary to what may be popular opinion, antibiotics are natural substances, i.e. they are present naturally in the environment. Antibiotics are substances produced by living organisms, usually molds, that inhibit the growth of bacteria. Thus, antibiotics occur in moldy feed, in soil, and in other natural environments. Commercial production of an antibiotic involves growing the appropriate mold in a fermentation vat and collecting the antibiotic that is produced. The first antibiotic to be discovered was penicillin, which is produced by a bread mold.

Antibiotics used as feed additives may function as growth promotants. The mechanisms by which they cause the effect are not completely known. They may alter the balance of microorganisms in the gut to favor those bacteria that improve nutrient utilization. They may favorably influence the absorption of nutrients. They may reduce the population of toxin-producing organisms. Finally, they may prevent or cure low-level disease conditions, with a consequent favorable effect on animal performance.

Concern has been expressed that the feeding of antibiotics to livestock may result in the development of pathogens that are resistant to them. This may decrease the effectiveness of antibiotics when they are required to control disease outbreaks. Of further concern is that the resistance factor may be transferred to human pathogens, making human diseases difficult to treat with antibiotics. One method of avoiding these potential problems has been the development of antibiotics that are to be used only for livestock. An example is virginiamycin. This antibiotic has been tested in Europe and shows some effectiveness as a growth promotant in rabbits.

Rabbits are particularly sensitive to adverse effects of antibiotics in feeds. The microbial balance of the hindgut can be altered when antibiotics are fed, leading to proliferation of pathogenic organisms such as *E. coli* and *Clostridia* species. These bacteria produce toxins that cause damage to the gut lining, diarrhea, and death from enterotoxemia. Administration of antibiotics for treatment of disease can also lead to diarrhea and death.

In view of increasingly rigid restrictions on the use of antibiotics and the sensitivity of the rabbit's digestive tract to their effects, it is probably more useful for the rabbit industry and rabbit scientists to attempt to develop management and nutritional practices that give satisfactory performance rather than including antibiotics routinely in the feed. There is a worldwide trend toward the elimination of the use of antibiotics as animal feed additives.

Probiotics (direct-fed microbials)

The term "probiotics" has been coined to describe live microbial organisms that are fed to animals. They are also referred to as "direct-fed microbials," which is the preferred term in the feed industry. Most often probiotics have been preparations of *Lactobacillus acidophilus*. The rationale for the use of these organisms is that by feeding them, they grow in the digestive tract and, by competitive inhibition, reduce the growth of pathogens. Feeding *Lactobacillus* organisms often reduces the *E. coli* levels in the intestine of pigs, for example. Some studies with swine and poultry suggest favorable effects on growth rate, feed efficiency, and disease incidence, while other studies show no effect. Proponents of probiotics suggest that the beneficial effects are greatest in animals exposed to stress or other unfavorable conditions. In most cases, the probiotics must be fed in meal-type diets or administered in the water, because they are killed when feed is pelleted. Some commercial probiotic products are microencapsulated to ensure their stability during pelleting.

Numerous studies have shown beneficial effects of commercial direct-fed microbial products when fed or given in the water to weanling rabbits. The effects include reduced enteritis, decreased mortality, and improved feed conversion. There is little if any influence on weight gain.

Prebiotics

Prebiotic is a fairly new term. Prebiotics are non-digestible (by the animal) substances that selectively stimulate some beneficial microbes in the intestine, with potential benefits for rabbit health. They tend to stimulate both natural gut microbes and those added as probiotics. In general, prebiotics are composed of sugar molecules joined together (oligosaccharides). Some examples include fructose oligosaccharide (FOS), mannose oligosaccharide (MOS), and galacto-oligosaccharide (GOS). Fructose, mannose and galactose are sugars. Some European research suggests improved growth and reduced enteritis when prebiotics are fed to rabbits.

Pellet binders

Substances such as bentonite (clay) and lignin sulfonate (a derivative of wood) are used in feeds as pellet binders. These are quite important in rabbit feeds. Pellet quality is important in a rabbit diet, and the use of a binder is an effective means of making a good, firm pellet. Binders such as bentonite do not affect growth rate or cause enteritis but do reduce the amount of fines in the feed.

Flavoring agents

Feed flavors have been developed for the purpose of stimulating the intake of feeds that may be unpalatable. There is little scientific evidence that they accomplish this goal. In general, feed flavors have a pleasant aroma that appeals to the buyer of the feed but doesn't seem to alter animal performance. If a feedstuff or feed is unpalatable, it is apparently difficult to mask this with a flavor additive. Some studies have found that thyme is a flavor that rabbits seem to find palatable.

Salt

Rabbit diets should contain 0.5% trace mineralized salt. This will take care of the sodium chloride requirements, as well as provide the trace minerals, such as iron, copper, zinc, and iodine. Salt spools are unnecessary, since a properly balanced commercial diet will contain sufficient salt. Salt spools or blocks corrode cages and feeders. The only situation in which a salt spool should be considered is in backyard rabbit production, if the rabbits are fed primarily greens with very little pelleted feed. If salt spools are used, they should be hung so they do not contact metal parts of the cage or feeder.

Copper sulfate

Copper sulfate has been widely used as a feed additive to reduce enteritis and improve feed conversion in poultry, pigs, and rabbits. It exerts its effect in the digestive tract by inhibiting the growth of pathogenic bacteria. It is commonly used to provide 250 parts per million of copper. Addition of this level of copper sulfate is effective in treating enteritis outbreaks in post-weaning fryer rabbits. Concerns about its use include the environmental effects of increased copper in the manure, which could possibly cause pollution problems. It should also be noted that sheep are very sensitive to copper toxicity and should not be fed diets that have supplementary copper sulfate as a feed additive. It is advisable that use of copper sulfate as a feed additive in rabbit diets be restricted to periods of enteritis outbreaks.

Yucca and quillaja

Extracts of the yucca plant (*Yucca schidigera*) contain components that bind ammonia. They serve a physiological role in this desert plant as a means of storing nitrogen so that the yucca may grow rapidly when infrequent rains occur. When added to the feed, yucca extract passes through the digestive tract of animals and binds ammonia in the excreta, thus reducing the release of ammonia into the air. This is very useful in confinement animal facilities, such as poultry and rabbit houses. Rabbitries often have poor air quality, with high humidity and ammonia levels. Ammonia dissolves in water droplets in the air and has a corrosive effect on the nasal passages of rabbits. This allows *Pasteurella multocida* bacteria to colonize, producing respiratory disease (snuffles). The use of commercial preparations of yucca extract in rabbit diets can produce significant lowering of ammonia levels in the air, improving the welfare and health of the rabbits and the caretakers. A dietary level of 100 ppm pure yucca powder is recommended. The original source of the ammonia in the excreta is the protein in the diet. Excess dietary protein results in the excretion of more nitrogen in the urine and feces. Yucca is also a rich source of saponins.

Quillaja saponaria is a tree native to Chile. Like yucca, it is a rich source of saponins. Dietary saponins modify gut microbes in a favorable manner. Quillaja also has immunostimulatory properties, increasing resistance to a disease challenge.

Enzymes

Numerous enzyme preparations are commercially available. The most useful are those that improve the digestibility of glucans in barley and oats. Glucans are water-soluble gums that cause the contents of the digestive tract to be viscous or gummy, interfering with nutrient absorption. Their effects are most apparent in poultry, which show a good response to enzyme (glucanase) supplements. However, the microbes in the rabbit hindgut digest glucans, so there is no response to glucanase enzyme supplementation in rabbits. Similarly, commercial sources of the enzyme phytase improve phosphorus availability in poultry and swine but are not useful in rabbit diets because gut microbes produce adequate phytase. There is one case where rabbits do respond to dietary enzyme supplements. Sources of protein-digesting (proteolytic) enzymes can aid in breaking down hairballs in the stomach by digesting the mucoproteins (mucus) that hold the hairballs together. Pineapple and papaya juice contain proteolytic enzymes (bromelain and papain, respectively). Some commercial feed containing proteolytic enzymes is marketed for feeding to Angora rabbits, which are very susceptible to hairballs.

Feed Formulation, Preparation, and Processing

Diet formulation

The formulation of diets for livestock involves calculating the optimal balance of available feedstuffs that will meet the nutritional requirements of the animal to provide the desired level of production. Because livestock are almost always raised with the hopes of generating a profit, it is usually desirable that the ration provide the most economical performance to produce the maximum economic return. This is called least cost ration formulation.

In order to formulate a ration effectively, certain information is needed. To manufacture a good diet for lactating rabbits and their litters, it is necessary to know the nutrient requirements of lactating does. Unfortunately, the nutritional requirements of rabbits have not been well established, but reasonable estimates have been made, as listed in Tables 8.1 and 8.2. The use of these nutrient requirement figures requires a certain amount of informed judgment. First, it should be recognized that these figures are not "cast in stone" but are estimates of the requirements of average animals. Some nutrients are more important than others. In formulating a rabbit ration, it is very important to be concerned with the protein requirement but not important to be concerned with meeting the thiamine, riboflavin, and manganese requirements, for example. This is because it is extremely unlikely that a deficiency of these nutrients will occur with any combination of common feedstuffs. Thus, a nutritionist needs to be selective in assessing which nutrients are worthy of consideration in ration formulation.

After deciding upon the nutrient requirements to be met, the next step in ration formulation is to list the available feedstuffs that are suitable for the animal in question. The cost of each feedstuff should be noted and its content of critical nutrients listed. Generally, "book values" are used for many of the nutrient values, because it is too expensive and time-consuming to get a complete analysis on each batch of feed ingredients. Many ingredients, such as soybean meal, are quite consistent in their composition.

After listing the nutrient requirements to be met and the composition and cost of the available feedstuffs, the next step is to combine the ingredients in the optimal proportions to meet the nutritional requirements at the lowest cost. This process has been greatly simplified by the use of computers. Virtually every feed company formulates diets using a computer. The availability of inexpensive microcomputers makes it technically feasible for a rabbit raiser to formulate diets. However, most rabbit raisers are unlikely to have as much knowledge of nutrition, feedstuffs, and ration formulation as professional nutritionists employed by feed companies, so it is generally more effective to leave this process to the professionals. For those who wish to pursue the subject further, additional information on the mechanical details of ration formulation can be obtained from the books cited in the Further Reading section at the end of this chapter. Finally, judgment is needed in assessing the formula selected by the computer. Although the formula may be mathematically sound, it may be a combination of ingredients that is not palatable, won't make a good pellet, etc. The experience of the nutritionist is needed to anticipate these problems.

Feed processing consists of subjecting feeds to various treatments that may improve their nutritional value, destroy toxins, increase palatability, improve ease of handling, etc.

Pelleting is the most important feed processing procedure used in the preparation of rabbit rations. Rabbits show a strong preference for pelleted feed over the same diet in a mash form. Pellets should be solid and firm, with a minimum of fines. Pellets should be 6 mm or less in length and 5 mm or less in diameter. Weanling rabbits will waste large quantities of feed if the pellets are too large; they will take one bite of a pellet and let the rest drop through the cage. The pelleting process allows a variety of feedstuffs to be mixed together and then cohesively bound in a compact, homogeneous package. The animals are not able to sort out the ingredients, so they eat the entire balanced ration. Feedstuffs are processed in various ways prior to pelleting. Grains should be rolled or ground, to break down their cellular structure and facilitate digestion. Corn has a waxy covering that resists digestion. In fact, whole corn will pass undigested through the entire digestive tract of a cow. Corn should be rolled or ground. Alfalfa and other roughages should be ground prior to pelleting. There is some indication that the fineness of grind of grains and roughages can influence the rate of food passage through the gut, which in turn may influence the digestibility of the feed and the development of enteritis. Small feed particles are retained in the rabbit cecum, whereas large particles are excreted more rapidly. The retention of small particles for a longer period may allow pathogenic bacteria to grow in the hindgut, causing enteritis. Therefore, it is probably advisable that feed ingredients for rabbits be coarsely, rather than finely, ground.

In the pelleting process, the feed ingredients are first mixed and then put through a pellet die. This consists of a chamber containing holes through which the feed is forced. As it comes out of the die, knives chop off pellets of the desired length. The diameter of the feed pellet is determined by the size of the holes in the die. As the die size is reduced, the energy required to pellet the feed is increased and the rate at which feed can be pelleted is reduced. In order to maximize the rate at which feed can move through the mill, steam is often injected into the mixture before it enters the pellet die. Steam adds both heat and moisture. The heat accelerates the softening of ingredients and the release of natural adhesives in the ingredients. The addition of molasses usually increases the pelletability of feeds; it can be premixed ahead of the pellet mill or injected directly into the conditioning chamber. Molasses should be injected with steam in very fine droplets, to blend it evenly with other ingredients and to prevent it from congealing on the equipment. Some types of ingredients, such as sugars, dry milk powder, and whey, have a tendency to caramelize during pelleting. They develop a glassy consistency and plug the pellet die.

Feed manufacturing and pelleting are as much art as science. Different ingredients and various combinations of ingredients can behave differently in the mill – some produce good quality, firm pellets, and other combinations cause problems. It is difficult for a large feed mill to prepare small batches of feed. Custom mixes should be used only by rabbit producers who use several tons of feed a month.

Heat treatment is necessary for certain types of feeds. For example, to destroy a number of inhibitors that they contain, soybeans must be heated before being fed to livestock.

If for some reason it is necessary to feed a mash diet, coarsely ground or rolled grains should be used. If finely ground products are used, the feed should be dampened to prepare a wet mash. The addition of molasses will aid in providing a palatable mix and will retard spoilage. After a period of adaptation, rabbits will consume these diets in adequate amounts. In most cases, however, it is advisable to use a pelleted commercial diet.

Feed storage

If stored in a dry, rodent-proof location, rabbit feed can be kept for a considerable period. With prolonged feed storage, there is a loss of vitamin activity and the possible development of rancidity. In humid areas, rabbit feed with a high content of alfalfa meal tends to absorb moisture and swell. The pellet structure breaks down, and mold growth may occur. However, buying feed in large quantities does result in a lower cost per ton of feed. Producers with large herds should consider the use of bulk tanks. These reduce labor costs of feed handling. Also, storage conditions are generally better when bulk tanks are used than when feed is stored in sacks. Bulk feed is less expensive than sacked feed because of lower labor and sacking costs involved. Since metal tanks may “sweat,” causing moldy feed, wood or plastic tanks should be used if feed is to be stored for a prolonged period. Some feed companies use large nylon bags that hold a ton or more of bulk feed. A forklift, front-end loader, or other lifting machinery is necessary for handling them.

Feed requirements and feed conversion

The total feed requirements needed to produce market fryers are dependent to a considerable extent on the composition of the diet. The higher the energy (TDN) content of the feed, the less feed that is required per unit of weight gain. Conversely, the lower the energy content, the more feed that is required. Thus, it is possible to observe considerably different levels of feed intake, depending on the type of diet used. In the final analysis, it is the cost of production (cost of gain) that is of prime importance, not the price per ton of feed.

As a rule of thumb, a New Zealand White doe and litter will consume about 45 kg of feed from breeding to eight weeks of age. Weanling rabbits will consume about 55–170 g of feed per day, depending on their size.

Feed conversion is the kg of feed consumed divided by the kg of body weight gain. It is commonly referred to as the feed:gain ratio. Weanling rabbits will consume about 3 kg of feed per kg of gain. As a rule, it will take 1.6 to 1.8 kg of feed for a doe and litter per kg of gain of the litter. Considering the fact that rabbit rations are typically quite high in roughage and low in energy, the feed:gain ratios commonly observed are remarkably good. Rabbits are as efficient as broiler chickens in their conversion of protein and energy into meat.

Rabbit producers should be aware that it is the cost per kg of fryer produced that is the “bottom line” figure, rather than the cost per ton of feed. If Feed A costs $440 per metric ton and Feed B costs $495 per metric ton, which is the better buy? If feed conversion is 3.7 on Feed A and 3.1 on Feed B, then the cost per kg of gain are 81.4 cents on Feed A and 76.8 cents on Feed B. Thus, Feed B is actually a better buy.

Feeding systems

The two basic feeding systems are *ad libitum,* or free choice, feeding and limit feeding, in which a controlled or limited amount of feed is offered daily. Each feeding system has its advocates. Free choice feeding, in which the hoppers are kept full of feed, is less labor intensive than limit feeding. It is widely used for does with litters and for weaned litters. Another advantage is that there is less crowding at the feed hopper. Advocates of limit feeding assert that this system forces rabbit raisers to visually observe each cage every day so that they are more likely to notice animals off feed or other signs of illness. Limit feeding may also reduce enterotoxemia. In areas of high humidity, it may not be possible to provide more than a single day's ration. You should be careful not to restrict feed intake to the extent that weight gains are severely affected.

A good manager will watch the feed hopper and the droppings closely. If the droppings become soft, it may be necessary to supplement the diet with some hay or other fibrous feed. If no feces are being excreted, palpate the abdomen to examine the cecum. If it has become impacted, the rabbit will likely develop mucoid enteritis (now called mucoid enteropathy). Cecal impaction may be caused by insufficient roughage in the diet or by feed that is too finely ground. Finely ground particles in the gut seem to decrease intestinal motility, which causes constipation and impaction.

Creep feeding

Creep feeding involves feeding the nursing kits a special feed to which the doe does not have access. The creep feed is a high-energy, high-protein feed. While creep feeding may give a slight improvement in growth rate, most producers find that the extra cost of the creep feed and the extra labor involved do not always justify the use of this system.

Examples of diet formulas

A wide variety of diet formulas can be used. Typical rabbit diets will include a roughage source (e.g., alfalfa), a grain (e.g., barley, corn, and oats), a protein supplement (e.g., soybean meal), salt, and mineral and vitamin supplements. The selection of particular ingredients will depend largely on their relative cost and availability (Table 8.10); these are just examples – many other diets of similar composition may be satisfactory or preferable.

Enteritis occurs on a wide variety of commercial diets. Unfortunately, the present state of knowledge on rabbit nutrition does not offer a complete explanation for this problem. Currently, there is no magic diet formula that will prevent enteritis. This is a major problem on a worldwide basis. The low enteritis diet shown here gave a marked reduction in enteritis at the Oregon State University Rabbit Research Center as compared to other diets containing cereal grains. The addition of one kg of copper sulfate per metric ton of feed may sometimes aid in reducing enteritis.

Grazing Rabbits

Attempts have been made to raise rabbits in large pens or warrens to utilize grazing crops

Table 8.10. Examples of diet formulas.

Low Enteritis Lactation/Grower Diet

Ingredient	**Percentage of Diet**
Alfalfa meal	54.0
Soybean meal	21
Trace mineralized salt	0.5
Dicalcium phosphate	0.25
Molasses	3.0
Tallow	1.25
Wheat mill run	20.0

Buck and Gestating Doe Diet

Ingredient	**Percentage of Diet**
Alfalfa meal	50.0
Oats	45.5
Soybean meal	4.0
Salt	0.5

Lactating Doe Diet

Ingredient	**Percentage of Diet**
Alfalfa meal	40.0
Wheat	25.0
Sorghum	22.5
Soybean meal	12.0
Salt	0.5

and save labor, but there are so many unfavorable factors involved that this system has not met with much success. Considerable investment is required because fences must be constructed that will keep the rabbits in and predators out (Fig. 8.4). Raising grazing crops in small enclosures is also expensive, and sooner or later internal parasites, especially coccidiosis, become a problem with the rabbits.

When a number of does are maintained in an enclosure, it is impossible to keep any accurate individual breeding or kindling records. The practice of allowing does to kindle in burrows rather than in nest boxes could be followed only in areas where the climatic conditions were such that the ground would not freeze or become wet and soggy. When the does do kindle in burrows, they usually take care of their litters satisfactorily. If they are forced to use nest boxes in the pens, they are not discriminating in nursing, so some litters may get proper nourishment and others may not. Unless the pens are unusually large, there frequently will be fighting and injuries among the does and bucks. Harvesting the fryers requires considerable labor.

Orphan Litters

Occasionally a doe will die at kindling time or before the litter is old enough to eat the feeds that are given to more mature rabbits. If it is desirable to hand-raise the litter because of exceptional production or show records, in order to maintain some particular bloodline, or for sentimental reasons, this can be done, although commercially this practice is not sound.

Fig. 8.4. Grazing rabbits outside a research laboratory in Germany. Note that the surrounding building provides protection from predators. (Courtesy of J.I. McNitt)

It will be necessary to feed the orphans with an eyedropper or a doll's nursing bottle and to use goat milk or synthetic cat milk, available at pet stores. Another recipe is evaporated milk diluted 50:50 with water, with an egg yolk and 1 tablespoon of corn syrup added to each cup of mixture. The milk should be heated to the point at which it feels comfortable when dropped on the back of your hand. When the young are 12 to 14 days of age, they should be offered oatmeal and a few blades of fresh growing grass or a small quantity of tender leaves from garden vegetables. They can be taught to drink out of a saucer and to begin to eat small quantities of the rations fed to the rest of the herd by the time they are 15 to 18 days of age. The quantity may be increased gradually as the young mature, but overfeeding should be avoided. It is essential that all feeding equipment be kept in a sanitary condition; this is especially important where milk is fed.

It is also possible to foster orphan kits to other does (Fig. 5.13). This is an advantage of breeding several does at once; if a doe dies, unless it is from a disease such as mastitis, her litter can be fostered to other does with litters of the same age. The fostered kits will usually be readily accepted.

Conditioning Show Rabbits

Properly balanced rations that are fed to the general herd will be satisfactory for feeding rabbits that are being conditioned for shows, but the quantity fed must be regulated to meet each individual's requirements so as to have the desired development and finish when show time arrives. Small quantities of fresh green feed or root crops, especially carrots, are used by some breeders as a stimulating and regulating food. Others feed bread, raisins, and milk because of their food value and to add variety to the ration. Sunflower seeds are an excellent conditioning feed because of the oil they contain, which enhances the glossiness of the rabbits' fur.

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9

Toxins in Feeds

Many feedstuffs contain toxic factors. Although many people are concerned about synthetic chemicals in our food chain, it is desirable to maintain perspective by being aware that there are a great many natural toxins in food and feeds, including a number of extremely dangerous compounds. Most of the serious food-related episodes of damage to human or animal health have involved natural toxins. These include "food poisoning" caused by bacterial toxins; the deaths and sickness of thousands of people in Europe from ergot in rye and other grains; milk sickness in frontier America that depopulated entire villages because of a milk-transferred toxin from a poisonous plant; deaths of livestock and waterfowl from algae in water; and the loss of over 100,000 turkeys in England from aflatoxin in peanut meal. Some of the most lethal compounds known, such as the botulism toxin and aflatoxin, are natural compounds.

To keep the subject of toxicity in realistic perspective, it is also necessary to be aware of relationships between dose and effect. Virtually everything is potentially poisonous. This includes water (force-feeding about four times the daily requirement of water to an animal will kill it), protein, salt, copper, zinc, iron, vitamin A, vitamin D, etc. Thus, the relationship between dose and toxicity is important. The mere presence of a toxin in a feed is not necessarily bad; what is critical is whether it is present at a level that will cause adverse biological effects (the dose makes the poison). Biologists believe that there is a "threshold level" for a toxin; at concentrations below the threshold (the non-effect level), the toxin is in fact nontoxic.

Some of the more important toxins are listed and briefly discussed below. More information on natural toxins in feeds and their effects on animal performance is provided in the books cited in the "Further Reading" section at the end of this chapter.

Goitrogens

Goitrogens are substances that inhibit the synthesis of the thyroid hormone thyroxin. Their presence in feeds results in the development of an enlarged thyroid gland, called goiter. Goitrogens are found in members of the *Brassica* group, including cabbage, cauliflower, kale, rape, and mustard. Goitrogens were discovered when laboratory rabbits were fed a diet of raw cabbage and developed goiter. Moderate amounts of cabbage or other greens will not cause problems. Varieties of rapeseed low in glucosinolates (a type of goitrogen) have been developed, so rapeseed meal can be used safely in rabbit feeding. Low glucosinolate rapeseed meal is commonly referred to as canola meal.

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Gossypol

Cottonseed meal contains a substance called gossypol. It is toxic to animals, causing tissue damage and, in some animals, male sterility. Gossypol occurs in both free and bound form in the meal. It is the level of free gossypol that is of significance. Free gossypol can be "tied up" by the addition of ferric sulfate to the feed. This procedure has been used to detoxify cottonseed meal for swine feeding. Studies at the Oregon State University Rabbit Research Center indicated that cottonseed meal can be safely used in rabbit rations at moderate levels (5 to 10% of the diet). The level of gossypol in cottonseed meal varies according to the variety of cotton. Because gossypol increases the resistance of the plant to pests and diseases, new varieties of cotton tend to have higher gossypol contents. Cottonseed meal is less valuable than the cotton fiber or the cottonseed oil, so the quality of the meal is a minor consideration in plant breeding.

Lectins (Hemagglutinins)

Lectins are substances in beans that, when added to a blood sample, cause the red blood cells to agglutinate, or clump together. This is why they have been called hemagglutinins. In the living animal, they are not absorbed and so do not affect the red blood cells. However, in the digestive tract they cause damage to the intestinal wall and reduce the absorption of nutrients. As a result, growth is reduced. Soybeans, broad beans, and common beans, including pinto, kidney, and navy beans, all contain lectins. For this reason, raw beans should not be fed to rabbits. Cooking destroys lectins and other toxins, such as trypsin inhibitors, so heat-treated beans can be safely used.

Mimosine

Mimosine is a toxic amino acid found in the tropical forage plant *Leucaena leucocephala*. This plant has tremendous potential as a protein source in tropical countries (Fig. 9.1). Unfortunately, the mimosine in it causes alopecia (loss of hair) and in ruminants causes goiter. *Leucaena* is quite palatable to rabbits, which consume it readily (Fig. 9.2). The leaves contain over 30% protein. *Leucaena*, when fed along with other tropical forages, can be very effectively used by rabbits as a protein source. It should not be fed for extensive periods at more than 10% of the total dry weight of the diet, or it may cause mimosine toxicity problems. Plant breeders in Australia and Hawaii are developing low mimosine varieties of *Leucaena*, which should improve the feeding value of this high

Fig. 9.1. A rabbitry in Haiti surrounded by *Leucaena*, which can be harvested for feeding to the rabbits. (Courtesy of P.R. Cheeke)

Fig. 9.2. Rabbits eating *Leucaena* in a rabbitry in Haiti. (Courtesy of P.R. Cheeke)

protein plant. In cattle and other ruminants, certain rumen microbes detoxify mimosine. It has not been determined whether these microbes could be introduced into rabbits. Mimosine is absorbed from the small intestine, so it is unlikely that cecal microbes could be effective in detoxifying mimosine.

Mycotoxins

Mycotoxins are toxic substances produced by fungi or molds that grow on feeds. Moldy grains may be toxic. The exact consequences of feeding moldy feed to rabbits cannot be precisely predicted because there are a large number of different molds and mycotoxins that could be involved, with varying effects.

Among the major mycotoxin groups are aflatoxins, produced by molds (*Aspergillus flavus* and *A. parasiticus*) that grow on grains and other feeds (e.g. soybeans and cottonseed meal). Problems with aflatoxins were first observed in 1961, when more than 100,000 turkey poults died in England. This outbreak, called Turkey X Disease, was traced to the presence of mold toxins in peanut meal. Subsequent studies have identified numerous specific aflatoxins (aflatoxin B1, B2, G1, G2, M1, etc.). They cause severe liver damage and, with chronic low doses, cause liver cancer. In rabbits, aflatoxins cause animals to go off feed and water, to become dehydrated and lethargic, and to develop liver damage and jaundice.

Numerous other mycotoxins that contaminate grains are known. They include citrinin, ochratoxin, T-2 toxin, fumonisin, and zearalenone. These toxins cause acute kidney and liver damage, adverse effects on reproduction, and death. It is believed that in some cases mycotoxins may cause enteritis in rabbits, while in other cases, feeding moldy feed does not induce enteritis.

Another important mycotoxin is ergot. Ergot is a substance produced by a mold (*Claviceps purpurea*) that infects the seed heads of rye, oats, wheat, triticale, and Kentucky bluegrass. Ergot alkaloids also occur in endophyte-infected tall fescue grass. Ergot affects the central nervous system and the smooth muscles. It causes the blood vessels in the feet and legs to constrict, cutting off circulation. This may cause gangrene. Ergot may also cause abortion. Rabbits may shuffle their feet continuously, suggesting pain in the extremities.

Sweet clover contains a substance called coumarin. If sweet clover hay becomes moldy, the mold growth converts coumarin to a substance called dicumarol. Dicumarol is an inhibitor of vitamin K and causes a vitamin K deficiency. This vitamin functions in the clotting of blood, so in vitamin K deficiency, spontaneous hemorrhaging occurs. Feeding moldy sweet clover may thus cause excessive bleeding and death. The rat poison warfarin acts in a similar manner, killing rats by internal hemorrhaging.

Nitrates

Nitrate is a simple nitrogen-containing ion, NO_3 which can be chemically reduced to nitrite, NO_2. Nitrite is about 10 times as toxic to animals as nitrate. Nitrite ions oxidize hemoglobin, the oxygen-carrying pigment in blood, to a compound called methemoglobin, which is incapable of carrying oxygen. As a result, nitrite-poisoned animals die from a cellular lack of oxygen.

Some common plants accumulate nitrates. These include pigweed (*Amaranthus* spp.), lamb's-quarters (*Chenopodium* spp.), Sudan grass, alfalfa, oats, corn, and wheat. Soils high in nitrogen from heavy fertilization or manuring lead to nitrate accumulation by plants. Herbicide treatment with 2,4-D increases nitrate concentrations. Nitrate poisoning is primarily a problem in ruminants (e.g., cattle and sheep), because plant nitrates are converted to nitrites in the rumen. Acute poisoning of ruminant animals may occur when forage nitrate exceeds 1.0% (10,000 ppm) or 1500 ppm nitrate in water. The toxic level in rabbits is likely to be more than this. Rabbits would be expected to be quite tolerant, because nitrate would be absorbed as such rather than being converted to nitrite in the gut. Nitrate poisoning of rabbits would seem to be an unlikely problem and has not been documented.

Oxalates

Oxalic acid is found in some plants, such as *amaranthus*, spinach, and chard. Rhubarb leaves are poisonous because of their high oxalate content. Oxalic acid forms a complex with calcium and renders it insoluble as calcium oxalate. If oxalic acid is absorbed, it combines with the blood calcium and precipitates it. This causes a rapid drop in serum calcium levels and causes tetany. Greens such as *amaranthus*, spinach, and chard can be fed to rabbits at moderate levels with no problems from oxalate toxicity. Pigs have been poisoned by feeding on wild pigweed (*Amaranthus retroflexus*) and lamb's-quarters (*Chenopodium album*), because of their oxalate content.

Pyrrolizidine Alkaloids

Some plants contain toxic pyrrolizidine alkaloids, which cause irreversible liver damage. In the U.S. Pacific Northwest, the poisonous plant tansy ragwort (*Senecio jacobaea*) is widely distributed. This plant contains these alkaloids. Rabbit raisers in the Northwest might be concerned about possible contamination of alfalfa with tansy ragwort and the effect this might have on their rabbits. Fortunately, rabbits are very resistant to the pyrrolizidine alkaloids, unlike animals such as cattle and horses. It is of interest that the forage crop comfrey (*Symphytum officinale*) also contains these alkaloids. Again, because rabbits are resistant to their effects, comfrey can be safely fed to rabbits. Because comfrey has been shown to cause cancer in rats, direct human consumption of comfrey may not be advisable. Comfrey-containing herbal products have been banned in some countries, such as Canada. Crotalaria, which grows in the southern United States and other warm areas, is another poisonous plant that contains pyrrolizidine alkaloids.

Saponins

Alfalfa and other leguminous forages (e.g., clovers) contain substances called saponins. Saponins are bitter and reduce the palatability of these forages. Alfalfa meal at high levels in rabbit feeds generally causes some palatability problems, resulting in excessive feed wastage. This appears to be due to the saponin content, causing the feed to be bitter. Plant breeders are developing low saponin strains of alfalfa, which should increase the value of alfalfa as a rabbit feed. An interesting side effect of saponins is that they reduce serum and tissue cholesterol levels. It is possible that the low cholesterol content of rabbit meat may be partially due to the saponin content of alfalfa meal, which is generally a major constituent of rabbit diets.

Saponins in feed additives such as yucca and quillaja (see Chapter 8) may have some beneficial properties, such as stimulating the immune system.

Trypsin Inhibitors

Soybeans and most other beans contain proteinaceous substances (trypsin inhibitors) that interfere with the action of certain digestive enzymes, such as trypsin and chymotrypsin, in animals. They cause reduced protein digestibility, enlargement of the pancreas, and reduced growth. Raw soybeans should not be fed to rabbits. Commercial soybean meal has been cooked to destroy trypsin inhibitors, so it is a high-quality feed that is safe to use. Extruded soybean products are also satisfactory.

Urea

Urea is a source of non-protein nitrogen (NPN) that is commonly fed to cattle and other ruminants. It is converted by bacteria in the rumen into protein. The bacterial action in the rabbit hindgut does not utilize much urea. Therefore, urea should not be used in rabbit feeds as a partial replacement for protein. It is converted in the rabbit gut to ammonia, which is absorbed and can cause poisoning.

Poisonous Plants

At one time, it was common for forage crops such as alfalfa to be heavily contaminated with weeds, including toxic plants such as milkweed and nightshade. With the advent of herbicide use for weed control, this problem has virtually disappeared. Alfalfa grown for the commercial feed industry (e.g., dehydrated and sun-cured alfalfa meal used in rabbit feeds) is generally of very high purity with little weed contamination.

Numerous garden ornamentals and wild plants commonly found in pastures and uncultivated areas are toxic to animals. Common garden flowers that are poisonous include lupines, delphiniums, and foxgloves. A few foxglove leaves (Fig. 9.3) contain enough poisonous cardiac glycosides to kill a rabbit. Before picking leaves of various plants and feeding them to rabbits, you should be familiar with the local plants and be aware of any poisonous ones. A number of house plants, including dieffenbachia, are toxic. Pet rabbits should not be allowed access to such plants. Any exposure of rabbits to poisonous plants is likely to be due to the accidental feeding of toxic plants as green feeds rather than to their presence in commercial diets.

Fig. 9.3. Foxgloves are common garden ornamentals that contain very toxic cardiac glycosides, and their leaves should not be fed to rabbits. (Courtesy of P. R. Cheeke)

Herbal Remedies

During the twentieth century, tremendous advances were made in the control of human and animal diseases. Antibiotics and other drugs with highly specific antimicrobial activity and vaccines against diseases have been developed. As part of a “back to nature” or “more natural” approach to life, some people have tended to reject some of these modern techniques and have adopted more traditional folk wisdom and herbal remedies. Many extravagant claims have been made for the medicinal effects of various herbs, such as comfrey, as a cure for cancer, and chamomile as an aid to recovery from illness. While in a few instances efficacious drugs used in traditional medicine have been developed from plants (e.g., reserpine, quinine, digitalis), in most cases herbs have little or no therapeutic value. Generally, the supposed basis of action is irrational. Ginseng root, for example, owes its reputed medicinal effects to its somewhat human-like shape! Many herbs do contain toxic substances, but in most cases the concentration is not sufficiently high to cause poisoning. The use of herbs to control diseases in the rabbitry is without foundation but probably does no harm other than perhaps delaying the implementation of more effective medication or treatment.

Agricultural Chemicals: Pesticides and Herbicides

Modern agriculture involves the use of a variety of types of chemicals for the control of weeds, insect pests, and plant diseases. Although there is widespread concern about their safety, it should be recognized that exhaustive testing for efficacy and safety is required before new chemicals are released and that stringent regulations on their use are enforced. There is very little evidence that residues of sprays on feed or crop plants are deleterious to humans or animals. Poisonings that occur are almost always due to accidental consumption of concentrates or sprays or to exposure while applying the materials. New chemicals tend to be more selective and less damaging to non-target species than materials formerly in use. For example, compounds containing copper, arsenic, and mercury were at one time widely used in crop-spraying programs and caused significant contamination problems. It is also well to consider that before herbicides were available, contamination of grains with poisonous weed seeds caused many poisonings of humans and animals. The use of herbicides has eliminated these problems.

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10

Rabbit Diseases and Health Problems

One of the most devastating and discouraging aspects of raising rabbits is disease. The death of a beautiful litter or doe is not only an economic loss, but it also has an emotional impact on the rabbit raiser. Hours of work and generations of breeding can be wiped out overnight by disease. However, disease and death are an integral part of any livestock operation. This is particularly true in rabbit raising. Mortality in some rabbit herds can be as high as 40% of all animals born. Sometimes, animals are found dead that looked perfectly normal a few hours before. This high rate of mortality can be so discouraging that it may cause some rabbit raisers to give up the business. As discussed in Chapter 21, there are a few rabbit diseases that also infect humans.

The success or failure of your rabbit operation depends on your ability to keep disease at a minimum. Most diseases occur because of management mistakes or lack of knowledge. The total loss of rabbits from disease averages 20 to 40%; this includes the kits born dead, the nest box deaths, the fryer deaths, and the loss of does and bucks.

General Considerations

Disease is defined as "a morbid process having a characteristic number of symptoms." A disease may affect the whole body or any of its parts, and its cause may or may not be known. Building upon this definition, you should be aware that disease comes about because of interactions between disease-producing agents and the host (the rabbit in this case). These disease-producing agents are continuously in the environment of the rabbit. The logical question to ask, then, is, "Why aren't all rabbits sick?" In answer to this question, a number of factors are involved. First, rabbits differ in their genetic resistance to disease. Some animals may have more resistance to specific diseases than others. In the case of snuffles, for instance, some animals appear to be quite resistant. The disease is caused by a bacterium called *Pasteurella multocida*. Sometimes when one rabbit has snuffles, one in the next cage is unaffected, even though it is being exposed to *Pasteurella*. Apparently, this animal has a set of genes that makes it resistant.

Another factor to consider in disease is the concentration of the disease-producing agent. We know that viruses exist in the environmental surroundings of rabbits. But if the number of virus particles in the environment is kept low, the number actually attacking the rabbit will be relatively few. The natural defense mechanisms of the rabbit may be able to cope with a few virus particles, but if a large number are present, the defense mechanisms are overwhelmed and a disease is produced. The concentration of organisms is related to both sanitation and the density of animals in

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the building. With any animals raised in close confinement, disease seems to increase almost proportionally as the number of animals in a given space increases. The typical rabbit raiser starts an operation with a few rabbits in a barn or shed, and all seems to go extremely well, with little disease, excellent conception, and beautiful rabbits. Because things are going well, he or she decides to double or triple the size of the herd. However, the space remains the same. The grower decides to double tier or reduce the space between the rows or use any other combination of space-saving ideas. This results in overcrowding, and problems begin.

Still another factor that compromises management when a herd is increased is a decrease in the time that you have for each individual rabbit. Therefore, there is a tendency to miss the first signs of trouble. You don't see the soft stool, the missed meal, the increased amount of hair on the cages, etc.

Ventilation, sanitation, and observation are three of the most important factors involved in disease control. Diseases are usually caused by some type of organism. It may be a bacterium, a virus, a protozoan, an arthropod, or some other kind of organism. Air dilution through ventilation is a very effective method of reducing the numbers of some organisms. The numbers of a disease-producing organism may determine whether a disease is produced. Air dilution is one of the reasons that you find fewer respiratory problems in well-ventilated barns where the air the rabbit breathes is changed often.

The other method of reducing the number of potential disease organisms is physically or chemically removing them. This is called sanitation. The manure is removed, the cages and nest boxes are disinfected, and the hair on the cages is removed. All of these procedures reduce the number of disease-causing harmful agents. A single rabbit hair can carry thousands of bacteria or viruses.

Observation, of course, refers to training yourself to look for signs of initial discomfort in animals. A sick animal is somewhat like a sick human, except the animal doesn't make such a big fuss about it. It doesn't want to eat, may not drink, is lethargic (doesn't want to move much), may have a dull appearance in its eyes, may have a rough hair coat, and generally is unthrifty in appearance. If you miss these signs when they occur and you don't notice anything until there is a profuse nasal discharge or diarrhea, it's generally too late to do much about it. However, if you see the initial signs, a treatment of one kind or another may not only be helpful but may save the life of the animal.

Quarantine

All sick rabbits and those that have been exposed to contagious or infectious diseases should be isolated. Those that have been displayed at shows or new stock that has been purchased should be kept separate from the herd and held in quarantine for at least two weeks. These precautionary measures may prevent spread of infection in the rabbitry in case communicable diseases are in the incubation stage at the time the animals are isolated.

During quarantine, rabbits should be examined closely every day for signs of disease, especially a nasal discharge or diarrhea. The use of a broad-spectrum antibiotic (such as oxytetracycline) may be advisable if rabbits have been purchased from questionable sources. Antibiotics in the drinking water or feed can also be used to decrease the gastrointestinal micro flora (bacteria, etc.). As the antibiotics are withdrawn, a new micro flora population will be established from the environment near your rabbitry. Some breeders give probiotics to their rabbits to introduce beneficial microorganisms to the gut. Overall, these measures will make introduction of the animal into your herd much easier. Quarantine areas should be separate from the main herd or rabbitry. Rabbits housed in quarantine should be cared for after the husbandry of the main herd has been accomplished. This procedure reduces the chance that diseases will be spread from the quarantine area to the main rabbitry. It is always a good idea to wash and/or disinfect your hands after treating sick rabbits or rabbits in quarantine, as a number of disease agents can be carried on your hands. Separate clothing and foot covers for wearing in the quarantine area should also be considered.

Diagnosing Diseases

Some diseases can be diagnosed by the observation of clinical signs while the rabbit is living. Other diseases cannot be diagnosed without a post-mortem examination and, in some cases, special techniques. As a rabbit raiser, you should become very familiar with the anatomy of a rabbit and the normal appearance of the internal organs. In addition, the normal physiological characteristics should be learned. You can accomplish this by learning a few facts, such as the normal rectal temperature, 38.9–39.4°C (102–103°F); the normal pulse rate, 140–150 beats per minute; the normal respiration rate, 50 to 60 breaths per minute; and the normal general appearance of a healthy rabbit stool (manure). You can learn the normal appearance of the internal organs only by repeated examination of these organs when normal rabbits are slaughtered. Then, when a rabbit dies for some unknown reason, you will be prepared to do your own post-mortem examination. With a little practice, you can become proficient in diagnosing the more common diseases and, with this information, be able to take immediate measures for preventing an outbreak of a certain disease.

In making the post-mortem examination, remove the pelt to facilitate examination of the carcass. After removing the pelt, place the animal on its back and make a midline incision through the body wall. This will reveal the internal organs (Fig. 10.1). Examine the lungs and the heart in the thoracic cavity. If the lungs are normal, they will be a pale pink color. If the lungs are purple or have purple and pink splotches or yellow or white spots, they are probably diseased. Hemorrhages and red spots in the lungs may be seen if the animal has struggled while dying. Next, examine the organs in the abdominal cavity (the thoracic and abdominal cavities are separated by the diaphragm). The large organ closest to the diaphragm is the liver. It should be purplish red, very smooth, and shiny. A change in color or the presence of white spots signals disease. On the underside of the liver, you will see a greenish-yellow sack. This is the gallbladder. Normally it is quite small, but if the rabbit has been off feed for 24 hours or longer, it will be enlarged (distended with bile) and quite turgid.

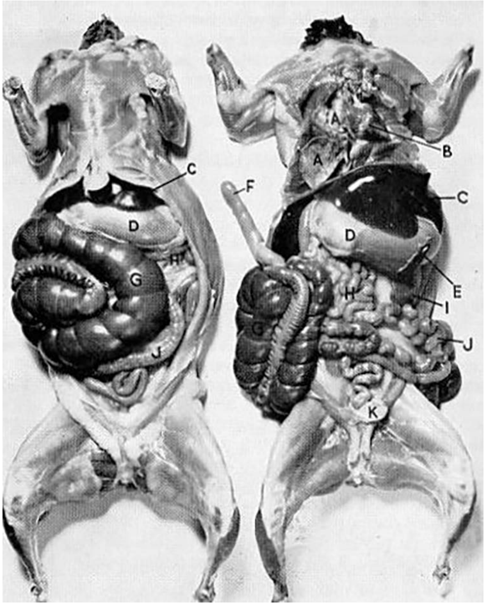

Fig. 10.1. Location and identification of the internal organs of the rabbit. A, lungs; B, heart; C, liver; D, stomach; E, spleen; F, vermiform process (appendix); G, cecum; H, small intestine; I, kidney; J, large intestine; K, bladder. (Courtesy of USDA)

Next examine the digestive tract (Fig. 10.2), starting with the stomach. The stomach lies under the liver. It should be filled with a very wet mix of rabbit feed and water. Occasionally you will see fecal pellets (manure) in the stomach. This is normal, as rabbits practice cecotrophy (eating their own fecal pellets). The long tubular structure coming from the bottom of the stomach is the small intestine. Its contents are scant and almost slimy. The small intestine empties into a large organ called the cecum. The contents of this part of the digestive tract should be semi-solid (somewhat like putty). If you find the cecum and/or small intestine to be two to three times normal size and the contents very watery and foamy, you should suspect an enteric problem (enteric refers to the intestines). You may also see a reddening of the walls of these organs due to hemorrhage. The cecum empties into the colon, or large intestine. This organ is smaller than the cecum and normally should contain the round fecal pellets. Diseases in this organ would be signaled by vaseline-like contents or no fecal pellets.

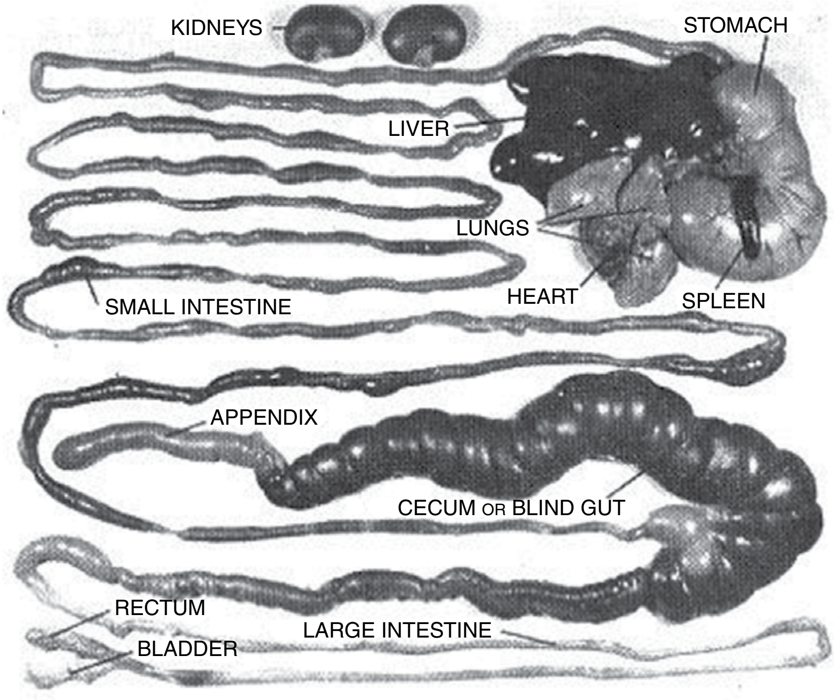

Fig. 10.2. Digestive tract of a healthy rabbit. (Courtesy of USDA)

After examining the digestive tract, look at the kidneys, located underneath the digestive tract and normally encased in fat. They are two walnut size organs lying on either side of the backbone. They should be brownish to purple, with a smooth surface. A rough surface, change in color, or white spots indicate disease. The bladder and reproductive organs are the last structures to be examined in an internal postmortem examination. The bladder is located at the posterior end of the abdominal cavity. It looks like a small balloon when filled with urine. The bladder wall is normally quite thin, and the normal urine is cloudy. Because the rabbit excretes large amounts of calcium, the urine will often feel a little granular due to calcium crystals. The penis and testicles in males and the ovaries and uterus in females should be examined (Figs 11.1 and 11.3). Each ovary is located at the end of the uterine horn near the kidneys. The ovaries are very small, about bean size. They often will have little blister-like structures on them that contain the developing eggs. The uterus should be about the same color as the body wall. An enlarged uterus containing a whitish fluid indicates disease.

If you are continuing to have a disease problem that you cannot diagnose, take both sick and dead rabbits to your local veterinarian or to a state diagnostic laboratory. Many veterinarians are becoming more experienced in rabbit diseases and are now receiving training in the treatment of minor animal species, such as rabbits.

Major Rabbit Diseases and Health Problems

All rabbit diseases are important, especially if it is your rabbit that is involved. However, it is not the purpose of this chapter to provide an in-depth treatise on all rabbit diseases. The major diseases will be covered in some detail and some of the less frequently occurring diseases will be presented.

Pasteurellosis

Virtually all conventional rabbitries are infected with *Pasteurella multocida*. Many rabbits carry this organism in their respiratory tract even when showing absolutely no signs of nasal discharge. The term "pasteurellosis" covers a multitude of clinical conditions all caused by *P. multocida*. By far the most common manifestation of pasteurellosis is the condition called snuffles. However, pasteurellosis is also evidenced by pneumonia, abscesses, weepy eyes, pyometra (uterine infection), orchitis (testicular infection), wry neck, and sometimes mastitis.

Snuffles (rhinitis)

There is no such thing as a cold in rabbits. Mucopurulent nasal discharges (pus) that many people attribute to colds are almost invariably caused by *P. multocida* in conjunction with another bacterium called *Bordetella bronchisepticum* (Fig. 10.3). The condition is not a transient one, like a cold, but one with permanent adverse effects on the animal. The preliminary signs of sneezing and discharge should be differentiated from dust or drinking water in the rabbit's nose. Usually if the sneezing continues, and especially if you begin to feel a matting of the fur on the inside of the front feet (a rabbit uses its front feet to wipe its nose), you can be quite confident that your rabbit has snuffles. Snuffles is extremely contagious. Each time a rabbit sneezes it contaminates the surrounding area with thousands of bacteria. People themselves can spread these bacteria on their hands and clothes (the chance of rabbits contracting snuffles at a show or fair is extremely good unless you are very careful and take precautions). Rabbits can pass it to each other by contact, and equipment and cage accessories easily transmit the organism. The other forms of pasteurellosis mentioned above generally begin appearing after snuffles is noticed. Strict culling or isolation of rabbits with snuffles will keep the problem from getting out of hand.

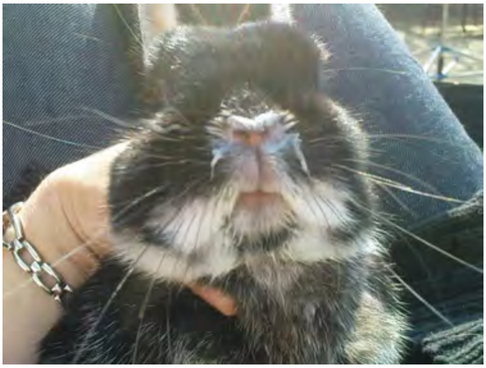

Fig. 10.3. Snuffles, showing the typical nasal discharge. (Courtesy of Eric Stewart)

Rabbits can be treated for snuffles with a number of antibiotics. This treatment at first may appear to have been successful. The sneezing stops, as does the discharge, but as soon as the rabbit is stressed (often it is reproductive stress), it breaks with the disease again, and this time it is more difficult to treat. Enrofloxacin (trade name, Baytril) has been moderately successful when used to treat snuffles. The drug has been found to be effective in about 70% of the cases when administered at the rate of 5 to 10 milligrams per kilogram of body weight. A rate of 2.5 to 5.0 mg/kg twice daily is the most effective. While the clinical signs of snuffles are alleviated since the drug is bactericidal, so some rabbits may continue to carry the *P. multocida* organism. This can present a problem in large rabbitries because successfully treated rabbits may still act as carriers and spread the disease. The drug has been used most successfully in pet rabbits. Tetracycline in the drinking water at the rate of 300 mg/liter for seven days may be of some benefit.

Vaccination for *P. multocida* has been tried many times by both researchers and rabbit growers with little success. Vaccines have not been successful because there are many different strains of *P. multocida,* each of which would require its own vaccine. In addition, immunity has been shown to last only a few weeks. By far the most important factor in controlling snuffles is prevention. Strict sanitation, good ventilation, and strict culling aid in preventing the disease. Any rabbit displaying signs of snuffles should be immediately culled unless it is a pet.

Sanitation of cages and equipment with a 1% solution of sodium hypochlorite (bleach) will help kill residual *P. multocida*. However, bleach is corrosive to galvanized metal and may reduce the longevity of the cages.

Ventilation is very important in the control of snuffles since both humidity and ammonia are involved in transmission and development of this condition. Ammonia is produced by the action of bacteria on the urea excreted in rabbit urine. Urea is produced by rabbits and other animals from excess amino acids. Thus, a high dietary protein level will increase the amount of urea excreted, resulting in elevated levels of ammonia produced. High concentrations of ammonia in the atmosphere can have adverse effects on both animals and humans in the rabbitry. People working in poorly ventilated livestock facilities may develop headaches and respiratory problems. Ammonia increases the susceptibility of rabbits to snuffles and pneumonia. Exposure to ammonia damages the sensitive tissues of the nasal passages, allowing *P. multocida* to colonize the tissues. Problems from ammonia can be minimized by reducing the amount of the gas formed and by increasing its rate of removal from the building. Decreased ammonia production can be achieved by frequent removal of the feces and urine. High humidity also increases respiratory disease, so methods of cleaning that minimize the use of water might be advantageous.

Proper building design with adequate ventilation can help to reduce ammonia and snuffles problems. In temperate areas, long, narrow buildings with open sides for natural ventilation give the best results, sometimes even alleviating the need for fans.

Pneumonia

If snuffles is allowed to go untreated, or if the number of cases in the rabbitry continues to increase, rabbits will begin to die from pneumonia. Pneumonia is an inflammation of lung tissue, resulting in reduced oxygen uptake by the blood. It is one of the leading causes of death in rabbits. It also leads to poor weight gains, rough hair coats, and generally unthrifty rabbits. Young rabbits may die acutely with no signs or symptoms.

Rabbits that have their heads tipped back or show open-mouth breathing often have pneumonia. Rabbits suffering heat stress may also show these signs and need help to cool down (see Fig. 12.1). In albino rabbits, a change in eye color from the bright pink to a bluish pink is very suggestive of pneumonia. This is due to poor oxygenation of the blood; the bluish pink color in the eye results from capillaries on the retina becoming bluish because of lack of oxygen. The lips may also show a bluish color. Another suggestive sign of pneumonia is sudden death of fryers or does when they are stressed due to moving, breeding, etc. A post-mortem examination of dead rabbits will reveal pneumonia. The pink lung tissues will be turned a liver color (purplish), or part will be pink and part will be purplish (Fig. 10.4). Often there will be fluid in the chest cavity. It may be clear or cloudy. All of these signs point toward pneumonia. Occasionally other bacteria are involved, but by far the greatest cause of pneumonia is *P. multocida*. By the time one is able to diagnose pneumonia clinically, there is very little chance of treating it in the individual rabbit. Both broad-spectrum antibiotics and sulfa drugs have been tried with little success.

Abscesses

Abscesses are often caused by *P. multocida*. They are a common condition in rabbitries with poor ventilation and sanitation. Abscesses

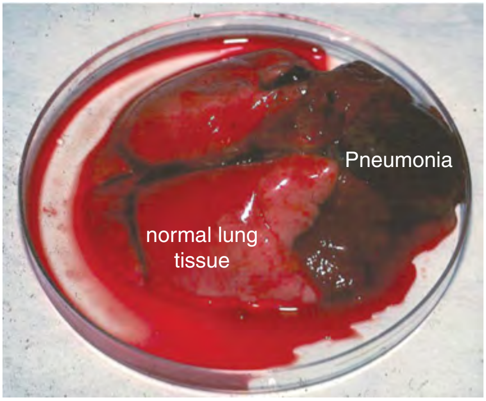

Fig. 10.4. Rabbit lungs showing classic pneumonia. The darker color of the anterior lobes is the result of pneumonia. (Courtesy of N.M. Patton)

are usually seen in the subcutaneous areas and occur when the *Pasteurella* organism invades a break in the skin caused by a scratch, a cut, or a sore. Abscesses can also occur internally. These usually result from a septicemia (organism in the blood). Treatment of an external abscess involves lancing it, draining the purulent material (pus), and putting the rabbit on broad spectrum antibiotics. However, antibiotics, such as penicillin and gentamicin, kill gram-positive bacteria in the digestive tract, leading to proliferation of gram-negative bacteria that cause enteritis. Be sure that the incision made in the abscess is quite large to allow proper drainage. Ideally the abscess should heal from the inside to the outside. When a small incision is made, the outside heals first, and a new abscess is soon started because of poor drainage. In the long run, however, prevention is much preferred over treatment, as treated rabbits often show a recurrence of the problem and may well act as carriers of the *Pasteurella* organism. In most rabbitries it is probably best to cull such rabbits immediately.

Metritis and orchitis

These are problems with the reproductive system that can be caused by *P. multocida*. Metritis, an infection of the uterus, is sometimes called pyometra. Orchitis is an infection of the testicles (Fig. 10.5). Both of these conditions are commonly observed in rabbitries that have poor ventilation, poor sanitation, and a high incidence of snuffles.

Fig. 10.5. Orchitis in the right testicle of a New Zealand White buck. (Courtesy of N.M. Patton)

Metritis should be considered whenever you have a doe that readily accepts the buck but will not conceive. Although there are many other causes of poor conception rates, metritis can be a factor. The *P. multocida* organisms gain entrance into the uterus by one of two methods. They enter either during kindling (due to dirty nest boxes) or with the semen from bucks with infected testicles. Metritis, or pyometra, is diagnosed by observing yellowish white discharge from the doe's vent. White material in the urine may also be due to excess calcium in the diet, but it has a sandy, gritty feel and the doe has normal conception. However, metritis can occur without discharge. Sometimes there will be an elevation of the rabbit's rectal temperature above 39.4°C (103°F). If the infection is of long standing, that sign may not readily be observed. Palpation of the uterus is helpful in diagnosing metritis. If the uterus feels enlarged or full of fluid, it is very suggestive of this infection. The only practical treatment for this condition is culling the rabbit from the herd or, in the case of a pet rabbit, having a veterinarian perform an ovariohysterectomy.

Orchitis is a rare condition in male rabbits. Either one or both testicles become enlarged and sometimes feel hot to the touch. The organism *P. multocida* has gained entrance to the testicle either through the urethra in the penis or from the bloodstream (septicemia). This problem becomes extremely dangerous in a rabbit herd, because a buck will spread *P. multocida* bacteria with each ejaculation. Does bred to this buck may develop metritis. Therefore, you should frequently examine the buck's testicles for changes in size, color, or temperature. If any abnormalities are observed, the buck should be isolated, and if the change persists, the buck should be culled. Antibiotic treatment is of limited value.

Wry neck

This condition, involving continual twisting of the head, (torticollis) is usually caused by *P. multocida* infection in the middle ear (otitis media). This infection affects the equilibrium of the rabbit (Fig. 10.6). It is somewhat analogous to the feeling you get when there is water in your ear. Treatment is not effective, so rabbits with this condition should be culled. There is nothing wrong with the meat from these rabbits as it can be safely eaten.

Weepy eyes (conjunctivitis)

This condition, (Fig. 10.7), which is often seen in young rabbits in the nest box and sometimes in older does, can be caused by several different bacteria. *Staphylococcus aureus* is most often isolated, but *P. multocida* is the second most common bacterium found. If the infection is detected early, it can easily be cleared up with ophthalmic antibiotic ointments. Ointments containing chloramphenicol are particularly effective. If the infection persists or returns, a blocked tear duct can be anticipated. If a rabbit is valuable, it can be taken to a local veterinarian who can open this duct by inserting a catheter and flushing the duct while the rabbit is under anesthesia.

Fig. 10.6. A typical case of wry neck. (Courtesy of D.J. Harris)

Fig. 10.7. A case of weepy eye in a New Zealand White. (Courtesy of N.M. Patton)

Enteric diseases

A major cause of death in fryer rabbits is the complex of diseases called enteritis or enteric syndrome. Many years ago, it was believed that all diarrheal problems were caused by the same disease. In fact, it was primarily called mucoid enteritis. More recently it has been shown that enterotoxemia, Tyzzer's disease, and coccidiosis, as well as the classic mucoid enteritis (now called mucoid enteropathy), are all separate diseases. Enteric diseases play a major role in the success or failure of raising rabbits. They can cause severe death loss as well as growth retardation due to poor feed conversion.

Enterotoxemia

This disease was first described by the Rabbit Research Center at Oregon State University in 1978. The clinical signs of profuse diarrhea, dehydration, reduced feed intake, and rough hair coat are readily observed in rabbits. A typical case of enterotoxemia is shown in Fig. 10.8. Although enterotoxemia can affect rabbits of any age, it is seen most commonly in fryers four to eight weeks of age. These sick rabbits die very quickly, usually within 12 to 24 hours.

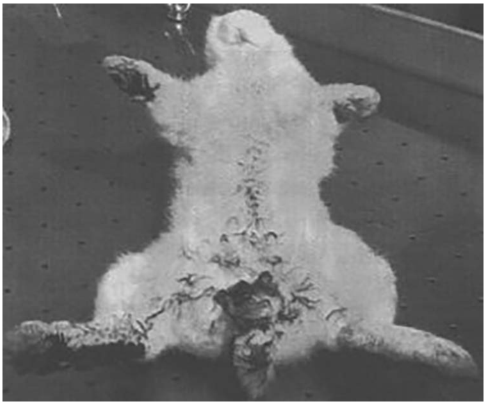

Fig. 10.8. Enterotoxemia in a rabbit, with the typical soiling of the legs and anal area. (Courtesy of OSU Rabbit Research Center)

As many rabbits are weaned during this age period, the stress of being separated from their dam and changing cages has been suggested as a factor.

Post-mortem examination of rabbits dying of this disease shows an enlarged cecum and sometimes an enlarged small intestine. The colon is generally empty. In about 70% of these rabbits, a reddish-colored cecum is observed. This is due to hemorrhage in the wall of the cecum.

Several bacteria have been suggested as the cause of this disease, including *Clostridium perfringens* Type E, *Clostridium spiroforme,* and *Escherichia coli*. Toxins have been found in rabbits dying from enterotoxemia. The iota toxin produced by *Clostridia* spp. has been detected in the luminal contents of the digestive tracts of many dead fryer rabbits. While *E. coli* placed surgically in the intestines of rabbits has been shown to produce diarrhea, neither *E. coli* nor *C. perfringens* has been shown to cause enterotoxemia when given orally to rabbits. However, *C. spiroforme* given orally to rabbits has produced classic enterotoxemia, suggesting that it is the predominant organism involved.

Enterotoxemia is more common when diets low in fiber and high in energy are fed than when high-fiber diets are used. Diets high in starch from grains may cause carbohydrate overload of the hindgut, yielding glucose, which is necessary for toxin production by *C. spiroforme*. It has also been stated by "old-time" rabbit raisers that when they fed rabbits alfalfa hay and whole oats, few diarrhea-related deaths were seen. Perhaps current methods of feeding high grain diets to rabbits in order to get maximum weight gain are partly responsible for the increased number of cases of enterotoxemia. Successful treatment of enterotoxemia is difficult. Broad-spectrum antibiotics, such as oxytetracycline, in the water give short-term relief from the disease, but it often will return when the antibiotics are discontinued. The feeding of hay or straw to rabbits is of help in preventing the disease; however, outbreaks have occurred in rabbitries that routinely feed hay. Alfalfa hay may not be effective if the rabbits eat only the leaves, which are low in fiber, and refuse to eat the stems. Restricting high-energy feed to both does and fryers has helped in severe outbreaks, but there seems to be a very fine line between feeding enough to not interfere with weight gains and feeding too much, which results in enterotoxemia. Perhaps the most successful treatment is to change feeds. Preferably the change should be to a lower energy feed with a higher fiber content, but changing to any new feed may be beneficial for only a short period of time.

Enterotoxemia seems to be cyclic. It strikes a rabbitry and then disappears, only to return at a later date. It is seen more often when the weather is changeable in spring and autumn and when rabbitries get overcrowded and the sanitation level decreases. It is not known whether the disease is contagious. Enterotoxemia or "overeating disease" is a common problem in sheep, and a vaccine is available to prevent it. There is no effective vaccine available for rabbit enterotoxemia. Even if a vaccine for rabbit enterotoxemia were developed, it would likely be too expensive for routine use with fryers. Ultimately, the best solution may be the development of diets, resistant stock, or management systems that reduce the incidence of enterotoxemia.

In addition to bacteria, viruses may be involved in enteritis. Several reports during the last two decades have shown rotavirus to be involved in cases of profuse diarrhea in rabbits. Rotavirus is a member of the family Reoviridae and is considered to be only mildly pathogenic. Rotavirus alone seems to cause only a short-term diarrhea and the young rabbit usually recovers. However, it has been known to cause high mortality in one- to three-week-old rabbits if the doe has a poorly-developed immune system.

The current theory concerning enterotoxemia involves virus, bacteria, and diet. The virus initially invades the intestinal epithelium, causing significant cellular death. If *C. spiroforme* bacteria are present in the cecum and a diet rich in carbohydrate is available, the bacteria begin to proliferate and produce a toxin. The toxin, absorbed through the damaged intestinal wall, is transported via the circulatory system to the heart and brain of the rabbit and causes a lethal toxemia.

Mucoid enteropathy and Epizootic rabbit enteropathy

Mucoid enteropathy and epizootic rabbit enteropathy (ERE) are two serious digestive diseases of the European rabbit with many clinical similarities and characterized by an absence of macroscopic and histological inflammatory lesions. This last point justifies the modification of the name: scientists have changed the traditional name of mucoid enteritis and epizootic rabbit enterocolitis to mucoid enteropathy and epizootic rabbit enteropathy. The reason for this is that the suffix "itis" means "inflammation." There is no redness or inflammation of the intestines with this condition, so the suffix "opathy," which means "illness," has been substituted. They are both considered intestinal dysbiosis (alteration in the composition of the intestinal microbiota). Another common point distinguishes them: the origin of the observed disorders is still not known, even if hypotheses have been put forward. Nevertheless, they differ in their geographical distribution, their circumstances of appearance and their capacity for dissemination, certain lesional aspects, and probably the nature of their causes.

Mucoid enteropathy is a syndrome described in rabbits for over 50 years, mainly in Great Britain and the USA. It corresponds to a disturbance of digestive transit, leading to two types of consequences: a partial blockage of the cecum, the contents of which become abnormal, and a massive production of translucent mucus in the colon. It affects rabbits sporadically. Although mucoid enteropathy is more common in young rabbits aged 4–14 weeks, cases have occasionally been reported in older animals. It is a major cause of morbidity and mortality.

The classic symptoms of mucoid enteropathy are distention of the abdomen and jelly-like stools coming from a sick rabbit. In addition, the rabbit drinks large quantities of water, will not eat, and wastes away over a period of several days. The sick rabbit often grinds its teeth, making a unique noise. It also exhibits the "water bottle" sound if picked up and shaken. The body temperature is usually subnormal. The disease is progressive and often fatal: the mortality rate is very high (30 to 80%). Rabbits can die within 1 to 3 days with an acute manifestation. In the case of the chronic disease form, rabbits can survive 4 to 10 days before dying.

Post-mortem examination generally shows an impaction in the digestive tract. The most common site is at the ileocecal junction (where the cecum joins the small intestine), but it also can occur in the cecum or anywhere along the small intestine (Fig. 10.9). Several studies

Fig. 10.9. Intestines from a rabbit with mucoid enteropathy. Note the swollen, mucus-filled intestine (arrow). (Courtesy of N.M. Patton)

have demonstrated the role of impaction in causing mucoid enteropathy. The cause of impaction is not known, but most likely is due to a lack of fiber in the diet. Distension of the proximal colon is also usually observed, which contains a characteristic clear, mucous exudate. The stomach and jejunum are also distended with clear fluid and gas.

Unfortunately, the exact cause of the disease has not been determined. It appears that the digestive tract ceases to function properly. The impaction might be a result of too little water consumption or something happening to the intestine that allows too much water to be absorbed out of it, allowing cecal material to be formed into an impaction. The digestive tract of the rabbit has two sets of waves of muscle contraction that move material through the digestive tract. One is the major peristaltic contraction that propels material, especially large fiber particles, toward the rectum. The other set is an antiperistaltic wave or contraction that moves smaller particles backwards from the large intestine toward the cecum. This material is collected in the cecum and then periodically released as cecotropes (night feces) for reingestion (cecotrophy). When a rabbit becomes constipated (impacted), the normal intestinal motility is depressed. It is not known whether the impaction causes the malfunction or the malfunction causes the impaction. Rabbits that are supplied with inadequate water seem to have a higher incidence of mucoid enteropathy. However, the disease cannot be reproduced by simply restricting water intake.

Food origin has also been suspected, and the use of high-energy and low-fiber rations is often considered a risk factor. More precisely, it has been proposed that feed that has finely ground fiber particles causes more mucoid enteropathy than feed that has large fiber particles. The reasoning is that finely ground fiber is taken back to the cecum by antiperistaltic waves and sets up conditions for constipation, while large fiber particles pass down the colon by the peristaltic waves and are excreted as "day" feces (Fig. 10.10). Although the size of the fiber particle is still in question, an increase in fiber does seem to prevent mucoid enteropathy. In fact, alfalfa hay that is more stem and less leaf seems to be better for rabbits than the reverse. The addition of grass hay with its high fiber content may also be beneficial in preventing mucoid enteropathy. Finally, mucoid enteropathy has been associated with signs of dysfunction of the autonomic nervous system. In rabbits exhibiting this disease, degenerative abnormalities (vacuolation, chromatolysis) were observed in the neurons of the celiac and mesenteric ganglia and in motor neurons of the autonomic nervous system in the spinal cord. These lesions could be the cause of hypomotility of the digestive tract which could be the cause of cecal dysbiosis and other abnormalities observed in mucoid enteropathy. A breeder can present this technical information to their local veterinarian when a case of this disease is suspected.

There is no effective treatment for mucoid enteropathy. By the time the animal is observed to be affected, the disease has generally progressed to a terminal state. In herds where the incidence of mucoid enteropathy is high, changing to a new batch of feed with a higher fiber content will usually eliminate the disease.

Fig. 10.10. Three types of feces seen in rabbits: normal, cecotrophes, and mucus. (Courtesy of N.M. Patton)

Subcutaneous and oral fluids (electrolytes) seem to be beneficial in the treatment of pet rabbits.

Rabbit epizootic enteropathy (ERE) is a very contagious disease that appeared in France and Spain at the end of 1996 – beginning of 97. Originally, it was characterized in the field, in the absence of antibiotic therapy, by considerable abdominal bloating and watery diarrhea, associated with very high mortality rates (30 to 80%). It therefore clinically resembles mucoid enteropathy, with which it can be confused, but unlike the latter, it spreads very quickly both within the farm and between farms as a contagious disease mode. It quickly spread to many countries in Europe and then was described in North Africa. Mexico was affected in the early 2000s, then Turkey, and finally China in 2013. Despite significant improvements made in recent years to reduce the impact of ERE (generalization of strict breeding, food rationing, better control of environmental factors, etc.), this pathology remains a major constraint for the rabbit industry.

The clinical signs generally resemble those observed in mucoid enteropathy: in addition to diarrhea and mortality, there is generally pronounced abdominal bloating. These symptoms are sometimes associated with cecal paresis and the presence of mucus, especially in the colon and sometimes in the small intestine. However, no macroscopic lesion of congestion or inflammation is visible, in particular in the cecum. Usually, at necropsy, major dilation of all segments of the digestive tract including the stomach is observed, the contents of which are very liquid.

The pathogen responsible for this disease has still not been identified. A reference inoculum (called TEC, made from the cecal contents of sick animals), partly characterized, was developed and made it possible, with the use of specific pathogen-free (SPF) rabbits, to clearly define the disease. The direct role of food has been ruled out, but it has been shown that if feed is contaminated with the virus it can serve as a passive vector and remain virulent for several months. The hypothesis that a virus is involved as a primary agent in the development of the disease is now excluded. It is now accepted that the cause of ERE is of bacterial origin, probably at least one rather anaerobic but aerotolerant bacteria, not cultivable on usual media and producing a toxin that acts very quickly at the start of infection. These agents remain to be identified.

ERE is a highly contagious disease, and is spread through the respiratory and digestive tracts. It can thus be transmitted by direct or indirect contact: control rabbits placed with experimentally inoculated rabbits or in neighboring cages of inoculated rabbits develop the disease with a delay of 2 or 5 days, respectively, post-inoculation. Various studies have made it possible to specify risky or, on the contrary, protective breeding practices: late weaning after 35 days is often associated with the development of the disease; the transfer of mothers rather than young rabbits reduces post-weaning stress and limits the cohabitation of animals of different ages in fattening rooms, thus reducing the risks; finally, a too high density of animals in the fattening room is associated with the onset of the disease.

The control of ERE is based on usual hygiene and biosecurity measures, gradual food rationing at the time of weaning, and, mainly in Europe, on the use of antibiotics in drinking water (especially bacitracin and tiamulin).

Coccidiosis

There are two types of coccidiosis, an intestinal form and a liver form. Both forms are capable of producing a diarrheal disease that must be considered when enteritis is observed. Coccidiosis is caused by a protozoan parasite that invades the epithelial cells of either the bile duct or the intestine or both, depending on the species of *Eimeria* involved. There are 10 different coccidia species of the genus *Eimeria* that infect the intestine. The most common species of the ten identified in the rabbit gut are *E. perforans, E. media* and *E. magna*. They seldom cause significant disease, but are readily seen in fecal samples. On the other hand, *E. intestinalis* and *E. flavescens* are the most pathogenic, but seldom occur in well-run rabbitries. While the damage to the digestive tract can be great when the infection is severe, generally the intestinal coccidia are of little concern. The intestinal coccidia are more of a nuisance than anything else. Most conventional rabbitries have some degree of intestinal coccidiosis, and most people accept this as part of raising rabbits. The effect of these parasites on weight gains is not known. Not much attention is paid to the disease until enteritis outbreaks occur. The role of coccidiosis in enterotoxemia and mucoid enteropathy has been questioned by a number of researchers. Some believe it is involved, whereas others think it is an incidental finding. Enterotoxemia has been reported in rabbits that are known to be free of coccidiosis.

From a practical point of view, liver coccidiosis, caused by *Eimeria stiedae*, is a much bigger problem. The damaged bile duct epithelium causes large pea-size yellow spots on the liver (Fig. 10.11), thus resulting in its condemnation by the inspector in the slaughter plant. Rabbits can become emaciated and die as a result of severe liver coccidiosis. Diagnosis is usually made at necropsy or slaughter.

The treatment of coccidiosis seems to be a continual battle. Sulfaquinoxaline has been the drug of choice for years. It is generally administered in the drinking water at 0.04%. However, it can be mixed in the feed at 0.025%. If it is used in the water, it is recommended that it be given continuously for at least two weeks. If it is used in the feed, it is given for three weeks. There are many different schemes for giving this drug, and some are more effective than others. Other sulfa drugs at various dosages and some of the newer coccidiostats, such as amprolium and monensin sulfate, have been used occasionally but have not been approved in the United States for addition to rabbit food. Feed-grade sulfaquinoxaline is not readily available. Most drug companies have discontinued its production. Therefore, the water treatment is most commonly used. Lasalocid, one of the newer coccidiostats, has recently been approved for use in rabbits at 75–125 g/ton of feed and has been proven to be quite effective in treating hepatic coccidiosis.

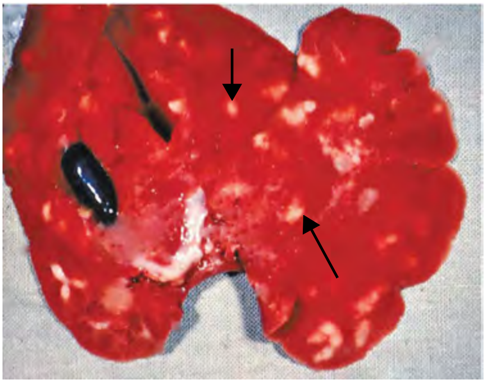

Fig. 10.11. Rabbit liver showing yellow, pea-sized spots of coccidiosis. (Courtesy of N.M. Patton)

A very effective method of controlling some types of coccidiosis is the daily removal of fecal material from the cages with a wire brush. The term “self-cleaning cages” is a misnomer, as very few cages are completely self-cleaning. High-fiber diets result in large fecal pellets that do not drop through the wire. These fecal pellets are the major source of coccidiosis infection. The fecal pellets contain the oocysts (eggs) of the protozoan parasite. The oocysts are not infective until they have sporulated. The period of sporulation, which must take place outside the rabbit, is at least 24 hours. Therefore, daily removal of the fecal pellets breaks the cycle by eliminating this source of infection. Rabbitries using this method of control can prevent the liver form of the disease, but the intestinal form seems to persist, although it tends to be benign.

Tyzzer’s disease

In 1917 a man by the name of Tyzzer discovered a disease in Japanese waltzing mice. A diarrheal disease similar to the one in mice has been found in rabbits. The clinical signs of profuse diarrhea and rapid death (12 to 48 hours) are seen in primarily fryer rabbits. Post-mortem signs are very similar to those of enterotoxemia, except for salt-grain-size white spots in the liver (Fig. 10.12). When special stains are used, microscopic examination of these white spots often reveals the long, slender rods of the bacterium *Clostridium piliformis*. No treatment for the disease has been effective. In severe outbreaks, complete elimination of the herd, followed by thorough cleaning and disinfection of the rabbitry, has allowed repopulation.

Mastitis

Mastitis is an infection of the mammary glands of the doe. It is sometimes called blue bag. It must

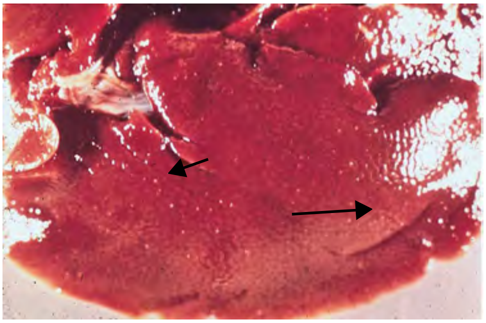

Fig. 10.12. Liver from a rabbit with Tyzzer's disease showing salt-like white areas of necrosis (arrow). (Courtesy of N.M. Patton)

be differentiated from full mammary glands (caked breast or caked udder), which occur when a litter is weaned, dies, or stops nursing. It is often caused by the bacterium *Staphylococcus aureus* but can also be caused by *P. multocida* and several other bacteria. The mammary glands swell up, turn red, and become very painful. Sometimes the affected glands will turn blue or abscess. Does will not let the young nurse, and the lactating glands become more swollen.

The bacteria gain entrance into a mammary gland through the teat canal, a wound, or the bloodstream (septicemia). Mastitis is much more common in first and second litter does and in some herds is a major problem. Rabbitries that experience a lot of weepy eye problems (also caused by *Staphylococcus*) seem to have a higher incidence of mastitis.

Any time a nursing doe goes off feed, mastitis should be considered, and her mammary glands checked. If it cannot be determined whether the glands are swollen, take the doe's rectal temperature. Does with mastitis often have increased temperatures of 40°C (104°F) and above. Antibiotic therapy at this early stage often reverses the condition, and the doe is able to continue to nurse her litter. If too many days pass without treatment, the glands will become bluish, abscessed, and very hard. The litter will likely die, and the doe may also. If the doe dies, never foster the litter to a new doe. The infected young may spread the bacterial agent to the mammary glands of the new doe.

Treatment of mastitis can be accomplished with injectable antibiotics. If the condition is detected early, oxytetracycline (20 milligrams per kg) injected into the muscle of a rabbit daily for three days is quite effective. A long-acting injectable oxytetracycline has been found to be helpful in treating mastitis. Other antibiotics may also be effective. The question as to whether to save a doe that has had mastitis is best answered on an individual basis. If the infection occurs again in the next lactation, cull the doe. If mastitis is not seen again, you can retain the doe. Disinfecting nest boxes, cages, and ancillary equipment is extremely important in reducing the number of cases of mastitis. Thirty ml of sodium hypochlorite bleach per liter (3.8 oz/gal) of water is a very effective disinfectant against both bacteria and viruses. A number of remedies using poultices, hot compresses, etc. have been tried on the mammary glands to reduce the swelling and inflammation. They seem to be of questionable value in rabbits.

Other Rabbit Diseases and Health Problems

There are a number of other diseases and conditions that may affect rabbits. These are seen occasionally and can be of importance to individual rabbit raisers. In the following section they have been arranged alphabetically, with a brief description of each.

Bordetellosis

Bordetella brochiseptica is a small gram-negative rod that can cause pneumonia without the presence of *P. multocida*. Pasteurella-free rabbits may carry *B. brochiseptica* and develop bordetellosis. The incidence of this infection may be quite high, but the number of cases of pure *B. bronchiseptica* are relatively few. The clinical signs are very similar to pneumonia caused by *P. multocida*. About the only way to differentiate the two is by culturing the offending bacterium. Treatment with Enrofloxacin at the rate of 2.5 to 5.0 mg/kg (1.1 to 2.3 mg/lb) twice daily or with Tylocin 2.0 to 4.0 mg/kg (0.9 to 1.8 mg/lb) twice daily may be of some benefit. Sanitation of cages and equipment with a 1.0% solution of sodium hypochlorite will help kill *B. bronchiseptica*. Remember however, that the solution is corrosive to metal.

Broken back

Broken back is a condition that occurs fairly regularly in rabbitries. A rabbit (usually a doe but occasionally a buck) is observed dragging its hind feet. The rabbit may have partial feeling in the feet but does not seem to have control of them. Radiographs of the vertebrae of this rabbit will disclose a fracture or dislocation, usually in the lumbar area. The nerves in the spinal cord are damaged, and the rabbit loses motor control of the hind legs. In a severe case the rabbit will also lose control of the bladder and bowels. There is no realistic treatment, and the animal should be humanely euthanized. Extremely valuable or pet rabbits with the condition can be given cage rest, because if the dislocation is only a partial one, it may be self-correcting over a long period (two to three months). The animals may appear to be in little pain.

The cause of the broken back condition is usually improper handling or improper carrying of heavy rabbits. Rabbits can dislocate their vertebrae by the quick movements of the hind legs when picked up. Rabbits in cages by themselves sometimes appear to panic when startled and cause this injury. Therefore, one should be cautious when entering a rabbitry and especially with strangers. It is useful to talk or make noise when entering to announce your presence. A radio providing constant soothing music or fans providing a constant background noise are very helpful in keeping the rabbits tranquil.

Buphthalmia (congenital glaucoma)

This genetic disease in rabbits is characterized by having one or both eyes protruding somewhat from the eye socket. A slight cloudiness of the cornea may be seen as the animal ages. The condition is usually seen in rabbits older than three months of age. This rabbit should be culled as well as both of its parents because the disease is caused by an autosomal recessive gene often with incomplete penetrance.

Cannibalism

Does that eat their young often do so because of mismanagement. The diet may be inadequate, but more commonly something is allowed to upset the breeding does, and cannibalism occurs. Strangers in the rabbitry, predators, construction noise, and the moving of does just before kindling have all been incriminated. Certain lines of rabbits or families within a line are much more nervous than others. These nervous rabbits are more apt to cannibalize their young. If a doe cannibalizes two litters in a row and it is not due to management error, the doe should be culled.

Colibacillosis

This enteric disease is caused by a gram-negative rod called *Escherichia coli*. The disease seems to be a major enteric disease in Europe, but is seen less frequently in the United States. A toxin-producing type of *E. coli* called enteropathogenic *E. coli* or EPEC has been shown to be the cause of this secretory diarrhea. Colibacillosis strikes young rabbits between 21 and 42 days of age. The young rabbits not only have a diarrhea which often stains the perineal area, but may also be febrile and anorectic. The stress of weaning at a young age is definitely a factor in outbreaks. The intestines are often hemorrhagic and edematous with the intestinal contents more fluid than normal. These young rabbits die so quickly that treatment is seldom attempted.

Dystocia

Dystocia means difficult birth. While this is not a big problem with rabbits, it does happen occasionally. Baby rabbits are born either head first or tail first, so breech births are no problem.

However, dystocia is generally seen in a doe that has only one or two kits *in utero*. The fetuses seem to be abnormally large, and the doe is unable to pass them through the birth canal. Parturition is then delayed, the kits die, and sometimes even the doe will die. Treatment for this problem depends on the severity. The drug oxytocin (1 to 2 units per doe) can be administered by injection. If the fetuses are not lodged in the birth canal, they will be passed by the doe even if they are dead. If a fetus is lodged, surgery may be necessary.

It has become common practice in some rabbitries to administer oxytocin on day 32 or 33 of gestation, if one is sure the doe is pregnant. This will often result in the delivery of a live litter, unless severe dystocia has occurred.

Ear mites

Ear mites or ear canker is a common malady in most rabbitries. It is caused by the parasite *Psoroptes cuniculi,* which establishes a home in the external ear canal. The life cycle of *P. cuniculi* is 21 days. This parasite causes damage to the external ear canal, and the ear produces a brownish exudate (Fig. 10.13). The irritation caused by ear mites elicits a reaction from the rabbits. They scratch their ears with their hind feet, which can introduce bacteria into the ears, quickly setting up an infection. Ear mite infestations can become so severe that rabbits lose condition and reproductive performance is impaired.

Fig. 10.13. A New Zealand White rabbit with ear mites. (Courtesy of N.M. Patton)

The presence of ear mites is easily detected by close inspection of the external ear canal. The mites themselves can be seen under a microscope but usually are not visible to the naked eye. Ear mites are readily treated by using any number of ear mite medications. Most have a mineral oil base, with some parasiticide, such as malathion, added. The 3×3×3 scheme is very effective in treating ear mites. Apply several drops of the medication with an eyedropper to the ear canal. Be sure to massage the base of the ear with your thumb and finger to spread the medication over the entire inner surface of the ear. This should be repeated for three days in a row, then every other day for three treatments, and then once a week for three weeks. Thus, this is the 3×3×3 treatment schedule. In rabbitries with a continuous ear mite problem, a routine treatment of every animal in the rabbitry one day a month will soon rid the rabbitry of this parasite. The transmission of ear mites to the young can occur very early. Therefore, junior replacements should be examined very closely for ear mites.

An injectable drug containing ivermectin is also effective in treating rabbits with ear mites. The drug is administered at the rate of 400 micrograms per kilogram (2.2 lbs) of body weight in a single injection. Your veterinarian can usually best determine the dosage rate with their drug of choice. All breeding and replacement stock should be treated. Because rabbits are infected with ear mites at an early age, all young rabbits not nursing a doe must be treated if the herd problem is to be eliminated. Rabbits to be used for meat should not be injected.

Encephalitozoonosis

Encephalitozoonosis, also called nosema, is caused by a protozoan parasite called *Encephalitozoon cuniculi*. This disease is seldom noted except during post-mortem examinations. It is believed by many veterinarians that it is much more common in rabbitries than most people realize. Occasionally, rabbits will exhibit neurological symptoms, such as convulsions, tremors, and even partial paralysis. Generally, no symptoms at all are observed. Post-mortem examination of rabbits affected with encephalitozoonosis reveals the kidney surface to be pitted (like someone stepped on it with hobnail boots), and in some cases the entire kidney is shrunken (Fig. 10.14). This parasite also attacks the brain (resulting in neurological signs), but this is not readily observable unless a microscopic examination is done. The disease organism is shed from infected rabbits through the urinary tract. The urine from infected rabbits then becomes the means of transmission. No treatment is known. It should be noted that the meat from infected rabbits is safe to eat.

An enzyme-linked immunosorbant assay (ELISA) has been developed that can detect antibodies against this disease. A florescent antibody test (FA) is also available. All that is required from the suspect rabbit is a serum sample that can be submitted to a diagnostic laboratory.

Fibroma

Rabbit fibroma virus (a member of the Leporipoxvirus group) is generally not a problem in domestic rabbits but is seen occasionally. It is most often seen in cottontail rabbits. The virus causes a benign tumor called a fibroma. This tumor appears as small subcutaneous nodules in young rabbits. The nodules may appear anywhere on the body, but most often on the legs and feet. They often seem to run together. These tumors normally disappear after a few months. The virus can be transferred from one rabbit to another by mosquitoes or other flying insects. Because this condition is rare in domestic rabbits, it is not of much economic importance.

Heat prostration

This is a big problem in tropical areas or in other areas where the temperature goes above

Fig. 10.14. Rabbit kidney with a pitted surface caused by *Encephalitozoon cuniculi*. (Courtesy of N.M. Patton)

32°C (90°F) or even where the temperature is lower than 32°C if there is high humidity. If the temperature inside the rabbitry goes over 32°C, does that are very near kindling may die from heat prostration. Baby rabbits in poorly ventilated nest boxes may also die from overheating. The major sign of heat prostration in the doe or any adult animal is rapid respiration that may even progress to open-mouth breathing (see Fig. 12.1). If open-mouth breathing occurs, the animal is in real trouble. Baby rabbits in the nest box become very active and upset. They move around in the box trying to find a cool area.

Heat prostration can be prevented by cooling the rabbitry down or by cooling the rabbits themselves. Shade trees help immensely in hot weather. Trees are very effective because the transpiration of water from the leaves removes a great deal of heat, thus having a cooling effect. Fans, sprinklers, and water evaporation will also help cool the rabbitry. Removing all the nesting material from the nest box helps the young. Draining water lines and recharging them with cold water or emptying water crocks and refilling them with cold water several times daily in extremely hot weather is very beneficial, as rabbits will not consume as much warm water as cold water. The cool water will help regulate the internal temperature of the rabbit. If everything fails and the temperature continues to rise, the animals themselves should be wet down. Sprinkling water on heavily pregnant does and on young rabbits has a cooling effect. Dipping an adult rabbit in a bucket of cold water, adding a frozen jug of water or chunk of ice for a pregnant doe to stretch out against, or adding a wet towel to the cage for the doe to lie down on may also be effective. Any method to reduce the rabbits' temperature is helpful, as they have no sweat glands.

Hepatitis E

Several years ago, Hepatitis E viral antibodies in domestic rabbits on two farms in Virginia were reported. There were no signs of disease. Hepatitis E virus (HEV), a member of the family Hepeviridae, is the causative agent of hepatitis E in humans. This virus is a health concern in many developing countries and areas such as Southeast Asia, North and West Africa, India and Mexico. Sporadic cases of hepatitis E have also been reported in some industrialized countries including Japan and the United States. However, it is quite rare in these countries and is usually seen in individuals who have been visiting developing countries. In humans the symptoms are jaundice, weight loss, liver enlargement, abdominal pain, nausea, vomiting, and fever.

Hepatitis E virus has been identified in several other animal species including pigs, chickens, rats, mongooses, and deer. A zoonotic spread of the virus from animals to humans is a possibility as the virus is spread by ingesting contaminated food or water.

Hutch burn

This is not a disease but a condition seen in adult rabbits (usually does). It is often confused with rabbit syphilis and may be hard to differentiate without the use of a dark-field microscope or other methods. The membranes of the genital area become reddened and chapped. A very strong smell of urine is generally noticed. The perineal area (around the vent) is generally wet, and the hair may begin to fall out in chronic cases. The area can become infected with bacteria and develop into an extremely inflamed, smelly mess. There are two factors involved in this condition. Usually, it is seen in an adult doe that is having an incontinence problem. Urine continually leaks from the urethra and vent, and the area becomes urine-soaked. The other factor involved is sanitation. Wet, dirty cage floors may be a contributing cause. Generally, it is best to cull rabbits with hutch burn, especially if they are dribbling urine. If the cause is strictly wet floors and dirty cages, then antibiotic salves and ointments are beneficial, but the condition will return unless cage sanitation is improved.

Listeriosis

Listeria monocytogenes is a bacterial agent that causes a meningoencephalitis in adult rabbits and metritis with fetal mortality in pregnant does. It can also cause a septicemia in young rabbits. Generally, a rabbit is depressed and weak and may show signs of incoordination, rolling, or convulsions. The most consistent lesion at necropsy is liver necrosis. The pinpoint white spots may be few in number or almost completely cover the liver. Diagnosis involves characterization of lesions and isolation of the bacteria. Early diagnosis and treatment with broad-spectrum antibiotics, such as the tetracyclines, are helpful in the control of this disease. Listeriosis is not common in domestic rabbits. Listeriosis is also seen in humans and the bacteria may be transferred from rabbits to humans.

Malocclusion

Malocclusion (buckteeth) in rabbits (Figs 10.15 and 10.16) is generally considered to be a heritable condition. It has been described by some geneticists as an autosomal recessive gene sometimes with incomplete penetrance, however the exact mode of inheritance is controversial. It is likely that a predisposition to malocclusion is caused by a number of genes. Parents with normal teeth can both be carrying a recessive gene for malocclusion, and 25% of their offspring may have the condition. It should also be pointed out that rabbits can injure their mouths, especially by biting or pulling on cage wire, and show evidence of malocclusion but never pass it on genetically. The problem is in being able to tell whether it came from an injury or whether it is inherited. To be safe, most rabbit raisers simply cull all animals with malocclusion, including the parents that produce the malocclusion. This may be a little too drastic, and you might repeat the breeding of parents producing malocclusion to see whether the condition repeats before culling a particularly good line of rabbits. One option would be to test mate the parents to a known genetic carrier as described in Chapter 15.

The practice of clipping or shortening the overgrown incisors, although acceptable for pet rabbits, is sometimes an act of deception by persons selling breeding stock. Neither the affected animals nor their offspring should be offered for sale as breeding stock.

Fig. 10.15. Rabbit skull showing severe malocclusion. (Courtesy of J.I. McNitt)

Mange

Many rabbits are infested with mites (Fig. 10.17). These minute external parasites live in the fur and cause very little trouble. Occasionally the population gets too large, and a dermatitis results. The hair coat may look unthrifty, or loss of hair may occur in a number of places, most commonly on the back of the neck. The two most common fur mites are *Cheyletiella*

Fig. 10.16. A rabbit with malocclusion. (Courtesy of S.D. Lukefahr)

Fig. 10.17. A magnified view of a fur mite on a hair. (Courtesy of OSU Rabbit Research Center)

parasitivorax and *Listrophorus gibbus*. Diagnosis is made by examining hair shafts under a microscope or with a magnifying glass. If only a few rabbits are involved, a kitten flea powder is very effective in ridding them of mites. If many animals are affected, then the entire herd should be treated. A 0.5% malathion dip works well. Dipping should be done on a warm day. All the rabbits are completely submerged (one at a time) in a dipping vat and then placed in the sun or a warm room to dry off. Ten days later the procedure is repeated. Ivermectin given subcutaneously at 0.2 to 0.4 mg/kg (0.2 mg/lb) is also quite effective.

Moist dermatitis

This condition is generally seen in an older doe with a large dewlap (the fold of skin under the neck area). If open watering devices, such as crocks or cans, are used, the doe has a tendency to get the dewlap wet repeatedly. This provides an environment conducive to bacterial or fungal growth, and an infection and inflammation result. The hair may slough off, and the area can become infested with fly maggots. It also may turn green if *Pseudomonas* bacteria become involved. Prevention is the best treatment: change to a watering device or system that will prevent the dewlap from getting wet. As most commercial rabbitries use automatic drinking valves, this condition is observed much less frequently than previously.

Myxomatosis

Myxomatosis is a devastating viral disease of rabbits caused by the myoma virus, a member of the Leporipoxvirus group. The virus was purposely introduced into Australia to kill wild rabbits. In the United States, it has been observed in rabbits in several states. Myxomatosis is transmitted from wild to domestic rabbits by mosquitoes and fleas, which act as mechanical vectors. In the Pacific Northwest, the virus that causes this disease is carried in the wild by the brush rabbit, *Sylvilagus bachmani*. This rabbit acts as a reservoir for the virus and does not seem to be affected by it, although it may develop skin tumors that soon regress. However, when a mosquito transmits the virus to a domestic rabbit, a severe fatal disease often occurs.

There are two forms of the disease, an acute, rapid-killing form and a long-term chronic form. In the acute phase of the disease, there are very few noticeable symptoms – you will simply find dead rabbits. Rabbits of all ages are affected. If you are very observant, you may see a slight redness of the eye a day or two prior to death. At this point, the rectal temperature will be elevated to 40.6 to 41.1°C (105 to 106°F). You may also note that the rabbit does not eat well. In the chronic form of the disease, the eyelids, lips, face, and sometimes ears swell up to gigantic proportions. Hence, it is sometimes called big head disease. Characteristic lesions are shown in Fig. 10.18. Another sign that will almost always confirm myxomatosis is the swelling of the vent area in does and the scrotum and

Fig. 10.18. The swollen head of a rabbit with chronic myxomatosis. (Courtesy of OSU Rabbit Research Center)

prepuce in bucks. If this is observed along with swollen eyelids, you can be quite sure that the disease is myxomatosis.

Another point to consider in trying to diagnose the disease is the time of year. Myxomatosis can occur almost any time of year but is most frequently seen in late summer and early autumn (the bad mosquito time). There is no treatment. Antibiotics are not effective against viruses. A vaccine is used in Europe, where this disease is common, but it is not approved for use in the United States. The only method of combatting the disease is to euthanize affected rabbits immediately. If you kill and burn or bury diseased rabbits, you can keep the disease in check. If you suspect myxomatosis, take a rabbit to a diagnostic laboratory for confirmation of the disease. Microscopic examination of mucosa cells of the eyelids will disclose the large cytoplasmic inclusion bodies. Once the disease has been confirmed, immediately euthanize all sick rabbits. Whenever a rabbit goes off feed or appears abnormal, take the rectal temperature. If the temperature is elevated above 40°C (104°C), euthanize the rabbit and burn or bury the carcass. Because the disease is so deadly, it is better to make a mistake and put down a rabbit that doesn't have myxomatosis than to allow one to live that does have it. Keeping flying insects out of the rabbitry is helpful in preventing the disease; however, the disease can also be transmitted by direct contact and by your hands. People living in Oregon and California should be very careful about sending rabbits to shows and fairs in the late summer and in the fall. Any sick rabbit should be immediately removed in order to protect the others at the show.

Historically, myxomatosis was first described in laboratory rabbits in 1897 in Uruguay. It was shown to be caused by a virus that occurred naturally in a benign form in the Brazilian wild rabbit, *Sylvilagus brasiliensis*. Mosquitoes and other biting winged insects were the vectors carrying it to domestic rabbits. The first case of myxomatosis diagnosed in the United States was near San Diego, California, in 1930.

In the 1920s, myxomatosis was suggested as the answer to the rabbit problem in Australia. Field tests were conducted on an isolated island in England containing large populations of wild rabbits. The tests were a failure. Much later it was discovered that the island selected was the only one in the area on which the rabbit flea, a vector of myxomatosis, did not occur. The Australian government conducted a number of tests and in 1950 introduced the virus on a large scale. In moist areas, where mosquitoes were common, millions of rabbits were killed, and "myxo" was hailed as a saviour of the livestock industry because the rabbits had been eating all of the forage, leaving little for the cattle and sheep. The success in Australia prompted a French scientist to introduce the virus to control wild rabbits on his estate in France. The virus spread beyond the estate and caused an epidemic of myxomatosis in wild and domestic rabbits in Europe. It spread to England, probably carried by fleas on birds, and decimated the wild rabbit population there. An interesting account of myxomatosis and its ramifications in English agriculture is given by R.M. Lockley (1974).

Necrobacillosis

This disease is rare in the United States. Sores first appear on the lips, which become swollen and painful. These sores progress to small abscesses, ulceration, and necrosis of the skin on the face, head, and neck area. The lesions may extend to the liver and the lungs, causing the animal to become emaciated, with death occurring in several weeks. The causative organism is a bacterium called *Fusobacterium necrophorum*. Poor sanitation, especially dirty cages, is a predisposing factor. The organism is quite sensitive to aerobic conditions and will not live long when exposed to the air. If detected early, the disease can be treated effectively with penicillin.

Nest box death

Newborn litters are very susceptible to death. As many as 5–10% of the litters born die each year. Death losses are more common in the cold months than in the more temperate months. A number of different causes have been suggested and probably all are involved to one degree or another. A doe pulling inadequate fur for the nest is definitely a factor. Poor condition of the doe and her inability to produce adequate milk is another cause. Some have suggested that overfeeding a doe immediately after kindling may produce a toxic milk situation. Kits found dead in the nest box with full bellies lend credence to this theory. Obviously, a doe that urinates or defecates in the nest box is liable to lose her litter. There may be pathogenic bacteria involved in these death losses with *Staphylococcus* being a prime suspect. Whatever the cause, daily inspection of the nest box is critical to reducing these losses.

Fur from another nest box can be added to one without fur. Wet and dirty nest boxes can be replaced with boxes containing clean dry bedding. Obviously, the ability to add heat to the rabbitry or nest box would be helpful. As does only nurse their young once or sometimes twice a day, a calm environment is essential for good litter survival. There are certain does that lose their litters almost every time they kindle. These does are just poor mothers and should be culled from the herd.

Papilloma

Papilloma results from a virus that causes wart-like growths on the ears, eyelids, and faces of rabbits. Although the disease is seen most commonly in cottontails, it can also occur in domestic rabbits. The wart-like masses often split. The lower portions are pinkish and soft to the touch. A wart often gets knocked off, and bleeding occurs. The virus is transmitted by flying insects.

Pinworms

Pinworms are common parasites of rabbits. These small white worms, about 1cm (0.4 in) in length, are found in the cecum of many rabbits (Fig. 10.19). They shed eggs that are passed with the fecal pellets, and the worm itself is occasionally seen on freshly passed feces. Pinworms do very little damage and are usually just an unsightly nuisance. It is only in a

Fig. 10.19. Rabbit pinworms. (Courtesy of N.M. Patton)

debilitated rabbit that a heavy pinworm load will become significant. Pinworm eggs can become airborne when dried and often contaminate feed and water supplies. Transmission of this parasite comes from other rabbits ingesting contaminated feed and water. If treatment becomes necessary, piperazine citrate is used in the water. The dosage is 100 milligrams per 100 milliliters (3.4 oz) of water. In large rabbitries, 4 ml (cc) of 34% piperazine is added per liter of water. Treatment should cover three days and then be repeated twice at 30-day intervals. A thorough cleaning and sanitizing of the rabbitry helps reduce the possibility of reinfection. Rabbit pinworms do not transmit to children.

Pregnancy toxemia

This condition, also called ketosis, occurs much more often in some rabbitries than in others. The most common signs are lethargy, dyspnea and sometimes CNS (central nervous system) problems. Female rabbits suddenly die shortly before or shortly after kindling. On post-mortem examination the most obvious lesion is a yellow or tan liver caused by an accumulation of fat in the liver cells. This infiltrating fat interferes with the normal metabolic processes of the liver and the breakdown of the fat into metabolizable energy. The result is the formation of ketone bodies from fat – thus the name “ketosis”. Generally, the feeding of diets low in carbohydrates triggers the animal to break down body fat to meet its energy needs. This is more common to occur in young pregnant does (“young doe syndrome”) since they have higher energy requirements.

An affected doe gradually reduces or stops feed intake. In some cases of pregnancy toxemia, a hairball is found in the stomach. This may cause the doe to go off feed, but the body still requires energy for maintenance. Fat is taken from fat deposits and transported to the liver to be converted to metabolizable energy, but not all the fat is utilized. Treatment for this disease is seldom attempted, as the diagnosis is generally not made until a post-mortem examination. Injections of glucose have been found to be helpful in cattle with a similar disease.

Pseudotuberculosis

This is a fairly common disease in certain rabbitries. The etiologic agent is a bacterium called *Yersinia pseudotuberculosis,* which can also affect humans and other animals. It is a general wasting type of disease characterized by poor appetite, depression, emaciation, and death. Granulomatous nodules are seen at post-mortem throughout the intestine and occasionally in the liver, spleen, or lungs. This disease is most commonly seen in rabbitries with poor sanitation. The organism seems to thrive under such conditions and enters the rabbit orally or through abrasions in the skin. Treatment is not effective. Affected animals should be euthanized and should not be used for human consumption. Prevention can be accomplished by increased awareness of sanitation shortcomings and making the necessary changes to improve the sanitation.

Rabbit hemorrhagic disease

Rabbit hemorrhagic disease (RHD) (also known as viral hemorrhagic disease, or VHD) is a fatal viral disease in rabbits that was first reported in China in 1984 in Angora rabbits imported from Germany. Whether they were already infected or became infected after arriving in China was never determined. In addition, there is a great deal of intercontinental movement of both live rabbits and rabbit meat between China and Europe. Thus, the original direction of spread may never be known. The result is the same, however, in that both Asia and Europe first experienced the devastating results of this disease, which then spread to all continents. RHD can now be considered endemic in most parts of the world (Europe, north Africa, Australia, New Zealand, etc.). The causative agent was characterized as a specific calicivirus, the rabbit hemorrhagic disease virus (RHDV), a small nonenveloped very resistant virus; it can persist at least 3 months in the dried state on cloth at room temperature, and several weeks in decomposing rabbit carcasses. The different strains of “classic” RHDV only affect wild and domestic members of the species *Oryctolagus cuniculus*, the European rabbit. A new RHDV-related virus, called RHDV2, emerged in France in 2010 and since then has spread quickly in Europe and the Mediterranean basin, causing significant losses in farmed and wild rabbits. In 2015, RHDV2 was first detected in Australia and, presently, in many countries, it is replacing "classic" RHDV. The RHDV2 host spectrum is broader than that of RHDV as it can also infect and induce disease in different European hare species (*Lepus europeus*, *Lepus capensis*, *Lepus corsicanus*, *Lepus timidus*), and various hare (*Lepus californicus* and *Lepus alleni*) and cottontail (*Sylvilagus audubonii* and *Sylvilagus Nuttallii*) species in North America. These new original biological characteristics very significantly modify the global epidemiological situation of RHD.

RHD had never been reported on the North American continent until a December 1988 USDA field bulletin describing an outbreak of RHD in Mexico. No one knew how the outbreak started, but it was suspected that the initial virus may have come in with a shipment of frozen rabbit meat from China. The disease spread to 159 separate rabbitries in Mexico, with one focus only 400 miles from the U.S. border, causing high mortality. Rigorous control practices were successfully employed on a large scale to eradicate the disease (more than 110,000 rabbits died or were euthanized in the affected area).

The first confirmed case of RHD caused by "classic" RHDV in the United States was reported in in 2000. In March of that year, a small group of Palomino and Californian rabbits in Iowa were diagnosed with the disease and, by April, 25 of 27 rabbits had died. The other two diagnosed rabbits were euthanatized and the farm was quarantined for two years.

Since this first case, other small outbreaks occurred between 2001 and 2010 (2001 in Utah and Illinois, 2005 in Indiana, and 2010 Minnesota). The quarantine of premises and slaughter of infected and suspect rabbits has proven to be quite effective in controlling the spread of RHDV.

RHDV2 was first introduced in North America in August 2016 (in a recreational farm in Québec, Canada; source of introduction unknown), but without subsequent spreading. Unfortunately, in 2018, new outbreaks of RHD caused by RHDV2 strains were reported in Canada (in April, on feral rabbits in Vancouver Island) and, for the first time in USA, in Medina County (Ohio; in September on pet rabbits), the two strains being genetically very close to a strain isolated in Spain in 2011. Since these two initial outbreaks, many cases have been reported in the USA, Canada, and Mexico, especially in 2020–2021, both in populations of domestic rabbits and wild lagomorphs (rabbits and hares).

After infection with "classic" RHDV, adult rabbits seem to be most commonly affected, and rabbits younger than 6–8 weeks. However, even in the absence of maternal antibodies, young rabbits generally do not develop clinical signs develop clinical signs or pathological lesions, but develop lifelong immunity. Conversely, RHDV2 strains are pathogenic for very young animals, clinical signs and mortality being observed in young rabbits less than 15 days old. There appears to be a wide range of morbidity (percentage of exposed rabbits that become infected). It can be as low as 30% or as high as 80%. Mortality among "classic" RHDV infected rabbits reaches 95 to 100%, this rate being generally slightly lower after RHDV2 infections. The incubation period varies between 1 and 6 days (generally 1–3 days after "classic" RHDV infection, and 3–5 days after RHDV2 infection). The virus can invade the respiratory tract or the digestive tract or can invade through scratches or abrasions in the skin. Experimentally, the virus has produced the disease when introduced orally, intramuscularly, or by intraperitoneal injection. The virus may also be transmitted by aerosols, direct contact, equipment used with the meat or by-products, and possibly insects or rodents as vectors. The virus has been shown to persist for as long as 215 days in certain environments.

There seem to be three forms of the disease. In the peracute form, all that is seen is a dead rabbit in the cage. In the acute form of the disease, the rabbit shows depression, goes off feed, and has difficulty breathing. This rabbit dies in one or two days and exhibits incoordination, shaking, and evidence of pain prior to death. It may also show a blood-stained mucus nasal discharge (Fig. 10.20). When the affected rabbit is first observed, the rectal temperature may be increased 1.5 to 2°C (normal rectal temperature is 39.4 °C (103°F)). The third form of the disease seems to be much

Fig. 10.20. A rabbit showing the bloody nasal discharge that is symptomatic of viral hemorrhagic disease. (Courtesy of Medicina Veterinaria)

milder (subacute). The rabbits appear sick (jaundice, loss of weight, and lethargy), death may occur within 1–2 weeks, but some rabbits recover and become immune to reinfection.

Consistent pathological lesions are found during post-mortem examination of affected rabbits. As the name of the disease suggests, the most commonly observed findings are hemorrhages throughout the body organs. The lungs have petechial (pinpoint) to ecchymotic (bean-size) hemorrhages covering the surface. These same kinds of hemorrhages may be seen in the bronchi and bronchioles of the lungs and in the trachea. The mucus membranes of the nose and throat may also show hemorrhages. Hemorrhages are commonly seen in the liver, kidneys, spleen, heart, and lymph nodes and sometimes along the digestive tract. A bloody nasal discharge seen in times of moderate ambient temperatures often serves as a warning.

The second major common lesion is seen in the liver. The liver is extremely swollen and brownish red in color. The tissue breaks apart easily. Examination of the liver under a microscope reveals many areas of necrosis (dead cells) and inflammation. Vascular thrombosis (blood clots in the vessels) is also found. Thrombosed vessels are seen not only in the liver but in other organs as well. Infarcts due to blood clots are occasionally seen in the brain. Intranuclear inclusion bodies are observed in the liver, spleen, and kidney cells.

RHD develops so quickly and kills so rapidly that treatment does not appear to be practical. Most efforts should be concentrated on prevention. In areas where the virus does not circulate into a wild animal reservoir population, control through stamping out is possible. Therefore, after the first emergence in 1988 in Mexico, a quarantine and slaughter method of control was quite successful. All rabbitries where the disease was diagnosed were quarantined and the sale of their rabbits was prohibited. All rabbits were euthanized by government officials and the owners were paid for their rabbits or given new rabbits four weeks later.

Prevention is helped by good sanitation and disinfection procedures. Using a strong viricidal disinfectant on all equipment both inside and outside the rabbitry may be beneficial. Restriction of visitors or some type of visitor disinfection procedure may be necessary to prevent the entrance of the disease. The quarantine of rabbits taken to shows or fairs should be considered. A one-week quarantine of any returning or newly acquired rabbit would be sufficient because the incubation period is quite short, although, because of other diseases, a two-week quarantine is preferred.

It must be emphasized, however, that hygiene and biosecurity measures alone are insufficient to control the disease in countries where the virus circulates endemically and in wild populations. These measures must be supplemented by vaccination of domestic animals. Therefore, mainly in Europe, several vaccines are available (specific for “classic” RHDV or RHDV2, most often combined, the level of cross protection being too low). The protective immunity developed after vaccination may last as long as 12 months. Very recently, since the emergence of RHDV2 in 2020, Mexico’s government authorized the production and marketing of their own specific vaccine. At the time of the writing of this book edition, a new vaccine for RHDV2 was approved for use by the USDA that is highly effective against both RHDV and RHDV2. The vaccine is available through MedGene Labs (https://medgenelabs.com/rhdv2/).

Although this disease has been prevalent for several decades now, RHD could still have a major impact on rabbits in Canada and the United States. The recent emergence of RHDV2 in North and Central America poses a real threat to domestic rabbit populations and wildlife. Uncontrolled endemic circulation of the virus could be devastating. Millions of rabbits worldwide have succumbed to this disease, and perhaps millions more will be affected if strict measures are not implemented.

Rabbit pox

This rare viral disease of rabbits has been reported mostly in laboratory rabbits, and seldom in commercial or show rabbits. It is caused by a pox virus and can cause mortality as high as 75% in young rabbits. The lesions include lymphadenitis (inflammation of the lymph glands) and papular nodules (blisters) on the mucous membranes. A vaccine is available to combat this disease.

Rabbit syphilis (venereal spirochetosis)

This disease has many names, including vent disease and spirochetosis. Whatever it is called, it can become a major problem in a rabbitry if left untreated. The disease is characterized by small blisters or reddish raw sores on the external genitalia of both does and bucks. In severe cases, crusty scabs and sores will appear on the nose and lips of rabbits (due to their practice of coprophagy). Another noticeable sign is a decrease in conception rate and a reluctance on the part of the doe and the buck to mate. Rabbit syphilis must be differentiated from “hutch burn” caused by dirty cages and from bacterial infection of the genitalia.

Rabbit syphilis is caused by the organism *Treponema cuniculi*. With a dark-field microscope or other methods, this organism, a spirochete, is quite easily seen in scrapings of the syphilis lesions (sores). If rabbit syphilis is suspected, an infected rabbit with lesions should be taken to a veterinarian. There is also a blood serum test for this disease. It is a “Rapid Plasma Reagent” test, or RPR. The problem with this test is that it detects antibodies and tells only whether the rabbit has been exposed to the *Treponema* organism, not whether it has an active case of the disease. Dark-field microscopy is a useful test for a conclusive confirmation. Rabbits that have been treated with antibiotics will not show the spirochete in the scrapings.

Rabbit syphilis is quite easily treated. Each rabbit is injected once per week for three consecutive weeks with a long-acting penicillin product at a dosage of 40,000 IU/kg (18,182 IU/lb) of body weight or with procaine penicillin 40,000 IU/kg for three to five days. This is the only way to completely rid a herd of this disease. Unfortunately, this treatment may cause an outbreak of diarrhea, and several rabbits may die. The diarrhea is a result of the antibiotics causing changes in the bacterial population of the gut, allowing the proliferation of some organisms that produce lethal toxins. This side effect can be prevented by increasing the fiber in the diet through the feeding of hay or straw. It is recommended that free-choice hay or straw be started two days prior to penicillin treatment and continued throughout the entire three weeks of treatment. The use of broad-spectrum antibiotics (such as tetracyclines) in the water to treat this disease is another possibility that might alleviate the problem of diarrhea.

Syphilis can be passed to the young from the doe by contact. Therefore, if syphilis is in the herd, all rabbits, including the junior virgin breeding stock and nursing kits, must be treated to completely eradicate the disease. Nursing kits generally receive the antibiotic through the mother’s milk. However, it might be a good idea to market all the nursing young when they reach market weight during or shortly after the treatment period.

Loaning a buck to service someone else’s rabbits is a good way to bring syphilis back to your herd. If you want to develop a rabbit stud service, keep a separate buck just for this purpose, and do not use him in your rabbitry. Check his genitalia frequently.

Red urine

Rabbit urine is somewhat unusual compared to that of other livestock. It often contains large amounts of calcium carbonate or calcium oxalate, which forms deposits on cages (Fig. 5.18), walls, and floors. A rabbit absorbs calcium efficiently and excretes the excess mainly in the urine. A red coloration of the urine may be seen (Fig. 10.21). This seems to be a normal phenomenon in the rabbit and does not indicate a

Fig. 10.21. A jar of rabbit urine showing white calcium carbonate settled at the bottom and reddish pigmented urine above. (Courtesy of D.J. Harris)

disease problem. The pigment is especially apparent when the urine is alkaline. Certain types of feeds, such as alfalfa and *Leucaena,* seem to increase the intensity of the pigmentation of the urine. The pigment is most likely a porphyrin. It might be derived from phenolic compounds (tannins), which many forages and feed ingredients contain.

Ringworm (dermatophytosis)

Fig. 10.22. Typical rabbit ringworm. Note the hair loss, but also the lack of a circular pattern that is seen in other species. (Courtesy of N.M. Patton)

Favus, or ringworm as it is commonly called, is a fungal disease of rabbits. It is characterized by crusty, shallow sores on the face or feet that increase in size if not treated (Fig. 10.22). Generally, hair is often lost in circular patches over the lesions (thus, the name “ringworm”). This disease is caused primarily by two genera of fungi: *Microsporum* and *Trichophyton*. There are several species of fungi in each group capable of infecting rabbits. Some of these are also transmissible from rabbits to humans and vice versa. Ringworm is very contagious, so precautionary measures must be taken when handling affected animals. Gloves are essential, and you should wear clothing that can be boiled or discarded. Disinfect cages used by infected animals. Ringworm lesions are most common on young rabbits, especially the nursing young, but can also occur on adult rabbits. In European countries ringworm has been a major problem. Confirming the diagnosis of a suspect case of ringworm is generally done by a veterinarian or at a microbiology laboratory. Hair or skin scrapings are taken and placed on culture medium. The fungal spores grow slowly, often taking two weeks or more to reach the vegetative stage necessary for diagnosis.

The treatment of ringworm depends on whether it is an individual or herd outbreak situation. Several medications are available that can be applied to the skin surface. By far the least expensive is ordinary iodine. An ointment containing hexetidine is very helpful in treating isolated cases of ringworm. If a herd problem is encountered, the drug griseofulvin is the best choice. Each rabbit should receive an oral dose of 25 milligrams of griseofulvin per kilogram (11 mg/lb) of body weight. The drug can be put in the feed at the rate of 800 milligrams per kilogram of feed (1.6 lb/ton) and fed for 15 to 25 days. This treatment is effective, but the drug is extremely expensive. A water-soluble form of griseofulvin is available. Griseofulvin should not be given to pregnant does as it may cause teratogenesis (birth detects) in the newborn. Be sure to wash your hands after treating rabbits as ringworm can be transmitted to humans.

Salmonellosis

This disease is common in certain areas of the United States. The disease, an enteric diarrheal condition, is generally caused by the bacterium *Salmonella enterica*. These organisms are spread by fecal contamination, and one infected rabbit can easily contaminate a whole herd. This is an example of why quarantine of newly purchased rabbits is essential. The disease can be transmitted to rabbits from humans that are carriers of salmonellosis. The reverse is also possible.

The disease in rabbits is characterized by a profuse diarrhea, with septicemia and death being very common. Abortions are also part of this disease. Mortality is greatest in young rabbits and pregnant does. At necropsy the most common lesions are hemorrhagic and ulcerative changes in the intestine. The liver and spleen are enlarged and may contain pinpoint white spots.

Prevention is by far the best treatment, but streptomycin and nitrofurazone treatment have been shown to be effective. Treated animals may recover but can be carriers of the organism, spreading it to others in the herd. Wild birds and rodents have also been shown to be reservoirs of the organism.

Sore hocks

The scientific name for this disease is *ulcerative pododermatitis*. However, the name "sore hocks" is much more descriptive in that what you see is a loss of hair on the foot pads and a big sore on the hocks (Fig. 10.23). This disease should be suspected whenever you see a rabbit sitting with more weight on the front feet than normal or sitting in the nest box for long periods of time. Also, the rabbit will walk with an unusual motion, as if walking on eggs. An inspection of the feet quickly reveals sore hocks. The disease can affect all four feet, but it is usually first observed on the hind feet.

Fig. 10.23. Sore hocks. (Courtesy of OSU Rabbit Research Center)

There seems to be a genetic predisposition for this disease. Certain lines or strains of rabbits within a breed will show a higher incidence of sore hocks than others. Generally, the more susceptible rabbits show a lack of dense fur on the pads themselves. Poor body condition may also increase susceptibility. Other factors that are involved in this disease are the type of wire on the cage floor, the cleanliness of the cage floor, and the condition of the cage floor (rusty or rough, etc.). Rabbits with sore hocks tend to become thin and emaciated. This may be due to a subclinical septicemia or to the reluctance of the rabbits to move to the feeder and eat. Although numerous bacteria have been isolated from sore hocks, the predominant one is *Staphylococcus aureus*.

Once sore hocks occur, it is extremely difficult to rid the rabbit of the problem, and damage to the foot is permanent. Recurrence of the disease is very common. Placing boards or mats in the cage is helpful but increases your sanitation problems. Removing the rabbit from its cage and placing it in a pen on the floor with sawdust or hay helps the feet to heal, but soon after you return the rabbit to a cage it may develop sore hocks again. Salves, ointments, sprays, and many other medications have been tried, and with diligence you can sometimes get the sores to heal. However, it is generally much more economical to cull the rabbit; and by all means do not save any breeding stock from this animal. Sore hocks seems to be a major problem in Rex and Mini Rex rabbits. This is due to the short guard hair on the feet. Through selection for thick fur cover on the pads, this problem can be eliminated, even in the Rex and Mini Rex breeds. It is also a problem in giant breeds, such as the Flemish Giant.

Modern cages are often supplied with plastic slat floors. The slats are 3 cm (1.2 in) wide and are placed 1.3 cm (0.5 in) apart. The slats materially reduce the incidence of sore hocks.

Splay leg

True splay leg in rabbits appears to be a simply inherited genetic disease. It is likely due to the rabbit inheriting two recessive genes from its parents. The hind legs of the rabbit stick out behind. They are not paralyzed, and the rabbit moves by wriggling along on its belly and pulling itself along with the front legs (Fig. 10.24). Occasionally all four legs are affected. The animals eat normally but are often traumatized by litter mates. Breeding stock should not be saved from parents with offspring showing this disease. Splaying of the legs may also be a result of physical injury or vitamin deficiency.

Staphylococcosis

This disease syndrome is somewhat similar to pasteurellosis in that the organism *Staphylococcus aureus* causes a number of different conditions. The most damaging of these is staphylococcal mastitis, which has been discussed under the heading "Mastitis."

Fig. 10.24. A rabbit with splay leg. (Courtesy of N.M. Patton)

Another major manifestation of this syndrome is staphylococcal septicemia. This occurs when S. *aureus* gains entrance into the cardiovascular system and begins multiplying rapidly, quickly resulting in death. Staphylococcal septicemia is fairly common in kits one to three weeks of age. The organism gains entrance into a kit through the milk from an infected mammary gland or through small cuts or abrasions on the skin surface. Death is very rapid, and about the only lesions seen during post-mortem examination are salt-sized white spots on the liver. Occasionally small pustules or bumps are seen on the skin of a dead kit, but usually just a dead kit is observed in the nestbox. Diagnosis is generally dependent on isolating the *S. aureus* from the heart blood.

Staphylococcus aureus will also cause conjunctivitis in rabbits (discussed under "Weepy Eyes") and abscesses. The bacterium is ubiquitous and is resistant to a number of antibiotics. The disease in its septicemic form causes death so rapidly that it is difficult to treat. Penicillin streptomycin, tetracyclines, gentamicin, chloromycetin, the nitrofurans, and many other antibiotics have been used against this disease with limited success. The best defense once again is prevention. The liberal use of disinfectants and excellent sanitation help keep this syndrome to a minimum. Disinfecting nest boxes after each use is essential if staphylococcal mastitis and conjunctivitis are to be controlled. Nest boxes should be disinfected again before being placed in the cages. Cages, feeders, and watering devices should be disinfected periodically (30 ml of bleach in 1 liter of water (3.8 oz/gal) is an excellent disinfectant).

Tapeworms

In rabbits, tapeworms can occur as both adults and larvae. The adult forms are rarely found in domestic rabbits, but larval tapeworms are occasionally seen in poorly managed rabbitries. The most often observed larval forms are those of *Taenia pisiformis*. They cause a tortuous white tract through the liver as they migrate and then form a bladder-like cyst in the abdominal cavity (Fig. 10.25). Rabbits acquire tapeworm

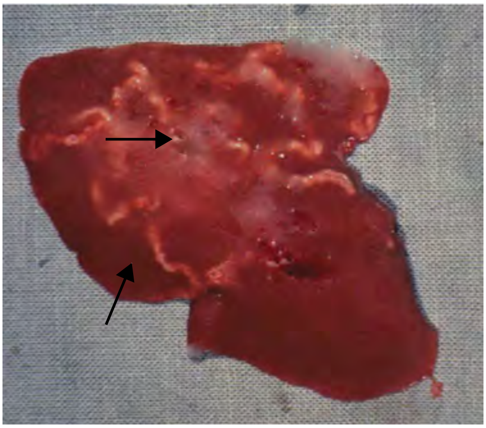

Fig. 10.25. Rabbit liver showing the tortuous tracts of tapeworm migration. (Courtesy of N.M. Patton)

infections from contaminated feed and water. The life cycle of this particular tapeworm is very interesting. The adult tapeworm is found in the dog. The eggs are shed with the dog's feces. If rabbit feed is contaminated by the dog feces, rabbits may become infected by ingestion of the eggs. The larvae released from the eggs migrate through the digestive tract wall and penetrate the liver. Then the larvae leave the liver and form fluid-filled cysts, which attach to the abdominal wall, the organs, or the mesenteries. Treatment for this parasite is not practical, so prevention is the method of control. Prevention is accomplished by excluding dogs from the rabbitry or making sure that they do not contaminate feed or bedding.

An adult tapeworm, *Cittotenia variablis*, is occasionally seen in rabbits. It is a flat, ribbon-shaped worm made up of numerous segments. It attaches to the epithelial surface of the intestine but causes little pathology and is usually seen at necropsy.

Toxoplasmosis

This is a protozoal disease caused by *Toxoplasma gondii*. The disease occurs in both domestic and wild rabbits but is not common in either. There are two forms: the acute and the chronic. The acute form is characterized by anorexia, fever, lethargy, and central nervous system symptoms, such as convulsions and paralysis. Death is usually seen in about a week after symptoms are detected. With the chronic form either no symptomatology is seen, or a very slow progressive emaciation is observed that ends in paralysis and death. Transmission of the parasite can occur from rabbits eating feed contaminated by cat feces (cats can shed the parasite in their stool), or it can be passed from a doe to her offspring through the placenta. Diagnosis of the disease usually occurs at necropsy. Extensive necrosis of lymph nodes, liver, spleen, and lungs may be observed histologically. Various serological tests are also helpful in diagnosing this disease. Treatment of toxoplasmosis is not practical, and emphasis should be on prevention. Cats should be kept out of the rabbitry or prevented from contaminating feed and water supplies.

Trichobezoars (hairballs)

Trichobezoars, or hairballs, are a common occurrence in large rabbit herds, but seldom cause extensive digestive problems. They are especially common in Angora rabbits. Because of the normal grooming habits of the rabbit, a certain amount of hair is ingested. This hair normally passes through the digestive system and exits with the fecal material. This process seems to work much better with high-fiber diets. A lack of fiber in the diet not only slows down the passage of hair, but it also causes the rabbit to ingest more hair to make up for the lack of fiber in the diet. As excessive hair is taken into the stomach, it begins to clump together and eventually forms a mat or ball (Fig. 10.26). The opening from the stomach to the small intestine is quite small, and the hairball cannot be passed. When the hairball becomes very large, it eventually causes the rabbit to stop eating, resulting in starvation. Rabbits with trichobezoars have been known to live as long as three weeks without eating. Whenever a rabbit goes off feed and the temperature is normal, a hairball should be considered. Palpation of the stomach can often help in the diagnosis because large trichobezoars can be detected.

Fig. 10.26. A trichobezoar from the stomach of a rabbit (right). Note the similarity of the shape to the rabbit stomach (see Fig. 10.2). (Courtesy of N.M. Patton)

Prevention is by far the best treatment. Feeding diets high in fiber or adding hay or straw to low-fiber diets reduces the incidence of trichobezoars. If, however, a hairball is detected, treatment should begin immediately. If the rabbit is a valuable animal, the best method of treatment is surgical removal of the hairball by a veterinarian. If that is not an option, then one of the home remedies can be attempted. Many types of lubricants, such as mineral oil, have been tried with limited success. No amount of lubricant can make a large hairball pass through a small hole. Another home remedy is the use of fresh or frozen pineapple juice. A proteolytic enzyme called bromelain is contained in pineapple juice. This enzyme helps to break up the hairball so it can be passed through the digestive system. Best results have been obtained by giving 10 milliliters (cc) of fresh or frozen pineapple juice for three consecutive days, while at the same time feeding free-choice hay or straw. The pineapple juice can be administered with an eyedropper or a spoon, but the method of choice is through a stomach tube. Mangos, kiwi fruit, and papayas may also contain similar proteolytic enzymes. Canned pineapple juice is not as effective as fresh or frozen because the canning process destroys the digestive enzyme.

Tularemia

Tularemia is primarily a disease of wild rabbits. Few cases have ever been detected in domestic rabbits. The bacterial organism involved is *Francisella tularensis*. The rabbits appear sluggish and are obviously sick. Grayish-white spots are seen in the liver at necropsy, but diagnosis depends on culturing the organism on special media or by serological tests. Rubber gloves should be worn whenever a suspect animal is handled as the disease is transmissible to humans through punctures in the skin.

Urolithiasis

Urine from an adult rabbit is normally cloudy because of the excretion of excess calcium (Fig. 10.21). While this causes a build-up of calcium to occur in one corner of the cage (a rabbit normally selects a latrine area of the cage), it isn't really a problem for the animal itself (see Fig. 5.18). Occasionally the calcium comes out of the urine solution in the bladder and begins to form a stone called a urolith (bladder stone). A urolith is usually made up of calcium carbonate or calcium oxalate. If the stone is quite small, it will be passed the next time the rabbit voids. If there are a number of these small stones, the urine has a "sandy" feel to it.

A large urolith can become a problem. The stone is retained in the bladder, and the size increases as more calcium crystals are added to the outside surface. Eventually the urolith becomes too large to pass through the urethra. Blood may occur in the urine as the stone begins to irritate the bladder wall. When this occurs, a radiograph will reveal the presence of the urolith. Surgery is required to remove the calcium stone if the rabbit has great value. Follow-up treatment to prevent recurrence is necessary. Two methods of treatment are used. First, change the diet. Take the animal off rabbit pellets that contain alfalfa. Alfalfa is quite high in calcium. If possible, switch the rabbit to a diet of timothy hay and rolled oats. Fresh greens can also be added. Second, try to make the urine more acidic. Calcium tends to precipitate much more readily in alkaline urine. If the urine can be acidified, the calcium stays in solution and flows out with the urine. There are several urine-acidifying drugs on the market that are used primarily for cats. Consult your veterinarian for help in obtaining drugs to try with your rabbit. A rabbit with this problem that is not of great value is generally culled from the herd.

Uterine adenocarcinoma

Uterine adenocarcinoma is a common tumor in rabbits, especially pet rabbits. Does with this condition have altered reproductive performance. Fertility is reduced, as is litter size. Other symptoms are fetal resorption and dystocia. The tumor is diagnosed by a radiograph and biopsy. In commercial rabbits it is usually seen at necropsy or slaughter (Fig. 10.27). Ovariohysterectomy is the treatment of choice in pet rabbits if detected early. In fact, with pet rabbits this surgery in young does not only eliminates the possibility of uterine adenocarcinoma but may also prevent undesirable behavioral changes.

Vitamin A deficiency

A number of reports have been published that deal with vitamin A deficiency in rabbits. The original reports were focused on hydrocephalus, which is one of the major conditions seen

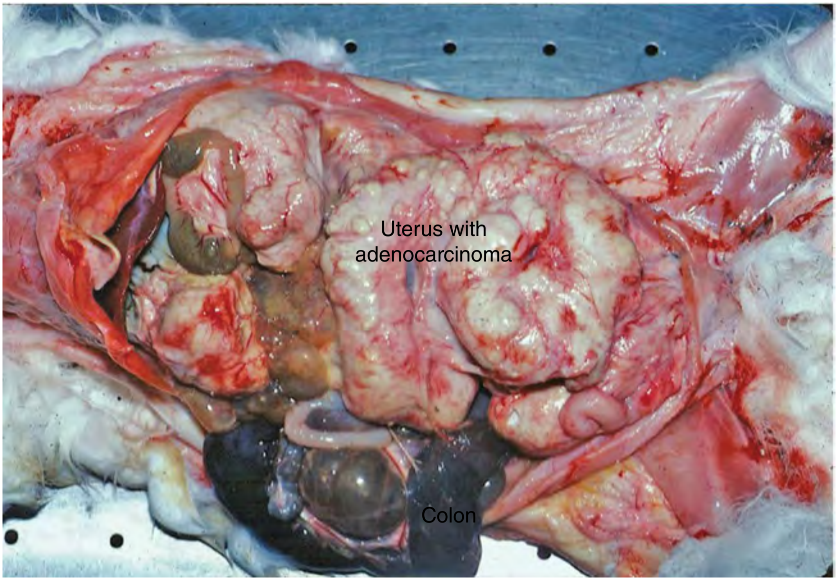

Fig. 10.27. Uterus of a rabbit with uterine adenocarcinoma. (Courtesy of N.M. Patton)

with deficient levels of vitamin A in the diet. It can also be the result of a genetic defect. Some of the later reports listed other adverse effects that are primarily observed during the reproduction process. These changes in the reproductive parameters are usually seen before hydrocephalus is observed. Decreased litter size, poor conception, abortions, and resorptions are all part of the syndrome. The tips of the ears begin to droop on breeds of rabbits with erect ears. Crooked legs may occur with severe vitamin A deficiency. An increase in sore hocks and weepy eye is also common. Most of these clinical symptoms occur because of the deleterious effects that a lack of vitamin A has on epithelium, cartilage, and bone.

The decrease in reproduction is due to the effect of vitamin A deficiency on the reproductive organs. Premature degeneration of the ovum and reduced numbers of fertilized ova occur. The hydrocephalus (water on the brain) that results from vitamin A deficiency is characterized by a distention of the portion of the skull that covers the brain. A hydrocephalic newborn rabbit is usually born dead and is recognized by a dome-shaped head (Fig. 10.28) or by a larger than normal fontanelle (soft spot) at the apex of the skull. The enlargement of the head is due to an increase in the size of the ventricles (cavities) of the brain, which become filled with a clear, colorless fluid. Rabbits that live show signs of nervous system dysfunction. Wry neck, incoordination, and loss of equilibrium are common. Hydrocephalus is found in kits born to does that show low vitamin A levels in the blood. When maternal blood levels fall below 20 micrograms per 100 milliliters (cc) of serum, hydrocephalus appears in the young.

Fig. 10.28. Vitamin A deficiency caused the hydrocephalus in the kit on the left. (Courtesy of OSU Rabbit Research Center)

Commercial diets in general supply adequate amounts of vitamin A or b-carotene, with b-carotene converted to vitamin A by the rabbit. However, b-carotene deteriorates quite rapidly in stored hay and pellets. In fact, hay stored longer than 90 days may lose as much as 90% of the b-carotene value, depending on the temperature and conditions of storage. Therefore, it is wise to be sure synthetic vitamin A has been added to the diet. Most commercial companies are now adding 4400 to 11,000 IU (International Units) per kg (2000 to 5000 IU per lb) of diet, depending on the season of the year.

Scientists at the Oregon State University Rabbit Research Center showed that excess levels of vitamin A can cause symptoms and lesions in rabbits similar to those produced by a deficiency of vitamin A. Although the levels used were quite high, it is conceivable that a mistake in adding vitamin A to the diet could cause conditions resulting from an excess of the vitamin. Liver biopsy and subsequent vitamin A analysis are required to demonstrate excessive levels of vitamin A. Checking serum vitamin A levels is not adequate to demonstrate an excess condition, because the serum levels can be normal even when excess vitamin A is present.

The treatment of vitamin A deficiency can be accomplished immediately by injecting all does, bucks, and junior replacement stock with vitamin A (11,000 IU per kg (5000 IU per lb) of body weight). It can also be accomplished by adding vitamin A to the diet; however, this is somewhat slower. If an excess vitamin A condition is found, the rabbits are generally culled, because depleting a high level of stored vitamin A in the liver takes months or years even when vitamin A and b-carotene are severely reduced in the diet.

Young doe syndrome

The term “young doe syndrome” came about because the disease seems to be more prevalent in first and second litter does, but it can occur in does of any parity (number of litters). A doe kindles a fine, healthy litter, and when the litter is 4 to 10 days of age, the doe dies. Sometimes diarrhea is observed. Sometimes it is noted that the doe is off feed for a day or two. In other cases, nothing out of the ordinary is noticed except for a dead doe.

Enterotoxemia is the major cause, but staphylococcal mastitis can also cause this syndrome. When enterotoxemia is the cause, a post-mortem examination will almost always show an inflamed cecum, with increased amounts of fluid in the upper digestive tract. Because the toxin from *Clostridia* spp. is so potent, the rabbit will die in 12 to 24 hours. If the cause is mastitis, the death may be somewhat slower. If the initial signs of being off feed and having a high temperature are missed, it will appear that a normal doe has died suddenly. The toxins from the bacteria staphyloccoci that have invaded the mammary glands pass into the blood system, overwhelm the defenses, and kill the doe. Careful observation, immediate attention, and treatment of does off feed may save them from the mastitis phase of young doe syndrome.

The enterotoxemia phase can also be prevented. It is common to restrict the feeding of does during gestation and then to put them on full feed or double feed when they have kindled. This may lead to enterotoxemia. If you are going to use restricted feeding, then a more gradual increase in the feed will completely eliminate young doe syndrome due to enterotoxemia. Gradually increasing the feed by 30 g (1 oz) a day or every other day from kindling until full feed is reached has been quite effective in eliminating this disease.

Further Reading

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11

Rabbit Reproduction

Reproduction is a complex process that requires coordination between the male and the female. The primary means of such coordination is through the nervous system and by hormones, which are substances carried in the blood from special glands to the organs upon which the hormones have their effects. The hormones may stimulate changes in the organs themselves (as in ovulation), or one hormone may stimulate a target organ to secrete a second hormone that, in turn, is carried to another organ, where it has an effect.

Because of such complexity, it is difficult to describe rabbit reproduction completely in a single chapter. The purpose of this chapter, therefore, is to provide an overview of the processes and the major hormones involved in reproduction. Special emphasis has been placed on those aspects that are of direct concern to the rabbit producer. Readers wishing more detailed information regarding this topic are directed to books that deal specifically with reproductive physiology.

The Male

Organs of reproduction

The reproductive organs of the male fall into four basic categories: the primary sex organs, accessory sex glands, ducts, and external genitalia (Fig. 11.1).

The testes are the primary organs of reproduction of the male. They produce spermatozoa (sperm) and hormones (androgens), which affect reproductive function and behavior. The paired testes are ovoid structures measuring about 35 × 15 millimeters (1.4 × 0.59 in) and weighing approximately 2 grams (0.071 oz). The testes are essentially sacs of coiled tubules within which the sperm are formed. This process, known as spermatogenesis, involves changes from a rather normal-looking spheroidal cell into the highly specialized spermatozoon, which has transmission of genetic information to the ovum as its only function. Sperm development begins in the walls of the tubules, and as the spermatozoa develop, they move toward the center, or lumen, of the tubule. Among the cells of the tubule walls are Sertoli (sustentacular) cells, which nourish the developing spermatozoa. Once the sperm reach the lumen of the tubule, they are transported through the tubule by fluid pressure. This transport takes the sperm to the top of the testis and out into the epididymis.

Androgens are produced by Leydig (interstitial) cells, which are found among the tubules. These cells are under the control of hormones from the anterior pituitary, which is located at the base of the brain. These controlling hormones regulate the levels of the

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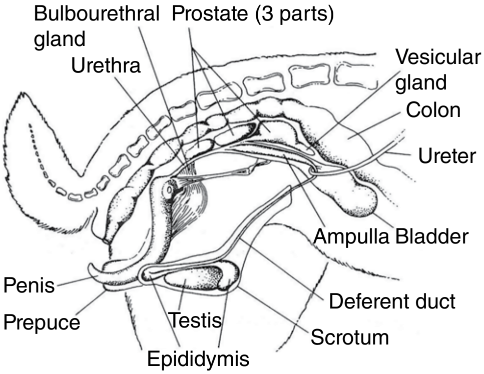


Fig. 11.1. The reproductive system of the male rabbit. (Modified from *Laboratory Anatomy of the Rabbit*. 1990. McLaughlin, C.A. and R.B. Chiasson, 3rd edn, Wm. C. Brown Publishers.)

androgens in the blood, which, in turn, control spermatogenesis and sexual activity or desire of the buck. It is the lack of androgens that makes the castrated male disinterested in females or in fighting with other bucks.

The accessory sex glands of the male include the vesicular, prostate, and bulbourethral glands. All these glands produce secretions that are added to the spermatozoa to form the ejaculated fluid known as semen. The functions of these secretions include adding fluid volume to the ejaculate to facilitate movement of semen through the male and female reproductive tracts, providing nutrients and buffers for the spermatozoa, providing a gelatinous plug to seal the female tract, and providing substances that stimulate contractions of the vagina and uterus of the female to enhance movement of spermatozoa through the tract.

The ducts through which the sperm move after leaving the testes proper include the epididymides, deferent ducts, and urethra. The epididymides lie close to the top of the testes and function as a place for maturation of the spermatozoa. Spermatozoa that have not undergone a period of maturation in the epididymides are incapable of fertilizing eggs. The epididymides also serve as a place for storage of spermatozoa; fertile spermatozoa have been recovered from epididymides after eight weeks of storage. The normal time required for movement of sperm through the epididymides is 8 to 10 days.

The deferent ducts carry the sperm from the epididymides to the urethra and also function to some extent in sperm storage. The accessory sex glands normally add their secretions to the semen at or near the junction of the deferent ducts and the urethra.

The urethra is the common passageway for semen and urine. It carries semen from the junction with the deferent ducts to the end of the penis, from which the semen is ejaculated into the vagina of the female. The bladder empties into the urethra just beyond the point of junction of the urethra and deferent ducts.

The external genitalia of the male include the penis, the scrotum, and the prepuce. The penis is an erectile organ that is used for insertion of the ejaculate into the female tract. The penis is normally flaccid and rests in the prepuce, as shown in Fig. 11.1. It becomes rigid from constriction of the penile veins at the time of breeding. Since arterial blood continues to flow into the organ, it becomes turgid and can thus penetrate the vulva and vagina of the doe. The erect penis is held forward along the abdomen. There is a sensitive tip on the penis, known as the glans penis. Stimulation of the glans penis by the vagina of the female (or by a properly prepared artificial vagina) results in ejaculation. This is due to a reflex contraction of the duct system that forces out spermatozoa stored in the deferent ducts and the last third of the epididymis. Fluids from the accessory glands are also released into the deferent ducts and the urethra at the time of ejaculation. After subsidence of erection, the penis is pulled back into the prepuce by muscular contraction.

The scrotum of the rabbit consists of two relatively hairless sacs that contain the testes. These function to protect the testes and to provide an area with a lower temperature than that of the body cavity, since spermatogenesis cannot occur at body temperature. The testes of the rabbit can move freely in and out of the abdomen and so are not always found in the scrotal sacs.

The prepuce is a fold of skin on the abdomen which protects the penis.

Spermatozoa

Spermatozoa are highly specialized cells that carry genetic information from the male through the female reproductive tract to fertilize the ova of the female. Each spermatozoon has a head that carries the genetic information and a tail that provides propulsion by its whip-like movements (Fig. 11.2). The portion of the tail nearest the head is known as the midpiece and contains organelles, such as mitochondria, which function in metabolism and provide energy for movement of the tail. Spermatozoa do not begin to swim (become motile) until they are ejaculated into the vagina of the doe, where there is a higher concentration of oxygen than in the male tract.

The testis produces 50 to 250 million sperm each day. The numbers of sperm produced may be affected by breed, age of the buck, and nutrition. Production of spermatozoa begins at puberty and is continuous throughout the reproductive life of the buck. Most unejaculated sperm degenerate in the epididymides, and the components are resorbed into the blood. Some sperm may be passed in the urine.

Reproductive activity of the buck

Bucks reach sexual maturity between four and eight months of age, depending on breed and level of nutrition. In a study of New Zealand White bucks, daily sperm output was found to increase from 20 weeks of age to a mature level at about 31 weeks of age. The normal ejaculate volume for mature bucks is 0.4 to 1.5 ml, with an average of about 0.7 ml. Sperm per ejaculate is highly variable among bucks as well as among successive ejaculates from the same buck and varies from 10 to 300 million spermatozoa per ml, with an average of around 150 million. The number of spermatozoa ejaculated depends on the breed of the buck, recent use, and level of stimulation. There is also indication that there may be short cycles of three to eight days' duration in some of the semen characteristics, such as sperm concentration. In the wild, testicular size is greatly reduced in the autumn and reaches a peak in late spring.

The number of sperm and the volume of ejaculate required for fertilization are unknown, but studies using artificial insemination have shown that sperm concentrations of less than 1 million sperm per ml can result in pregnancy. It is thus likely that most ejaculates will contain sufficient sperm for fertilization unless, as sometimes happens, an ejaculate is produced that is totally devoid of sperm (an aspermic or "dry" ejaculate). Such "dry ejaculates" can occur following repeated ejaculations. In other words, the buck's motivation to copulate has exceeded his ability to produce sperm. Thus, breeders should be careful not to use bucks excessively. Besides resulting in an infertile mating, another consequence would be to induce pseudopregnancy.

The Female

Organs of reproduction

The organs of reproduction of the female include the ovaries, oviducts, uterus, cervices, vagina, and external genitalia (Fig. 11.3).

The ovaries, the female's primary organs of reproduction, produce the eggs, or ova, and hormones (primarily estrogens and progestins). They lie within the abdominal cavity, with one on each side, near the kidneys. The ovaries are ovoid structures about 20 × 10 mm (0.79 × 0.39 in) and weigh 0.5 to 0.75 g (0.018 × 0.026 oz), depending on the activity of the ovarian components. The central portion, or medulla, of each ovary consists of connective tissue containing nerves and blood vessels. The outer layer, or cortex, contains the ova in various stages of development, as well as other types of tissue, including blood vessels, nerves, and muscle fibers. At the time of a doe's birth, thousands of undeveloped ova are contained in the germinal epithelium layer of the cortex. From the time of puberty until death or the end of the reproductive life of the female, groups of these undeveloped ova undergo development and are shed (ovulated), or they degenerate. The oviduct is the site of fertilization, functions in a maturation process of spermatozoa known as capacitation, and is the location where early embryonic development occurs (Fig. 11.3). The upper end of the oviduct is spread into the ostium tubae, which partially surrounds the ovary. On the edges of

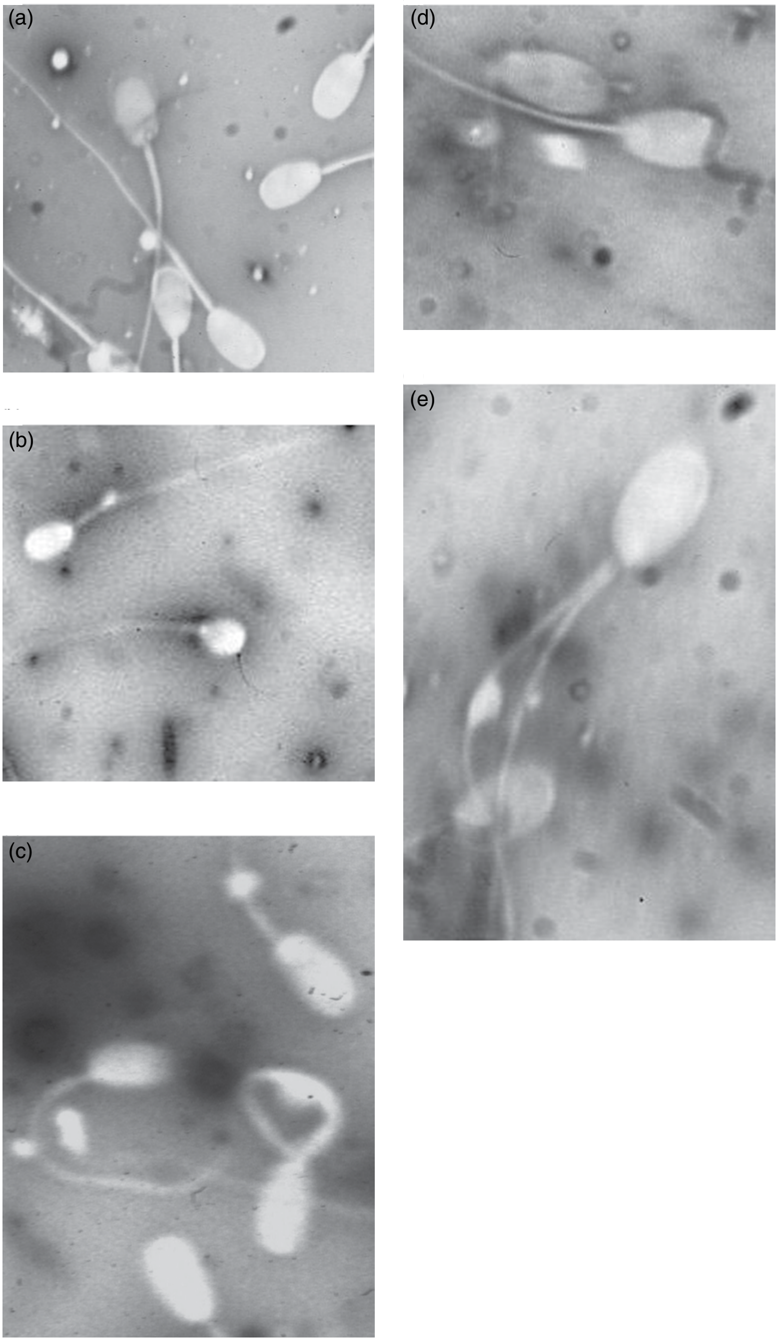


Fig. 11.2. Rabbit spermatozoa. (a) Normal rabbit spermatozoa; note the protoplasmic droplets on the tails of some sperm. The granular material in the background is normal in rabbit semen. (b) Spermatozoon with a round head. (c) Defective spermatozoon showing a coiled tail. (d) Spermatozoon with a broken midpiece. (e) Spermatozoon with a double tail. (Courtesy of J.I. McNitt)

the ostium tubae are numerous small projections known as the fimbria. These nearly cover the ovary. Beating of the fimbria causes waves of movement of fluid toward the opening of the oviduct and, at the time of ovulation, sweeps the ova into the oviduct.

The uterus is the organ in which most of the embryonic development occurs (Fig. 11.3). It also provides muscular force by contraction for the expulsion of fetuses at birth. The uterus of the rabbit is formed of two distinct horns, which do not join to form a body.

Each horn of the uterus connects into an individual cervical canal, which opens into the common vagina (Fig. 11.4a, b). The cervices function as muscular plugs to keep the uterine horns closed except at the time of mating and parturition (birth or kindling).

The vagina is the site of sperm deposition at mating and acts as a channel for the young at parturition.

The external genitalia of the doe include the urogenital sinus, which is continuous with the vagina and is the chamber into which the urethra empties urine. The external lips of the urogenital sinus form the vulva, which can be used as an indicator of sexual receptivity of the doe. A doe with a moist red or pink vulva is much more likely to accept service than a doe with a pale, dry vulva. The clitoris lies within the urogenital sinus, with the sensitive portion, the glans clitoris, projecting into the urogenital opening. Because the urethra opens into the vaginal sinus posterior to where the sperm are deposited (Fig. 11.3), urination by the doe following breeding does not necessarily interfere with fertilization.

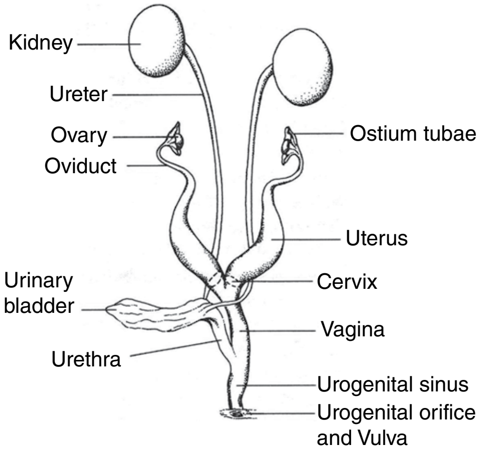


Fig. 11.3. The reproductive tract of the female rabbit. (Modified from *Laboratory Anatomy of the Rabbit*. 1990. McLaughlin, C.A. and R.B. Chiasson, 3rd edn, Wm. C. Brown Publishers.)

Estrus and ovulation

Does become receptive to bucks at about 3½ months of age and become capable of conception at 4 or 4½ months. These ages will vary with the breed of rabbit, the smaller breeds

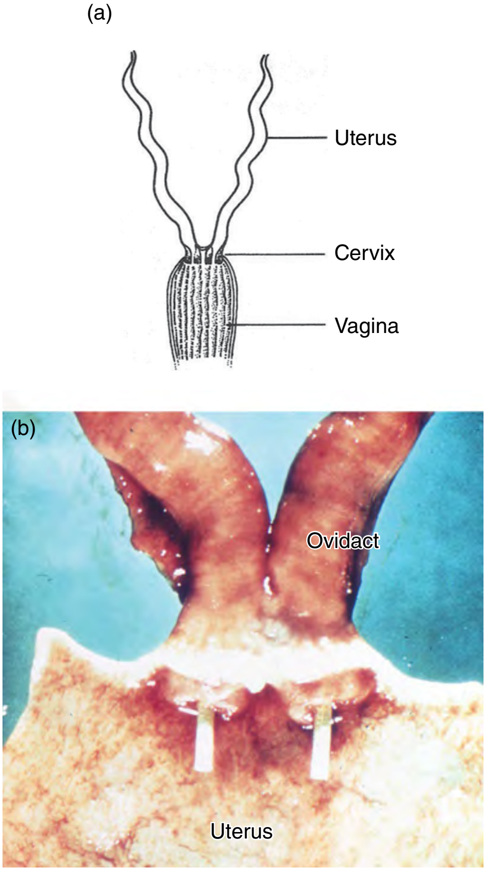


Fig. 11.4. (a) A drawing of the double cervix of the rabbit. (Courtesy of Wolters Kluwer Publishing). (b) Dissection of uterus showing dual cervical openings (with a piece of paper in each opening). (Courtesy of N.M. Patton)

generally reaching puberty earlier than the larger breeds. The level of nutrition will also affect the age of onset of reproductive function. It is generally not advisable to breed a doe during the first month that it is capable of reproduction, because it is still growing and the attainment of mature size may be prevented or delayed if the doe is also expected to produce and feed a litter at this time. However, undue delay in breeding may result in breeding difficulties if a doe becomes too fat. Also, delayed breeding may make a doe more susceptible to hairballs.

Rabbits do not have a precise estrous cycle as is found in many other animals. At the time of puberty, follicle-stimulating hormone (FSH) from the anterior pituitary gland located at the base of the brain begins inducing growth of follicles, with the corresponding development of ova within them. The ova begin development with a single layer of follicle cells surrounding them. The number of follicular cells gradually increases until numerous layers are present. As a follicle develops further, a fluid-filled cavity forms, with the ovum located in the center upon a hillock of cells. By this time, the follicle has enlarged to such an extent that it bulges from the surface of the ovary. At ovulation the outer layer of the follicle ruptures, and the ovum is expelled along with the fluid.

The follicles produce estrogens, which are the hormones that cause the female to be receptive to the male. Follicular development generally occurs in waves, with 5 to 10 follicles on each ovary at the same stage of development at any one time. Follicles continually commence development, so follicles at several stages of development are always present. When follicles reach mature size, they actively produce estrogens for about 12 to 14 days. After this period, if ovulation has not occurred, these follicles will degenerate, with a corresponding reduction in the estrogen level and receptivity. After about 4 days a new wave of follicles will begin producing estrogen, and the doe will become receptive once again. The doe thus has a cycle of 16 to 18 days, with about 12 to 14 days of receptivity and 4 days when the doe will refuse to mate. This timing is extremely variable because of individual differences, sexual stimulation, and environmental factors, such as nutrition, light, and temperature.

Ovulation in the rabbit occurs only after induction by an external stimulus, such as mating. This includes stimulation of the anterior vagina by the penis as well as pressure on the hindquarters from mounting by the buck. Intense sexual excitement or mounting of the doe by other rabbits may also induce ovulation. This may result in a condition known as pseudopregnancy. An ovulatory stimulus results in the release of luteinizing hormone (LH) from the anterior pituitary. This hormone causes rupture of a number of mature follicles on one or both ovaries approximately 10 hours after the stimulus occurs. The number of ova shed from each ovary is one factor that determines the litter size. Other factors include the number of shed ova that are fertilized by the sperm and the number of fertilized eggs that go through the entire intrauterine development process. For clarity, the remainder of this discussion refers to a single ovum and its development, but it should be borne in mind that similar processes are simultaneously occurring with up to 20 other ova.

When the ovum has been shed from the ovary, LH stimulates changes in the follicular cells that rapidly develop into a corpus luteum (yellow body), which produces hormones known as progestins. These are necessary throughout pregnancy for the development of the embryo, which becomes a fetus. The primary action of the progestins is to stop muscular contractions of the uterus and to stimulate the production of nutrients for the embryo and fetus.

The corpus luteum begins actively secreting within three days after ovulation and continues throughout pregnancy. The hormone output increases until about the 15th day of pregnancy and remains at a high level until the last week, when the hormone level begins to fall. The progestins control uterine function, especially inhibition of muscular activity so that the embryo and fetus can remain in the uterus and be nourished throughout pregnancy. The progestins also inhibit sexual receptivity in the pregnant female, although follicles continue to develop and produce some estrogen throughout pregnancy. It has been shown that the estrogen is required for the corpus luteum to continue secreting progestins. Since follicles are present at the end of pregnancy, the doe is sexually receptive and capable of ovulation immediately after parturition.

Pseudopregnancy

If ovulation does not result in pregnancy, either because of lack of fertilization by the spermatozoa or because of an abnormal stimulus, such as mounting by other does or excitement, the doe may become pseudopregnant. In this condition a corpus luteum is formed, with the subsequent production of progestins. The doe may not be receptive during the period of pseudopregnancy, which lasts 16 to 18 days. If mating does occur during pseudopregnancy, it often is not fertile, since the hormones of the corpus luteum interfere with capacitation of the sperm and movement of the spermatozoa through the female tract. At the end of pseudopregnancy, the doe may engage in behavior normally seen at or near kindling, such as nest building and lactation.

Fertilization, implantation, and pregnancy

At the time of mating the buck deposits several million spermatozoa in the vagina of the doe. These move by contractions of the female tract and by swimming to the middle portion of the oviduct, where fertilization occurs. The first sperm are found in the oviduct within 15 to 20 minutes of mating, although the majority are not found there for several hours. Of the millions deposited into the vagina, only a few thousand actually reach the site of fertilization.

Before the sperm are capable of fertilizing the egg, they must undergo a series of changes known as capacitation. These changes require approximately 6 hours. Since ovulation occurs 10 hours after mating and the ova remain viable for only 6 to 8 hours, it can be seen that at the time the freshly ovulated ova move into the oviduct, the sperm are just reaching a stage when fertilization can occur. This is important, as it has been shown that as the sperm or ova age, the proportion of ova that are fertilized declines and the proportion of abnormal embryos increases.

When the ova are released from the follicle, they are swept into the oviduct and move to the middle third of the oviduct, where fertilization occurs. This movement generally takes less than 10 minutes. Fertilization refers to the entry of a spermatozoon into the egg and fusion of the genetic material of the male and the female (syngamy). Once one sperm has entered the ovum, changes occur in the egg membrane that function to prevent entry of additional sperm. Cellular division and development of the embryo begin almost immediately after syngamy. The developing embryo remains in the oviduct until the 8- or 16-cell stage is reached.

This takes 72 hours, after which the embryo migrates to the uterus, where it floats in the uterine fluid and is nourished by it. During this period, nutrients enter the embryo by diffusion through the cell membranes. After seven days the embryo becomes too large to be properly nourished solely by diffusion, so it becomes attached to the wall of the uterus, and the placenta (afterbirth) begins to form. This process is known as implantation. The placenta provides protection for the embryo and a close connection between the embryonic and maternal circulatory systems. There is no direct connection between these two systems, although the two blood supplies pass very close to each other in their respective vessels. In this fashion, oxygen and nutrients can diffuse through the vessel walls from the doe to the young, and the wastes from the young can diffuse out to the circulatory system of the doe. Transport of oxygen and nutrients within the embryo is carried out by the embryonic circulatory system.

Because the doe has two entirely separate uterine horns and two cervical openings, there is no opportunity for movement of embryos from one horn to the other. Such movement is often seen in litter-bearing species such as the pig, in which there is a common body of the uterus and a single cervix, allowing balancing of the numbers of embryos in the two horns. No such balancing is possible in the rabbit, so the embryos in one horn result from fertilization of ova shed from the ovary on that side only.

Pregnancy in rabbits lasts an average of 31 to 32 days but may be as short as 29 days or as long as 35 days. The longer gestation periods are generally seen when there are only a few young in the litter (see Fig. 5.6). These young are usually heavier at birth (as high as

90 g or 3.2 oz) than those from larger litters that are carried for a shorter period of time.

Embryonic growth is not constant. At day 16 of pregnancy, the embryos of New Zealand White does average 0.5 to 1 g; at day 20, about 5 g; and at birth, about 60 g (2.1 oz). Birth weights vary from 25 to 90 g (0.88 to 3.2 oz), depending on the age and breed of the doe and the number of young in the litter.

Parturition and maternal care

During the last week of pregnancy, the corpus luteum secretes prostaglandin F_{2a}, which destroys the corpus luteum and markedly reduces progestin secretion. There is also an increase in the hormone prolactin, which stimulates the behavior known as nest building. Nest building is seen a few days before parturition and involves building a “material nest” of hay, straw, or whatever nest material is provided. In the day or so prior to kindling, there is a loosening of the hair on the belly, thighs, and dewlap. The doe pulls this hair (see Fig. 5.11) and interweaves it with the material nest to form the “maternal nest” (see Fig. 4.17). The quality of the maternal nest and the time at which the nest building occurs depend on the breed of the doe, her previous experience (the quality of the nest tends to improve with successive litters), the nesting material available, and the season of the year.

Parturition occurs in response to a decrease in the progestin levels (which maintain the uterine muscles in a quiet state during pregnancy), an increase in estrogen and prostaglandin $F_{2\alpha}$ levels, and the sudden release of the hormone oxytocin from the posterior pituitary. The exact stimulus for this release is not known. Oxytocin, estrogen, and prostaglandin $F_{2\alpha}$ stimulate contractions of the uterine musculature, which force out the kits. Reflex contractions of the abdominal musculature also assist in the birth process.

Parturition in the rabbit can occur at any time, taking about 30 minutes, with individual kits born at intervals of 1 to 5 minutes. The doe crouches in the nest and licks each of the young as it is delivered. This dries the kits, removes blood and tissue debris, and stimulates breathing and blood circulation. The firstborn kits generally begin nursing before the rest of the litter is born. This may assist in the birth process, since the suckling stimulus will result in the further release of oxytocin. The entire litter is generally delivered at one time, although it is sometimes spread over one to two days. Occasionally a single fetus will be delivered a day or more before the remainder of the litter. The kits are hairless (Fig. 11.5), blind, and deaf at birth. In rare cases, the litter is delivered three or four days before milk production begins. These kits often die of starvation because the doe cannot feed them. The cause for this behavior is unknown.

When parturition is complete, the doe eats the placenta and dead kits. This is common behavior among animals, even non-carnivores like the rabbit. Since the waste material may attract predators or act as a medium for the growth of bacteria, such behavior increases the chances of survival of the young.

The number of young in the litter and their total and individual weights depend on the breed of the doe, her nutritional status, her age, and her environment. The small breeds, such as the Polish, generally produce four or

Fig. 11.5. Newborn rabbits. (Courtesy of N.M. Patton)

fewer young, whereas the larger breeds, such as the New Zealand White, the Californian, and the Flemish Giant may average 8 to 10 kits in each litter. Litters of up to 18 kits are occasionally seen. Poor nutrition may result in the production of small, weak, or dead kits or may result in resorption of the entire litter. Similarly, overly fat does may not carry their litters through the entire gestation period. First litters are generally smaller than second and subsequent litters. After the seventh or eighth litter, size again declines.

Some does, especially those that are young or exceptionally nervous or those that are disturbed during kindling, may give birth outside the nest (scattering) or may eat some or all of the young (cannibalism). The causes of these abnormal behaviors are not known, although they are most often seen with does that build poor nests. A doe that persists in either behavior for several successive litters should be culled. Scattering of the litter often results in loss of the kits because rabbits, unlike other species such as cats, do not return kits to the nest.

The doe normally nurses the litter only once each day for about four or five minutes, usually at about the same time each day. This normal once-a-day nursing is critically dependent on a minimal amount of suckling stimulation, especially if there are at least six kits in the litter. Sometimes a doe with less than six kits will tend to jump into the nest box several times a day, which puts the litter at risk of injury. Cross-fostering can largely prevent this problem. Prior to her arrival for nursing, the kits move to the top of the nest material to facilitate reaching the nipples. The kits change nipples very frequently during the early part of suckling, remain relatively quiet through the middle of the period, and then begin moving rapidly toward the end. Despite being blind, the kits can rapidly locate the doe's nipple and suckle due to their perception of a chemical cue ("mammary pheromone") that the doe emits from glands found in the skin of her belly region.

At the end of suckling, the doe deposits several fecal pellets in the nest box and abruptly leaves. This is independent of whether the kits are still nursing. The kits are stimulated to urinate by wet or cold, so because of the dampness from nursing, they all urinate. They then begin a pattern of behavior that includes digging through the nest material for 15 to 30 minutes. This serves to fluff and dry the nest. After this, the kits form into a group and remain quiet for about 22 hours when they again move to the top of the nest material to await the doe.

Contrary to popular belief, the doe does little to maintain the nest or the kits. She may lick one or more of the kits during suckling, but this appears to be for recognition rather than for stimulation of urination and defecation as previously thought. There is no evidence that the doe needs to lick the kits for stimulation of either of these functions.

The doe may sit in the nest at times other than when she is nursing, but she pays little attention to the kits. This very often is because the doe has sore hocks or is sick. In fact, does often seem oblivious to the squeals of young upon which they happen to be standing. Some does may be defensive about their young and jump into the nest if the kits are disturbed. This may cause injury to the kits and should be avoided or prevented if possible. More aggressive does may stomp when upset or may attack by biting or scratching.

Lactation

The growth of the young during the suckling period, especially during the first three weeks, greatly affects their later performance. For this reason, lactation can be considered as much a part of the reproductive process as ovulation, pregnancy, or parturition.

The mammary glands of the doe generally consist of eight physiologically distinct sections, four along each side of the abdomen (Fig. 11.6). The number may vary from 6 to 12. The glandular tissue of the rabbit is similar to that of other species and consists of hollow, ball-shaped structures known as alveoli, where the milk is actually formed. The milk moves from the alveoli through a series of ducts to the gland and teat cisterns. The teat itself is the external opening of the gland and consists of the external protuberance (nipple), with five to eight central canals through which the milk flows during suckling. The mammary gland also contains blood and nerve supplies and variable amounts of fat.

Milk is formed in the alveoli by direct diffusion of constituents from the blood, by modification of substances from the blood, and by synthesis within the cells of the alveoli using materials that diffuse into the cells from the blood. Milk formation is a continuous process. As the milk is formed, it is stored in the alveoli and upper parts of the duct system until a suckling stimulus causes let-down of the milk and it enters the lower duct system.

The mammary glands of the doe begin forming when it is still an embryo. After birth, development stops until puberty, when increased levels of estrogen result in partial development of the duct system. The elevated progestin levels of pregnancy stimulate development of the alveoli. Prolactin release at the time of parturition initiates milk production. Stimulation by this hormone is responsible for continued milk production during the lactation period.

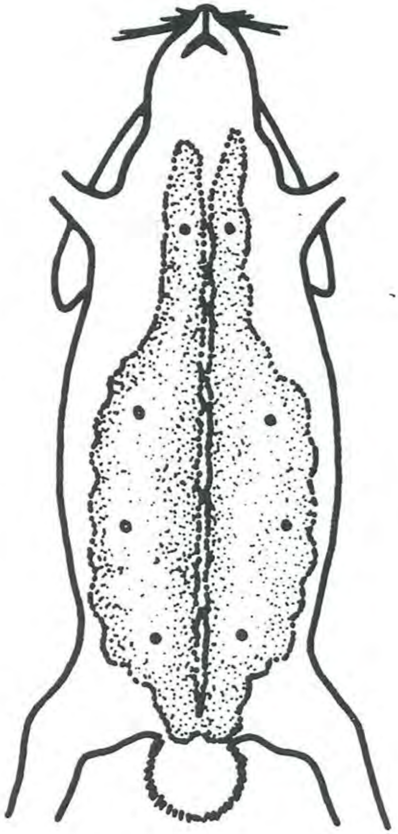


Fig. 11.6. Mammary tissue of the rabbit. Shading indicates mammary tissue and dots the nipples. (Courtesy of Walters Kluwer Publishing)

Although milk production is a continuous process, the milk is unavailable to the young until a stimulus causes the release of oxytocin. This hormone causes the contraction of the muscles around the alveoli and forces the milk down the duct system to the gland and teat cisterns. Suckling by the young forces the milk past the teat sphincter and into their mouths.

The quantity and composition of the milk produced by the doe vary throughout lactation, as shown in Table 11.1. The quantity of milk produced increases until the end of the third week of lactation and declines thereafter. At that point the kits generally start eating solid food, and the milk of the doe becomes less important to the performance of the young.

The first milk produced by the doe after giving birth is known as colostrum. As shown in Table 11.1, this first milk has more fat and lactose and less ash than later milk. Calcium and phosphorus levels are also lower, and the vitamin A activity is higher. In other species, such as the cow, sheep, horse, pig, and goat, there is a substantial increase in protein content as well. This is because of the high levels of antibodies (proteins that confer resistance to disease). These are transferred in the milk from the mother to the offspring to provide protection from disease until the young can manufacture their own antibodies. In the rabbit, the

Table 11.1. Approximate quantity and composition of milk produced at various stages of lactation in Fauve de Bourgogne does.

	Days after birth				
	1	7	14	21	24
Milk yield (g/day)	50	160	220	240	220
(oz)	1.8	5.6	7.7	8.5	7.7
Water (%)	69	74	74	73	67
Protein (%)	14	14	13	13	16
Fat (%)	15	9	9	10	14
Lactose (%)	1.6	0.9	1.0	0.9	0.8
Ash (%)	1.6	2.1	2.2	2.4	2.6

Source for quantity data: Lebas, F. 1968. *Annales de Zootechnie* 17: 169–182.

Source for composition data: Lebas, F. 1971. *Annales de Zootechnie* 20: 185–191.

maternal antibodies are transferred to the fetus during pregnancy. During the second half of the gestation period of the rabbit, maternal antibodies are absorbed by the fetal membranes for transfer to the developing fetuses. These antibodies function for the first few weeks of life. In addition, during nursing does often leave a few fecal pellets in the nest. Kits have been seen to nibble on these and it is thought that this may also provide them with antibodies. This is known as passive immunity. As they age, the young rabbits are capable of making their own antibodies (active immunity).

Colostrum is produced for two or three days, after which there is a decrease in the fat and lactose content. After day 21, the composition changes again with a decrease in the water and lactose (milk sugar) contents and an increase in the contents of protein, fat, and ash (which represents the mineral matter, such as calcium). Table 11.2 is a compilation of approximate milk composition figures for various species and has been included for comparison purposes. Among the listed species, the rabbit has milk that is higher in fat than the milk of the others except the rat. The rabbit's milk also exceeds that of all the other listed species in the level of ash and protein. The lactose level is lower. The milk of the rat is, in many respects, similar to that of the rabbit, although rat milk has a much higher level of fat.

A typical lactation curve is shown in Fig. 11.7. The shape of the curve is influenced by the breed-back schedule. With a short breed-back, the decline occurs sooner and more rapidly than with longer breed-back schedules. As the litter gets older, the amount of prolactin declines, so there is a decline in the amount of milk produced. When the litter is weaned, there will be no suckling stimulus and the alveoli will fill with milk. Filling of the alveoli inhibits milk formation.

Table 11.2. Approximate milk composition of various species.

	%Composition				
	Water	Protein	Fat	Lactose	Ash
Rabbit	74	13	9	1	2.2
Cow	88	3	4	5	0.8
Goat	87	4	4	5	0.8
Human	87	2	4	7	0.3
Cat	82	9	3	5	0.5
Rat	68	12	15	3	1.5

Data compiled from various sources by J.I. McNitt.

Artificial Insemination

Artificial insemination (AI) of rabbits can be a useful technique in large operations. The primary advantages are two-fold: first, a large number of does can be bred at one time regardless of their receptivity to the buck, and second, genetic progress can be accelerated due to using only superior sires. This eliminates the time required for checking each doe; provides large batches of kits of uniform age; and allows an all-in, all-out system of management in which does are put into a building where they all kindle within a two- or three-day period. The litters are all weaned the same day, and the does are moved to another house. The fryers are then grown out and all marketed together. While the house is empty it can be cleaned and disinfected before a new batch of does is brought in. Artificial insemination also allows more extensive use of each buck, which reduces the feed and cage requirements.

Artificial insemination is not a solution to breeding difficulties and will not raise fertility in a rabbitry where such problems exist. Skill is

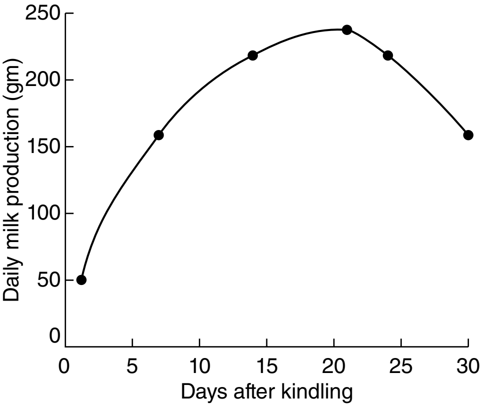


Fig. 11.7. Milk production of does during the first 30 days of lactation. (Courtesy of OSU Rabbit Research Center)

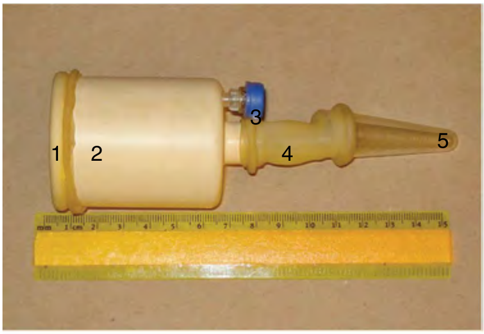
required, some equipment will need to be purchased, and strict hygienic practices must be followed to prevent spread of disease. Furthermore, an ovulatory drug must be given to each doe to induce ovulation. This will cost at least 25 cents per doe (and probably more) and must be obtained and used under veterinary supervision.

The following brief description of the process is meant to provide background information. Anyone considering the use of AI in a rabbitry should carefully study all the literature available and discuss the process with growers who are using it or have used it before making any investment.

Semen is first collected from the bucks by using an artificial vagina (AV) (Fig. 11.8). It may be purchased ready to use or be constructed from available materials. It consists of a stiff outer liner, such as a section of 2.5 cm (1 in) car radiator hose or PVC pipe. The inner liner should be flexible rubber or plastic tubing, such as that used in hospitals after surgery to provide drainage from large incisions. This inner liner is folded back over the outer liner on both ends, and the cavity between is filled with air and warm water. The collection tube can be attached to the AV by means of a collection cone, as shown in Fig. 11.8, or connected directly to the AV. The collection cone can be of any rubber material that will fit tightly over the collection tube at one end and the outer liner at the other. Fingers cut from disposable surgical gloves are ideal for this purpose. If necessary, rubber bands can be placed over these junctions to hold them together. If rubber bands are used, they must be counted when placed on the AV and again when they are removed. If any are missing, check the buck's penis to ensure that a band hasn't slipped off and constricted it. If this happens and the band is not removed, the buck may have to be euthanized. The collection tube can be any small vial that will hold at least 5 milliliters of ejaculate (metric units are used in AI). The bottom cut off a plastic graduated centrifuge tube works well for this.

Semen collection can be accomplished using a doe (Fig. 11.9) or a rabbit skin. The former is often necessary when training a new buck to the use of an AV. The AV, lubricated with a small amount of water-soluble lubricant, such as K-Y jelly, and inflated with air and water at the suitable temperature, is held under the doe. The index finger can also be used to hold the doe's tail down. When the buck mounts and makes copulatory thrusts, the AV is directed onto the penis. If the temperature, texture, and pressure are correct, this will induce ejaculation.

Once an ejaculate has been collected, it should be evaluated to determine the total number of spermatozoa, the proportion that are alive and motile (moving), and the proportion that are morphologically normal. The concentration of spermatozoa is determined using a hemocytometer, which is a special microscope slide made for counting concentrations of blood cells. The proportions of live and motile spermatozoa can be estimated by placing a



1. Inner liner 3. Air and warm water injection port
2. Outer liner 4. Rubber tubing 5. Collection tube

Fig. 11.8. An artificial vagina for use with rabbits. (Courtesy of J.I. McNitt)

Fig. 11.9. Semen collection from the buck; the technician is holding the AV near the doe's vulva. (Courtesy of D.J. Harris)

drop of semen on a microscope slide. A drop of extender (2.9% sodium citrate or 0.9% saline) is mixed with the semen, and a cover slip placed on top. When the slide is viewed under a microscope at 400× magnification, individual spermatozoa can be seen. Moving the slide around to observe a number of fields will permit an estimate of the proportion actively swimming. To study the morphology of the spermatozoa, a smear of semen mixed with eosin-nigrosin stain should be made on a slide. When this dries, the spermatozoa can be individually observed under an oil immersion lens (1000× magnification).

From the time of collection until the semen is used for insemination or cooled for storage, the ejaculate and all glassware, solutions, and equipment with which it comes into contact must be maintained at 37°C (99°F). This is necessary to prevent cold shocking the spermatozoa, thereby reducing the conception rate. A number of solutions may be used to dilute and extend the ejaculate, but 2.9% sodium citrate and 0.9% saline are the simplest and cheapest to make up, and they each work as well as others as long as the semen is used within a few days.

One million or fewer spermatozoa are required to breed a doe, but it is usually recommended that 10 to 20 million be used. Depending on your technique, the volume of material that is inseminated may be from 0.2 to 1.0 ml. The total volume of extended semen that can be made up from the ejaculate is determined by the following equation. For example, suppose the total number of sperm in a 0.5-ml ejaculate is 100 million, motility is 65%, and 10 million spermatozoa are to be included in each 0.4 ml insemination (insem.) aliquot. The total volume needed would then be:

$$((\text{Total sperm}/\text{sperm per insem.}) \times (\text{Motility}/100)) \times \text{Vol. per insem.} = \text{Total Volume}$$

$$((100\ \text{million}/10\ \text{million}) \times (65/100)) \times 0.4 = 2.6\ \text{ml}$$

Since the ejaculate volume was 0.5 ml, the amount of extender to be added is 2.6 − 0.5 = 2.1 ml. This will allow breeding six does (2.6/0.4 = 6.5) from the one ejaculate. If greater extension rates are used, even more does can be serviced from each ejaculate.

After the semen has been extended, it will remain viable for several hours at room temperature or, if refrigerated at 5°C (40°F), will be usable for two or three days. Before the extended ejaculate is placed in the refrigerator, it should be allowed to cool slowly to room temperature. When using semen that has been stored for any length of time, it is advisable first to make a microscopic check to ensure that the sperm are still viable.

For insemination, the doe is held on her back (Fig. 11.10), and the insemination pipette is gently inserted into the vagina so the tip is just outside the cervical openings, where the semen is deposited. Since the doe is an induced ovulator, a drug must then be given to induce ovulation so fertilization can occur once the spermatozoa have moved into the oviduct and undergone capacitation. Early attempts at AI used human chorionic gonadotropin (hCG),

Fig. 11.10. The position of the doe for artificial insemination. (Courtesy of OSU Rabbit Research Center)

a natural form of luteinizing hormone (LH), but this was not suitable for commercial use because does developed antibodies to the large drug molecule, which rendered the does sterile after two or three treatments. Furthermore, hCG had to be administered into the ear vein. It has since been discovered that the release of LH is under the control of another hormone called gonadotropin-releasing hormone (GnRH). This is a relatively simple compound with molecules 100 times smaller than those of the gonadotropins. Because they are smaller, they do not induce antibody formation. Furthermore, they can be simply administered intramuscularly, and synthetic forms can be made. Two synthetic GnRH compounds used in rabbit AI are Lutal and Receptal, which are available in Europe and in other countries. However, they are not available for use with rabbits in the United States because they have not received Food and Drug Administration approval. There are GnRH compounds now available in the United States, however, that are used for the treatment of ovarian cysts in dairy cattle. Some will induce ovulation in rabbits but must be used under veterinary supervision. New methods have been developed that consist of including the “ovulation-inducing” agents within the semen itself.

Careful use of AI in large herds is technologically feasible and will allow service of 100 or more does in a single day, with a 70 or 80% conception rate. This will result in the production of 70 or more litters within a two-day period – a potential of 500 to 700 or more fryers of the same age. The technique of AI requires skill, attention to detail, an initial investment, and a serious commitment on the part of a grower but may result in significant savings in time and money as well as more rapid genetic improvement.

Artificial insemination is widely used in large herds in Europe. This allows organizing herds into groups in a program known as cycled production. Under this system, each doe in a group is bred on the same day every five to six weeks. At the time of AI, does are injected with equine chorionic gondaotropin (eCG) (formerly known as pregnant mare serum gonadotrophin; PMSG), which is a natural form of the hormone FSH. This increases the number of ova released and increases litter size. This treatment, however, also may lead to ineffectiveness due to the formation of antibodies. Because of increasing emphasis by animal welfare groups on “natural” production methods and reduction of hormone use, there is increasing interest in the use of biostimulation methods to get the same effects. These programs may include manipulating lighting regimes, limiting access of the lactating doe to the litter, or manipulating the doe by changing cages, putting several does together, or providing other natural stresses.

In commercial operations, does produce about eight litters annually. Hence, for most of the time, does are concurrently pregnant and lactating, which may adversely affect fertility. One popular biostimulation method is to separate the litter for one day between 9 to 12 days of age. After the return of the litter and nursing, the doe can be immediately rebred either naturally or artificially. However, there may be certain long-term consequences pertaining to the kits when used later for reproduction. Bucks may have a higher incidence of mounts but without ejaculation and both bucks and does may have higher response levels to stress (increased corticosteroid secretions).

Winter Breeding Depression

The syndrome of “winter breeding depression” has been alluded to in the discussions on feeding, temperature, and lighting. A more detailed discussion of this syndrome is warranted, as it seems to be a universal problem in rabbitries in areas where there are marked changes in the environment from one season to another. The typical syndrome as seen by the rabbit raiser is as follows. First, it is noted that does won’t breed. The bucks are willing, but the does are non-receptive. The vulvas are pale and dry, and the does will not accept service. Then the raiser begins to notice that, when breeding does occur, the does abort or resorb the litters, or the litters are very small (three or four kits), or the kits are born dead or weak. When a weak litter is born, the doe sits in the nest box with full mammary glands but the young are too weak to nurse and die within two to three days.

Wild rabbits are seasonal breeders, with the highest activity occurring in the spring and early summer and none during the late fall and winter. Although rabbits have been domesticated for hundreds of years, there appear to be persistent seasonal rhythms in reproduction and other physiological phenomena. Rabbits kept in an environmentally controlled building with a constant temperature of 19°C (66°F), 60% relative humidity, and 14 hours of light each day, still showed strong seasonal trends in body temperatures over the course of a 3½ year study, as shown in Fig. 11.11. The highest values occurred during the late autumn and early winter. Does housed outdoors have highest concentrations of LH in the blood in the winter and lowest in the fall (Fig. 11.11). The decline in LH levels through the summer and fall is related to a decrease in the growth and maturation of follicles, resulting in a seasonal decline in receptivity and conception.

Although there is basic physiological evidence for the existence of winter breeding depression, and many growers are sure they observe it, research using large numbers of animals over long periods of time has failed to provide unequivocal evidence that this phenomenon exists. Until such information is obtained, it is difficult, if not impossible, to design studies that will test methods to keep rabbits in full production throughout the year. The cause of the lack of consistency in research results is that "season" is a complex of factors, including light, temperature, humidity, winds, feed, and management, that not only have individual effects, but also may interact to have combined effects. To further complicate the problem, "reproductive efficiency" is also complex and includes aspects of doe receptivity, buck fertility, ovulation rate, conception rate, implantation rate, resorption rate, litter size and number born, litter size and number born alive, and litter survival. There is also the problem that the effects of a particular environmental stressor may not be seen for one or several months after the stress is applied. Until research results are available that indicate the exact causes of seasonal variations, growers are forced to utilize those management systems that work best in their rabbitries to overcome these persistent seasonal effects.

One of the most important factors in overcoming winter breeding depression is to ensure that the quality and quantity of feed are adequate. With the advent of high-fiber feeds (with consequently lower energy levels) and the use of restricted feeding, does often do not get sufficient energy to keep warm and to maintain reproduction during periods of cold. Even when full feeding is practiced with low-energy feeds, the rabbit's stomach may not have the capacity to hold the amount of feed necessary to meet its energy requirements. Providing feed *ad libitum* or changing to a feed with a higher energy level may bring dramatic results, with the does back in normal production within a few weeks.

The provision of a longer lighting cycle may also help overcome the breeding decline.

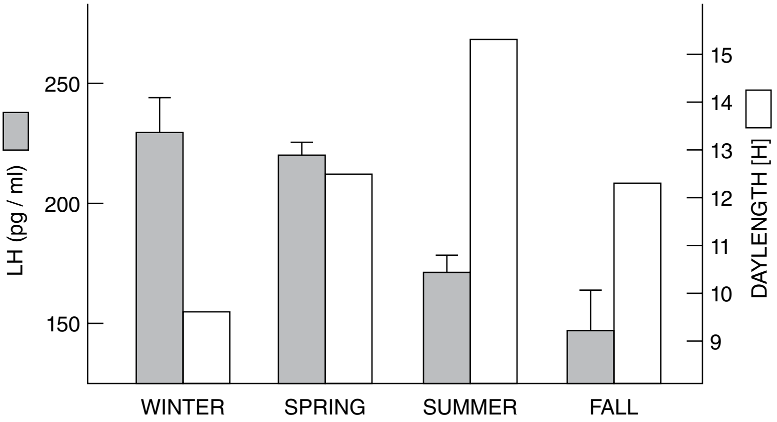


Fig. 11.11. Seasonal changes in blood luteinizing hormone levels in does. (Courtesy of Bahr, J.M. and O.K. Dial. 1982. Effect of day length on reproductive hormones in the domestic rabbit. *J. Appl. Rabbit Res.* 5: 6–7)

The current recommendation is to provide 16 hours of light each day or to use a lighting period as long as the longest day in your region.

Embryo Transfer

Embryo transfer (ET) is a technique in which embryos from a donor animal are flushed from the reproductive tract and introduced into a recipient animal to grow to term. This procedure has been extensively used in the cattle industry. Highly productive (and expensive) cows are stimulated with hormones to produce numerous ova (superovulated) and then bred by AI to a superior bull. The fertilized ova are removed and inserted into other cows of lesser genetic quality where they mature and produce superior calves. The advantage of this procedure is that numerous calves, instead of just one, can be produced from one genetically superior or elite cow each year. There are potential applications of this technique in rabbit production. Embryos from genetically superior does can be collected and introduced into recipient animals as a means of rapidly increasing the numbers of high-quality stock.

In rabbits, embryo transfer is a surgical procedure, with collection from the donor and transfer to the recipients performed at the oviductal or uterine sites (see Fig. 11.3). Less trauma and more efficient embryo recovery occur, and smaller volumes of medium are used for flushing when the oviduct rather than the uterus is used. The does are anesthetized, and a ventral midline laparotomy is performed. Embryos are collected from the oviduct by retrograde flushing (flushing back up the oviduct) from the uterotubal junction. Embryos are collected in flushing dishes and, prior to transfer, are evaluated with a dissecting microscope to eliminate abnormal ova. The rabbit embryo is unusual in that it has an extra-cellular mucin coat in addition to the zona pellucida, the latter of which is the usual covering in other species. This mucin coat is a mucopolysaccharide layer secreted around the zona pellucida by the oviduct epithelium. This thick coat is an impediment to microdissection work with rabbit embryos.

To ensure successful embryo transfer, the recipient doe should be in a similar reproductive phase to the donor animal. This is done by sham-mating the recipient to a vasectomized buck or injecting with LH or hCG at the time the donor is mated, to cause ovulation. The embryos are inserted into the oviducts of the recipient does with a micropipette. Following the transfer, both donor and recipients should be watched closely for several days to ensure that the animals do not tear the sutures or incisions and to observe for signs of infection.

Cloning

A relatively new genetic innovation is the ability by scientists to produce clones (Fig. 11.12). Basically, a clone is a "carbon copy", genetically speaking, of the same animal. The first successfully cloned mammal was a sheep named Dolly who was produced by Dr Ian

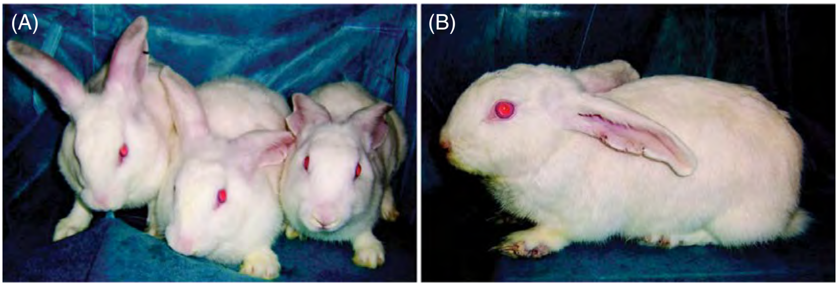


Fig. 11.12. (A) Three cloned rabbits and (B) the donor rabbit. (Courtesy of Li S., X. Chen, Z. Fang, J. Shi, and H.Z. Sheng. 2006. Rabbits generated from fibroblasts through nuclear transfer. *Reproduction* 131(6): 1085–1090. doi: 10.1530/rep.1.01065. PMID: 16735547)

Wilmut and his team at the Roslin Institute in Scotland. Dolly lived to seven years of age, but eventually died of progressive lung disease that was suspected to be due to imperfections associated with the cloning technique. Since then, cloning has become a fairly common practice in the animal industry, although the cost is exorbitant. Perhaps in the near future the cost of producing cloned animals will become more affordable.

The technique of cloning is complicated and involves many critical steps. Cloning involves the transfer of the nucleus containing genetic material from one cell of an animal (a process called nuclear transfer) to an egg (oocyte) from a different animal in which the nucleus has previously been removed. The cloned cell is then incubated and later, as an embryo, is transferred to a host animal, much like the routine method of embryo transfer.

In summary, artificial insemination, embryo transfer and cloning in rabbits should be considered only with high-quality superior breeding stock: either highly productive commercial (meat, Rex fur, or Angora wool) animals or prize-winning show rabbits. However, a general concern among geneticists worldwide is that greatly limiting the number of breeding animals in a breed or population could lead to the substantial loss of genetic variation, which is the key to future genetic progress. This effect would further result in increased levels of inbreeding, which generally would reduce performance.

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12

Rabbit Behavior

The study of the behavior of domestic animals is a rapidly developing aspect of animal science. There are several reasons why interest in this field is burgeoning. Perhaps of greatest importance is the increased emphasis on raising livestock in confinement, necessitating a scientific knowledge of the animals' normal behavioral patterns so that production facilities and management can be designed to maximize both the comfort of the animals and the income generated from them. The aim of such an understanding is for humans to provide good animal welfare conditions and proper management.

The development of confinement livestock production systems has been encouraged by economic considerations. It is often more economically efficient and profitable to raise animals in a small area and to harvest their feed mechanically than to allow free-ranging conditions. In the United States, farmland has become very costly, making it prohibitively expensive to raise animals such as pigs and chickens on pasture, as was formerly done. The relatively low cost of human food in the United States is due to the continual intensification of agricultural production techniques. A return to less intensive agriculture would increase the cost of food to the consumer.

The development of scientific knowledge of animal behavior is a necessary component of good husbandry and is not just a defense against animal activist groups. A thorough knowledge of normal behavioral patterns and of what is and is not stressful can lead to increased efficiency in animal production and handling. As an example, it has been found that cattle can be handled with much less stress and excitement if chutes are curved and solid-sided rather than straight and open-sided. This type of animal-handling facility puts much less stress on both the cattle and the handlers than old-style corrals, and yet, to the uninformed, it might appear that it is less humane to the animals. Perhaps similar improvements in rabbit handling, if indeed they are needed, could be developed.

Ethology: the Science of Behavior

Ethology is the scientific study of animal behavior. Ethology as a science is an attempt to understand the biological, rather than the psychological, basis of behavior. Behavior is the response of animals to internal or external stimuli. Ethologists consider behavior an aspect of the animal's phenotype (P), and they recognize that behavior is influenced by hereditary (H) and environmental factors (E) acting in synchrony. Thus, for a given behavior:

$$P = H + E$$

For some behaviors, H is much greater in importance than E. In some cases, it is appropriate to call these instinctive behaviors. Insects exhibit many behaviors that are instinctive.

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Much of their behavior is determined almost completely by their genes. Environmental factors, such as learning and experience at performing a given behavior, are generally less important in the insect world than they are as an influence on rabbit behavior. For an individual animal, the hereditary component (H) is fixed at the time of conception and cannot be changed by the husbandry specialist. However, this person can greatly influence the behavior of individuals through control of the environment of their animals. Nutrition, housing, animal mixing, weaning age, and all other aspects of management can influence phenotypic behavior (P) because they are part of the environment (E). A knowledge of the behavioral patterns of animals can be very helpful in developing facilities and systems of management that mesh with the animals' normal behavioral patterns and thereby minimize stress. The results not only improve the quality of life of domestic animals but also increase their productivity. It is probably true that a contented animal is also a productive one, whereas an animal under considerable stress is likely to be less productive, particularly with respect to reproduction. To assess whether current management systems are humane and, if not, what changes need to be made, it is necessary to understand animal behavior and what constitutes stress. An objective or measurable means of assessing stress levels of animals is needed. Stress levels are frequently judged by the measurable levels of circulating stress hormones such as cortisol and norepinephrine.

A basic tenet of animal behavioral research is that the study of wild animals provides clues to the normal behavior of domestic members of that species. The behavior of wild rabbits might yield information useful in establishing optimal methods of raising domestic rabbits. Enthusiasm for this approach should be tempered by considering that the rabbit was domesticated 500 to 2000 years ago and has been subjected to both artificial and natural selection ever since. Thus, what is optimal for a European wild rabbit might not be optimal for a New Zealand White, an English Angora, a Rex, a Flemish Giant, or a Netherland Dwarf. Consideration of the situation concerning wild rabbits can nonetheless be informative.

Domestication of Rabbits

The original site of domestication of the rabbit is not totally clear. All domestic rabbit breeds have been developed from the European wild rabbit (*Oryctolagus cuniculus*), which is thought to have evolved on the Iberian Peninsula (Southern France, Spain, and Portugal).

Domestication is defined as that condition in which the breeding, care, and feeding of animals are controlled by humans. It is different from mere taming; a pet lion may be tamed, but lions are not domesticated. Domestication often, but not necessarily, results in the loss of the ability of an animal to return to the wild. Feral animals are domestic animals that have reverted to the wild state, such as feral cattle and pigs in northern Australia. It is not common for domestic rabbits to become feral. In most situations in which rabbits have become pests, the European wild rabbit is the culprit. The best-known case is of feral rabbits in Australia. This occurred largely because of the absence of predators to control the population. Most domestic breeds, such as the New Zealand White, are not well adapted to life in the wild and are easy targets for predators. As a result of selection in captivity, their body conformation has changed greatly, which, among other things, has affected their ability to outrun predators. In a very few instances, domestic rabbits have been pests on isolated islands where there was a lack of predators and have caused severe damage to the vegetation (see Fig. 21.9). In general, however, the likelihood of feral rabbit populations developing from escaped domestic rabbits is remote. In North America, even the European wild rabbit has been unable to survive in the wild, except on the isolated San Juan Islands of the state of Washington and in the Canadian province of British Columbia.

Behavior of Wild Rabbits

A brief description of the behavior of wild rabbits will be given as a background for the discussion of the behavioral characteristics of domestic rabbits. "Wild rabbit" in this context refers to the European wild rabbit, and not to cottontails, jack rabbits, etc., which are of different genera from *Oryctolagus*. The behavior of wild rabbits has been studied by a number of scientists. Lockley (1974) provided a fascinating account of the behavior of wild rabbits in Wales. He constructed an artificial warren with a glassed-in viewing area that permitted him to observe wild rabbits in their burrows and to record their living patterns.

There are two distinct social hierarchies formed in the breeding groups. The males compete for access to breeding females, whereas the females compete for access to breeding warrens. Wild rabbits generally live in communal groups of one to three males and one to five females. There is usually a dominant female. The formation of a group is primarily a function of female behavior, with the males attracted to the group of females. The males exhibit a peck-order ranking (dominance hierarchy) with one dominant male. Territory for the group is established by the dominant male setting the boundaries by chin gland secretions and feces and urine deposits. Complexes of interconnecting burrows (warrens) are dug by the females, with little or no participation by bucks in this activity. Does construct a new nest for each litter. In areas of abundant feed, such as new territory being occupied by rabbits, post-partum breeding occurs, with the does rebreeding within two days of kindling. The male usually senses, probably by smell, that the doe is about to give birth and follows or guards her closely. Shortly after she first leaves the nest, mating takes place. At four weeks of age, the litter is fairly independent, and the doe rejects its attempts to nurse. The doe builds a new nest in preparation for the arrival of the new litter in a few days. Mortality of the young rabbits at weaning is often high, mainly because of predation. The kits are kindled in a nest inside the warren. The doe blocks off the entrance to the burrow with earth, opening it once a day to go to the nest to nurse the litter. These behavioral traits of post-partum breeding and once-a-day nursing have persisted in domestic rabbits and are normal behavioral patterns.

In areas of abundant feed and low incidence of disease and predation, there is a high survival rate of the young, and the females may begin breeding in the year of their birth. The rabbit population can expand rapidly. As the number of animals grows, there is increasing social stress among individuals. There is more fighting both within and between groups. Natural birth control measures begin in response, either due to the aggression or to lack of feed. Birth control in the rabbit is accomplished by the process of fetal resorption. Under conditions of stress or dietary inadequacy, the female resorbs the fetuses up to day 19 of gestation. In addition, as population density becomes high, hierarchical relationships develop, and the aggressive persecution of subordinate individuals inhibits their reproductive processes. There may also be instances of does killing the offspring of other does, referred to as infanticide.

Populations of some species of rabbits and other small herbivores tend to be cyclic. Snowshoe hares and lemmings exhibit this tendency. When conditions are favorable, the high reproductive potential allows for a very rapid population expansion. As aggressive tension with the high density of animals begins and as the food supply becomes limited, population “crashes” occur, with huge decreases in animal numbers. This may be a result of reduced reproduction, disease outbreaks among the weakened animals, and/or increased predator numbers. Predator populations tend to increase coincident with the increase in their prey. After a population “crash,” the small numbers of surviving animals find a situation of lots of space, little stress between groups, and abundant feed, so the explosive population increase begins anew. The European wild rabbit doesn’t usually experience cyclic changes in populations, although since the widespread distribution of myxomatosis and other contagious diseases in Europe, there are frequent population “crashes”.

Behavior of Domestic Rabbits

Behavioral patterns allow animals to adjust to changes in their environment. Animals have various instinctive behaviors, which are inherited characteristics. Other behavioral responses are controlled primarily by physiological factors associated with environmental conditions. The nervous system and the endocrine glands (pituitary, thyroid, adrenals, testes, and ovaries) are pivotal factors in regulating behavior.

In general, domestic rabbits have retained most of the behavioral characteristics of wild rabbits. The major differences in behavior between domestic and wild rabbits seem to be in the animals' responses to confinement. Wild rabbits do not adapt well to being caged and may fail to breed or may exhibit other signs of stress. Even females born in captivity as a result of egg transfer from wild to domestic females have nervous dispositions and may not mature sexually. Domestication has thus resulted in an animal with a more placid disposition that is not stressed by confinement, while retaining most of the behavioral repertoire of its wild ancestors. Other wild lagomorphs, such as the European hare and the jack rabbits of North America, rarely tolerate domestication and cannot be successfully raised in cages.

Systems of Rabbit Behavior

Behavioral scientists have characterized several systems of behavior, as listed below, and some of these will be discussed because of their relevance to domestic rabbit production.

- ingestive
- eliminative
- sexual
- maternal
- social
- shelter-seeking
- investigative; and
- behavioral disorders.

Ingestive behavior

Feeding behavior

The digestive system of the rabbit is adapted to a herbivorous diet, including adaptations involving the teeth, the enlarged hindgut for fermentation, and the separation of cecal contents allowing for coprophagy. Food is masticated thoroughly, so it is finely ground when it enters the stomach. When greens are fed or rabbits are grazing, the number of jaw movements may be as many as 120 per minute, resulting in thorough mastication of the forage. In the wild, rabbits feed primarily at dawn and dusk. Similarly, domestic rabbits consume much of their feed during dawn and dusk feeding periods.

Rabbits are very selective in their feeding behavior and in the wild will nibble selected plant parts. Rabbits, in common with other herbivores, generally select leaf rather than stem, young plant material rather than old, and green material rather than dry, resulting in a diet that is higher in protein and digestible energy and lower in fiber than the total plant material available. Domestic rabbits are "finicky" and will readily go off feed. They are much more sensitive to slight changes in the feed than other livestock. Sometimes they will refuse to accept a new diet and will starve rather than even taste the new feed. This fastidious behavior frustrates both rabbit raisers and feed manufacturers.

Contrary to common belief, there is little evidence that rabbits possess "nutritional wisdom," allowing them to select feedstuffs to provide the nutrients they require. The exception is salt, for which animals do have an appetite. It is not valid to conclude that the diet selected by wild rabbits accurately reflects their nutritional needs and that the ration for domestic rabbits should be formulated on the basis of what wild rabbits consume. The food consumed by wild rabbits reflects what plants are available in their territory, rather than inborn appetite patterns. However, there is growing evidence in other livestock species that selectively graze, such as cattle and sheep, that nutritional wisdom does exist.

The feed intake of rabbits, in common with that of other animals, is regulated according to energy need. Animals eat to satisfy their energy requirements. If they are fed a low-energy diet, they will consume more than they will of a high-energy diet, but the total caloric intake will be about the same in each case. This is illustrated in Table 12.1. As the percentage of alfalfa meal in the diet increased, the feed consumption was higher, but the daily caloric intake was similar in all cases.

Animals regulate their energy intake by means of the nervous system and blood levels of compounds used in energy metabolism. For example, food intake in the pig is controlled by

Table 12.1. Effect of increasing the percentage of dietary alfalfa on feed and energy intake.

Dietary alfalfa (%)	Digestible energy (kcal/kg feed)	Avg. daily feed intake (g)	Avg. daily energy intake (kcal)
10	3482	108	374
20	3327	105	350
30	3160	110	349
40	2974	116	344
50	2788	131	365
60	2602	134	349
74	2342	148	346

Source: Pote, L.M., P.R. Cheeke and N.M. Patton. 1980. Utilization of diets high in alfalfa meal by weanling rabbits. *J. Appl. Rabbit Res*. 3(4): 5.

the level of glucose in the blood (blood sugar). When the blood glucose level becomes depleted, cells in the appetite center of the brain (a region of the brain called the hypothalamus) detect the low glucose level and initiate responses via the nervous system to inform the pig that it is hungry. Species of microbes living in the digestive tract may play a related role by sending chemical messages to the brain. In ruminant animals, the blood levels of certain volatile fatty acids (the major absorbed sources of energy in ruminants) play a similar role. Because rabbits utilize both blood glucose and volatile fatty acids as cellular energy sources, it is not certain which is the principal blood component regulating feed intake, but it is likely to be the blood glucose level.

Although dietary energy level appears to be the major factor controlling the amount of feed consumed, other factors have an influence on feed intake. Palatability refers to the complex of factors, including taste and texture that influence the acceptability of a feed to an animal. Recognized taste responses are sweet, salty, bitter, and sour. Rabbits, in common with nearly all animals, show a preference for sweetness. It has been shown that rabbits have a marked preference for a diet containing table sugar (sucrose) or molasses, in comparison to the same diet without this material. Rabbits seem to be quite tolerant of bitterness and, in fact, may even show a preference for a certain degree of bitter taste in their diet. This is an important factor leading to the suitability of alfalfa as a feedstuff for rabbits but not for other non-ruminants such as swine and poultry. Alfalfa contains bitter compounds called saponins. Pigs and poultry show an aversion to alfalfa at quite low levels in the diet, whereas rabbits will readily consume high alfalfa levels. The aversion of pigs and poultry seems to be in part due to the saponin content of alfalfa.

Another major factor influencing feed intake is environmental temperature. Actually the effect is that of modifying energy requirements. As the temperature drops, rabbits must generate more heat in order to maintain their body temperature. This heat is generated by metabolism of energy sources, such as glucose; so to meet this increased metabolic demand, a higher level of feed intake is required. Thus, in the winter in cold climates, rabbits will consume much more feed than they will in the summer. It is probably less expensive to let the rabbits generate the heat they need from a higher feed intake than it is to heat the entire rabbitry with a heater.

The feeding behavior of rabbits can be influenced by social factors. If animals are caged individually, their feeding pattern and feed intake may be different than if they are caged in groups. When two or more animals are caged together, more feed may be eaten because of increased stimulation to eat (feedlot competition) or a reduction of anxiety. On the other hand, overcrowding in a cage may result in competition for feeder space, with some animals not getting adequate feed intake for maximum performance. Submissive animals may be prevented from eating and may die from starvation (starve-outs).

Feeding problems and vices

Given a choice, most animals prefer to continue eating a feed with which they are familiar.

This probably has survival value in that it may protect the wild animal from consumption of toxins. Some rabbits seem to be particularly unwilling to accept a change of feed and will refuse to consume any of the new feed for several days. In extreme cases, they will starve rather than eat an unfamiliar feed, even though the feed is of adequate quality.

One feeding vice of rabbits is scratching feed out of the feeder and wasting it. This is called scrabbling. Often this vice begins after a change in feed, particularly if the new feed is less palatable than the one they are accustomed to. This vice becomes a habit that is not easily broken. The use of scrabble guards (wire mesh placed over the feed) in the feeders can be helpful with chronic feed wasters. Pellet quality is important in prevention of feed waste. A firm pellet, with a minimum of dust or fines, is desirable to reduce scrabbling or feed selection. Rabbits show a marked preference for pellets over the same diet in a non-pelleted form.

Fur chewing is another vice of ingestive behavior. In most cases, this is associated with a diet too low in fiber or protein and is corrected when the diet is changed as needed. Feeding hay often breaks an episode of fur chewing. A block of wood placed in the cage will provide fiber and help keep the rabbits' teeth worn down. A soft drink can for the animals to "play" with will redirect their energies.

Drinking behavior

Drinking (or consumption of water as part of the diet) is necessary to replace body water losses. Losses of water include the urine, plus water vapor in the expired air. The latter is particularly important as a cooling mechanism in rabbits under high environmental temperatures; the evaporation of water results in the dissipation of heat. The sensation of thirst develops as water is lost from the body, causing a concentration of the blood and other body fluids.

Rabbits need to learn to drink from automatic watering nipples. Normally the young rabbits learn by mimicking the drinking behavior of the doe. Some individuals may not learn to use the water nipple and instead lap water spilled on the cage and on the fur of animals that have learned to drink. When these animals are subsequently caged individually (if they are replacement stock), they may suffer from water deprivation because of their inability to use the waterer. It is advisable with newly weaned litters to let the water nipple drip slightly so that the rabbits learn to use it.

Eliminative behavior

Rabbits excrete two types of feces: the hard (day) feces and the soft (night) feces. The separation of particles in the hindgut resulting in the formation of these two types of feces has already been discussed. Technically, the soft feces are more appropriately called cecotropes, because they are cecal contents. The consumption of its soft feces (a process called cecotrophy) provides the rabbit with vitamins synthesized by the bacteria in the cecum, as well as with bacterial protein. Coprophagy is a behavioral and anatomical adaptation that allows the rabbit to utilize herbage efficiently. The cecotropes are consumed directly from the anus, so keeping rabbits in wire cages has no effect on coprophagy. In fact, it is quite difficult to devise ways for experimentally preventing coprophagy in rabbits (see Fig. 7.8).

Urination is an eliminative function and also part of territorial behavior. In the wild, bucks establish territorial boundaries by rubbing their chin glands on objects (chinning) and urination. Urination also functions in aggressive behavior, as bucks squirt urine at rivals in establishing a pecking order. Urination also has a role in sexual behavior. The urine of adult female rabbits, when sprayed on the noses of young males, suppresses their sexual development.

Rabbits tend to excrete their droppings at a particular site, so pet rabbits can be trained to use a litter box. In a cage, rabbits will generally have one area that they use as a latrine. This area should be given particular attention in cleaning, and the nest box should not be placed in that part of the cage.

Sexual behavior

Wild rabbits exhibit various types of courtship behavior, but this is generally not important in domestic rabbits, because the doe is taken to the buck and mating occurs almost immediately. The doe is taken to the buck, rather than the buck to the doe, because of territorial behavior. If the buck is put in the doe's cage, the doe may attack him and inflict serious injury, even castration, or the buck may explore the new cage, in preference to breeding the doe.

Copulation proceeds rapidly in rabbits. If the doe is receptive, she raises her hindquarters to allow copulation. The buck mounts and performs several rapid copulatory movements to effect intromission, followed by penetration of the vagina and ejaculation. The ejaculatory thrust is so vigorous that the buck's hind feet are lifted off the ground, and because his forelegs can't grip the doe sufficiently, he may fall backwards or sideways, often emitting a snort or cry. The falling over and/or the cry is indicative of ejaculation.

If the doe is not immediately receptive, the buck may initiate various courtship rituals, such as licking. However, mating is not likely if the doe is unreceptive, so if copulation does not occur within a few minutes, the doe should be removed and placed with another buck. If this is similarly unsuccessful, breeding should be attempted again the next day or two days later. Instead, a different doe can be presented to the buck before he becomes exhausted.

A plug of mucus usually forms in the vagina following the mating or coitus. It is not essential for a fertile mating. The plug is formed from gel contained in the ejaculate.

Sexual behavior is greatly influenced by hormones. In bucks, testosterone is the major hormone affecting behavior. The enthusiasm of a buck for mating is called libido and is controlled by testosterone levels. Libido is one of the criteria that should be used in the selection of replacement bucks. Does may exhibit a breeding cycle of uncertain length. There appear to be cycles of female attractiveness to the bucks. Does that are receptive often exhibit a congested, moist vagina with a reddish coloration. The more or less constant receptivity of does is of survival advantage in the wild, allowing rabbits to respond rapidly to changing environmental conditions and reproduce at favorable times.

Rabbits are induced ovulators, ovulating 10 to 11 hours after coitus or after mechanical or hormonal stimulation when bred by artificial insemination (AI). For AI, an injection of hormone is given to induce ovulation. Ovulation may also be induced by contact with other females, resulting in pseudopregnancy.

As is the case with wild rabbits, domestic rabbits will breed within a few hours following kindling. Their receptivity and fertility are high in the immediate post-partum period.

Maternal behavior

Normal maternal behavior in the rabbit involves selecting a site for a nest, building the nest, and giving birth to and successfully raising the young to weaning. These behavioral patterns are strongly influenced by hormones.

Nest building begins several days prior to parturition (kindling). The first behavior, digging, starts six to eight days before kindling. This declines, and one to three days before kindling, the doe carries hay or other nest material in her mouth to form the material nest. Hair pulling is generally not seen until the day before or even not until kindling. The nest box should be placed in the cage on the twenty-eighth or twenty-ninth day of gestation. If it is put in too early, the doe may use it as a latrine. Nest building involves two processes: hair loosening and actual building of the nest. About five days before kindling, the hair begins to loosen, and the doe plucks the loosened hair to mix with other material (hay, straw, shavings, etc.) to form the maternal nest. During early gestation, the ratio of the two reproductive hormones estrogen and progesterone is such that progesterone predominates, although the ratio is reversed near the end of the pregnancy period. These changes may be involved in the initiation of hair loosening and nest building. The shift to estrogen dominance and the secretion of prolactin seem to be the factors that trigger nest building at the conclusion of both normal pregnancy and pseudopregnancy.

The quality of the nest has a great influence on the survival of the young. A first litter doe often fails to make an adequate nest or may have her litter on the wire (i.e. the cage bottom). This may be a reflection of immaturity in the development of the hormonal system.

The subterranean or drop nest box, which is below the level of the cage floor, allows the rabbit to mimic its natural tendency to kindle in a burrow and thus may be superior to a nest box placed in the cage. Attempts to prevent on-the-wire births by placing fur in the nest box to induce the doe to make a nest are not generally effective. The quality of the nest tends to improve over the first three parities, suggesting that learning processes are involved in addition to hormonally induced behavior.

Parturition is initiated by hormonal changes. Impending parturition in the rabbit is suggested by behavioral changes, such as restlessness and increased time spent in the nest box. Occasionally does do not kindle on time, resulting in prolonged gestation. Injection of oxytocin can be used to induce parturition if necessary.

Following parturition, the doe cleans both the nest box and the kits, consuming the placenta and mucus. This behavior is helpful in preventing bacterial build-up and disease in the nest box and eliminates scents that might attract predators.

Certain abnormal maternal behavioral patterns may occur. A first litter doe is particularly likely to have her litter on the wire or fail to build a nest. Other common abnormal behaviors are cannibalism and neglect of the litter. Cannibalism (infanticide) occurs when the doe begins to devour the kits after she has eaten the placenta. Some evidence suggests that this is related to the level of feeding. Does on restricted feeding or on a low-energy diet, which therefore do not gain much weight during pregnancy and lose weight after parturition, show the highest incidence of cannibalism. Handling by strangers and disturbances in the environment can also induce both cannibalism and neglect of the litter. Moving the doe to a new cage a few days before kindling can result in an increase in abnormal maternal behavior. Abnormal maternal behavior is most likely to occur when the mother is subjected to stress. The stress can be nutritional (improper amount or type of diet), weather related (heat or cold), or social (mixing with strange animals), or can have many other causes, including rough handling or being frightened by a predator. Stress increases the incidence of poor nests and infant mortality.

Rabbits are non-retrieving animals. A cat will retrieve her kittens and bring them back to the nest, but a rabbit will not. A baby rabbit that gets out of the nest box is doomed to death from exposure unless it is retrieved by the rabbit raiser. An advantage of the subterranean nest box is that if a kit crawls out of the nest box or is carried out by attachment to a teat when the mother leaves after nursing, it may fall back in by itself.

In the wild, rabbits nurse their young once a day. The kits are in the nest in a burrow, and the doe blocks the entrance with earth. Once a day, she removes the covering and goes into the nest for a few minutes to nurse. This behavior has obvious survival implications, in that the young remain hidden from predators and traces of the doe's scent are minimized. Domestic rabbits likewise will normally nurse only once per day. At other times the doe pays little attention to the kits, again reflecting the wild behavioral pattern that has survival value.

Social behavior

Wild rabbits are territorial animals and live in groups, as previously described. Domestic rabbits are normally caged individually as adults or as litters when young, so the formation of a social structure is inhibited. Rabbits regard their cages as their territory and mark the boundaries by urination and "chinning." Rabbits secrete a colorless fluid from glands beneath the jaw and mark objects by rubbing the chin on them (chinning). These glands are much larger in bucks than in does; the fur under the chins of bucks may become matted with the secretions.

Because of their territorial behavior, rabbits display aggression when caged in groups. Their teeth and the claws on their powerful hind feet can inflict severe wounds in fighting. For this reason, it is inadvisable to keep more than one rabbit per cage after they have reached sexual maturity. In addition, when does are housed together, mounting behavior may result in pseudopregnancy.

Weaning is a stressful situation for young rabbits. Research suggests that weaning stress is less severe if the young are weaned at four weeks compared to six weeks. The stresses associated with mixing rabbits from different litters often result in outbreaks of enteritis. This is probably caused by irregular feeding and the effects of hormones such as adrenalin on the motility of, and the blood supply to, the digestive tract.

Rabbits communicate by sight, smell (olfaction), and hearing. Vocalization is of minor importance, with the major sound being a high-pitched scream uttered when a rabbit is terrified. Thumping with the hind feet communicates warning or fear. A stranger in the rabbitry can cause the rabbits to show fear with thumping, followed by the animals dashing around the cages in panic. This may result in broken backs. If frequent visitors to a rabbitry are anticipated, it is advisable to train the animals to be accustomed to noise by playing a radio continuously. Visitors should move slowly and quietly in the rabbitry and avoid sudden moves or loud noises that might startle the rabbits. The rabbit raiser should make a practice of talking to the animals as a calming influence.

The principal means of communication is olfaction. Rabbits secrete pheromones (chemical attractants or stimulants) that convey information to other rabbits about an individual's physiological state, including its sex, age, reproductive status, and individual identity. Bucks produce pheromones in their chin glands and, by chinning on objects, mark their territory. Pheromones are secreted by the anal and chin glands and are found in the urine. The anal gland secretion coats the fecal pellets.

Shelter-seeking behavior

Wild rabbits inhabit burrows, or warrens. These are dug by the animals and expanded with new tunnels over long periods of time. The warrens protect wild rabbits from predation and also protect them against high temperatures. Domestic rabbits have retained in their behavioral patterns some burrow-making tendencies, but to a lesser degree. In studies comparing domestic and wild rabbits, the domestic animals were less vigilant to potential danger. They took flight only in response to extreme stimuli and never sought refuge in burrows. They tended to remain above ground during their resting periods. For these reasons, domestic rabbits have been able to survive in the wild mostly on islands where predators are few or absent. All the successful mainland invasions have been of the European wild rabbit.

Environmental Factors Affecting Behavior

Behavior of animals is influenced by genetics and the environment. There are various basic biological cycles, closely intertwined with day length and the seasons. Some animals are seasonal breeders, with the reproductive period coinciding with the most favorable periods for survival of the young. Most breeds of sheep breed seasonally, with mating occurring in the autumn so that the lambs are born in the spring, when the availability of feed is highest. In sheep, the breeding season is controlled by changes in day length and light intensity. These light, or photoperiod, effects are perceived by the pineal gland, a specialized tissue of the brain that produces the hormone melatonin.

In rabbits, there is some evidence for seasonality in breeding, with a “winter decline” in fertility often described by rabbit raisers. This is confounded by environmental temperature effects, both on the rabbits and on the rabbit raisers. In some cases, poor breeding performance may reflect the reluctance of the rabbit raiser to spend as much time in a barn in the winter, when it is cold, as they might devote during other periods of the year. Experiments with controlled lighting have not shown substantial differences between rabbits kept under natural lighting and those with controlled photoperiods. The effects are obviously complex, and we do not currently have sufficient information to describe them adequately. There are noticeable environmental effects on behavior related to body temperature regulation. In hot environments, rabbits breathe rapidly, throw their heads back and stretch out in their cages (Fig. 12.1). The rapid breathing helps to dissipate water from the lungs, removing heat (as heat of vaporization of water) from the body. Stretching out maximizes surface area, facilitating loss of heat. Under cold conditions, rabbits increase their physical activity to increase metabolic heat production. When resting, they reduce their surface area by assuming a crouched posture and litters often huddle together as a group. Feed intake is increased.

Fig. 12.1. A doe experiencing severe heat stress that is panting rapidly. Rabbits with short-coupled bodies, thick fur coats, and short ears are highly vulnerable to succumbing to heat stroke. (Courtesy of S.D. Lukefahr)

Rabbits are of Mediterranean origin and adapt best to climatic conditions that are not extremely cold or hot. They are not very tolerant of high temperatures and experience substantial heat stress when the temperature reaches about 30°C (86°F). Pregnant does and rabbits with respiratory disease are particularly susceptible to heat stress. The burrowing habit may have evolved as a means of minimizing exposure to high temperatures. In hot areas, underground rabbitries or units that simulate underground conditions (Fig. 12.2) may be housing systems that will reduce heat stress problems.

Fig. 12.2. A small rabbitry in Italy with concrete indoor units (left) connected to wire cages on the right. The floors of the wire cages are made of plastic slats that are 3.0 cm (1.2 in) wide separated by spaces 1.3 cm (.5 in). Note the flowers growing on top of the tubes connecting the wire and concrete portions of the units. (Courtesy of consortium (Green Rabbit Leprino of Viterbo), Italy)

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13

Principles of Rabbit Genetics

Rabbit breeders who consistently produce superior stock, whether for backyard, commercial or fancy use, generally have a basic understanding of fundamental genetics. The subject of genetics is often complicated and requires dedication and patience, but a basic knowledge of genetics is critical if a rabbit raiser wishes to select most effectively to improve herd quality for traits of interest. Actual rabbit breeding experience involving planned matings, accurate production and pedigree recordkeeping, and rigorous selection and culling practices will be the ultimate test of one's applied knowledge and understanding of genetics.

The purpose of this chapter is to introduce the subject of genetics as it pertains to practical rabbit breeding. The following three chapters will address the more specialized aspects of rabbit genetics, such as breeding systems, selection strategies, and coat color inheritance.

An effective way of introducing the subject is to define and illustrate relevant terms, processes, and concepts involved in the inheritance and the expression of genetic material.

Genes: the Basic Units of Inheritance

The nucleus is an organelle found in most body cells, such as those in bone, muscle, and skin. Within the nucleus are fine, thread-like structures called chromosomes, which are the largest units of inheritance. There are a total of 44 chromosomes in rabbit cells; 22 chromosomes were inherited from the sire and 22 from the dam. Located on the chromosomes are the basic units of inheritance, known as genes. The specific location or point on a chromosome where a particular gene is found is called a locus. (The plural of locus is loci.) A gene is made of the compound DNA (deoxyribonucleic acid). Like chromosomes, genes are inherited in pairs. One chromosome may carry hundreds, even thousands, of genes. To date, the locations of many specific genes on chromosomes, the "genetic map", have been established (Fig. 13.1); chromosome pairs appear in order of their size and the sex chromosomes appear last.

The main purpose of the gene, as the basic unit of inheritance, is the storage of information (blueprints) needed to manufacture a specific protein. Proteins are major constituents of enzymes, fur, and hormones, and of muscle and skin tissues that are responsible for forming and maintaining a healthy body. Genes contain the blueprints that "code" for specific amino acids, which are the building blocks of all proteins. For example, a gene may code for the synthesis of melanin protein pigments, which results in the distribution of these colored pigments in the fur.

A gene may have two or more versions, referred to as alleles. For example, three alleles

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Fig. 13.1. Cytogenetic map showing the chromosomes bearing identified genes to date in the rabbit. (Courtesy of Chantry-Darmon, C., M. Bertaud, C. Urien, S. Chadi-Taourit, M. Perrocheau, C. Rogel-Gaillard, and H. Hayes. 2005. Expanded comparative mapping between man and rabbit and detection of a new conserved segment between HSA22 and OCU4. *Cytogenet. Genome Res.* 111:134–139)

exist at the A locus on Chromosome 4 that affects coat color in rabbits. The A allele codes for agouti-type (wild-type) fur, the a allele codes for non-agouti black fur (self), and the a^t allele codes for the tan fur pattern. (Agouti refers to bands of color on the hair while self refers to solid coat color, such as black or chocolate). The specific protein that produces the agouti color pattern is called the agouti signalling protein (ASIP). A rabbit possesses either two identical alleles or two dissimilar alleles for each locus, with one allele inherited from each parent. Whereas an individual rabbit may have no more than two alleles per locus, a population may contain several alleles at the same locus (e.g., A, a, and a^t).

New genes arise as a result of mutation, which is defined as a sudden heritable change. This is Nature's way of creating new genetic variation in populations, which is critical in ensuring the population's ability for adaptation to future changes in the environment. However, gene mutations are exceedingly rare with only 1 mutation occurring for each 100,000 to 1,000,000 gametes per locus per generation in a population. Further, most mutations are lost in a few generations. Most mutations that occur are harmful because of metabolic, physical, or nervous conditions that are the result of the loss of a specific protein function. Desirable mutations are more likely to be propagated in a population owing to selection. One mutation in rabbits that occurred centuries ago was albinism. This gene is found on Chromosome 1. What actually causes this condition is a change in the DNA code for the enzyme tyrosinase (see TYR on Chromosome pair 1 in Fig. 13.1). This enzyme is required for pigment formation. In the case of albinism, tyrosine is non-functional; hence, colored pigments cannot be synthesized. Today, premium prices are paid for white-coated fryers, since their white hairs are less noticeable on the carcass, although in the wild the albino gene would be undesirable because the rabbits would be more noticeable to predators. However, when a new trait suddenly appears in a herd, it is usually not due to a new mutation but is simply the result of mating related animals, which exposes a less dominant or recessive gene that is less commonly expressed in the herd.

There are two forms of cell division, mitosis and meiosis. Mitosis is the form of division involving body cells. In mitosis a cell divides, producing two identical daughter cells with the same genetic make-up as the parent cell. This explains how a rabbit grows. Meiosis is the form of cell division that results in the formation of the sex cells (sperm and ova). During meiosis a separation occurs between paired chromosomes (called segregation), forming the specialized sex cells. As a consequence, only one chromosome (and therefore only one gene per locus) of each chromosome pair is found in the sex cell, or gamete, which thus has only 22 chromosomes. This process occurs in the testes and the ovaries, where gametes are formed.

Mendelian Genetics

In the middle of the nineteenth century, an Austrian monk, Gregor Mendel, observed that certain characteristics of garden peas (e.g., flower color and seed shape) were simply transmissible as inherited units from parent to progeny. He kept a detailed diary of his breeding experiments, which was later rediscovered and published. The basic understanding of the processes or laws of inheritance – segregation, independent assortment, and recombination – is credited to Mendel. During the twentieth century, a “genetic revolution” occurred involving major scientific breakthroughs into the unraveling of the mysteries of gene control and expression. These breakthroughs continue (e.g., DNA tests, genomic maps of species, gene editing, and cloning) and should ultimately benefit humankind if they are responsibly controlled. A new revelation in the science of genetics is the topic of epigenetics. Epigenetics involves a process called fetal programming whereby maternal cues during pregnancy can result in certain genes being literally turned on or turned off. For example, in cattle poor-quality forage during pregnancy may result in the cow reprogramming the fetus such that specific genes are turned on to improve forage digestibility (e.g., more effective enzymatic activity) that will later benefit the fetus as an adult. For domestic rabbits fed nutritionally complete diets there is less of an opportunity for this event to occur. More research is needed to elucidate the importance of epigenetics in rabbits.

Segregation involves the separation of members of each chromosome pair, which occurs when gametes are formed during meiosis. Each chromosome member will carry only one allele per locus. When genes are inherited independently, regardless of other genes present on the same chromosome, this is called independent assortment of genes. This process will result in more gametes possessing different gene combinations. Recombination occurs when members (alleles) of each gene pair recombine during the process of fertilization, thereby restoring all gene pair members and the norm of 44 chromosomes in the newly formed rabbit. More specifically, recombination refers to new combinations of genes resulting from meiosis. Segregation, independent assortment, and recombination ensure that ample genetic variation, the raw material for genetic improvement, is maintained in the rabbit population.

Other Basic Genetic Terms

A body cell (muscle, bone, glandular cell, etc.) containing a complete set of 44 paired chromosomes is also called a somatic cell. The numbers of chromosome pairs normally found in somatic cells for humans and several livestock species are listed in Table 13.1. A sex cell contains only one gene member from each chromosome pair. Therefore, a sex cell from a rabbit has 22 chromosomes, whereas a body cell contains 44 chromosomes. Upon fertilization, pair members of chromosomes unite, restoring the chromosome number to 44 (22 from sperm + 22 from ova). Thus, for a given chromosome pair, one chromosome was inherited from the sire and the other was inherited from the dam. The same can be stated

Table 13.1. Number of chromosomes for humans and domesticated livestock species.

Species	Pairs of chromosomes	Total number
Chicken	39	78
Cattle	30	60
Horse	32	64
Human	23	46
Rabbit	22	44
Sheep	27	54
Swine	19	38

of genes, since chromosomes carry genes. The newly fertilized egg, which possesses 44 chromosomes, is referred to as a zygote. After many cycles of cell division, the zygote becomes an embryo. After the embryo implants in the uterine wall, it is called a fetus.

The pair of chromosomes determining the sex at fertilization are called the sex chromosomes. In mammals, a normal sperm cell contains either an X or a Y sex chromosome, whereas a normal ovum contains only an X chromosome. Females are XX, and males are XY; thus the sperm determines the sex of the offspring at the time of fertilization. Figure 13.2 displays this phenomenon. All chromosomes other than the sex chromosomes are called autosomal chromosomes. The rabbit has 21 autosomal chromosome pairs and 1 sex chromosome pair. Linkage refers to genes located close together on the same chromosome that tend to be transmitted together as a block of genes rather than independently. Linkage limits recombination of genes during the formation of gametes.

Sex linkage is similarly defined except that genes on the X sex chromosome are involved. The classic example of a sex-linked trait is that of the calico cat, which is always female (XX). On one X chromosome there is a gene for black fur color, while on the other X chromosome there is a gene for orange fur color. A female cat with this inherited condition will be black and orange (calico). Sex linkage for fur color in rabbits has not been reported. On the other hand, a sex-limited trait can be expressed by only one sex, such as milk production in the doe or sperm production in the buck. Genes involved in expression of sex-limited traits are primarily located on autosomal chromosomes and involve equal contributions from the sire and the dam. Therefore, the ability of a doe to produce milk, for example, depends on the genes transmitted from both her dam and her sire.

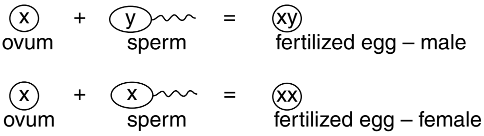

Fig. 13.2. Determination of sex at fertilization. (Courtesy of OSU Rabbit Research Center)

Gene Expression

The genetic make-up of a rabbit is called its genotype or more broadly its genome. One gene pair, several pairs, or even hundreds of pairs may be involved in the expression of a particular trait of interest. For example, assume two bucks are agouti in fur color. Agouti is Latin for "wild-type," as in the coat color of wild European rabbits, cottontails, and jack rabbits. However, when the agouti bucks are mated to albino does, one buck produces only agouti offspring while the other buck produces nearly equal numbers of agouti and albino offspring. Based on these breeding results, the genotype of the first buck is AACC and the genotype of the second buck is AACc, where A codes for agouti, C for full color, and c for albinism. Although both bucks have agouti fur color, they clearly have different genotypes.

The phenotype refers to the observed expression of a trait due to combined environmental and genetic influences. In the previous example, both genotypes AACC and AACc resulted in the same phenotype – agouti color. Another example, a rabbit's genetic potential for growth rate is also determined at fertilization. However, its genotype plus the environment provided (e.g., the amount of milk produced by its dam, its management, and the diet it receives) will also regulate how fast the rabbit actually realizes its phenotypic potential. The extent to which genetics influences a trait is called heritability. In other words, heritability is the proportion of the total observed (phenotypic) variation of a trait that is due to genetics.

Heritability is typically estimated based on trait records from animals and their relatives reared in the same herd environment. To illustrate this concept, if a trait of interest is 0% heritable, all variation among individuals in a herd is due to the environment. For a trait that is 50% heritable, one-half of the variation observed between individuals is due to genetic effects, the other one-half is due to environmental effects. Accordingly, if all the observed variation between individuals is due to genetics, such a trait is 100% heritable. In a successful breeding program, the traits that are most highly heritable and of economic importance should be emphasized. This subject is covered in depth in Chapter 15.

Some traits are influenced by only a single gene pair (or a few gene pairs) and are said to be simply inherited. A dominant gene masks the expression of its paired recessive allele. In the previous example of fur color, gene C codes for colored (agouti) fur, while gene c codes for non-pigmented white (albino) fur. Mating a colored rabbit with the CC genotype to an albino rabbit with the cc genotype would produce all colored offspring (Fig. 13.3). Since the colored rabbit can transmit only C genes and the albino rabbit can transmit only c genes, all of their offspring will have one C gene and one c gene, meaning that they will all have colored fur. Full color is thus dominant to no color pigmentation (albinism). The expression of colored fur over albinism when both genes (alleles) are present in the individual is called complete dominance. Letter symbols for dominant genes are usually capitalized, while those for genes that are not dominant are usually written in lower case. For a simply inherited trait, and using the above example, the only possible way for a rabbit to be an albino is if it has two c genes (cc). Albinism is therefore a recessive trait. To be clear, recessiveness is expressed only when both recessive genes are present in the individual.

An individual having identical alleles at a specific locus is referred to as a homozygote. When two recessive genes for a given gene pair are present (cc in the last example), the rabbit is homozygous recessive. If a colored rabbit is CC, it is homozygous dominant for coat color at that particular locus. In contrast, a heterozygote is an individual having dissimilar alleles (Cc) at a specific locus. When the genes of a given pair are dissimilar, the rabbit is heterozygous. Mating a colored heterozygote (Cc) to an albino rabbit (cc) would produce, on average, half colored (Cc) and half albino (cc) offspring, because of segregation of C and c genes in the formation of gametes.

Expression of dominance in the rabbit may not always be complete. Incomplete dominance is the term used when dominance is not complete or is partial between two alleles of the same gene pair or locus. For example, mating a Californian (c^hc^h) to a New Zealand White (cc) will produce heterozygotes (c^hc) that are more or less intermediate in color on the extremities in relation to the parent breeds (Fig. 13.4). The dominance is said to be

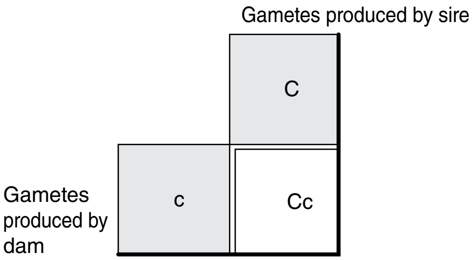

Fig. 13.3. Illustration of the genotype of the progeny produced by mating a colored homozygous buck with a homozygous albino doe. (Courtesy of OSU Rabbit Research Center)

Fig. 13.4. Incomplete dominance. The middle rabbit is a cross between a New Zealand White (right) and a Californian (left). The crossbred animal shows coloration of the extremities that is somewhat but not completely intermediate between that of the parental breeds. (Courtesy of OSU Rabbit Research Center)

incomplete because the c^h gene is expressed but not as strongly as in the homozygote and is closer to the homozygote phenotype (purebred Californian). Incomplete dominance (also called partial dominance) may be the result of one recessive gene tending to be dominant over another recessive allele. Likewise, incomplete dominance could occur between two different dominant genes at the same locus or between a dominant and a recessive gene.

Still other forms of gene expression or interaction exists. If the expression of genes at one locus is influenced by genes at another locus, this is called epistasis. In other words, the interaction between pairs of genes found at different loci results in a unique phenotype. Mating a blue rabbit (aaBBdd) to a chocolate rabbit (aabbDD), where a = black, B = agouti, b = chocolate, D = agouti, and d = blue fur color, will produce all black offspring that are genetically aaBbDd. The aa genotype prevents B and D from producing any other pigments besides black (melanin). Epistasis is further demonstrated when two black rabbits of this genotype are mated to produce offspring in the next generation. The results of such a mating are shown in Fig. 13.5. As a result of meiosis, both parents produce gametes with equal frequencies of aBD, aBd, abD, and abd genotypes. This mating will produce, on average, an expected ratio of nine black, three blue, three chocolate, and one lilac-colored ("blue-dove") offspring (see the photo of the Lilac rabbit in the Breeds Photo Gallery). Because of epistasis, the two homozygous-recessive gene pairs (bb, which codes for chocolate, and dd, which codes for blue) interact in producing lilac-colored fur, resulting in a unique phenotype. This is also an example of recombination.

Gametes produced by sire

Gametes produced by dam	aBD	aBd	abD	abd
aBD	aaBBDD black	aaBBDd black	aaBbDD black	aaBbDd black
aBd	aaBBDd black	aaBBdd blue	aaBbDd black	aaBbdd blue
abD	aaBbDD black	aaBbDd black	aabbDD chocolate	aabbDd chocolate
abd	aaBbDd black	aaBbdd blue	aabbDd chocolate	aabbdd lilac

Fig. 13.5. Illustration of epistasis with a 9:3:3:1 phenotypic ratio of offspring, where both the sire and the dam have the genotype aaBbDd. (Courtesy of OSU Rabbit Research Center)

Gametes produced by sire

Gametes produced by dam

	aCE	aCe	acE	ace
aCE	aaCCEE black	aaCCEe black	aaCcEE black	aaCcEe black
aCe	aaCCEe black	aaCCee tortoise-shell	aaCcEe black	aaCcee tortoise-shell
acE	aaCcEE black	aaCcEe black	aaccEE albino	aaccEe albino
ace	aaCcEe black	aaCcee tortoise-shell	aaccEe albino	aaccee albino

Fig. 13.6. Illustration of recessive epistasis with a 9:3:4 phenotypic ratio of offspring, where both the sire and the dam have the genotype aaCcEe. (Courtesy of OSU Rabbit Research Center)

Another type of epistasis is recessive epistasis. For example, if an albino rabbit with black ancestors (aaccEE) is mated to a tortoise-shell rabbit (aaCCee; a red rabbit with dark points), the offspring will be black with the genotype aaCcEe. Mating two black rabbits of this genotype will yield the results shown in Fig. 13.6. This mating will produce, on average, an expected ratio of nine black, three tortoise-shell, and four albino rabbits. In this case, albinism is a recessive epistatic condition; any rabbit that is homozygous recessive for the albino alleles (cc) is albino, regardless of the genotype for coat color at any other loci. This is again because the enzyme (tyrosinase) responsible for synthesizing color pigments is defective which causes albinism. For this reason, all New Zealand White rabbits are albino, since they have the cc genotype. The tortoise-shell color is also an epistatic condition, since both gene pairs (aa and ee) code for black and red fur, although concentrated on different body regions. Further information on coat color genetics is provided in Chapter 16.

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14

Breeding Systems

In most rabbit herds, some type of breeding system is practiced. Inbreeding, linebreeding, outcrossing, crossbreeding, and random mating are the most common breeding systems currently utilized. Each of these breeding systems manipulates the genetic variation present in a rabbit population for a trait or traits of selective interest. However, the best breeding system for a rabbit producer depends on many factors. Initial genetic quality of the base herd, type of operation (fancy vs commercial), economics, the physical environment in which production occurs, and personal preference are a few such factors. For example, within a quality line of Britannia Petites, linebreeding may be preferred, while within a commercial meat herd, crossbreeding may be the desired breeding system.

Regardless of which breeding system is used, one essential record in maintaining knowledge of the breeding background of an animal is the pedigree. A pedigree is a simple description of the ancestry of an individual. The most popular pedigree is the bracket-style, as shown in Fig. 14.1. In this style, the upper ancestor for each bracket is the sire or male line for that particular individual, and the lower is the dam or female line. Each ancestor is shown separately for every mating involved that comprises the individual. To illustrate, in the more complete pedigree found in Fig. 14.2, Caesar was involved in four matings, so he is shown four times in the pedigree. He is thus a common ancestor of both the dam and the sire of Caesar V. When individual matings are written in the form “Caesar x Penny,” it is a common practice to list the sire first and the dam second.

For studying common ancestral relationships, an arrow-style pedigree is often more convenient because it is more condensed than a standard pedigree (Fig. 14.1). In this style, each individual is included only once. An arrow pointing toward an individual indicates inheritance of genes from an individual’s ancestor, while an arrow pointing away indicates gene transmission from the individual to its offspring. Note that the four matings of Caesar in the pedigree of Caesar V are indicated by four arrows pointing away from him. These matings produced Caesar II, Florence, Caesar III, and Charlene, which are paternal half sibs. The arrow-style pedigree includes only common ancestors and descendants on the direct “gene-flow” line from the common ancestors. Such a pedigree style is again more concise and is most useful in a herd composed of inbred and linebred families of rabbits.

In the discussion of breeding systems, the relationship of two individuals can be estimated and expressed numerically as the percentage of genes the two have in common. This relationship is affected by the breeding system used and may vary from 0% (no genetic relationship) to 100% (complete genetic relationship). Using the extremes as examples, two rabbits of different breeds could have a 0% genetic

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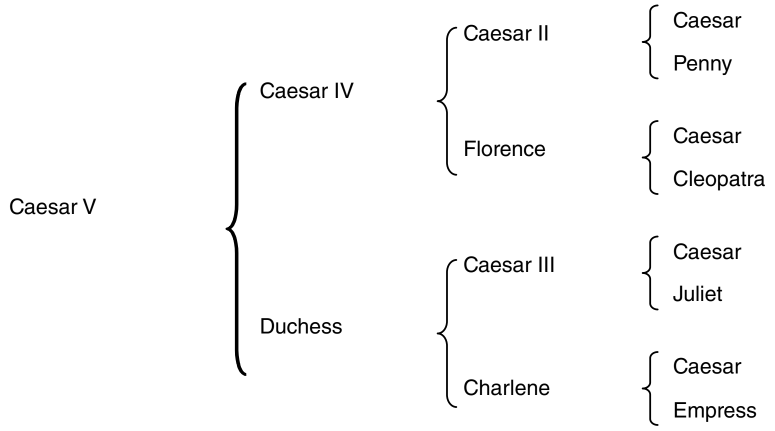
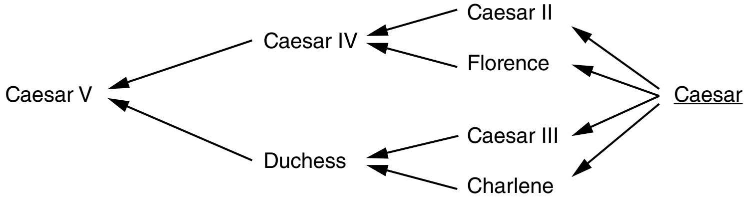


Bracket-style



Arrow-style

Fig. 14.1. Illustration of linebreeding with bracket- and arrow-style pedigrees (the common ancestor is underlined). (Courtesy of OSU Rabbit Research Center)

relationship, while two rabbits that are identical twins or clones would have a 100% genetic relationship. Relationships of 25% or greater are generally considered close in rabbit breeding. In addition, two individuals may share multiple relationships – for example, being related as both uncle–niece and cousins. Table 14.1 provides measures of the genetic relationships between specific relatives. In more sophisticated, large purebred rabbit operations, the use of computer programs that are capable of drafting both bracket- and arrow-style pedigrees for the entire rabbit herd can be extremely useful.

The genetic relationship coefficient is the percentage of genes that an individual has in common with another individual due to common breeding. A rabbit would have 50% of its genes in common with its dam, since it received half of its inheritance from its dam at the time of fertilization. As the number of generations in the pedigree increases between a rabbit and one of its ancestors, the percentage of genes in common with that ancestor decreases proportionally at the rate of one-half per generation $[(1/2)^{n}$, where n stands for the number of generations]. For example, an individual is related to its sire by 50% $[(1/2)^{1}]$, its grand-sire by 25% $[(1/2)^{2}]$, and its great-grandsire by 12.5% $[(1/2)^{3}]$. First cousins share the inheritance from one set of grandparents, and double first cousins by a replication of the same set of grandparents. Quantitative procedures for calculating genetic relationships are given in Bourdon's text *Understanding Animal Breeding* (see "Further Reading" at end of this chapter).

RABBIT RESEARCH AND TEACHING PROGRAM

TEXAS A&M UNIVERSITY-KINGSVILLE

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PEDIGREE FOR – Caesar V R356
DOB –4–23–2011
BREED - NZW
SEX - Buck

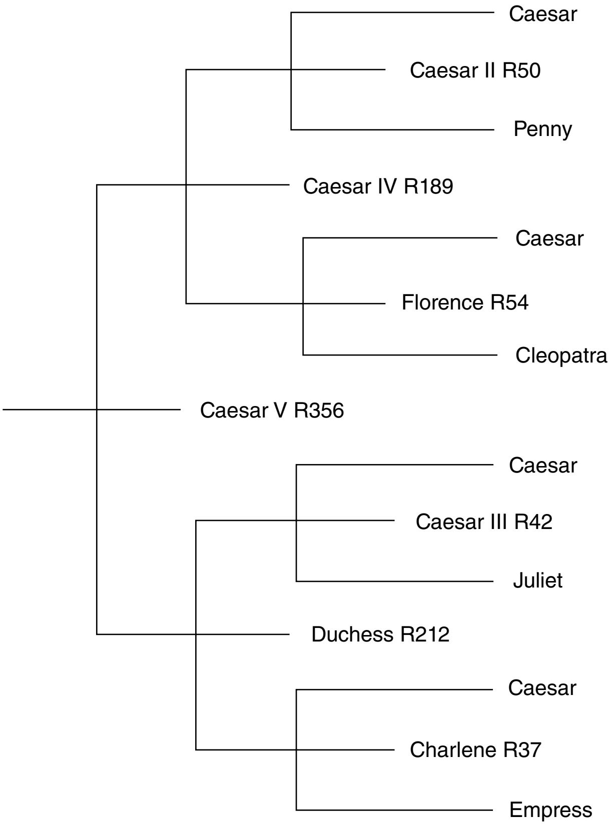

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Fig. 14.2. An example of a typical bracket pedigree. (Courtesy of S.D. Lukefahr)

Inbreeding

Inbreeding is the mating of individuals more closely related than the average of the population. Brother x sister (full sibs) and sire x daughter (progeny) matings are examples of close inbreeding. In fact, the degree of genetic relationship is 50% for both types of relationships.

Table 14.1. Genetic relationships between specific relatives.

Type of family relationship	Genetic relationship
Parent–offspring	50%
Brother–sister (full sibs)	50%
Quadruple great-grandparent–great-grand-offspring (e.g. Caesar, Fig. 14.1)	50%
Half-brother–half-sister (half sibs)	25%
Uncle–niece, uncle–nephew	25%
Aunt–niece, aunt–nephew	25%
Double first cousins	25%
Grandparent–grand-offspring	25%
First cousins	12.5%

Matings of lesser related relatives, such as grandsire x granddaughter or first cousins, in an attempt to concentrate the genes of a superior ancestor is a mild form of inbreeding called linebreeding, to be discussed more in the next section. The genetic effects of inbreeding and linebreeding are similar, although more extreme in the case of inbreeding. Under certain conditions, inbreeding can be invaluable to both commercial and fancy breeders. The main genetic reasons for inbreeding are:

1. To increase the level of homozygosity.
2. To aid as a test for screening carriers of undesirable recessive genes.

As the level of homozygosity is increased, alleles of each gene pair (one allele is derived from each parent) become concentrated or fixed through inbreeding. In other words, by mating a sire to his daughter, many of the same genes from the sire become concentrated or made homozygous in paired units in the inbred offspring. As the rate of homozygosity increases through inbreeding, heterozygosity decreases in a proportional manner. In addition, the inbred offspring are more homozygous and are more genetically uniform. Potentially, the initiation of applied inbreeding within a rabbit population in time creates distinct genetic lines, each line consisting of individuals with a close resemblance. Hence, the base population becomes subdivided into small lines as the level of homozygosity rises with each successive generation. Such a cumulative rise in homozygosity – more gene pairs becoming concentrated in the homozygous state – occurring within each inbred line is conversely resulting in a cumulative decline in the number of heterozygous gene pairs present.

The challenge for the breeder is to identify accurately those developing inbred lines that possess the desired set of superior performance or display characteristics. This is best achieved through strict culling and/or elimination of inferior inbred families or lines. Naturally, lines possessing a preponderance of unfavorable genes in the homozygous state will be less vigorous, resulting in lowered productivity. Alternatively, those inbred families or lines composed of individuals that possess an accumulation of desirable genes fixed in the homozygous state not only will permanently retain their superiority for traits selected but also will consistently transmit such superiority to their offspring. This phenomenon is referred to as prepotency. It should be mentioned, however, that even in the best lines of inbred stock, individuals may show somewhat less vigor in terms of health and reproductive-related performance than non-inbred individuals. This is referred to as inbreeding depression. Therefore, inbred stock generally require better management and protection from unfavorable environmental conditions. Reports of research on inbreeding of rabbits are scarce in the genetics literature. Two studies in Brazil reported a large decrease in body weight at 70 days and in total 21-day weight of the litter (a reflection of the milking ability of does) as inbreeding increased by 10% relative to non-inbred rabbits.

From a commercial standpoint, the primary advantage of producing inbred lines is for crossing purposes. Through crossing of unrelated inbred lines, the general result of vigorous and productive and more profitable hybrid stock is expected. For example, in the commercial poultry industry, inbred lines of superior stock are formed with the intended purpose of ultimate crossing. This approach has successfully resulted in the advent of the technologically advanced hybrid broiler and layer industries of today. Geneticists employed by breeding companies develop the inbred lines for crossing or hybridization. Commercial producers obtain the test-proven hybrid bird produced by the breeding companies. Such a sophisticated breeding approach is certainly possible for the commercial rabbit industry and has already been adopted in Europe and in China.

As a means of screening for carriers of undesirable recessive genes, inbreeding is a most effective breeding tool. The presence of an undesirable recessive trait, such as yellow fat in commercial meat stock, can be a serious problem. Through inbreeding, alleles become homozygous at a higher rate, so undesirable recessive genes become exposed and expressed phenotypically. Examples of several undesirable simply inherited genetic conditions (mostly due to recessive genes) are provided in Table 14.2. The reader should be aware that there can be several different genes or alleles involved in the same condition (e.g., buck teeth, dwarfism, and furless) and that not all undesirable genes involve recessives.

For example, a brother and a sister (full sibs) may both be carriers of the spina bifida gene (sb), but neither may ever produce a defective offspring when unrelated matings are involved. This is because expression of the sb allele is masked by its dominant counterpart. However, when these carriers are mated together, one-quarter of their offspring will be affected on average. Close test-matings involving full sibs, half sibs, and sire x daughter or dam x son progeny are most appropriate, because these close matings increase the probability or chances of expression of the homozygous recessive. This way, the breeder will know what undesirable recessive genes exist in their herd.

Another effective strategy is to mate either a confirmed carrier or an individual that is homozygous for the undesired condition, e.g., long wool growth, to a suspected carrier individual. In the latter test-mating of homozygote x suspected heterozygote, one-half of the offspring may be affected on average. In either case, at least eight normal offspring from the same or repeat test-mating should be scored before the breeder declares a previously suspected carrier not to be a carrier. Such planned matings are most useful to producers who want to ensure their stock is proven free of genetic defects.

Table 14.2. Some simply inherited genes expressed in the rabbit.

Locus	Alleles	Condition
Achondroplasia	ac	Shortening of limbs
Ataxia	ax	Loss of body coordination
Brachydactyly	br	Lack of nails, digits, limbs
Bupthalmia	bu	Similar to human glaucoma
Dachshund anomaly	Da	Form of dwarfism
Dwarf	Dw	Dwarf, hormonal deficit
Furless	nk	Fur is mostly lacking
Hemolytic anemia	ha	Hemoloytic anemic condition
Hypogonadia	hg	Underdeveloped testis and ovaries; sterility
Hydrocephalus[1]	hy	Hydrocephalus (“water on the brain”)
Hypogonadia	hg	Absence of sperm and ova (sterile)
Mandibular prognathism	mp	Malocclusion, or “buckteeth,” probably polygenic
Osteopetrosis	os	Fragile bones
Tremor paralysis	pt	Nervous disorders, sex-linked condition
Red eye	re	Red eye color
Spina bifida	sb	Spina bifida
Yellow fat	y	Yellow fat deposition

Information is from various sources. [1]Hydrocephalus may also be caused by a deficiency or surplus of dietary vitamin A.

For large-scale commercial production of meat rabbits, systematic use of inbreeding and outcrossing could be adopted. Such a system is called topcrossing. Since a high state of vigor is desirable in breeding does, it is considered best that they be crossbred or outcrossed (defined as the crossing of breeds or of lines of the same breed) through the crossing of superior inbred parental breeds or lines. However, since bucks represent a smaller proportion of the breeding herd, it may be economically feasible to create inbred lines to produce inbred herd bucks to mate to unrelated does, preferably of a different breed or linecross. Select, improved, inbred sires should produce more thrifty, more uniform, and higher-performing market rabbits than non-inbred sires originating from a common base population. This is to be expected for two reasons:

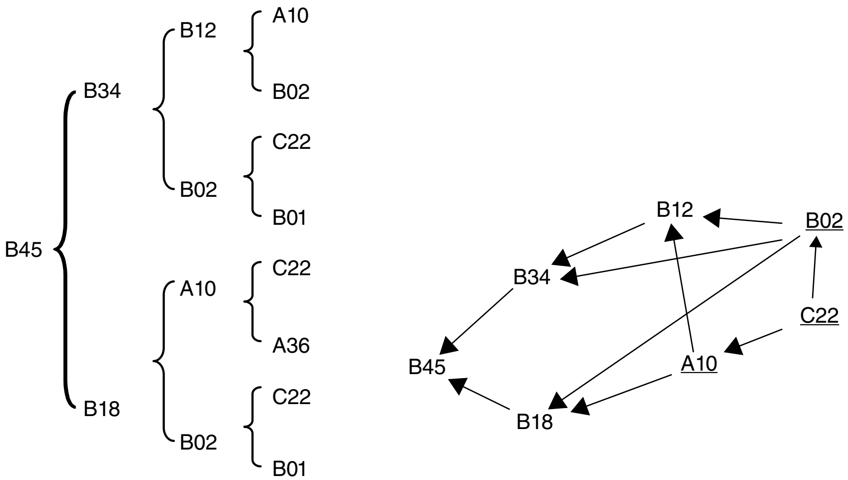
1. A relatively high proportion of gene pairs is in the heterozygous state in the progeny; therefore, expression of any less favorable recessive alleles is masked by their dominant allelic counterparts.
2. Consistent transmission of superior genes from the inbred sire to the progeny is achieved (due to the sire's high level of homozygosity).

Obviously, only experienced commercial rabbit breeders with a thorough knowledge of genetics, a large herd, and an accurate record-keeping system should consider using such an inbreeding–outcrossing breeding system. For most rabbit breeders such a program would be impractical. Furthermore, reduced reproductive and health-related performance within inbred lines may be discouraging.

Linebreeding

Linebreeding is an attempt to preserve or increase the genetic influence of a superior common ancestor through mating of less closely related individuals in a herd. A common ancestor appears on both sides of a pedigree such that both the sire and dam are related. Linebreeding is a mild form of inbreeding and typically involves purebred animals. Examples of less closely-related matings would be individuals with a common grandsire, granddam, great-grandsire, great-granddam, etc. A superior rabbit might be a grand-champion with excellent show table qualities or a commercial herd sire with a progeny average of 2.0 kg (4.4 lb) at eight weeks of age. Linebreeding continues to be valuable after the superior ancestor is dead, since its genes can still be concentrated through the matings of its relatives. The purebred pedigrees in Fig. 14.1 and Fig. 14.2 illustrate the use of linebreeding with pedigree styles commonly used by breeders and geneticists alike.

In this pedigree, Caesar is a grand-champion buck as well as a common ancestor. Caesar, the great-grandsire of Caesar V, appears four times in the pedigree. Caesar could be called the "quadruple great-grandsire" of Caesar V. The parents of Caesar V likewise have Caesar as their double grandsire. The genetic relationship between Caesar and Caesar V is approximately 50%, which is equivalent to stating that, on the average, one out of every two genes is shared between Caesar to Caesar V. If, on the other hand, Caesar had appeared only once in this pedigree (as a single great-grandsire), his average relationship to Caesar V would have been only 12.5%. Caesar V's genes have thus been concentrated four-fold without causing intense inbreeding depression. This is because Caesar is found farther back in the pedigree such that parents are less-closely related. The parents of both Caesar IV and Duchess are all paternal half-siblings with Caesar as their sire. As a result, Caesar V is inbred by 12.5% compared to 25% if Caesar instead had been the sire of Duchess. These numeric values reflect the average level of increased homozygosity. This example demonstrates how linebreeding concentrates genes of superior ancestor(s) but minimizes the level of homozygosity. The next pedigree represents the use of linebreeding in a commercial herd (Fig. 14.3). In this pedigree, three common ancestors appear: they are A10, B02, and C22. In the more condensed arrow-style pedigree it can be observed that arrows point away from the common ancestors for more than one path (generation), which is the direction of gene transmission from ancestor to progeny. Ancestors that appear on both sides of a bracket-style pedigree but not in an arrow-style pedigree are not common ancestors.



Bracket-style

Arrow-style*

*Common ancestors (e.g., A10, B02, C22) are underlined.

Fig. 14.3. Illustration of linebreeding showing multiple common ancestors with bracket- and arrow-style pedigrees (common ancestors are underlined). (Courtesy of OSU Rabbit Research Center)

If commercial herd sires A10 and C22 and dam B02 are proven superior for important traits, their genes and gene combinations can be concentrated by use of a linebreeding system, as shown in Fig. 14.3. In this pedigree, three common ancestors make up the linebred individual. A detailed study of the pedigree reveals several types of family relationships. The parents of B45 are related as maternal half-sibs as they have the same dam (B02). However, they are also both related to A10 and C22. B12 was produced from a paternal half-sib mating (A10 × B02), with C22 as their sire. B34, the sire of B45, was produced from a son x dam mating (B12 × B02). To B45, C22 is related as a double paternal 2nd great-grandsire, a paternal great-grandsire, and as a double maternal great-grandsire. B18, the dam of B45, is a full sib of B12. Because B45 has related parents it is inbred. The value for the inbreeding level for B45 is 31.3%. This value would be suitable for a selected buck as a herd sire because it would be prepotent. This means that it would more consistently transmit the same desirable genes due to its increased level of homozygosity. In contrast, the 31.3% inbreeding level is too high for commercial does because, instead, hybrid vigor (associated with outcrossing) as opposed to inbreeding depression is critical to optimal performance. In addition, by tracing the pedigree back to B45's common ancestors, the direct genetic relationship to AlO and B02 is 37.5% and 62.5%, respectively. Presumably, the direct relationship of B34 to C22 is 50% due to linebreeding. Hence, this genetic relationship between B45 and C22 is genetically equivalent to that of a simple sire–offspring. In addition, genetic software programs are used by geneticists to compute genetic relationships and inbreeding levels based on pedigrees. A more recent development is the use of computer programs that involve DNA samples of individuals to determine the molecular relationships between individuals. Such statistics are more accurate than estimates based on pedigrees.

It should be stressed that, in a linebred family, strict culling of individuals with poor performance should be maintained each generation to concentrate only the genes with favorable effects in the selected individuals. The genes and gene combinations of a superior common ancestor can be maintained or increased through the mating of its descendants.

Since linebreeding is actually a mild form of inbreeding, inbreeding itself is differentiated by the mating of closely related individuals in a herd (e.g., brother x sister, sire x daughter, son x dam) and is practiced to increase homozygosity rather than to concentrate the genes of a particular ancestor. Most commercial breeders prefer linebreeding over inbreeding, because a depression in health, growth rate, and reproductive performance may be observed when intense inbreeding is practiced. This depression occurs because undesirable genes (usually recessive) become homozygous or concentrated quite rapidly and, as a result, overall vigor is reduced. Linebreeding lessens this effect, although it still occurs at a milder rate. Strict culling of individuals with lower performance or expression of specific undesirable genes is critical to prevent the spread of undesirable genes whenever inbreeding or linebreeding is used. Select only the best!

It is imperative that the common ancestry or "family lineage" be indeed superior, as proven by accurate records, if it is to be preserved genetically through linebreeding. A relatively moderate to large base number of breeding animals (50 or more) within a linebred strain is essential to avoid intense inbreeding and/or to maintain genetic variation for traits of economic importance. It is wise to use several outstanding sires in a line in order to secure such genetic variation. Genetic variation and strict selection and culling are key components that will ensure the superior breeding merit of a linebred strain.

Outcrossing

Outcrossing is the mating of unrelated individuals or lines within the same breed (linecrossing). Technically, outcrossing also includes crossbreeding, which is the mating of different breeds (covered in the next section). Under several conditions, outcrossing is a good breeding option to consider. A few examples are:

1. When a genetic defect appears (e.g., malocclusion or yellow fat).
2. When the overall fitness or vigor of a line declines because of mild or intense inbreeding.
3. When the genetic quality or performance for a trait or traits is less than desired in a line.

The first example applies when a line of rabbits is known to transmit defective genes. It is generally advised that offspring from this line should not be saved as replacements (which is a most effective way of "weeding the genetic garden"). Often it is economically desirable to keep the "genetic carrier" parent breeders in the herd until their productivity declines. Through outcrossing, both objectives are met; the likelihood of further occurrence of the abnormality is decreased, and the breeders remain in the herd until unrelated young stock are available to replace them from other lines. To reiterate, no offspring should be saved from carriers of detrimental genes (e.g., hydrocephalus, malocclusion and spina bifida) unless they are test-mated and produce no defective offspring. A further discussion on selecting against deleterious recessive traits is presented in the section on the selection of qualitative traits in Chapter 15.

As stated previously, overall fitness or vigor generally declines eventually as a result of increasing the proportion of homozygous genotypes in a line or inbred strain through mild or intensive inbreeding. Outcrossing, on the other hand, reverses this trend by increasing the proportion of heterozygous gene pairs in the progeny. This effect will in itself restore physical vigor, because the expression of defective recessive genes is masked by dominant genes. It should be clearly recognized that undesirable genes affect not only qualitative traits, such as spina bifida, but quantitative traits, such as fertility and growth, as well. In commercial Leghorn chickens, hens are typically a linecross.

Genetic quality of a line may be considered inferior for one or several traits through inbreeding and/or a limited number of rabbits making up a line or a poor initial stock base. Flat shoulders, protruding hipbones (evidence of a narrow loin), and poor flesh covering over the rump or hindquarters may be a consistent weakness in a line. Within-line selection gives extremely slow improvement for these characteristics if genetic merit is poor and limited numbers are involved. By outcrossing several members of such a line to an unrelated line that exhibits excellent qualities for these traits, the line weaknesses can be quickly overcome. This is the process of upgrading a line within the same breed. Once an improved state has been reached, the line can be re-established through linebreeding if desired. Skilled breeders use both outcrossing and linebreeding over two or more generations to systematically introduce and concentrate superior genes.

The pedigree shown in Fig. 14.4 is representative of an outcrossed mating. Note that both the sire and the dam of rabbit XY0l are linebred, although to different ancestors (X10 and Y42). This is an outbred or linecross mating, since no relatives of rabbit XY01 are found on both sides of the pedigree (sire and dam sides). Suppose that this pedigree came from a commercial herd in which line X possesses excellent growth characteristics, but has poor texture and density of fur, as well as thin foot pads that make X susceptible to sore hocks. Line Y does not have the genetic growth merit of line X but it possesses excellent texture and density of fur and has thick foot pads. By crossing lines X and Y (outcrossing) the growth characteristics and fur qualities of the progeny should be above the average of both parental lines.

Outcrossing in the form of linecrossing may be the best breeding system for commercial producers who raise only one breed. Because masking of undesirable recessive genes and improved genetic merit may occur when outcrossing is properly practiced, improved breeding and growth vigor should increase performance and profits. A commercial breeder can expect to see a noticeable improvement in both vigor and performance of outcrossed compared to linebred or inbred stock, especially for health- and fertility-related traits, since these are, in general, more affected by undesirable recessives.

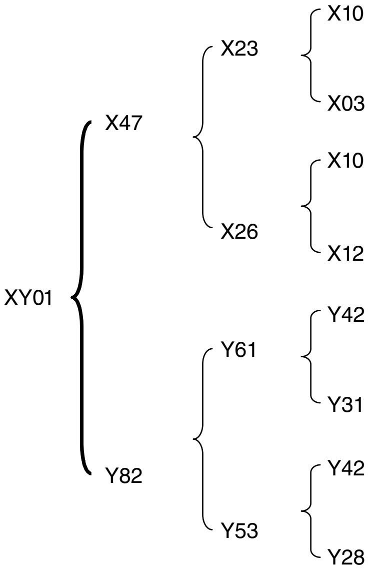


Fig. 14.4. A bracket-style pedigree of an outcrossed rabbit. An arrow-style pedigree cannot be drawn, since no common ancestor of XY01 appears on both the sire side and the dam side of the pedigree. (Courtesy of OSU Rabbit Research Center)

Crossbreeding

Crossbreeding is the mating of individuals of different breeds. It differs from linecrossing, which is the mating of unrelated individuals from different lines within the same breed. Although the genetic effects are similar for the two systems, the positive effects are more pronounced when crossbreeding is practiced. The major genetic effects of crossbreeding are:

1. To increase the level of heterozygosity or hybrid vigor.
2. To mask the expression of detrimental recessive genes.

Hybrid vigor

Heterozygosity is the term given to the degree to which one or several allelic pairs contain dissimilar genes. Because half the inheritance is derived from each parent, the level of heterozygosity of the offspring increases as the genetic relationship between the parents decreases. This concept applies to individuals of the same breed or of different breeds. Logically, a crossbred individual would have, on average, a higher level of heterozygosity than a purebred, since individuals of the same breed have more genes in common in the homozygous state. Hybrid vigor (heterosis) is the increase in fitness or productivity of crossbred or outcrossed offspring above the average of the parental breeds or lines that is due to the increased heterozygosity of the offspring. Dominance and favorable epistatic (i.e., favorable gene combinations) forms of gene action contribute to heterosis. The term “vigor” is commonly used to refer to health and reproductive traits.

Traits that may be significantly affected by hybrid vigor are litter size, conception rates, and growth traits. Hybrid vigor, or heterosis, is generally highest for reproductive and survival traits, intermediate for growth and feed efficiency, and lowest for carcass quality traits (Table 14.3). Numerous studies have demonstrated crossbred superiority above the average of parental breeds (hybrid vigor) for many commercially important traits. Rabbit breeding farms producing commercial hybrid stock are widespread in Europe and China. Hybrid vigor is also seen in other meat animal species (e.g., beef cattle, lambs, poultry, and swine) in which the vast majority are crossbred because of the economic benefits associated with the genetic effects of crossbreeding.

Crossbreeding and linecrossing increase the level of heterozygosity, thus masking the expression of detrimental recessive genes. This alone is the means by which gene pairs that may have been previously homozygous in the purebred parental generation become heterozygous in the crossbred generation (F_1 generation). Many traits are unfavorably affected by recessive genes that are expressed in the homozygous state. Crossbreeding tends to prevent their expression by substituting a favorable dominant gene for an undesirable recessive gene, thus altering gene pairs from the homozygous to the heterozygous state. However, it should be emphasized that dominant genes are not necessarily all good and recessive genes are not necessarily all bad. There are always exceptions when it comes to genetics. Because hybrids show increased vigor, greater uniformity in performance is usually expected in crossbred animals in the F_1 generation. Consequently, vigor, especially health and fertility, is improved. Growth-related trait performances also tend to be improved in crossbred animals.

Table 14.3. Levels of hybrid vigor for commercial traits in rabbits.[1]

Trait	Hybrid vigor in crossbred litters (%)	Hybrid vigor in crossbred dams (%)
Conception rate	_[2]	7
Litter size born	8 3	11
Longevity	_[2]	13
Milk production	_[2]	10
Litter size at 28 days	15 4	12
Litter weaning weight	11 8	11
Individual weight:		
56 days	2	1
70 days	4	_[2]
Litter weight at 56 days	5	6
Dressing percentage	1	2
Meat yield from carcass	1	1

[1] Heterosis estimates are from various literature sources.

[2] No estimate made.

To benefit from hybrid vigor in a commercial herd, breeders should follow several guidelines closely:

1. Obtain the best purebreds to produce hybrids.
2. Combine strengths of breeds systematically in a crossbreeding program.
3. Utilize hybrid vigor expressed by the dam and the offspring.

Logically, the best commercial hybrids are derived through the planned mating of the best purebreds. Of course, some lines of the same pure breed are more outstanding than other lines. Indiscriminate mating of arbitrarily chosen breeds (lines) to produce crossbreds is a way to generate poor-quality stock. The best purebreds would be rabbits from a productive line with proven records for traits such as fertility, milking ability (estimated by recording 21-day total litter weights), health, and weight of rabbits marketed.

Breed complementation

An example of optimal utilization of the breeds in a crossbreeding program would be to mate crossbred does of excellent maternal breeds (which produce many large litters and a good supply of milk) to bucks of another breed known for superior post-weaning gains, feed efficiency, and carcass merit. Whatever breed combinations are employed, the end goal should be to profitably produce marketable rabbits of good quality by eight to nine weeks of age.

The doe as well as the offspring should be crossbred to maximize the benefits of hybrid vigor. More specifically, a crossbred doe should have higher fertility, should produce larger litters and more milk, and should last longer in the herd than the average of the parental purebreds involved in the cross. Such an added effect expressed by hybrid does is called maternal heterosis. This is seen when the performance of Californian x New Zealand White does is compared to either purebred (Table 14.4). Offspring have more rapid gains because of the better mothering ability and milk production of their crossbred dam. If only one superior breed is available, then outcrossing of lines within the superior breed is recommended.

To produce does that are crossbred, it is best to choose breeds known for excellent fertility and mothering ability. A crossbred doe could then be mated to a buck of a third breed, preferably a fast growing and thrifty breed (Fig. 14.5). To capitalize on the vigor, it is best to market all of the three-breed cross offspring, since uniformity and profitability of production is greatest. Such a crossbreeding system is called a three-breed terminal cross. If the best maternal source available is a purebred, mating to a sire of another breed would produce what is called a two-breed terminal cross (Fig. 14.6). Replacements are generated through the mating of purebred parental lines. Actually, only a small proportion of the breeding rabbits in a herd would need to be purebred in order to sustain a predominantly crossbred operation. The purebred animals could also be purchased from a reputable seedstock producer. The rabbit producer must consider the material and financial resources available before engaging in such an endeavor.

A recent development in the rabbit meat industry is the utilization of large sire breeds, such as the Altex (Fig. 14.7) developed at Alabama A&M University and Texas A&M University-Kingsville. The breed was developed by crossing high-quality, purebred Californian (CAL), Champagne D'Argent (CHA) and Flemish Giant (FG) rabbits. The final composition of the Altex is ½ FG, ¼ CHA and ¼ CAL. These three breeds were included to provide sire traits, i.e., rapid and efficient body weight gains, high dressing percentage, and high meat-to-bone ratio. The Altex bucks are used on New Zealand White does (for their mothering ability) or on Californian x New Zealand White to provide

Table 14.4. Purebred and crossbred doe performance for reproductive traits.

Trait	CAL[1]	NZW	CAL × NZW
Experiment 1			
Conception rate (%)	70.5	64.1	71.8
Litter size born	8.0	8.9	10.6
Daily milk production (g (oz))[2]	145.7 (5.14)	189.0 (6.67)	191.9 (6.77)
Litter 21-day weight (kg (lb))	2.07 (4.56)	2.72 (6.00)	2.70 (5.95)
Litter size at 28 days	5.9	6.9	7.9
Litter weaning weight (kg (lb))	2.55 (5.62)	3.66 (8.07)	3.73 (8.22)
Experiment 2			
Fur weight of nest (g (lb))	11.8 (0.026)	18.0 (0.040)	16.1 (0.035)
Kit survival at birth (%)	87.6	89.5	91.2
Litter size at 28 days	6.1	7.2	7.0
Litter weaning weight (kg (lb))	3.01 (6.64)	3.64 (8.02)	3.69 (8.14)

[1] Doe breed group abbreviations: CAL = Californian; NZW = New Zealand White; CAL × NZW = Californian sire × New Zealand White dam. Note: Studies were all conducted in the U.S.

[2] Daily milk production was measured from 1 to 21 days.

Source for Experiment 1:

Lukefahr, S.D. 1983. Evaluation of rabbit breeds and crosses for overall commercial productivity. Ph.D. dissertation, Oregon State University, Corvallis.

Sources for Experiment 2:

Hamilton, H.H., S.D. Lukefahr, and J.I. McNitt. 1997. Maternal nest quality and its influence on litter survival and weaning performance in commercial rabbits. *J. Anim. Sci.* 75: 926–933.

Khan, M.A., and S.D. Lukefahr. 1996. Breed type comparisons for postweaning litter traits in rabbits. In: *Proc. 6th World Rabbit Congress,* Toulouse, France. 2: 299–304.

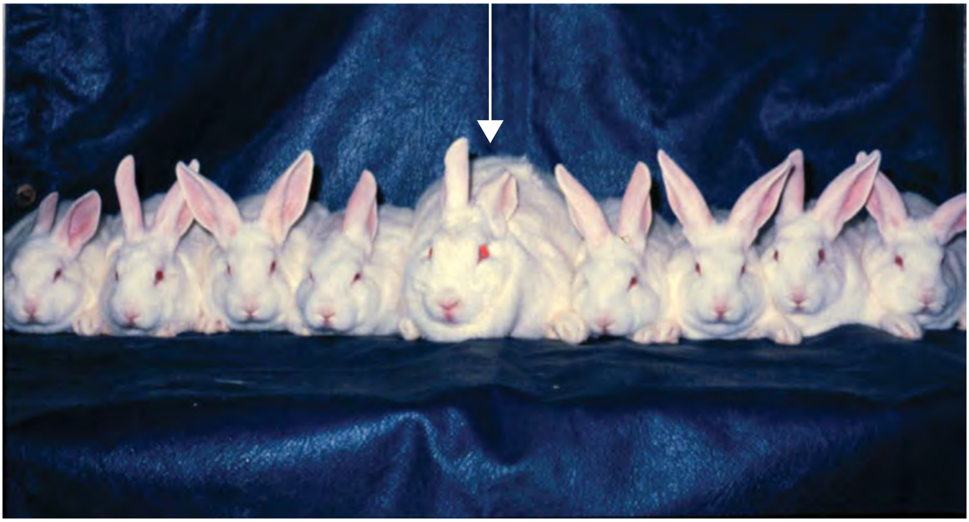


Fig. 14.5. A three-breed terminal cross. The doe (arrow), a Florida White × New Zealand White hybrid, was bred to a white Flemish Giant buck to produce the terminal-cross litter. (Courtesy of OSU Rabbit Research Center)

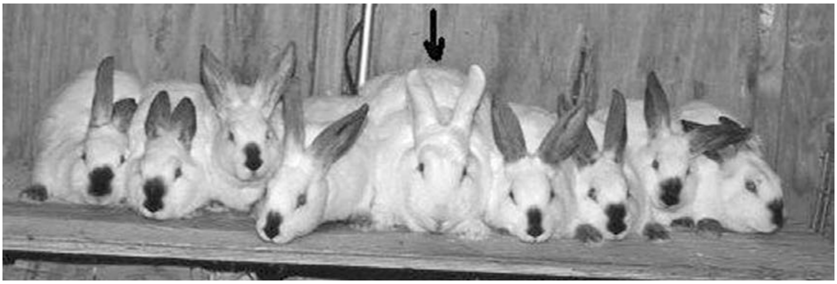


Fig. 14.6. A two-breed terminal cross. The offspring were produced by mating a Californian buck to a New Zealand White doe (arrow). (Courtesy of OSU Rabbit Research Center)

terminal cross fryers. In one experiment involving 460 litters, the purebred New Zealand White fryers averaged 1.83 kg (4.03 lb) at 70 days whereas the Altex x NZW crossbred fryers averaged 2.05 kg (4.51 lb). Large sire breeds or lines are crossed with commercially suitable doe breeds to produce terminal crossbred fryers (Fig. 14.8).

Results from several breeding experiments conducted in the U.S. are provided in Table 14.5. Generally, market weights are heavier in fryers sired by a large breed or line. Thus, the fryers can either be marketed earlier or be sold at the heavier market weight. The market weight improvement through judicious crossbreeding is referred to as breed complementation. This

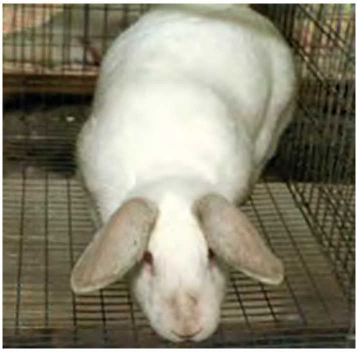


Fig. 14.7. An Altex buck. This breed was developed at Alabama A&M University and Texas A&M University-Kingsville. (Courtesy of S.D. Lukefahr)

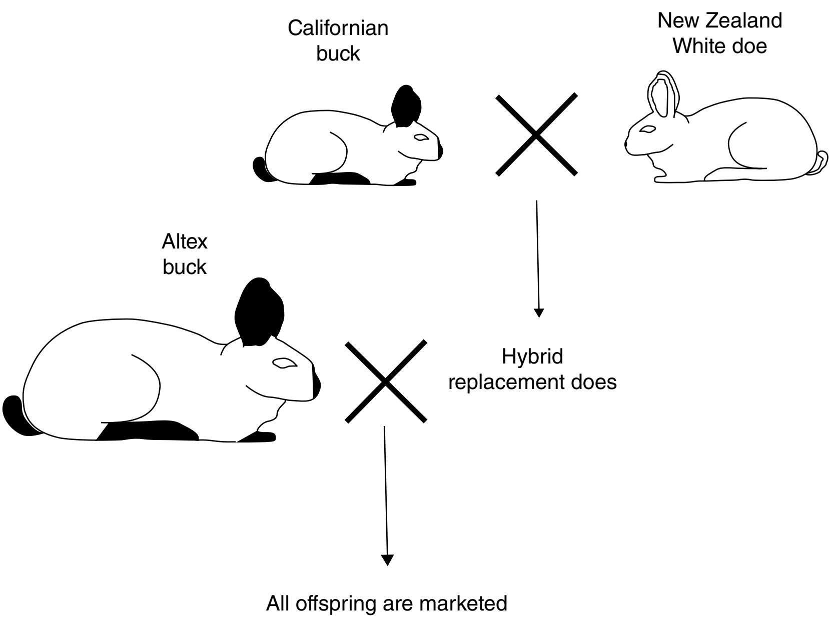


Fig. 14.8. A three-breed terminal cross. (Courtesy of OSU Rabbit Research Center)

means the superior genes for growth characteristics of the buck, complemented by the excellent genes for maternal qualities of the doe, lead to faster and more efficient growth. The studies shown in Table 14.5 also reveal that dressing percentages and meat-to-bone ratios are comparable to those of purebred New Zealand White commercial fryers.

Another system of crossbreeding, which is particularly popular in modern swine breeding, is rotational crossing, in which purebred males are mated with crossbred females. Each purebred sire breed is alternated (rotated) between successive generations. Two or more sire breeds may be involved in a rotational crossbreeding scheme (Fig. 14.9). The major advantages of this system are that female replacements are produced from crossbred dams, and both the dams and their progeny express hybrid vigor. Since the original pure breeds (possessing genes for high maternal qualities) are continually introduced, hybrid vigor level would be less than that for a first-generation (F_1) crossbred because the animals are not fully crossbred. A sufficient number of purebred animals would be needed only to yield purebred males for crossbreeding. These bucks could be purchased from a reputable breeder so all cages could be used for crossbred litter production. Rotationally crossbred does could also be mated to a large sire breed to produce a three-breed terminal cross.

New Breed Development

The development of new breeds is a regular activity in the livestock industry. In many cases the justification is to develop a new breed with the genetic qualities that are not found in present breeds. In fact, in the livestock industry most breeds were developed from a cross of two or more breeds that combined genes for a set of desired traits. Moreover, in the livestock industry, specialized dam and sire breeds exist which are crossed to produce more profitable crosses. As previously stated, dam breeds possess genes for maternal traits (e.g., litter size, milking ability, and longevity) while sire breeds possess genes for sire traits (e.g., growth rate, feed efficiency, and carcass yield). To illustrate, the example of the development of the Altex, a commercial sire breed, will be provided as previously described.

Table 14.5. Large- and medium-size sire breed performance for fryer traits.

Fryer breed type[1]	Market weight (kg (lb))	Feed:gain ratio	Dressing percentage	Meat-to-bone ratio
Experiment 1 (1983)				
NZW purebred[2]	1.65 (3.64)	3.02	50.4	3.12
FG purebred	1.74 (3.84)	3.09	52.0	3.24
FG × (FW × NZW)	1.67 (3.68)	3.24	52.6	4.23
Experiment 2[3] (1983)				
CAL-sired	1.35 (2.98)	4.59	54.5	4.02
NZW-sired	1.44 (3.17)	4.36	53.4	3.75
FG-sired	1.58 (3.48)	4.00	54.0	3.61
Experiment 3 (1991)				
CAL purebred	1.97 (4.34)	3.92	55.8	4.81
NZW purebred	1.95 (4.30)	3.30	53.9	4.12
CAL x NZW	2.08 (4.59)	3.69	55.4	4.45
Altex	2.19 (4.83)	3.21	54.7	4.32
Experiment 4 (1992)				
CAL x NZW	1.95 (4.30)	3.75	54.7	4.09
NZW purebred	1.91 (4.21)	3.60	52.4	3.81
CHA x NZW	1.98 (4.37)	3.84	56.3	4.35
PAL x NZW	1.86 (4.10)	3.78	54.9	3.93
Experiment 5 (2001)				
Altex purebred	2.00 (4.41)	3.04	–[4]	–[4]
Altex × NZW	2.05 (4.52)	3.41	–[4]	–[4]
NZW × Altex	1.94 (4.28)	3.42	–[4]	–[4]
NZW purebred	1.83 (4.03)	3.55	–[4]	–[4]

[1] Experiments 1 and 2 involved 56-day-old fryers, and experiments 3, 4, and 5 involved 70-day-old fryers. Note: In these experiments, because breeds were being evaluated there was no crossfostering of kits to standardize the litter size.

[2] Breed group abbreviations: CAL = Californian; NZW = New Zealand White; FG = Flemish Giant; FW = Florida White; CHA = Champagne d'Argent, and PAL = Palomino.

[3] CAL, NZW, and FG bucks mated to CAL, NZW, CAL × NZW, and NZW × CAL does.

[4] Data not available.

Source for Experiments 1 and 2:
Lukefahr, S.D. 1983. Evaluation of rabbit breeds and crosses for overall commercial productivity. Ph.D. dissertation, Oregon State University, Corvallis.
Source for Experiment 3:
Ozimba, C.E., and S.D. Lukefahr. 1991. Comparison of rabbit breed types for postweaning litter growth, feed efficiency, and survival performance traits. *J. Anim. Sci.* 69: 3494–3500.
Source for Experiment 4:
Roberts, J.D., and S.D. Lukefahr. 1992. Evaluation of Californian, Champagne d'Argent, New Zealand White and Palomino as potential sire breeds. I. Postweaning litter traits. *J. Appl. Rabbit Res.* 15: 274–286.
Source for Experiment 5:
Medellin, M.F., and S.D. Lukefahr. 2001. Breed and heterotic effects on postweaning traits in Altex and New Zealand White straightbred and crossbred rabbits *J. Anim. Sci.* 79: 1173–1178.

In the U.S., although many breeds of rabbit are found, most are bred for show. None are large with a desirable meat-type conformation. In the mid 1980s at Alabama A&M University, geneticists crossed two medium-sized meat breeds (Californian and Champagne D'Argent) with the Flemish Giant. While certainly large in body size and possessing genes for rapid post-weaning growth and high feed efficiency, the Flemish Giant was lacking in desirable meat type. Two F_1 stocks (Flemish Giant) were developed, which were then crossed to produce an F_2, foundation population of rabbits that had the breed composition of ½ Flemish Giant, ¼ Californian, and ¼ Champagne D'Argent (Fig. 14.10). In this generation, all genes existed for a set of desirable traits. The breeding objective was to develop a new

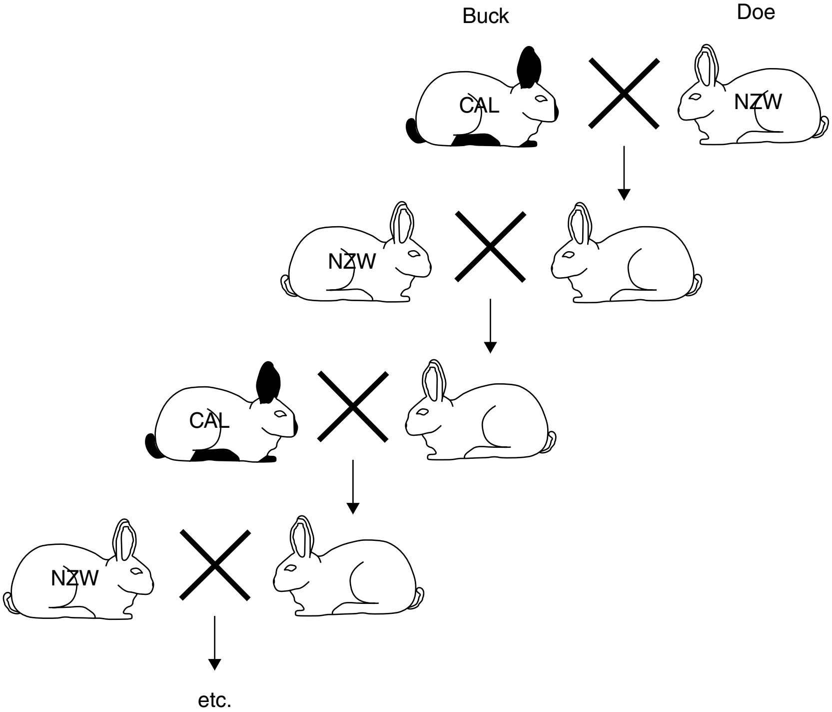


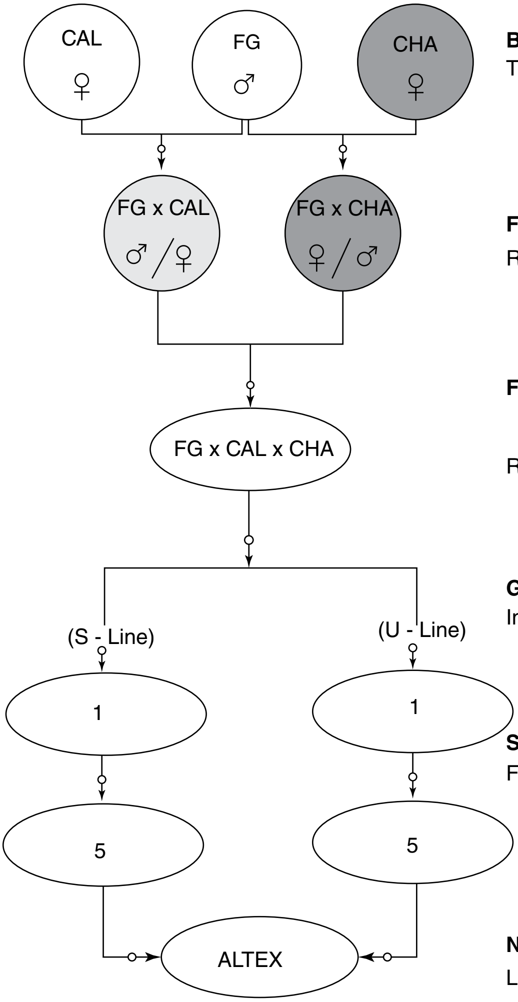
Fig. 14.9. A two-breed rotational crossbreeding system where the best does are saved as replacements. All bucks are marketed. (Courtesy of OSU Rabbit Research Center)

commercial sire breed that would transmit genes for rapid growth and high carcass yield. Ultimately, bucks of the new sire breed would be mated to predominantly purebred New Zealand White does to maximize both performance and heterosis expression in the terminal-cross fryers to increase profits. ("Terminal" again means that all offspring (bucks and does) are marketed.)

The next stage randomly separated the F_2 population into two lines: select and control. The control line involved no selection so that genetic progress could later be determined between the select and control lines. In the select line there was intense selection practiced for five generations for rabbits with the heaviest body weights at 70 days of age (Fig 14.10). Results showed that, after five generations of selection, average performance of select compared to control line rabbits for 70-day body weight was 2.21 and 2.09 kg (4.87 and 4.61 lbs). Because of positive correlations, genetic progress for 70-day body weight also occurred for the percentage of the loin primal cut (relative to total carcass weight) and lean-to-bone ratio of the loin primal cut (averages in generation five were 20.7% and 9.3%, respectively). In 1994, select line rabbits were moved to the rabbit program at Texas A&M University where continued selection was practiced for several more generations. Later the new breed would be called the Altex. As previously stated, in a subsequent experiment, purebred New Zealand White fryers averaged 1.83 kg (4.03 lb) for body weight at 70 days, whereas the Altex sire x NZW dam crossbred fryers averaged 2.05 kg (4.51 lb). Basically, the terminal-crossbred fryers could be marketed one week earlier than purebred NZW fryers.

Random Mating

The breeding systems discussed so far can effectively alter the genetic make-up of a rabbit population. In these breeding systems some



BREEDS
Three Breeds:
Flemish Giant (FG) - Sire source
Californian (CAL) and Champagne d' Argent (CHA) - Dam sources

F_1 LINES
Reciprocal crossing of F_1 lines

F_2 POPULATION
(½ FG: ¼ CAL: ¼ CHA breed composition)
Random differentiation into two closed lines: selected (S) and unselected (U)

GENERATION 0
Initial parental generation without selection

SELECTION
Five generations of intense selection for 70-day body weight in S line

NEW BREED DEVELOPMENT
Linecrossing of S and U to expand genetic base - final stage in development of the Altex breed

Fig. 14.10. A schematic representation of the breeding plan leading to the development of the Altex commercial sire breed. (Courtesy of S.D. Lukefahr)

form of selection or non-random grouping, as a basis for assorting parents to produce offspring in the next generation, is involved. In certain situations, however, it may be preferred to maintain genetic variation found in a stock line rather than to alter it. This can be achieved by practicing random mating within the line of a breed as a breeding system. Random mating is practiced when any individual, regardless of its genotype, has an equal chance of mating with any other individual. Following a single generation of random mating in a large population, all subsequent generations will possess the same genes with constant frequencies, assuming that no mutation, outcrossing, or selection occurs. Stated another way, the proportion of different types of gametes produced in a population is directly proportional to the respective gene frequencies in the preceding generation. Genes located on sex chromosomes will require several generations to achieve this constant gene frequency.

Random mating perhaps has greatest applications in laboratory rabbit lines rather than in commercial rabbit lines. For example, several different laboratory companies may choose the same genetic line of rabbits, to which similar experimental conditions or treatments are applied. Since among laboratories the same line of randomly bred stock is involved, observed genetic differences have essentially been standardized. This, in part, enhances the consistency of independent research findings. Often a computer-based software program is used by the scientist in determining random matings. For commercial breeders, random mating could be used to maintain high genetic quality in a line to which further selective improvement is not desirable. Only in rare instances, though, would this breeding option be seriously considered, since genetic improvement and profitability generally go hand in hand.

Summary

In summary, inbreeding and crossbreeding are essentially opposites in their respective genetic effects and consequences. When a producer prefers a purebred operation, inbreeding is useful in screening for carriers of undesirable recessive genes and, but only when combined with selection, in concentrating genes from superior individuals that comprise the line. Linebreeding has effects similar to but less intense than inbreeding, and is used to concentrate genes from specific individuals. Linecrossing, like crossbreeding, increases heterozygosity, but it occurs within a breed. Since there will never be a perfect breed for all traits of importance, crossbreeding is particularly useful in complementing breed strengths and in utilizing hybrid vigor to optimize herd productivity and profitability. Of course, this generally has been the rationale behind developing a new breed through crossbreeding – to combine desirable genetic characteristics from two or more breeds that are not all found in any one breed. In time, animals of a breed or line become mildly inbred since their pedigrees trace back to the same ancestral foundation. Random mating simply maintains the genetic variation that exists in a rabbit population. It is important for each rabbit breeder to use their knowledge of genetics to recognize when a change in the currently practiced breeding system is needed and decide how best to pursue improvement and/or maintenance of the genetic integrity of the stock in future generations.

Further Reading

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15

Genetic Selection for Herd Improvement

The economic success of a rabbit business depends to a large extent on the genetic quality of the herd. To improve the herd genetically, careful selection of young stock is critically important. The adage “Select the best and cull the rest” conveys the basic principle of selection. This sounds simple, but the challenge is to identify what is truly “best.” To achieve genetic improvement, specific breeding objectives must be defined. For a commercial meat herd this might be “To focus on rapid growth performance” or for an Angora herd “To increase average wool yield.” The trait(s) to be improved should be genetically transmissible (heritable) and should be ones that can be accurately measured. Selection can then be effectively pursued over several generations to genetically improve the desired traits and total herd output or productivity.

Traits or characteristics can be classified as either qualitative or quantitative. Qualitative traits, such as fur color, dwarfism, wool, and yellow fat, are influenced by one or only a few pairs of genes. Quantitative traits, such as milk production, growth rate, and carcass yield, are influenced by many pairs of genes. For some quantitative traits, hundreds of genes may be involved.

Selection for Qualitative Traits

Selection for desirable genes

Selection for a qualitative trait is a simpler and shorter process than selection for a quantitative trait. For example, white fur can easily be incorporated and maintained in a colored herd or line through the introduction of a white buck. To illustrate, the albino white buck (genetically cc) is mated to several homozygous colored does (genetically CC), where c is recessive for absence of color pigmentation (albinism) and C is dominant for full color expression. All progeny from these matings are heterozygous (Cc) and are colored. (If white progeny appear in a litter from this first-generation cross (F_1), then the dam is heterozygous for albinism.) For any F_1 progeny that are heterozygous, Cc, matings between these rabbits or rabbits from similar litters will result in progeny of which an average of 25% will be albino white (cc) (Fig. 15.1). Thereafter, mating albinos to albinos should always result in albino progeny. Another breeding adage is that “homozygotes breed true”. The qualitative trait has thus become fixed in the herd in only two generations of

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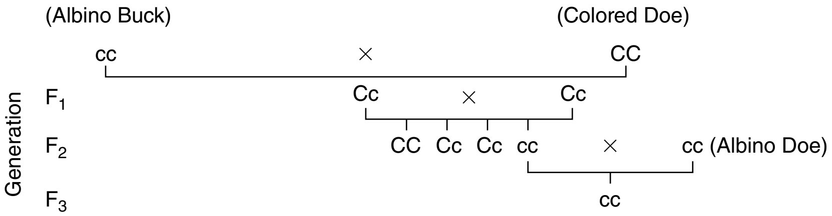


Fig. 15.1. Illustration of the incorporation of a gene for a qualitative, simply inherited trait into a herd. (Courtesy of OSU Rabbit Research Center)

planned matings involving selection for white fur. This same basic process could also be applied for producing dwarf, Lionhead, satin, or woolly varieties of rabbits.

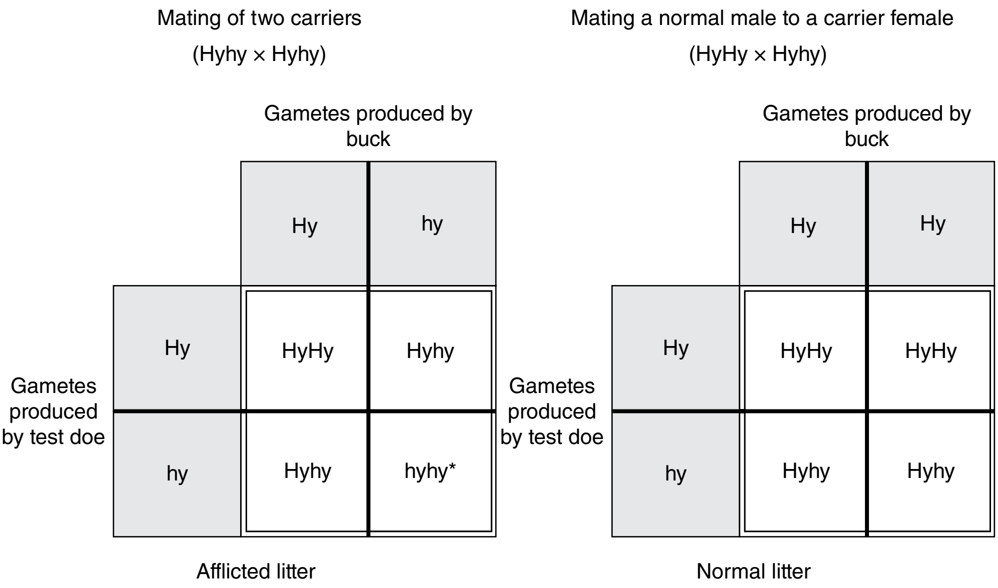
If a rabbit raiser desires to apply selection for a simply inherited qualitative trait, it is recommended that several unrelated breeding animals with the preferred trait (e.g., albinism) be introduced into the herd to avoid inbreeding and subsequent depression of reproductive, health, and growth traits in later generations. For the same reason, matings of offspring should be from different litters.

Selection against an undesirable gene

Qualitative traits are generally discrete in expression. A discrete trait occurs when a "yes" or "no" condition arises, usually with no intermediates. In other words, a rabbit is either colored or non-colored (albino), dwarfed or non-dwarfed, buck-toothed or normal-toothed, etc. One undesirable qualitative trait, hydrocephalus ("water on the brain"), affects newborn rabbits. Hydrocephalus is characterized by enlargement of the head due to excess fluid accumulation (Figs 7.4 and 15.2) and by death. Newborn rabbits can easily be scored as normal or hydrocephalic; there are no intermediates. The genetic cause of hydrocephalus is a simple recessive gene (hy). To select against this undesirable gene ("to weed the genetic garden"), breeders can use proven heterozygous carriers (Hyhy) as test animals and mate them to suspected carriers (Fig. 15.3). If a known carrier (test) doe is mated to a suspect carrier buck and no kits with hydrocephalus appear (out of at least eight young born in the litter), it is highly probable (about 90%) that the suspect buck does not carry this lethal gene and has the HyHy genotype instead. This is shown on the right side of Fig. 15.3. If the suspect buck is a heterozygous carrier of hydrocephalus (as shown on the left side of Fig. 15.3), 25% of the kits in the litter, for example, two kits from a litter of eight, should, on average, have the disorder (hyhy).

Fig. 15.2. Hydrocephalus in a rabbit kit. (Left, side view) (Courtesy of OSU Rabbit Research Center)

It should be clarified that hydrocephalus is not always a genetic defect. It can occur when pregnant does are fed a diet having too little or too much vitamin A. Diets that contain moderate



Mating of two carriers

(Hyhy × Hyhy)

Gametes produced by buck

Gametes produced by test doe	Hy	hy
Hy	HyHy	Hyhy
hy	Hyhy	hyhy*

Afflicted litter

Mating a normal male to a carrier female

(HyHy × Hyhy)

Gametes produced by buck

Gametes produced by test doe	Hy	Hy
Hy	HyHy	HyHy
hy	Hyhy	Hyhy

Normal litter

*Offspring having the hyhy genotype are genetically afflicted with hydrocephalus.

Fig. 15.3. Two examples of testing for hydrocephalus. (Courtesy of OSU Rabbit Research Center)

(20% or more) levels of alfalfa or that are supplemented with vitamin A should be adequate in vitamin A status to prevent hydrocephalus. This is discussed in more detail in Chapter 7. Another congenital genetic defect is the rare case of a cyclops rabbit (Fig. 15.4).

Selection for Quantitative Traits

The concept of heritability

Quantitative or "polygenic" traits are non-discrete (continuous) and may show many levels of expression. For example, 56-day market weights in a single litter may be 1.8, 1.9, 2.0, 2.1, and 2.3 kg (4.0, 4.2, 4.4, 4.6, and 5.1 lb). Quantitative traits include such economically important characteristics as fertility, disease resistance, growth rate, feed efficiency, milk production, density of fur, and carcass yield. Since quantitative traits are expressed in a continuous manner, graphing, for example, the 56-day weights of many rabbit fryers in a herd should portray a characteristic "bell-shaped curve" or normal distribution (Fig. 15.5).

Fig. 15.4. A rare congenital genetic defect involving a cyclops rabbit. (Courtesy of S.D. Lukefahr)

The vertical line in the center of the curve shows that the average weight of all the rabbits weighed was 1.5 kg (3.3 lb). The curve itself represents the percentage of the fryers expected at each of the weights between 0.9 and 2.2 kg. Quantitative traits are continuously (normally) distributed because their expression is a function of many genes, each with small cumulative effects. This type of gene expression is called additive gene action. To illustrate additive gene

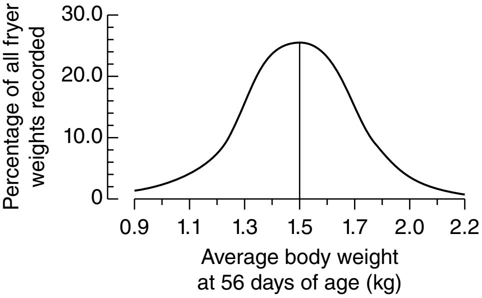


Fig. 15.5. Bell-shaped curve or normal distribution characterizing a quantitative trait. (Courtesy of S.D. Lukefahr)

action, suppose that one arbitrarily assumes that 100 genes influence 56-day body weight. If each gene contributes a potential for 0.02 kg (0.044 lb) of growth, cumulatively 0.02 kg (0.044 lb) times 100 genes results in a 2.0 kg (4.4 lb) rabbit.

Heritability (h^2) is the proportion of total measurable variation of a trait within a herd that is due to the expression of genes with additive effects. If a trait is 100% heritable, all variation measured among rabbits in a herd would be due solely to genetic expression with no environmental influences. In other words, any observed differences between rabbits for the same trait would be due only to genetic differences. If a trait is 50% heritable, one-half of the observed differences between individuals for that trait are due to genetics, and the other one-half are due to environmental factors. Degree of heritability does not reflect the number of genes involved in the expression of the trait or the degree that genes are transmitted from parents to offspring.

Heritabilities reported from the literature for a number of economically important traits are shown in Table 15.1. In general, traits related to fertility and disease resistance are lowly heritable ($h^2 < 15\%$), growth and feed efficiency traits are moderately heritable ($h^2 = 15–40\%$), and carcass traits tend to be highly heritable ($h^2 > 40\%$). These same trends exist in other livestock species.

To reiterate, heritability is a function of additive genetic variation present in the herd or population for the trait of interest. Fertility traits are lowly heritable presumably because, for thousands or millions of years, natural selection in the wild has favored rabbits that were above average genetically for fertility. Yet another breeding adage is “survival of the fittest”. After numerous generations of natural selection for fertility traits, genetic variation has invariably been reduced. Alternatively, natural selection has given little or no advantage to rabbits with above- or below-average dressing percentage. Because of little intervention from natural selection, genetic variation for carcass traits is generally considerable and may be exploited through artificial selection by breeders. Heritability is key to selection progress. In other words, the higher the heritability of a trait, the greater the opportunity to make genetic progress in response to selection.

Table 15.1. Heritabilities of quantitative traits in rabbits.[a]

Trait-related	Heritability (%)
Reproduction	
Litter size	0–15
Longevity	16
Milk production	27
Health	
Digestive disease mortality	3
Respiratory disease mortality	4
Survival to 56 days	6
Growth	
Body weights	13–23
Feed efficiency	29–34
Carcass	
Dressing percentage	24–50
Fat percentage	61
Intramuscular fat	54
Meat-to-bone ratio	45–50

[a] Range of figures from various literature sources.

Indirect selection for lowly heritable traits

To improve herd performance for traits of low heritability, providing a good management system (proper housing design, high-quality diet, artificial barn lighting, sanitation, etc.) would be much more effective than selection alone. However, if only environmental conditions are improved, a herd genetically inferior for a lowly heritable trait (e.g., litter size born) won’t surpass the performance of a well-managed, genetically superior herd for the same trait.

Despite the economic value of litter size traits, there is little justification for attempting to improve herd performance by selecting for litter size. A small litter size at birth is just as undesirable as an excessively large litter size. A statement such as "I save offspring only from does that give birth to at least 10 young and wean at least 8 young in each litter" is unsound from a genetic standpoint because of the very small influence of genetics on litter size and because of the disregard for other important traits that are more heritable, such as milk production and growth. In general, such a poor practice would result in little if any genetic progress.

Improvement of lowly heritable traits of economic importance should be achieved by establishing culling levels rather than by direct selection. This breeding practice is referred to as the independent culling method. The breeder decides on the culling levels to use. For example, does may be culled if they have two consecutive missed conceptions and/or if the average litter size born alive drops below six kits or the average number of kits weaned drops below four. The culling levels will vary according to herd fertility and individual preference. Litter size born alive reflects both the doe's fertility and mothering ability in producing live kits at kindling. Litter size weaned is largely determined by the ability of the doe to construct a good nest and to nourish her litter with an abundant milk supply. Bear in mind again that mothering ability traits are primarily influenced by environmental conditions rather than by the genetics of the doe.

To provide a more accurate basis for determining real producing ability, it is important to average the litter records of each doe rather than focus on single exceptional records. If a doe's average litter size at birth falls below the culling level, for example, of six young, the breeder should soon sell the doe for meat, and no offspring from the doe should be saved as replacements. An example is provided below on how to use the independent culling method that employs averages of doe performance trait records (Table 15.2).

Table 15.2. Litter records.

Doe	No. of records	Average litter size born	Average litter size weaned
A	2	6.0	3.5
B	5	9.2	7.3
C	3	7.5	7.0

For average litter size born alive and weaned, figure that the breeder might set culling levels at six and four young, respectively. Doe A falls below the minimum level of four weaned young, so this doe should be culled. Does B and C meet the criteria and should be retained.

Use of the independent culling method can also be applied to herd bucks. If the buck's average fertility rate falls below a set minimum level (for example, 70% pregnancy rate), the buck should be culled from the herd, regardless of the buck's merit for other traits. Culling levels for litter size traits for herd bucks is inappropriate because the size of the litter is determined by the number of eggs ovulated by the doe. As long as the buck is fertile, he has little influence on litter size born.

The long-term genetic consequence of use of the independent culling method for a lowly heritable trait, such as litter size, is to at least maintain (even possibly slowly improve) the herd average for that trait.

Direct selection for moderately to highly heritable traits

As previously noted, genetic progress for a trait is determined by the heritability and by how rigorously the young rabbits are selected. The formula that expresses this concept is:

$$G = h^2 \times S$$

where G is the genetic response to selection, h^2 is heritability, and S is the selection differential. Selection differential is the numeric difference between the average of the selected animals and the herd average for the trait of interest. As an example, suppose one hundred 56-day-old fryers in a herd have been weighed in a week, with an average weight of 1.6 kg (3.5 lb). The breeder needs to save 10 replacements (5 bucks and 5 does). The 10 replacements selected weigh an average of 2.2 kg (4.8 lb).

The selection differential is 0.6 kg (1.3 lb) (i.e., the select group average (2.2 kg) minus the herd average (1.6 kg)). If heritability for this trait is 0.20, the predicted genetic response (G) for the offspring would be G = 0.20 × 0.6 kg or 0.12 kg (0.26 lb). The predicted average performance of the offspring from the 10 selected parents would therefore be 1.6 (herd average) plus 0.12 (G), or 1.72 kg (3.79 lb). On the other hand, if all 100 rabbits had been saved for breeding, the selection differential would have been zero (i.e., 1.6 – 1.6 = 0). Hence, the genetic response due to selection (G) would likewise be zero since there was actually no selection at all. From this example it can be appreciated that the higher the heritability and the more intense the selection (proportionately fewer offspring are saved as replacements), the more rapid the expected rate of genetic progress.

Commercial meat rabbit breeders, to increase profits, should aim at selection practices that will result in rapid genetic improvement of economically important traits. Among important commercial traits are fertility, including libido (sex drive); disease resistance; litter size born; growth rate to market age; and carcass yield and quality. The independent culling method should be used for fertility- and health-related traits, as discussed earlier, whereas direct selection should be applied for the moderately to highly heritable economic traits.

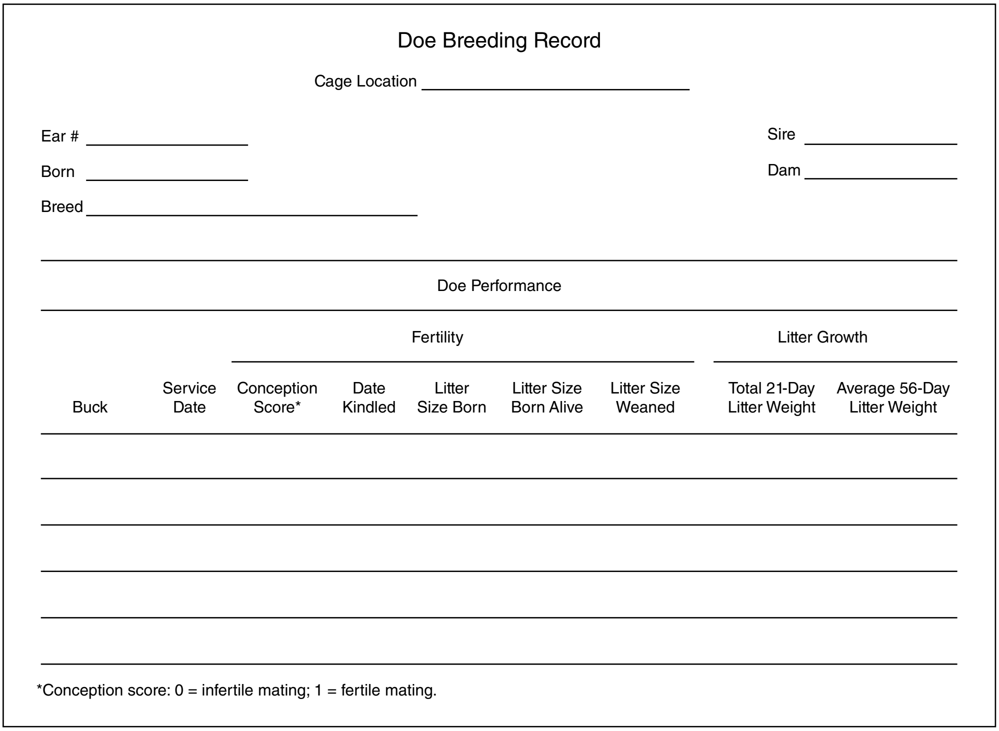
Feed efficiency (units of feed required for units of body gain) is a commercially important trait that is moderately heritable. However, because of the labor involved in weighing and feeding individually caged rabbits, and because of a positive genetic correlation that exists between feed efficiency and rate of growth (many of the same genes that improve feed efficiency also increase growth rate), selection of rabbits with heavy market weights is the most practical means of genetically improving feed efficiency.

Economically important traits to select for are milk production and market weight at 56 days. Since kits generally consume only milk until 21 days of age, total weight of the litter at 21 days is an excellent indicator of doe milk production. Weight at 56 days is mainly influenced by genetics and the number of rabbits in the litter. It is well known that the heavier fryers at 56 days are more likely to be from small litters, because of increased milk consumption by fewer kits during the pre-weaning period. To circumvent this association, it is advised that the best dams with several litter records be first identified, based on average milk production records and average 56-day market weight of their offspring. The best herd sires can also be identified on the basis of litter records that demonstrate the heaviest average 56-day market weight. Records from a minimum of 30 litters should be averaged for each sire to improve selection accuracy. Sire and dam record sheets suitable for recording these data are shown in Figs 15.6 and 15.7. After identifying the elite parents, the breeder should select the heaviest rabbit(s) at 56 days from within each litter produced by these elite sires and dams. This strategy reflects both family and within-family selection. Finally, all prospective replacements should be carefully inspected for physical soundness, such as thick foot pads, dense fur with good texture, good meat-type conformation, and normal teeth. Of course, only the best young stock should be selected, since their genes will determine the rate of genetic improvement realized in the next generation. This, in turn, will relate to increased business profits.

Herd dam and sire averages can be updated whenever new litters with total 21-day and average 56-day weights become available. It is a good practice to establish and know, in particular, the present rank of herd sires for their genetic merit for average 56-day market weight. Similar rankings can also be done on the basis of average milk production (21-day litter weights) of daughters from senior herd bucks.

The labor required to accurately measure and record 56-day market weight is more than economically justified when genetic progress results. Computer programs are available that can rapidly calculate individual dam and sire trait averages based on litter records. This greatly reduces the time it would take to perform so many hand calculations. Hence, the use of a computer program is a valuable tool for such genetic selection decision-making practices.

Fostering kits between litters should not substantially interfere with accuracy of selection. Fostered kits should be identified by some permanent mark (e.g., ear tag, tattoo, chick toe punch mark in ear) if replacements are to be chosen from the litter. If 56-day



Doe Breeding Record

Cage Location ____________________

Ear # ____________ Sire ____________

Born ____________ Dam ____________

Breed ________________________

Doe Performance

		Fertility					Litter Growth	
Buck	Service Date	Conception Score*	Date Kindled	Litter Size Born	Litter Size Born Alive	Litter Size Weaned	Total 21-Day Litter Weight	Average 56-Day Litter Weight

*Conception score: 0 = infertile mating; 1 = fertile mating.

Fig. 15.6. A sample doe performance record sheet. (Courtesy of S.D. Lukefahr)

individual weights are to be used as a basis of selection, weights of fostered kits should not be included.

Selection practices for fanciers

Fancy rabbit breeders achieve genetic progress in two ways: (1) among-herd selection and (2) within-herd selection. Among-herd selection occurs when stock is acquired from a reputable breeder with impressive show winnings to establish a line or to outcross with an existing one for the improvement of a particular show characteristic(s). The same reputable breeder more than likely obtained his or her stock from yet another reputable show rabbit breeder. This popular “trading-hands” selective approach is often more effective than waiting to achieve the same level of genetic improvement following several generations of within-herd selection. This is because show type and conformation traits (fur, muscle, and skeletal growth and development) are quite heritable but are also influenced by environmental factors (e.g., age, diet, management, and season). A breeder may simply desire to increase, say, shoulder width, by purchasing a rabbit that presumably has genes for outstanding width of shoulder. This is called corrective breeding. Further, it is not an uncommon practice among fanciers to cross their own line to even that of another breed to accomplish the same breeding objective of more rapidly improving a specific show trait or characteristic.

Another reason for effectiveness of among-herd selection practices is that most fancy herds are small (less than 10 does of the same variety or breed), so it is not possible for the breeder to be very rigorous or intense in selecting young stock. Being too selective in a small, closed herd (without regular introduction of stock from other herds) often puts the stock at risk of the adverse effects of inbreeding. To reduce inbreeding and ensure genetic diversity, it is also important that animals of the same variety or breed be purchased from (and sold to) a

Buck Breeding Record

Cage Location ______________________

Ear # ______________ Sire ______________

Born ______________ Dam ______________

Breed ____________________________

Buck Performance

		Fertility				Mortality	Litter Growth	
Doe	Cage Location	Date of Service	Conception Score*	Number Born	Number Born Alive	Number of Kits That Died from 1 to 56 Days	Litter Size at 56 Days	Average Litter Weight at 56 Days of Age

*Conception score: 0 = infertile mating; 1 = fertile mating.

Fig. 15.7. A sample buck performance record sheet. (Courtesy of S.D. Lukefahr)

number of breeders. Some dog breeds have been devastated by over-limiting the gene pool by matings to close relatives and by not testing for undesirable recessive genes.

In other words, within-herd selection is effective only when the herd size is adequately large and when superior genes for qualitative and quantitative show traits become concentrated in the line. As discussed in Chapter 14, this is accomplished usually through careful linebreeding practices that emphasize the contribution of outstanding common ancestors being highlighted through pedigree selection combined with selection and culling.

The secret for genetic success of show stock development is that the "best" stock is first acquired from one or more reputable breeders to establish a quality base line. Then, through sound within-herd selection practices involving several generations, "best" eventually becomes even better!

Selection practices for Angora breeders

Angora rabbit breeders primarily focus their breeding program on improving wool yield and quality traits. Heritabilities for wool yield and density characteristics tend to be moderate (Table 15.3). Hence, an opportunity exists to make rapid genetic progress through selection. Since heritability is moderate (15 to 40%), genetic progress for wool traits will largely be determined by how rigorously the breeder selects. This will in turn depend, in part, on the size of the herd. If the herd consists, for example, of only 2 bucks and 10 does, the breeder cannot practice intense selection because there will not be many offspring from which to select, despite the high degree of genetic influence for wool traits. This is as opposed to large offspring numbers produced in a 20 buck and 200-doe operation, where only 20 young bucks would need to be selected annually from at least 2000 total young bucks being produced in the same herd.

Table 15.3. Heritabilities for wool characteristics in Angora rabbits.[a]

Trait	Heritability (%)
Wool yield:	
Fleece weight	35
3rd or later harvest	23
Wool characteristics:	
Bristle diameter	39
Back bristle length	25
Back down length	16
Haunch bristle length	25
Haunch down length	15
Comfort factor	15

[a]Figures from various French literature sources.

Perhaps the most effective strategy for breeders of small herds is to purchase bucks for breeding from large operations where good wool production records are being used to identify genetically superior rabbits. In addition, if the primary trait of interest is wool yield, the breeder can place considerably more confidence in a rabbit with a high average wool yield based on several harvest records, as opposed to a rabbit with only one wool yield record.

Another strategy would be for small breeders to form cooperatives or associations wherein uniform standards of feeding, management, and trait recording procedures are consistently met. In addition, wool trait and pedigree records from breeders would be collected with the data analyzed to compute genetic scores called expected progeny differences (EPD), which reflect the numeric effects of all the animal's genes for a trait of interest. Rabbits with the best EPD scores are the best candidates for selection. This approach should reward participating members through more accurate among-herd as well as within-herd genetic selection to target wool trait improvement.

Recordkeeping

Systematic use of records of average herd production and individual rabbit performance is essential in developing a profitable business. Surprisingly, many producers are either unaware of the importance of herd production records or they are simply reluctant to maintain records. Perhaps the reason is because it takes a lot of time and diligence to keep good records, especially if weights are being recorded. It is possible, too, to get so carried away with the details of recordkeeping that other important management activities, such as sanitation and marketing, are neglected. Good records, from a genetic perspective, serve as a management tool for accurate stock selection to improve breeding stock quality and enhance rabbit business security.

There are several types of records commercially available to rabbit producers. Doe cage or hutch cards are popularly used in recording service dates, fertility success or failure, litter survival (total number born, alive or dead; fostered; and weaned), and litter weights at specific ages. Hutch cards can get lost or damaged, and performance information is also lost. This defeats the purpose of long-term recordkeeping. From the genetic selection standpoint, many manufactured hutch cards over-emphasize lowly heritable litter size traits. A better system is to highlight the more important litter weight traits (21- and 56-day litter weights) as measures of doe milk production and fryer growing ability.

Easily accessible permanent record sheets for all breeding stock are necessary in monitoring and projecting herd performance. An organized recordkeeping system may also be an asset when bank loans are sought. Permanent record sheet forms for herd and individual rabbit productivity are also commercially available. The record sheets can be kept together in a notebook or filed on computer for convenience. Preparation of monthly and annual herd average summaries is a sound business practice. For example, total feed costs and sales of fryers can be summarized at the end of each month to determine present herd output, feed efficiency, and net business returns. Over time, herd genetic performance, and seasonal and profit trends can be closely monitored to aid the producer in determining present herd quality level, in determining cash-flow status, and in making future business projections.

Pedigree records are a must for all breeding animals in the herd. Some hutch and permanent record forms include space for sire and dam identification, or even for three full generations. The commercial producer should use pedigree information, supplemented with performance records, as a tool in making wise replacement stock selection decisions and in avoiding closely related matings that might result in inbreeding depression of the offspring. Seedstock or fancy breeders should closely adhere to pedigree records in planning linebred matings to concentrate desirable genes from common ancestors or in planning test matings to screen offspring that are suspect carriers of undesirable recessive genes. A buyer of breeding stock should always request pedigree records from the seller.

Computers as an Aid to Genetic Selection

To reiterate, the challenge of maintaining a system of accurate and useful recordkeeping is not a simple one. Commercial producers with as few as 50 breeding does can usually justify the use of a computer as an accurate, labor-saving tool.

Computer packages programmed for utilization in rabbit production enterprises can aid in making a more accurate evaluation of breeding stock, and in substantially less time. The same computer program package can be used to print daily work sheets (e.g., matings to make, nest box entries, palpations, litters to be weighed, etc.) in a matter of just a few seconds.

A personal computer (Fig. 15.8) generally will pay for itself even in a small herd operation by reducing errors (e.g., forgetting to put in nest boxes) and by allowing the producer to spend more time looking after rabbits and less time keeping records. For fancy breeders, software packages are available that store and print pedigrees.

In terms of genetic improvement, the major livestock industries use computer programs and employ geneticists to provide breeders with expected progeny differences (EPDs) for economically important traits in their animals. EPDs are numeric genetic scores that reflect the numeric effects of all the animal's genes for a trait of interest. EPDs are the ideal criteria for selection. To briefly illustrate, performance and pedigree records from seedstock breeders

Fig. 15.8. A personal computer can provide a daily chore sheet, aid in genetic selection, and provide periodic financial statements. (Courtesy of J.I. McNitt)

are typically submitted to the headquarters of a breed association or a genetics organization. Here the data are pooled from many breeders to create one large dataset. Geneticists next use software programs involving an appropriate statistical model (i.e., incorporating factors such as trait heritabilities and mathematical adjustments for environmental effects such as year, herd, and age) that ultimately and simultaneously estimate the EPDs for all animals. The computed EPDs are then made available and used by breeders to determine which animals to select in their herds to achieve genetic progress. More recently, DNA samples of animals are also used to compute the even more accurate "genomic-enhanced" EPDs. This sophisticated EPD approach is especially effective when elite sires are chosen that are used in commercial artificial insemination programs.

Further Reading

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16

Coat Color Genetics of Rabbits

An appreciation of genetic variation can be gained by attending a rabbit show. For many, their first rabbit show remains a vivid memory. Besides the remarkable variation seen among breeds in such characteristics as body size, conformation, and behavior, perhaps the most intriguing feature is the splendid array in coat color. Discrete colors of black, chocolate, blue, red, and white, and the subtle shades of beige, lilac, sable, seal, and silver are seen. In addition to color, the diverse color patterns found in many breeds – agouti banding, brindling or harlequin markings, Dutch and English spotting, and tanning – further exemplify the array of combinations of coat color and color patterns that have been developed. Furthermore, the structure, texture, and type of fur – e.g., angora, lionhead, normal, rex, satin, and waved or astrex – provide a greater dimension to the genetic variation in color, pattern, and structure of the coat.

Prior to domestication, rabbits were all of the agouti or wild-type color pattern, characterized by alternating bands of black and red color on the hair shaft. This color condition was preferentially maintained in nature, because it visually blended into the rabbits' environment. Other colors arose in the wild, through genetic mutation undoubtedly, but being conspicuous to predators, including humans, such deviants had little chance of survival. It was not until the domestication of rabbits, likely first occurring in the seventeenth century in monasteries throughout Western Europe, that preservation and selective breeding of mutant colors began. The following is a brief history of the genetic discovery of various colors, patterns, and types of fur.

- By 1700: albino, black non-agouti, blue dilution, brown, Dutch spotting, red, and silver;
- 1700–1850: Angora, English spotting, and Himalayan;
- 1850–1900: harlequin, steel, and tan; and
- 1900–2000: blue-eyed white, chinchilla, dominant black, lionhead, naked, rex, satin, waved, and wide band.

It is interesting to note that over 500 years have passed since the rabbit was domesticated, but only about 20 color genes have emerged through mutation. This illustrates the low rate at which genetic mutations generally occur.

Classification of Major Coat Color Genes

The vast majority of genes that affect coat color are located on only four pairs of chromosomes. These genes have been categorized into a system referred to as the coat color series and are labeled A to E (agouti, brown, color, dilution, and extension). On one chromosome pair the

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genes of the A series exist, where A stands for agouti coloration. On another chromosome pair the genes of the B and C series are found, where B and C stand for brown and color, respectively. Because two sets of genes of the B and C series are located on the same chromosome, a condition called linkage exists. This is one of a few firmly established cases of linkage that involve major coat color genes. Other cases involve the Dutch and English spotting genes and the agouti and wide-band genes. On another chromosome pair the genes of the D series are present, where D stands for dilution of color, and on another pair of chromosomes the genes of the E series are found, where E stands for extension of black color.

At each of these five major chromosomal locations of the coat color series, a gene that produces agouti coloration may be present in a rabbit. Since the agouti gene is dominant, a rabbit that possesses at least one agouti gene at each of the A through E locations will have agouti coloration. However, different versions of a gene, referred to as alleles, may exist in place of the dominant agouti gene. Over the course of many generations, the agouti gene has given rise to numerous mutations, mostly recessive. At the A location ("locus") there are three alleles, at the B locus two alleles, at the C locus six alleles, at the D locus two alleles, and at the E locus five alleles (Table 16.1). An individual rabbit can have only two alleles present at each major gene location, one on each of the chromosomes inherited from each parent. The two alleles may either be duplicates of the same gene (homozygous) or be dissimilar (heterozygous). An excellent recent report on the molecular aspects and function of genes for coat color, pattern, and structure is provided by Fontanesi (2021).

A series

There are three alleles of the A series: A, a^t, and a. An allele with dominant gene action is symbolized with a capital letter: A for agouti. The specific protein that produces the agouti color pattern is called the agouti signalling protein (ASIP). Recessive alleles are symbolized with lower-case letters: a^t for tan and a for non-agouti. Three homozygous conditions are possible in a population of rabbits in which these three alleles are found: AA, a^ta^t, and aa, respectively. The lettering system denotes the genotypes of three different color classes of rabbits. The respective agouti, tan, and non-agouti color patterns observed are called the phenotypes. The genotype of a rabbit is ascertained by observing either its own phenotype or that of its offspring, or both. In recent

Table 16.1. Major coat color series of the rabbit.

Series	Gene name	Alleles	Colors
A-Agouti	Agouti signalling protein (ASIP)	A	Agouti
		a^t	Tan
		a	Non-agouti
B-Brown	Tyrosinase-related protein 1 (TYRP1)	B	Agouti
		b	Brown or chocolate
C-Color	Tyrosinase (TYR)	C	Agouti
		c^{chd}	Dark chinchilla
		c^{chm}	Medium chinchilla
		c^{chl}	Light chinchilla
		c^h	Himalayan
		c	Albino
D-Dilution	Melanophilin (MLPH)	*D*	Agouti
		d	Blue dilution
E-Extension	Melanocortin 1 receptor (MC1R)	E^d	Black agouti
		E^s	Steel agouti
		E	Agouti
		e^j	Japanese
		e	Red

years it has become possible to use DNA samples to determine an animal's genotype. Three heterozygous conditions are possible for the same population: Aa^t, Aa, and a^ta. A rabbit with the Aa^t or Aa genotype will have the agouti phenotype, because agouti is completely dominant. Although both a^t and a are recessives, a^t genetically prevails over a, producing a tan phenotype. With the homozygous recessive genotype aa, a rabbit will have the non-agouti or self-phenotype (i.e., solid color). Coat color genotypes of American breeds of rabbits are provided in Table 16.2.

The agouti phenotype is the result of black pigments (eumelanin) being distributed in the terminal band region, red pigments (pheomelanin) being distributed in the sub-terminal or intermediate band region, and black pigments being sparsely distributed in the base of the hair shaft. Agouti markings predominate throughout the head, back, and sides of the body coat, while the eye circles, under-jaw, nape of the neck, belly, and undersurface of the feet and tail are white or cream in color. Three types of hairs comprise the coat: primary guard hairs, secondary guard hairs, and underfur. Primary and secondary guard hairs are long and coarse. The underfur, or down, is relatively shorter and finer. It is the secondary guard hair that displays typical agouti characteristics involving terminal, sub-terminal, and base color bands, as found in many breeds.

The recessive a^t allele is responsible for producing a black dorsal coat lacking agouti coloration, while the eye circles, belly, and other undersurface regions remain light colored. In the Tan breed it is believed that additional genes, called modifying genes, are involved that cast a tan shade to these under-surface body regions.

The effect of the a allele, when in the homozygous state, is to obliterate the agouti condition by producing an entirely black coat. The black or self (solid-colored rabbit) phenotype is probably the most popular color variety in existence among present rabbit breeds.

B series

The dominant B allele codes for synthesis of normal agouti coloration. A rabbit with a bb genotype has brown rather than black color. This is because of a change (originally by mutation; referred to as TYRP1) in the function of the gene that otherwise codes for black melanin pigments. Instead, lighter "brown" pigments are formed. Some geneticists consider this effect as a type of dilution. TYRP1 stands for tyrosinase-related protein 1. The location of this gene is on Chromosome 1 and is near the locus responsible for albinism (TYR) and hence is considered to be linked. If a rabbit is an agouti (A_), the normally black ticking will be brown instead, as found in the Cinnamon breed. A tan marked rabbit will be a brown or chocolate tan with an a^ta^t bb genotype. A black non-agouti (aa) will be a chocolate self (aa bb).

C series

Several alleles are members of the C series, probably the most influential series in terms of color dilution or shade. As previously stated, this series is represented by genes found at the TYR locus. Six alleles are known, which can conveniently be ordered according to dominance as follows:

$C =$ full color; $c^{chd} =$ dark chinchilla; $c^{chm} =$ medium chinchilla; $c^{chl} =$ light chinchilla; $c^{h} =$ Himalayan; $c =$ albino.

The C allele allows for full color expression in the agouti, tan, or non-agouti rabbit and is dominant to all other alleles of the C series. Full color expression refers to the formation of both eumelanin (black) and pheomelanin (red) pigments that are distributed in bands in hair. Rabbits with c^{chd}, c^{chm} or c^{chl} alleles have a progressive dilution of red pigments. In addition, a $c^{chl}c^{chl}$ light chinchilla or sable (aa $c^{chl}c^{chl}$) rabbit will be of a still lighter shade if, instead, it is heterozygous $c^{chl}c^{h}$ or $c^{chl}c$. Also, because of incomplete dominance, a c^hc Himalayan or Californian rabbit is a faded version of the c^hc^h homozygote which has dark points. The cc genotype produces an albino rabbit, fully devoid of coat and eye pigmentation. This is because this condition is the result of a deficiency of an enzyme (tyrosinase) required in melanin synthesis, so color expression is inhibited. This is true even though the albino rabbit possesses other normal genes for coat and eye color.

Table 16.2. Coat color genotypes of American breeds of rabbit.

Breed	Genotype[1]	Breed	Genotype[1]
Altex	c^hc^h	Flemish Giant	
American		Black	aa
Blue	aa dd	Blue	aa dd
White	cc	Fawn	ee
American Fuzzy Lop[2]	ll	Light Gray	$c^{chd}c^{chd}$
American Sable	aa $c^{chl}c^{chl}$	Sandy	
Angora[2]	ll	Steel Gray	$c^{chd}c^{chd}$ E^SE
Argente Brun[3]	bb	White	cc
Belgian Hare		Florida White	cc
Rufus	ww	Harlequin[4]	
Tan	a^ta^t ww	Japanese	e^je^j
Beveren		Magpie	$c^{chd}c^{chd}$ e^je^j
Black	aa	Havana	
Blue	aa dd	Black	aa
Blue-eyed White	vv	Blue	aa dd
Blanc de Hotot	du^wdu^w EnEn aa	Broken	Enen
Britannia Petite		Chocolate	aa bb
Black	aa	Lilac	aa bb dd
Black Otter	a^ta^t	Himalayan	
Blue-eyed White	vv	Black	aa c^hc^h
Broken	Enen	Blue	aa c^hc^h dd
Chestnut		Chocolate	aa bb c^hc^h
Ruby-eyed white	cc	Lilac	aa bb c^hc^h dd
Sable Marten	a^ta^t $c^{chl}c^{chl}$ ee	Holland Lop[2]	
Californian	aa c^hc^h	Jersey Wooly[2]	ll
Champagne D’Argent[3]	aa	Lilac	aa bb dd
Checkered Giant		Lionhead[4]	MM
Black	Enen aa	Lop[4]	
Blue	Enen aa dd	Mini Lop[4]	
Chinchilla	$c^{chd}c^{chd}$	Mini Rex[4]	rr
Cinnamon	AA bb	Mini Satin[5]	sasa
Creme D’Argent[3]	ee	Netherland Dwarf[4]	
Dutch		New Zealand	
Black	du^ddu^w aa	Black	aa
Blue	du^ddu^w aa dd	Blue	aadd
Chinchilla	du^ddu^w $c^{chd}c^{chd}$	Broken	Enen
Chocolate	du^ddu^w aa bb	Red	ee
Gray	du^ddu^w	White	cc
Steel	du^ddu^w E^sE	Palomino	
Tortoise	du^ddu^w aa ee	Golden	ee
Dwarf Hotot	du^wdu^w EnEn aa	Lynx	bb dd
Dwarf Papillon		Polish	
Black	Enen aa	Black	aa
Blue	Enen aa dd	Blue	aa dd
Chocolate	Enen aa bb	Blue-eyed white	vv
English Spot		Broken	Enen
Black	Enen aa	Chocolate	aa bb
Blue	Enen aa dd	White	cc
Chocolate	Enen aa bb	Rex	
Gold	Enen ee	Amber	rr bb ee
Gray	Enen	Black	rr aa
Lilac	Enen aa bb dd	Blue	rr aa dd
Tortoise	Enen aa ee	Broken	rr Enen

Contunued

Table 16.2. Continued.

Breed	Genotype[1]	Breed	Genotype[1]
Californian	rr aa c^hc^h	Otter	sasa a^ta^t
Castor	rr	Red	sasa ee
Chinchilla	rr $c^{chd}c^{chd}$	Siamese	sasa aa $c^{chl}c^{chl}$ ee
Chocolate	rr aa bb	White	sasa cc
Lilac	rr aa bb dd	Satin Angora[2]	ll sasa
Lynx	rr bb dd	Silver[3]	
Opal	rr dd	Black	aa
Otter	rr a^ta^t	Brown	aa bb
Red	rr ee	Fawn	ee
Sable	rr aa $c^{chl}c^{chl}$ ee	Silver Fox[3]	
Seal	rr aa $c^{chl}c^{chl}$ ee	Black	aa
White	rr cc	Blue	aa dd
Rhinelander		Silver Marten	
Black	Enen aa e^je^j	Black	a^ta^t $c^{chd}c^{chd}$
Blue	Enen aa dd e^je^j	Blue	a^ta^t $c^{chd}c^{chd}$ dd
Satin		Chocolate	a^ta^t bb $c^{chd}c^{chd}$
Black	sasa aa	Sable	a^ta^t c^{chl} c^{chl} ee
Blue	sasa aa dd	Tan	
Broken	sasa Enen	Black	a^ta^t
Californian	sasa aa c^hc^h	Blue	a^ta^t dd
Chinchilla	sasa $c^{chd}c^{chd}$	Chocolate	a^ta^t bb
Chocolate	sasa aa bb	Lilac	a^ta^t bb dd
Copper	sasa	Thrianta	ee

[1] Only relevant gene(s) provided. (A blank represents agouti type.)
[2] See Table 16.6 for color genotypes of Angora varieties.
[3] Polygenic inheritance for silvering involved.
[4] See color genotypes for Rex breed as a guide.
[5] See color genotypes for Satin breed as a guide.

To clarify further, the true agouti has black ticked fur with an intermediate region of red pigmentation and a base of slate blue tone color. The effect of the c^{chd} gene is to change the intermediate or sub-terminal region of the hair from red to pearl white, as well as to change the color of the eye circle, belly, and other under-surface regions from cream to white. This gene limits the synthesis of red color, as is true of the other recessive alleles of the C series. The Chinchilla is one of the more striking breeds, with its characteristic coat pattern being displayed in rings of color seen by blowing on the fur (Fig. 16.1). Lighter shades of the common dark chinchilla can be made upon substitution of the c^{chd} allele with the c^{chm} and c^{chl} alleles in the homozygous state (Fig. 16.2). There is some speculation whether the c^{chm} allele actually exists. Recent molecular genetic studies suggest that only one chinchilla gene may exist. Instead, modifier genes may lighten the c^{chd} or darken the c^{chl} effects of these two prevalent genes. The c^{chl} gene is prevalent among several of the subtle blends of sable, seal, and siamese color in combination with the aa non-agouti genotype. Combining the genes for the tan pattern with the chin-

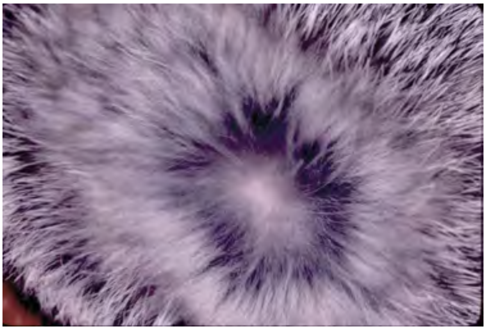


Fig. 16.1. The coat of the chinchilla rabbit contains five rings of color, including black ticking that makes up the outermost ring. (Courtesy of S.D. Lukefahr)

Fig. 16.2. Left to right: rabbits displaying light (c^{chl}), medium (c^{chm}), and dark (c^{chd}) chinchilla color patterns. (Courtesy of S.D. Lukefahr)

chilla genes (a^ta^t $c^{chd}c^{chd}$ and a^ta^t $c^{chl}c^{chl}$) produces the marten. Since the effect of the chinchilla gene is to largely inhibit red pigment coloration throughout the body, the marten still shows the tan pattern but simply lacks tan coloration. This condition exists in the Silver Marten and in color varieties of other popular breeds.

The c^h gene restricts coat color pigmentation to the extremities or points of the body: the nose, ears, feet, and tail. This is because the body temperature at these distal points is slightly lower than for the rest of the body, allowing this temperature-dependent gene to be expressed. Californian and Himalayan kits, when chilled shortly after birth, may develop a gray coat because of this temperature-dependent condition. This can also occur in the adult when the skin surface is exposed to cold temperatures, such as through fur pulling or chewing (see Fig. 5.17). Above a temperature of 25°C (79°F), the production of color pigments declines and faded points result. In rather extreme cases of prolonged high temperatures, a pointed rabbit may be indistinguishable from a true albino rabbit. In fact, because Californian and Himalayan marked animals have, for the most part, a white coat and pink or ruby-colored eyes, the term “pseudo-albino” is used to describe the false or mock albino condition.

D series

In the D series there are the dominant D and the recessive d alleles. As seen in the normal agouti coat, a rabbit with at least one D allele has the potential to exhibit dense color throughout pigmented regions of the body coat. Technically, dilution is associated with genes found at the Melanophilin (MLPH) locus. The effect of the d allele in recessive homozygotes is a dilution of color pigments throughout regions of the body coat. Specifically, hair pigment granules are clumped and irregularly distributed, leaving much empty space. This leads to greatly decreased light absorption and causes an increase in white light, which dilutes the strength of color seen by the eye. The effect is that black appears blue, chocolate appears lilac, and red appears cream colored. An agouti rabbit that possesses the dilution genes (genotype A_ B_ C_ dd) has blue ticked fur with a cream intermediate ring color and slate undercolor and is a blue agouti, also called an opal. If an agouti rabbit also possesses the recessive brown genes (genotype A_ bb C_ dd), the color is referred to as lynx, or more descriptively, a lilac agouti. Both the opal and lynx color varieties occur, for example, in the Angora, Lop, Netherland Dwarf, and Rex breeds.

Marten and Siamese varieties of smoke pearl result when the blue dilution dd genes are present in the same animal, as found in the Netherland Dwarf breed. Blue color varieties of Silver Martens and Tans have the dd dilution factor, and lilac color varieties have both bb brown and dd dilution factors. In the non-agouti self-rabbit, possession of the dd dilution factor produces an entire blue coat, while possession of both bb brown and dd dilution factors produces an entirely lilac coat. Because brown color pigments are irregularly dispersed throughout the hair follicle, the actual color usually detected is a bluish fawn or dove gray shade called lilac.

E series

Five alleles are common members of the E series, shown below in order of dominance:

E^d = dominant black agouti; E^s = steel agouti;
E = agouti; e^j = Japanese brindling;
e = red or yellow.

There are three dominant and two recessive alleles in this series. These alleles are each unique due to specific mutations as found at the Melanocortin 1 Receptor (MC1R) locus. The e allele is completely recessive to all other alleles of the series, while rather complicated interactions exist among the E^s, E, and e^j alleles. The E^d allele may cause black color ticking to extend completely into the intermediate agouti band of the hair, producing an entirely black coat, as also found in the non-agouti black rabbit (aa). More specifically, the otherwise normal agouti (genotype A_B_C_D_E_) that has at least one E^d allele displacing any of the other alleles of the E series will be black. The effect of the E^s allele is to cause partial extension of the black pigment into the intermediate agouti band. A narrow band of red or gray color in this hair zone is referred to as steel coloration and is seen in many breeds. A steel agouti rabbit is shown in Fig. 16.3. However, E^sE^s homozygotes display only traces or no steel coloration and appear entirely black, similar to E^d individuals. It is the E^s E heterozygote that is believed to be the genotype of the ideal steel (genotype A_B_C_D _E^s E). To make matters more complicated, there may be separate genes for light versus dark belly color as seen in the agouti coat.

The most intriguing allele of the E series is e^i, the Japanese brindling gene. It has two effects in the agouti (A_) in that it behaves as both E^d and *e* alleles. In a seemingly random manner, alternating patches of black and red color appear throughout the body. Ideally, according to the American Rabbit Breeders Association "The chest should be evenly divided with the black half chest and leg under the orange half face, and the orange half chest and leg under the black half face, thereby framing the face with its alternating color. The leg may be the same color as its side of the chest or alternate with the chest color… The rabbit which alternates the most frequently in color should have preference." (American Rabbit Breeders Association, Inc. 2020. *Standard of Perfection 2021–2025*.) On the other hand, certain individuals may show few "bands" or "bars" of alternating color and resemble either of the two extremes of black or red coat colors. The magpie harlequin has white instead of red-colored regions due to the action of the c^{chd} gene, which largely inhibits red color expression. Blue, chocolate, and lilac harlequin varieties also involve b and/or d genes. Rabbits with an *ee* genotype have the basic agouti coat pattern, except for the absence of black surface ticking on the head and ears, back, and sides. In other words, the *e* gene inhibits extension of black color (i.e., black eumelanin pigments are not synthesized); thus, it is commonly referred to as the non-extension allele of the E series). The red color variety (also referred to as cream, fawn, gold, or orange) is present within the Angora, Creme D'Argent, Dutch, English Spot, Flemish Giant, New Zealand, Palomino, Satin, and Silver breeds (Table 16.2). In A_ *ee* agouti rabbits, appealing shades of chocolate, blue, and lilac fawns can be developed by incorporating the bb and/or dd genes. Paradoxically, A_ *ee* rabbits that also have chinchilla genes (c^{chd}, c^{chm}, and c^{chl}) have a white coat. This is because the chinchilla gene effectively prevents red coloration, while the non-extension red gene prevents black or dark coloration, thereby resulting in little to no color expression. This is sometimes called a white or ghost chinchilla (Fig. 16.4).

Combining the non-agouti aa with the *ee* genes produces a red self rabbit with black

Fig. 16.3. A steel agouti rabbit. (Courtesy of S.D. Lukefahr)

Fig. 16.4. A white or ghost chinchilla rabbit. (Courtesy of S.D. Lukefahr)

points and underline, commonly called a tortoise-shell. Therefore, in the otherwise non-agouti black animal, the action of the *e* gene is incomplete in restricting all black pigmentation from the body. Chocolate, blue, and lilac tortoise-shells can easily be produced by selecting for the relevant genes, b and d. By combining the chinchilla and the non-extension red genes in the non-agouti black animal (genotype aaB_c^{chd}_D_*ee*), the pearl color is produced. The pearl, also known as a sable point or chinchillated tortoise-shell by some fanciers, has a white body coat laced with sooty dark ticking that intensifies at the points. As described above, chinchilla genes progressively produce fewer red color pigments, while the e gene is not fully capable of eliminating black color pigments. Combining these genes in the non-agouti rabbit results in delicately shaded pearl coloration. A lighter version of the pearl color exists in a rabbit that has the c^{chl} (light chinchilla) allele rather than the darker c^{chd} allele (dark chinchilla). This lighter animal, presumably with the genotype aaB_c^{chl}_D_*ee*, is better known as the siamese and the sable point.

An interesting condition, called the mock albino, can be synthesized by combining the Himalayan gene c^h with the non-extension red gene *e* in the agouti rabbit (genotype A_ c^hc^h *ee*). The action of the *e* gene is to prevent expression of dark coloration at the body points, producing an animal with a white coat that also happens to have pink eyes. In the non-agouti rabbit, the mock albino condition (genotype aac^hc^h*ee*) may appear as well. However, upon close observation of the body points, it usually becomes apparent that some dark ticked fur is present in such a mock albino. In other such cases, color occurs even though the eyes are pink (Fig. 16.5). Furthermore, mating a true albino (cc) that is known to possess any of the dominant alleles of the E series (E^d, E^s, or E) to a mock albino should result in colored offspring. In contrast, mating true albino stock will result in only albino offspring. Other possible versions of mock albino may involve the A_c^{chl}_*ee* and aa c^{chl}_*ee* genotypes.

A comprehensive list of coat color genetic combinations involving the five major A–E series and using two common alleles per locus in agouti and non-agouti varieties is presented in Table 16.3.

Fig. 16.5. A rare rabbit with Himalayan points, a magpie pattern and pink eyes. (Courtesy of S.D. Lukefahr)

Coat Pattern Genes

In addition to the primary genes of the major A–E coat color series, other well-recognized genes exist that also exert pronounced effects on the coat color pattern. Moreover, there are many minor (modifier) genes that, in a cumulative manner, tend to modify the expression of the major coat pattern genes. For example, modifier genes can largely account for the difference between rabbits with either excessive or minimal white spotting.

Dutch white spotting

A list of coat color patterns is provided in Table 16.4. The first set of genes is for Dutch spotting. The inheritance of Dutch spotting is quite complicated because both primary major and secondary minor genes are involved. The most widely accepted hypothesis is that there are three major alleles that belong to the Dutch spotting locus, one dominant and two recessives. The dominant allele (Du) produces no Dutch markings on the body coat. The recessives (du^d and du^w) impart the Dutch spotting. Allele du^d expresses minimal white spotting, while du^w expresses substantial white spotting. The degrees of Dutch white spotting have been graded according to the action of these three alleles in homozygous and heterozygous forms (Fig. 16.6).

Table 16.3. Coat color genotypes for agouti and non-agouti varieties.

Agouti version	Color description	Non-agouti version	Color description
A_ B_ C_ D_ E_	Agouti	aa B_ C_ D_ E_	Black
A_ B_ C_ D_ ee	Red (Fawn)	aa B_ C_ D_ ee	Tortoise-shell
A_ B_ C_ dd E_	Blue agouti (Opal)	aa B_ C_ dd E_	Blue
A_ B_ C_ dd ee	Blue fawn	aa B_ C_ dd ee	Blue tortoise-shell
A_ B_ $c^{chd}c^{chd}$ D_ E_	Chinchilla	aa B_ $c^{chd}c^{chd}$ D_ E_	Seal[1]
A_ B_ $c^{chd}c^{chd}$ D_ ee	White chinchilla	aa B_ $c^{chd}c^{chd}$ D_ ee	Black pearl[2]
A_ B_ $c^{chd}c^{chd}$ dd E_	Blue chinchilla (Squirrel)	aa B_ $c^{chd}c^{chd}$ dd E_	Blue seal
A_ B_ $c^{chd}c^{chd}$ dd ee	White chinchilla	aa B_ $c^{chd}c^{chd}$ dd ee	Blue pearl
A_ bb C_ D_ E_	Chocolate agouti (Cinnamon)	aa bb C_ D_ E_	Chocolate
A_ bb C_ D_ ee	Chocolate fawn	aa bb C_ D_ ee	Chocolate tortoise-shell
A_ bb C_ dd E_	Lilac agouti (Lynx)	aa bb C_ dd E_	Lilac
A_ bb C_ dd ee	Lilac fawn	aa bb C_ dd ee	Lilac tortoise-shell
A_ bb $c^{chd}c^{chd}$ D_ E_	Chocolate chinchilla	aa bb $c^{chd}c^{chd}$ D_ E_	Chocolate seal
A_ bb $c^{chd}c^{chd}$ D_ ee	White chinchilla	aa bb $c^{chd}c^{chd}$ D_ ee	Chocolate pearl
A_ bb $c^{chd}c^{chd}$ dd E_	Lilac chinchilla	aa bb $c^{chd}c^{chd}$ dd E_	Lilac seal
A_ bb $c^{chd}c^{chd}$ dd ee	White chinchilla	aa bb $c^{chd}c^{chd}$ dd ee	Lilac pearl

[1] The genotype of the seal is not conclusively verified. Studies indicate that one or more of the genotypes aa, aa $c^{chd}c^{chd}$, and aa $c^{chl}c^{chl}$ are involved.

[2] A paler version of the pearl is produced by substituting the $c^{chd}c^{chd}$ (dark chinchilla factor) for the $c^{chl}c^{chl}$ (light chinchilla factor) genes, which gives the siamese and sable point. Further, the genotype of $c^{chl}c^{chl}$ ee may also be involved.

Table 16.4. Major coat pattern genes in addition to the A–E series.

Locus	Alleles	Color of Color Pattern
Du – Dutch	Du	Normal,
	du^{d}	Dark Dutch, minimal spotting
	du^{w}	White Dutch, excessive spotting
En – English	En	English spotting
	en	Normal
si – Silver[1]	Si	Normal
	si	Silver coat surface
A – Viennese White	V	Normal
	v	White coat, blue eyes
w – Wide Band	W	Normal agouti band
	w	Wide agouti band

[1] Although si (silver) is reported in the literature as a major recessive gene, silvering is also influenced by additional modifier genes.

The dominant allele, Du, is actually incompletely dominant over both recessives and produces rabbits with little or no Dutch white spotting (grades 0–3). The white spotting that does occur is usually restricted to the nose, face, and/or feet. The heterozygous combination of the dark and white recessive Dutch alleles yields a rabbit with nearly ideal Dutch markings (grades 6–9). Unfortunately, heterozygotes do not breed true. However, some Dutch breeders have the reputation for consistently producing uniform ideal grade stock. The best explanation of this is that selection for modifier genes with favorable effects on expression of superior Dutch markings in recessive homozygotes ($du^{d}du^{d}$ and $du^{w}du^{w}$) has produced a herd near the ideal type also found in the $du^{d}du^{w}$ heterozygote. Response of the modifier genes to selection is relatively rapid and consistent with the breeder's objective.

English white spotting

The dominant English white spotting gene, En, gets its name from the English Spot breed. In

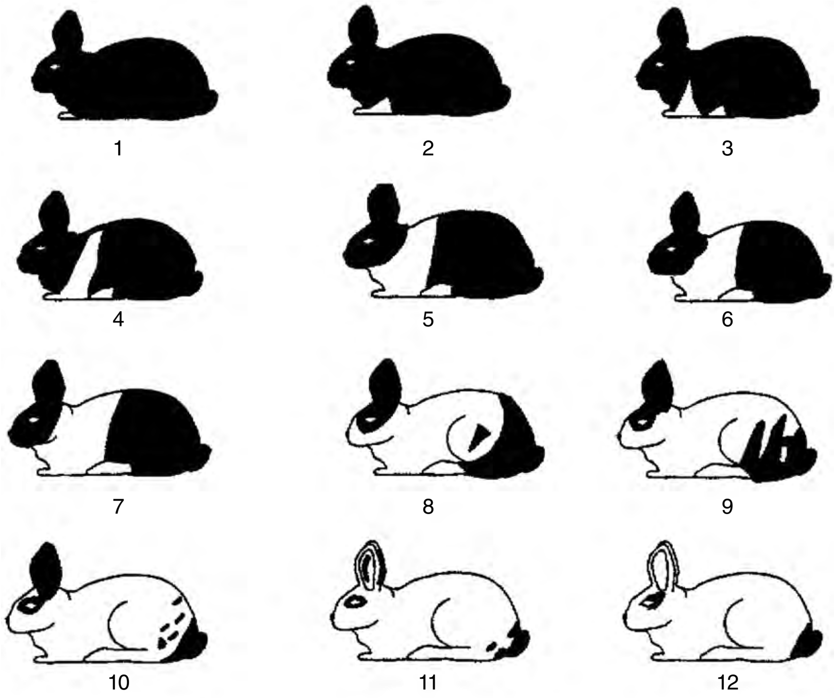


Fig. 16.6. Grades of Dutch white spotting. (Robinson, R. 1978. *Colour Inheritance in Small Livestock*, Fur and Feather, Idle, Bradford, UK. Courtesy of Fur and Feather)

general, this gene is referred to as the KIT gene by geneticists. The same gene is found, for example, in the Checkered Giant, Blanc de Hotot, Dwarf Hotot, Dwarf Papillon, and Rhinelander breeds. The Rhinelander possesses genes for English spotting as well as for Japanese harlequin brindling, producing a tri-colored animal of white, red, and black. The inheritance of English spotting is simpler than Dutch spotting, as illustrated in Fig. 16.7. The preferred phenotypes of the English Spot and the Checkered Giant breeds result from the heterozygous genotype Enen. The Enen heterozygote with the ideal phenotype (grades 5–7) will not breed true. Dominant homozygous rabbits, EnEn, are mostly white and are called Charlies (grades 8–12). The occurrence of grade 12 Charlies is particularly rare. At the other extreme, recessive homozygotes, enen, have no white spotting on the body (grade 0).

The number, size, and placement of spots is determined during fetal development, when color pigment-forming cells migrate from the spinal region (neural crest) to the head and down the sides of the body. Modifier genes are also involved in these spotting characteristics. Some studies in other species, such as mice and cattle, indicate that size and number of spots on the coat are quite heritable and could thus respond to selection. It is interesting that an association exists between migration of pigment-forming cells from the neural crest and the nerve supply to the digestive tract. The dominant homozygous rabbits, EnEn, are reported to have lowered gut motility and lack of nerve cell function in the gut wall. This condition is referred to as a type of megacolon abnormality syndrome. They also have higher mortality and very large, moist fecal pellets, which tend to adhere to the cage floor.

A unique genetic situation exists for coat color in the Hotot and Dwarf Papillon breeds. Rabbits have a completely white coat except for a circle of usually black color around each eye. The genotype for this breed is aa $du^w du^w$ EnEn. Genes for excessive Dutch and English

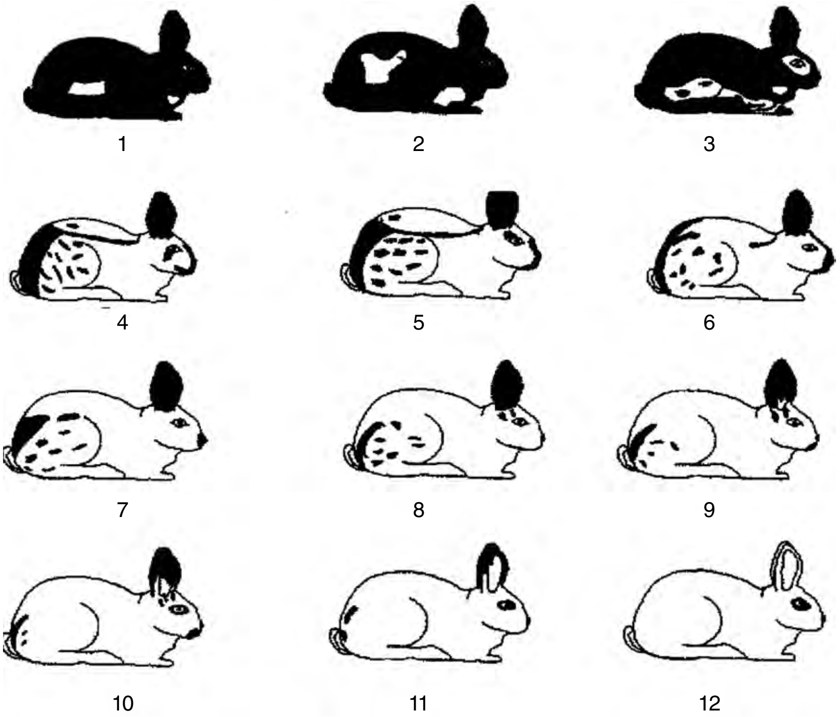


Fig. 16.7. Expression and inheritance of English white spotting (Robinson, R. 1978. *Colour Inheritance in Small Livestock*, Fur and Feather, Idle, Bradford, UK. Courtesy of Fur and Feather)

white spotting are combined in the same animal. Eye color is usually brown, although blue or mosaic eyes may be seen on occasion in some Hotots. Some individuals display only one eye circle and are referred to as boxers. This is believed to be a random non-genetic event that occurs during early fetal development. On the other hand, width of the eye circle is probably influenced by modifier genes. Of academic interest, the Dutch and English spotting genes are located very close together on the same chromosome (Chromosome 15), and therefore are said to be tightly linked (approximately a 1% probability of recombination). The significance of such a tight linkage lies in the great difficulty in producing desired recombinants ($du^w du^w$ EnEn) in subsequent generations from, say, Dutch x English Spot matings. In other words, the genes of relevance tend to be transmitted as a block of genes rather than as separate entities. A rare Dutch–English spotted rabbit with mosaic eye color is shown in Fig. 16.8.

Fig. 16.8. A Dutch–English spotted rabbit from Ghana, West Africa. (Courtesy of S.D. Lukefahr)

Silvering

The recessive silvering gene, si, is responsible for producing a preponderance of silver hairs throughout the body coat, such as found in the Champagne D'Argent breed. In the absence of the silvering gene(s), the Champagne would instead be a non-agouti, black-colored rabbit. In fact, young rabbits are first black colored, but within a few weeks of age, silver hairs begin to appear. It has been demonstrated that pigment-producing cells are physically stripped from the secondary guard hairs upon growth of the second coat. This action leaves silver hairs, a phenomenon somewhat similar to the aging process in humans. It has not been conclusively verified whether silvering is inherited as a simple recessive or is polygenic (involves many genes). Other breeds that display silvering include the Creme D'Argent, the Silver, and the Silver Fox. It probably would require only a minor breeding effort to develop new color varieties within the silver breeds through introducing the desired color by initial crossbreeding.

Viennese white

A common variety, for example, in the Beveren, Britannia Petite, Netherland Dwarf, and Polish breeds is the blue-eyed white. This condition is due to the presence of the Viennese white gene, v, in the homozygous state. One intriguing feature of this gene is revealed in the heterozygote (Vv) in which the Dutch spotting characteristics of a white facial blaze, white paws, and a white shoulder belt are exhibited. Hence, it appears to be associated with the KIT gene. Further, in the heterozygous state, gene v behaves as an incomplete dominant. A form of mock albinism exists when a rabbit possesses both c^h and v genes in the homozygous state. In the otherwise normal-appearing Himalayan-marked animal, the v gene restricts pigmentation from occurring at the points of the body. The coat becomes entirely white, and the eyes remain pink, making the animal resemble a true albino rabbit (cc).

Wide band

A recessive gene that causes an increase in the width of the sub-terminal agouti band of the hair shaft is called the wide-band gene (w). It is found in the Belgian Hare and possibly in certain varieties of the Rex, Silver, and Tan breeds. The effect of the gene is to make the sub-terminal band colors more visible with less dark surface color. Largely due to modifier genes, the extent of wide-band gene expression is variable from animal to animal. At the two extremes, for example, an animal could resemble a true agouti or could resemble a red agouti (AA *ee*) with no ticking shown. Similarly, Chinchilla rabbits that possess the wide-band gene (genotype $AAc^{chd}c^{chd}ww$) may show no black surface color or ticking. These are called ghost chinchillas because of excessive white pearling throughout the hair shaft. The base or undercolor remains a slate blue. Some Tan breeders contend that the w gene may be involved in yielding a prevalence of tan-tipped hairs in the coats of high-quality stock. This could also be the case in tan-patterned varieties of other breeds.

Modifier Genes

The role of modifier genes is, in many instances, critical in the phenotypic expression of coat color. They often also account for many mysteries in attempting to solve coat color cases. Each modifier gene by itself has a relatively insignificant effect on color. However, on a cumulative basis, modifier genes can make the difference between a poorly marked Dutch or one with ideal marking qualities. Other examples of their effects include the deep chestnut-red color found in the Belgian Hare, the definition of ring color in the Chinchilla, the degree of steeling in steel gray varieties, the extent of silvering in the Champagne D'Argent and Silver, and the dark bluing of the Blue Vienna. Since modifier genes behave in a cumulative or additive manner, directional selection can be practiced. For example, New Zealand Reds can be selected in one direction to produce animals with weak, light yellow coats or can be selected in the opposite direction to produce animals with rich, dark red coats. Selection for an intermediate red coat condition, called stabilized selection, can also be applied. Genetic progress achieved through directional or stabilized selection for modifier genes influencing coat color should be fairly rapid.

To better understand the role of modifier genes, they can be considered analogous to minus genes (–) and plus genes (+). Minus genes lighten, while plus genes darken color. In the New Zealand Red, animals that possess a majority of minus genes (– – – – + –) will have light yellow coats, while animals that possess a majority of plus genes (+ + + – + +) will have dark red coats. Animals with a near equal combination of minus and plus genes (– + – + – +) will have medium red coats. This concept can be applied to Dutch markings as well. Dutch rabbits with a preponderance of minus genes display more white spotting characteristics than those with a preponderance of plus genes. Selection toward increased white spotting should thus result in an increase in the presence of minus genes. As another example, selection applied at the modifier gene level in Lilac rabbits should produce either of the two extremes of blue or chocolate colors. This minus and plus gene action can apply to most forms of color and pattern expressions influenced by modifier genes.

Coat Structural Genes

Other genes affect hair coat structure (Table 16.5). The five genes presented – furless, angora, rex, satin, and waved – are all inherited as simple recessives.

Angora

The long-hair, angora wool gene, l, has been known for well over 100 years. Since the occurrence of this remarkable mutation, a thriving international angora wool industry has developed (see Chapter 22). The wool gene is also found in other species such as Angora goats, sheep, and possibly once even woolly mammoths. The hair of the angora rabbit grows rather continually in length, so the animal requires periodic clipping. This wool gene is referred to as FGF5 (Fibroblast Growth Factor) by molecular geneticists and is found on Chromosome 15. Wool characteristics, such as rate of growth, density of coat, and texture, are influenced by modifier genes and are generally considered highly heritable, so they should respond well to selection. Many varieties exist within the Angora breeds (Table 16.6).

In commercial meat breeds of rabbits, the occurrence of offspring with long, thin hair (called woollies) has been a nuisance. The frequency of incidence of the l gene can be reduced by mating woolly-type tester animals to suspect l carriers and culling confirmed carrier stock.

Table 16.5. Selected genes for coat structure in rabbits.

Locus	Alleles	Hair structure
f – Furless	F	Normal
	f	Furless
l – Angora	L	Normal
	l	Hair long, wool
r – Rex	R	Normal
	r	Hair short, rex[1]
sa – Satin	Sa	Normal
	sa	Hair thin, satin
wa – Waved	Wa	Normal
	wa	Hair waved, astrex

[1] Three pairs of rex genes found on different loci have been reported.

Furless

Furless, f, was first discovered in Russia and was reported as a condition in which "furless" rabbits (Fig. 16.6) apparently lack the soft, short underfur of the coat, possessing predominantly guard hairs. Furless goes by other names such as hairless and naked. Interestingly, there may be different alleles for this condition. A rare population of furless rabbits was maintained at Texas A&M University-Kingsville. Several years of research were conducted in summers to compare performance of furred and furless littermates from matings of parents that were heterozygous (carriers of the recessive furless gene). The studies revealed that furless rabbits consumed more feed and had faster growth rates than their furred littermates. Also, furless rabbits had better performance because they were apparently less stressed by the heat, taking fewer breaths and having fewer heart beats per minute (indicators of better heat resistance). The potential exists for furless rabbits to be raised in hot climates where they would be more suitable for meat production.

Table 16.6. Standard coat color genotypes of the Angora rabbit.

Varieties	
Agouti varieties	
Agouti	AABBCCDDEE
Chinchilla	AABB$c^{chd}c^{chd}$DDEE
Cinnamon	AAbb CC DDEE
Cream	AA BB CC dd ee
Ermine Silver[1]	AA BB $c^{chd}c^{chd}$ DD ee
Fawn[2]	AA BB CC DD ee
Lynx	AA bb CC dd EE
Opal	AA BB CC dd EE
Squirrel	AA BB $c^{chd}c^{chd}$ dd EE
Steel	AA BB CC DD E^sE
Non-agouti varieties	
Black	aa BB CC DD EE
Blue	aa BB CC dd EE
Chocolate	aa bb CC DD EE
Himalayan	
Black	aa BB c^hc^h DD EE
Blue	aa BB c^hc^h dd EE
Chocolate	aa bb c^hc^h DD EE
Lilac	aa bb c^hc^h dd EE
Lilac	aa bb CC dd EE
Marten	
Black	a^ta^t BB $c^{chd}c^{chd}$ DD EE
Blue	a^ta^t BB $c^{chd}c^{chd}$ dd EE
Chocolate	a^ta^t bb $c^{chd}c^{chd}$ DD EE
Lilac	a^ta^t bb $c^{chl}c^{chl}$ dd EE
Sable	a^ta^t BB $c^{chl}c^{chl}$ DD EE
Sable[3]	aa BB $c^{chl}c^{chl}$ DD ee
Siamese Sable[3]	aa BB $c^{chl}c^{chl}$ DD ee
Smoke Pearl	aa BB $c^{chl}c^{chl}$ dd ee
Tan	
Black	a^ta^t BB CC DD EE
Blue	a^ta^t BB CC dd EE
Chocolate	a^ta^t bb CC DD EE
Lilac	a^ta^t bb CC dd EE
Tortoise-shell	
Blue cream	aa BB CC dd ee
Bronze	aa bb CC DD ee
Lilac	aa bb CC dd ee
Sooty	aa BB CC DD ee
White varieties	
Blue-eyed white	__ CC__vv[4]
Red-eyed white	__ cc __

[1] There are two eye-color versions. Rabbits with $c^{chd}c^{chd}$ have marbled blue irises; those with $c^{chl}c^{chl}$ and the $c^{chd}c^{chl}$ heterozygote have brown irises.

[2] The genotype AAbbCCDDee also gives fawn color. This is generally considered to be a superior, more consistent coat color than that arising from AABBCCDDee.

[3] The coat color difference is due to modifier genes.

[4] Recessive gene for Viennese white color.

Source: S.D. Lukefahr. 1986. Basic inheritance of coat color in rabbits. *J. Appl. Rabbit Res.* 9: 168–174.

Fig. 16.9. A furless rabbit, resulting from a homozygous condition of the furless gene, f. (Courtesy of S.D. Lukefahr)

Rex

Three sets of rex genes (r^1, r^2, and r^3) have been reported. Each of these paired sets is presumed to exist on a separate locus, or chromosome location. The French rex gene, r^1, is the most common, prevalent in many of the American and European Rex breeds. It involves a mutation in the gene referred to as LIPH (Lipase Member H), which causes this shortened hair condition. The second rex gene, r^2, is sometimes referred to as the German short-hair gene and is virtually indistinguishable from r^1. Both of these genes, r^1 and r^2, have been demonstrated to be located on the same chromosome and are therefore linked. The third rex gene, r^3, has been called the Normandy rex gene and is quite indistinguishable from r^1 and r^2 in expression.

The effect of the rex gene involves the near absence of guard hairs, leaving primarily the underfur. Thus, the coat is composed of a short, plush fur of a luxuriantly soft quality. Certain pelt qualities involve modifier genes, such as age at which a prime pelt is first produced, fur density, length and texture, and size of the coat. These qualities are heritable to some extent and therefore can be improved through selection. In the past, the development of a Rex fur industry was pursued by various groups of Rex rabbit breeders.

Many coat color varieties occur in the Rex breed. Agouti, self, shaded, tan, tri-colored, and white varieties are represented, although the dark colors – black, castor, chinchilla, chocolate, sable, and seal – are in highest demand by the Rex garment industry. Genotypes for these coat colors are provided in Table 16.2. These particular varieties, for the most part, involve alleles only from the A, B, and C major coat color series. There exist, in addition to ARBA-recognized color varieties, various other colors of the breed (Table 16.7). Mating rabbits with common coat colors may combine genes to produce offspring with less common coat colors (e.g., red x blue to produce beige rabbits in the second (F_2) generation). The wide-band gene may be prevalent in the Rex breed and compensate for the reduced hair length. Many modifier genes also act to impart the preferred shade, tone, and pattern of color.

The Opossum Rex, once a British breed, is the result of two-generation matings that initially involve the long-hair angora and short-hair rex. Upon recombination of genes transmitted by the first cross generation (F_1), progeny in the second generation (F_2) with the genotype llrr, will appear at the rate of 1/16 probability. Although the F_2 rabbit of Angora and Rex breeding may display a long, limp coat of fur that is susceptible to matting, through selection this has been bred out of the Opossum Rex so the hairs are more erect and coarse. In addition, the silvering gene was introduced during development of the breed to mimic the true opossum coat. Photos of the Opossum Rex can be found easily on the Internet.

Table 16.7. Additional coat color varieties present in the Rex breed.

Color	Genotype
Beige	aa dd ee
Fawn	dd ee
Harlequin	e^je^j
Magpie	$c^{chd}c^{chd}$ e^je^j
Silver marten	a^ta^t $c^{chd}c^{chd}$
Smoke pearl	aa $c^{chl}c^{chl}$ dd ee
Tortoise-shell	aa ee
Tri-colored	Enen e^je^j

Satin

The first Satin rabbit appeared as a mutation in 1931 in a litter of chocolate Havanas. The satin gene, sa, is a simple recessive. The effect of the satin gene is to reduce the hair fiber diameter and to make the outer layer smoother, allowing for more light reflection, which results in the satin sheen quality. This change in the hair structure causes the coat to glisten and have a nearly transparent or glass-like appearance, which enhances the brilliancy of color. The degree of luster or sheen of the coat in the Satin depends on the condition of the animal and is also influenced by the cumulative effects of modifier genes. From the several varieties of coat color presently found in the Satin breed, it is possible through simple breeding strategies to produce many additional colors.

Waved

The wa gene, also a simple recessive, produces a wave-like effect in the Rex coat. The homozygous wawa rabbit is called an Astrex. It is interesting that this gene elicits its effect in rex coats. Further, the wavy condition may not be fully expressed until two years of age. The rate of wave structure development and the extent to which it occurs throughout the body coat are considered to be in part due to modifier genes. A photo of a rabbit with the wavy (Astrex) condition is shown in Fig. 16.10.

Fig. 16.10. A doe with the Rex and wavy coat characteristics. (Courtesy of S.D. Lukefahr)

Coat Color Breeding Schemes

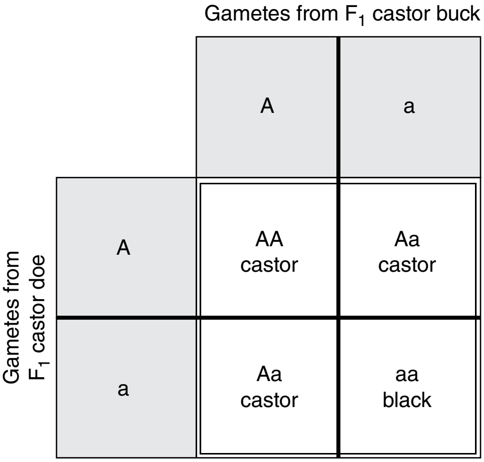
Using knowledge on specific genes that influence color, pattern, and structure of the coat, appropriate breeding methods can be developed to introduce desired genes or gene combinations into the line, strain, or breed of rabbits. Breeding methods to introduce desired genes or gene combinations include: (1) simple gene introduction, (2) multiple gene introduction, and (3) multiple gene recombination. A minimum of two consecutive generations of matings are usually needed to realize the primary breeding objective.

Simple gene introduction

Suppose in a line of commercial castor Rex it is desired to change the color to black. Figure that because this particular line of castors possesses excellent characteristics for body conformation and reproductive performance (fertility and litter size), it is desired to make the simple black color introduction without displacing the entire line. The first step made by the breeder is to obtain a minimum of two black Rex bucks (preferably not closely related) with sound conformation and proven records of good reproductive merit. Each black buck is then mated to several castor does. These matings are made at random, and each doe should be a random sample from the line as a whole. This random process is imperative in maintaining the genetic variability found in the line. The black bucks transmit the non-agouti black a gene. The castor does transmit the agouti (castor) A gene. All offspring will therefore have the Aa genotype. Because here it is assumed that all black and castor parents are homozygous for the agouti dominant genes found at the B, C, D, and E loci, only alleles at the A locus will be used. All F_1 (first-cross) offspring from the black x castor mating are heterozygous Aa and are castors since A is completely dominant.

At this stage of the breeding strategy, two options exist to secure the line of black Rexes from an original castor base: backcrossing or *inter se* (half brother–sister) matings. F_1 castor does could be backcrossed to an unrelated set of black bucks to produce black-colored offspring; half castor and half black progeny would be the expected outcome. However, the progeny of this backcrossed generation would possess only 25% of the ancestry from the original castor line. The better option may be to make *inter se* matings among F_1 individuals, the progeny of which will maintain 50% of their castor line ancestry in the subsequent F_2 (second-cross) generation (Fig. 16.11). In the F_2 generation, one out of four offspring is expected to be black. The breeder retains the best black-colored individuals (aa), thus establishing the line of black Rexes. Further selection may be desired to continue to improve fur, body conformation, and production characteristics.

In the next example of simple gene introduction into an established line, a dominant gene will be used. A breeder of French Lops decides to develop a line of broken (spotted) Lops. The breeder has a line of solid-colored (self) rabbits – black, blue, and chocolate – and wishes to produce these same colors but as broken varieties. To do so, the breeder acquires several broken Lop bucks with outstanding coat pattern characteristics (again, more than one buck should be used to enhance genetic variation and prevent subsequent inbreeding) and mates each at random to several self-Lop does. Since selection for coat pattern (broken) is the primary breeding objective, as



		Gametes from F_1 castor buck	
		A	a
Gametes from F_1 castor doe	A	AA castor	Aa castor
	a	Aa castor	aa black

Fig. 16.11. Illustration of the expected 3:1 phenotypic ratio of F_2 progeny, where both F_1 castor Rex parents are heterozygous Aa. (Courtesy of OSU Rabbit Research Center)

opposed to color, *per se*, only one locus, En, is relevant here. The English spotting gene, En, is the operative gene in the broken variety of Lops. Because of incomplete dominance, it is the heterozygous form Enen that yields the ideal broken pattern, although modifier genes are of critical importance in determining the extent of white spotting. Of course, heterozygotes do not breed true. Such matings will have an expected ratio of 1:2:1 of EnEn, Enen, and enen genotypes. EnEn homozygotes exhibit excessive white spotting, while enen homozygotes display no white spotting.

Figure 16.12 demonstrates the genetic results of broken x self matings within the Lop herd mentioned. Within each litter from a broken x self-mating, approximately half should be brokens and the other half selfs. The best heterozygous broken progeny are retained from several litters to establish the new line of broken Lops. The breeders should practice continual selection within this new line to conform the modifier genes to the ideal broken pattern standards.

Multiple gene introduction

A fancier of Netherland Dwarf agouti varieties (e.g., opal, lynx, and squirrel) has observed a cinnamon-colored male and decides to develop an additional agouti variety – cinnamon – using this buck. (Cinnamon color is more aptly described as a chocolate agouti; brown-tipped rather than black-tipped hairs are seen.)

The cinnamon-colored rabbit was the result of a chestnut agouti AA B_ D_ x lynx AA bb dd parental mating. Since the standard cinnamon has an AA bb DD genotype, then the chestnut agouti parent was a carrier for the b chocolate gene. It is further known that the cinnamon rabbit in question is heterozygous at the D locus (Dd). The breeder has a good basic understanding of coat color genetics and plans to cross their cinnamon rabbit to their line of lynxes, since the breeder has many more lynxes than chestnut agoutis, which will provide a broader genetic base.

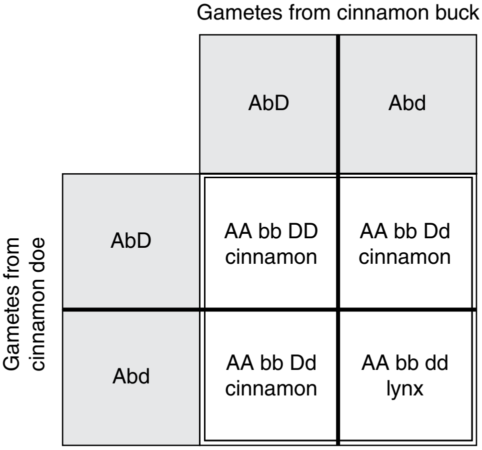
When the cinnamon buck approaches breeding maturity, several lynx does will be randomly chosen for mating. The expected results are shown in Fig. 16.13. The cinnamon-colored offspring will be retained from a number of litters. In the next generation of matings, cinnamon bucks and cinnamon does will be bred together. Each breeding pair will be from separate litters to minimize the rate of inbreeding. Half-sib matings will be involved. Results of these *inter se* matings are provided in Fig. 16.14. The cinnamons produced from *inter se* cinnamon matings will be homozygous or heterozygous at the D locus. The challenge now lies in the identification of the desired homozygous rabbit (genotype AA bb DD), which will breed true. This can be achieved by test-mating the cinnamons produced (genotype AA bb D?) with lynx, opal, or blue-colored rabbits, all of which are homozygous recessive

		Gametes from broken Lop buck	
		En	en
Gametes from self Lop doe	en	Enen broken	enen self

Fig. 16.12. Illustration of the expected 1:1 phenotypic ratio of linecrossed offspring resulting from a broken x self Lop mating. (Courtesy of OSU Rabbit Research Center)

		Gametes from cinnamon buck	
		AbD	Abd
Gametes from lynx doe	Abd	AA bb Dd cinnamon	AA bb dd lynx

Fig. 16.13. Illustration of the expected 1:1 phenotypic ratio of cinnamon- and lynx-colored offspring produced from similarly colored parental stock. (Courtesy of OSU Rabbit Research Center)



	Gametes from cinnamon buck	
Gametes from cinnamon doe	AbD	Abd
AbD	AA bb DD cinnamon	AA bb Dd cinnamon
Abd	AA bb Dd cinnamon	AA bb dd lynx

Fig. 16.14. Illustration of the expected 3:1 phenotypic ratio of cinnamon and lynx offspring produced from an *inter se* cinnamon mating. (Courtesy of OSU Rabbit Research Center)

dd. The breeder chooses to use her lynx bucks and does to test-mate with cinnamons for the detection of DD homozygotes. A cinnamon homozygote is confirmed when no lynx offspring are observed in a litter of eight kits or more. If fewer than eight kits are produced, the mating should be repeated. A 50% probability exists that each offspring will be cinnamon (or lynx) colored when the cinnamon parent is a Dd heterozygote. The chance of producing four cinnamon kits in a litter of four from this last mating is 1 in 16, while the chance of producing eight cinnamon kits in a litter of eight is only 1 in 256. Once several confirmed cinnamon homozygotes have been identified, these animals can be retained to establish a true breeding cinnamon line of Netherland Dwarfs.

Multiple gene recombination for producing new varieties

A breeder wants to develop a strain of Angora Rex rabbits (called the Opossum Rex breed in the UK). A random base sample of four black French Angora bucks (aa ll RR) and eight black Rex does (aa LL rr) was acquired. Each Angora buck was randomly mated with two Rex does. The F_1 progeny produced in this mating are double heterozygous (aa Ll Rr) and have normal-coated black fur. The genotype of the Opossum is aa ll rr, so a second generation (F_2) is necessary. Genetic results of F_1 *inter se* matings are shown in Fig. 16.15.

Through the normal genetic processes of segregation, recombination, and independent assortment, four classes of phenotypes for coat structure – normal, Rex, Angora, and Opossum – occur in an expected 9:3:3:1 ratio (assuming no linkage). This expected ratio is based on the average of many offspring. Rex and Angora are the original parental breeds used, and the other two classes of normal and opossum are the genetic recombinants. The breeder saves opossum-type rabbits produced from all 12 original grandparents. As a final color touch, the breeder decides to impart the effects of silvering to the opossum coat by matings involving the Champagne D'Argent breed. This process will again require F_1 and F_2 generations to recover the opossum coat condition with genes for silvering; hence, four generations and considerable patience are required. Additional generations of refined selection to develop an erect, stiff hair coat with a suitable degree of silvering may be desired by the breeder. Another breeding approach would be to develop two F_1 lines by crossing Champagne D'Argent to Angora and Champagne D'Argent to Rex rabbits. Next, the two F_1 lines would be crossed to produce the F_2 generation. Then cross F_2 generation rabbits and select those offspring that display the desired combination of genes. In this example, the experienced breeder can appreciate the fact that a new breed or variety does not occur in just one generation!

The final example involves a breeder of English Spot rabbits who wishes to produce blue fawn (cream) and blue tortoise (beige) colored versions of the breed. The homozygous genotypes for the cream and beige colors are AA BB CC dd *ee* and aa BB CC dd *ee*, respectively. Phenotypically, the cream can be described as a red agouti with blue tick casting, while the beige can be described as a non-agouti, blue-pointed tortoise. The breeder selects two English spot color varieties that collectively possess the genes of interest to produce creams and beiges (see Table 16.2).

Gametes from F_1 black, normal-coated buck

Gametes from F_1 black, normal-coated doe

	aLR	aLr	alR	alr
aLR	aaLLRR normal	aaLLRr normal	aaLlRR normal	aaLlRr normal
aLr	aaLLRr normal	aaLLrr rex	aaLlRr normal	aaLlrr rex
alR	aaLlRR normal	aaLlRr normal	aallRR angora	aallRr angora
alr	aaLlRr normal	aaLlrr rex	aallRr angora	aallrr opossum

Fig. 16.15. Illustration of the expected 9:3:3:1 phenotypic ratio of normal, Rex, Angora, and opossum-coated F_2 progeny produced from F_1 black, normal-coated inter se matings. (Courtesy of OSU Rabbit Research Center)

The gold variety has A, B, C, and e genes to contribute to the cream, and the blue or lilac has the needed d gene. The breeder decides first to cross gold and blue rabbits toward development of the cream version. Secondly, for producing the beige version, the breeder knows that matings involving gold × blue, gold × lilac, tortoise × blue, and tortoise × lilac could all eventually give rise to achieving this breeding goal. Because there are only a few English spots in the herd, the breeder chooses to make gold × blue matings, which will eventually yield both cream and beige. Gold bucks are mated with blue does, and vice versa. Initial results of this type of mating are given in Fig. 16.16. From this mating several F_1 bucks and does should be saved and inter-crossed to yield creams and beiges in the next generation. Close inbreeding should be avoided. Genetic and phenotypic outcomes of this second round of matings are as shown in Fig. 16.17.

Of the 64 genetic outcomes possible in the above mating, the probability of producing a cream is 3 in 64 and of producing a beige is 1 in 64. In contrast, since a given cream rabbit could be heterozygous at the A locus, it would be wise to test-mate with a

Gametes from gold buck

Gametes from blue doe

	ADe
adE	Aa Dd Ee agouti

Fig. 16.16. Illustration of triple heterozygous agouti-colored offspring produced from a gold × blue English spot mating. (Courtesy of OSU Rabbit Research Center)

black rabbit. A minimum of eight offspring should be scored for coat color. If all eight or more offspring result in no selfs or siamese colors, then chances are excellent that the given cream in question is homozygous and will breed true. Similarly, confirmed cream homozygotes can be retained to establish the English spot cream version. Further refined selection in subsequent generations may be desired, for example, to standardize the degree of fawn-blue shading of color. Since the beige is a triple recessive homozygote, it will invariably breed true when mated to another beige, so test-matings are unnecessary.

An excellent book by Robinson provides useful supplementary information on coat color genetics, as listed below.

Gametes from F_1 agouti buck

Gametes from F_1 agouti doe

	ADE	ADe	AdE	Ade	aDE	aDe	adE	ade
ADE	AA DD EE agouti	AA DD Ee agouti	AA Dd EE agouti	AA Dd Ee agouti	Aa DD EE agouti	Aa DD Ee agouti	Aa Dd EE agouti	Aa Dd Ee agouti
ADe	AA DD Ee agouti	AA DD ee red	AA Dd Ee agouti	AA Dd ee red	Aa DD Ee agouti	Aa DD ee red	Aa Dd Ee agouti	Aa Dd ee red
AdE	AA Dd EE agouti	AA Dd Ee agouti	AA dd EE opal	AA dd Ee opal	Aa Dd EE agouti	Aa Dd Ee agouti	Aa dd EE opal	Aa dd Ee opal
Ade	AA Dd Ee agouti	AA Dd ee red	AA dd Ee opal	AA dd ee cream	Aa Dd Ee agouti	Aa Dd ee red	Aa dd Ee opal	Aa dd ee cream
aDE	Aa DD EE agouti	Aa DD Ee agouti	Aa Dd EE agouti	Aa Dd Ee agouti	aa DD EE black	aa DD Ee black	aa Dd EE black	aa Dd Ee black
aDe	Aa DD Ee agouti	Aa DD ee red	Aa Dd Ee agouti	Aa Dd ee red	aa DD Ee black	aa DD ee tortoise	aa Dd Ee black	aa Dd ee tortoise
adE	Aa Dd EE agouti	Aa Dd Ee agouti	Aa dd EE opal	Aa dd Ee opal	aa Dd EE black	aa Dd Ee black	aa dd EE blue	aa dd Ee blue
ade	Aa Dd Ee agouti	Aa Dd ee red	Aa dd Ee opal	Aa dd ee cream	aa Dd Ee black	aa Dd ee tortoise	aa dd Ee blue	aa dd ee beige

Fig. 16.17. Illustration of the expected 27:9:9:9:3:3:3:1 phenotypic ratio of agouti, red, opal, black, cream, tortoise, blue, and beige-colored offspring produced from an F_1 *inter se* mating involving agouti-colored parents. (Courtesy of OSU Rabbit Research Center)

Further Reading

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17

Rabbit Shows

Among rabbit shows are specialty club, local, state, national, those held at county or state fairs, and the American Rabbit Breeders Association annual National Convention and Show (Fig. 17.1). All rabbit shows offer splendid opportunities for beginners and others interested in rabbit raising to acquaint themselves with the characteristics of the various breeds and varieties. They are especially beneficial to established breeders because the shows make it possible for them to connect and compete with other rabbit breeders and compare their results with their own rabbit breeding operations.

At larger shows, such as the ARBA Convention, additional meat classes bring together the commercial breeds and create much interest by exhibitors vying for top cash prizes. Classes include single fryers, meat pens of three fryers, single roasters, and single stewers. Meat pen and single fryer classes are more commonly found at county and state fairs as part of the junior market livestock show for 4-H and FFA clubs. Concluding the meat classes at fairs, these same rabbits are sold at a junior livestock auction where junior exhibitors can earn back money to subsidize their projects and even save money towards their college education. Meat class rabbits may be butchered and the carcasses judged as well.

The fur classes place special emphasis on the texture, density, length and overall condition of the rabbit coat. By carefully studying the winning animals in these classes, breeders become familiar with contemporary competition and the standards to aim for in their own operations. At the annual ARBA Convention, exhibited entries of plucked or shorn Angora wool, hand-spun Angora wool skins, and handmade garments of Angora wool create interest and add variety to the show.

Preparation of Rabbits for Shows

Probably the most important decision in preparing show entries is the selection of outstanding prospects for body type, head shape, color and markings, density and quality of fur or wool, unique breed-specific characteristics, and proper age for the particular class in which each animal will be entered. When possible, choose several rabbits for each class to condition for the show, because some will not come up to expectations. The larger the number of quality rabbits you have available for making a final selection, the greater your chances for having a show-ready entry for a particular class. Preparation of the animals for the show must be started in advance so they will be properly developed, have firm flesh, prime coats of fur, and be at the peak of condition at judging time. The breeding date for the does should be well planned so that the resulting show entries will have full advantage of the age limit for the class. All rabbits under six months of age are

Rabbit Production, 10th Edition (S.D. Lukefahr *et al.*)

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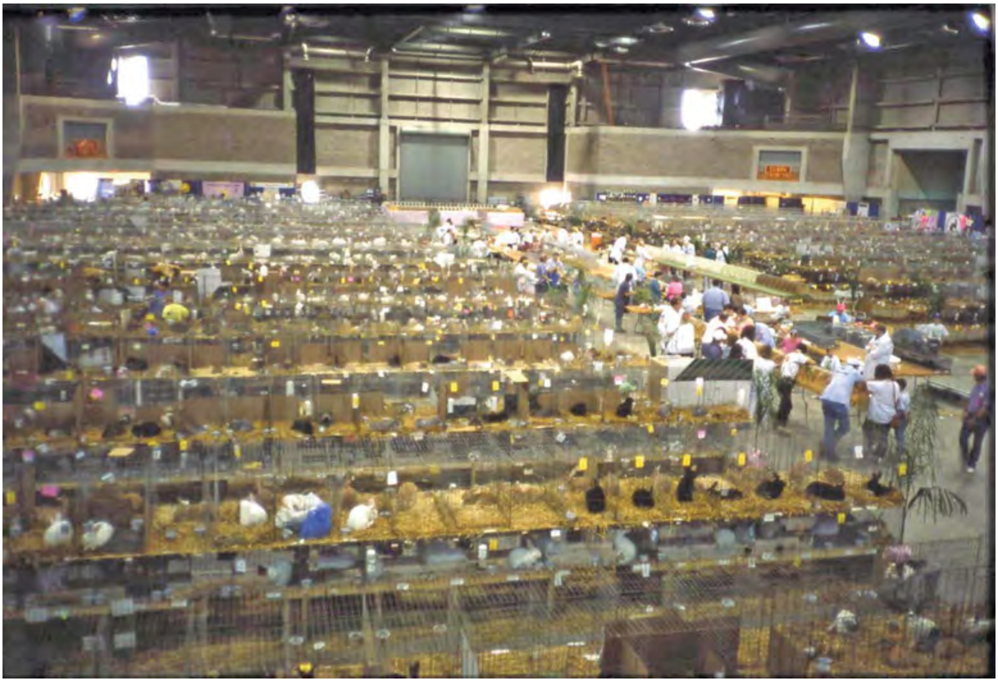


Fig. 17.1. American Rabbit Breeders Association Convention Show. (Courtesy of J.I. McNitt)

capable of competing in junior classes unless they exceed weight limitations. Many breeds allow faster-maturing juniors, which exceed weight limits, to be moved to compete in senior classes.

Most breeders feed their show rabbits the ration that is fed to the herd at large, but in many instances it is also a good practice to feed small quantities of green feed, hay, or root crops daily to stimulate the appetite and to keep the digestive system in good tone. Pelleted feed supplements are also widely used to target fur growth, flesh firmness, and optimal prime condition. The quantity of all the feeds should be regulated to meet each individual animal's requirements. Natural grains and bread are excellent supplements, especially for young rabbits that are being prepared for exhibition.

The prime condition of the pelt is always important in show rabbits. However, it is a rather difficult problem to handle with mature rabbits, for at certain seasons of the year they are in various stages of molt. The judge may overlook slight molting in an older rabbit if the individual animal is outstanding in other characteristics. This is notably true for breeds that put more emphasis in their breed standards on head size and bone mass, traits that develop with age.

You must regularly handle the prospective show rabbit to help it overcome any fright and to teach it to "pose" so it will show the breed characteristics to the best advantage. When the animal is alert, fresh, and well trained, it makes its best appearance (Fig. 17.2). Rabbits that are difficult for the judge to handle are quickly overlooked when the safety of the animal on the show table is in jeopardy.

In some cases, a rabbit may be handled as many as 20 or more times at a show. Therefore, it is especially important that the handling be done in such a manner that the fur is not pulled and the skin over the shoulders and muscles will not be bruised and become tender to the touch. Bruising will cause the rabbit to flinch and not show to the best advantage when being examined by the judge (Fig. 17.3). Rabbits that are accustomed to being handled by multiple people will be less

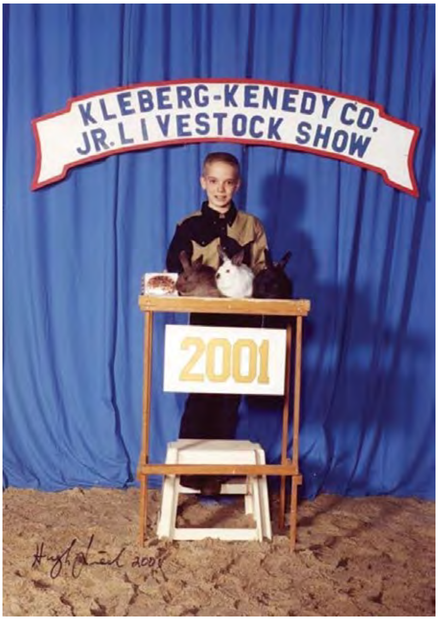


Fig. 17.2. A youth proudly displaying his Grand Champion pen of commercial meat class of rabbits. (Courtesy of S.D. Lukefahr)

likely to stress and depreciate on show day, and more likely to show off to their best potential. Taking rabbits to shows prior to traveling to larger, more prestigious shows is a beneficial practice.

Grooming the rabbit before the show and at the show by rubbing its coat with your hands and a small spritz of water, proceeding from the head to the tail, removes loose hair and gives the coat a renewed vibrance. When the rabbit is shedding, moistening your hands and stroking the coat in reverse (from tail to head) will facilitate removal of the dead hairs. Always conclude this grooming method with a final stroke from head to tail to smoothen the coat to its natural position.

Colored breeds, especially those with emphasis on depth of color, should not be subjected to strong sunlight, because it has a tendency to fade the coat and to give it a dull appearance. Some varieties are more susceptible to sunlight such as black, chocolate, and Siamese sable.

Hutch stains detract from the appearance of an animal. These can be removed from

Fig. 17.3. Judging rabbits at an ARBA-sanctioned show. (Courtesy of Allen Mesick)

white rabbits and from the white spots on the spotted breeds with hydrogen peroxide or a similar bleaching agent. Small quantities of talc may also be used, but all animals must be free of foreign substances during competition.

Every possible means should be taken to protect show rabbits. Often, they are subjected to a lot of jostling around in transit, to extreme fluctuations in temperature, and to sudden and radical changes in feed that cause them to go “off feed.” These factors may cause them to become listless and make a poor showing, so it is a good plan to have them arrive at the show in plenty of time to quieten down and become accustomed to their new surroundings before going on the show table. Maintaining an environment that is as similar to a rabbit’s normal home is key to minimizing stress and dually promoting eating and drinking. Exhibitors should furnish a supply of the feed to which the animals have been accustomed for use during the time they are at the show. Some exhibitors travel with gallons of water from home to use during the length of the show. Highly chlorinated water may detract an interest in drinking, and consequently affect feed consumption and overall show condition and vigour.

A rabbit should never be shown if there is any symptom of disease, for subjecting the sick rabbit to changes in temperature, feed, etc., will lower its vitality and make it easily susceptible to additional infections. Sick animals will be disqualified and will not be allowed to compete in the classes. In the meantime, they may expose other rabbits; and as a matter of fair play, it is not ethical to jeopardize the health of rabbits belonging to other exhibitors. Infections caused by *Pasteurella* or other microorganisms can be ruinous to a rabbit enterprise. All precautions should therefore be taken to avoid exposure.

Shipping Show Rabbits

Rabbits are transported to shows either in personal vehicles or, for long distances, as air cargo or excess baggage. In either case, the rabbits should be housed in carrying cages that allow them individual space to lie down and stretch out. Most cages have wire bottoms with pans underneath to collect urine and feces. Pet training pads are the best absorptive option for lining carrier pans, and are often preferred by airlines in lieu of wood shavings. If the rabbits are to be in the cages for some time, water bottles and some feed should be supplied. When shipping rabbits by air, be sure to check in advance to determine the airline’s requirements.

Judging and Showing

Shows can be held in any facility that provides shelter from the weather and sun and has good lighting, temperature control, and ventilation. In larger shows, cooping may be provided by the sponsors. For most one-day shows, the rabbits are kept in their carrying cages. Most shows are sponsored and run by local clubs affiliated with the ARBA or by local or state fairs and agricultural expositions. The sponsors will provide the necessary equipment and will publish a show catalog describing the sanctioned breeds, list of judges, entry fees and deadlines, and the general overview of the show.

The table used for the judging should be covered with carpeting or synthetic turf to prevent the rabbits from slipping and to make them feel secure. The judging coops should be constructed to make it possible for all the animals to be in full view of the judge. These coops should be secured to the table so that they may be opened and the rabbits easily brought out onto the table for inspection and comparisons. Judging coops may be constructed of wood, wire, or a combination of both. Wooden coops are heavier, more difficult to store, and less capable of thorough disinfection than full-wire equipment.

Much pleasure and camaraderie can accompany participation and winnings in shows, whether as a 4-H or FFA club youth project (Fig. 17.4) or as an ARBA-sanctioned event (Fig. 17.5). To facilitate this camaraderie, the opinions of the judges should be respected. The judges are selected because of their knowledge of the standard requirements for the different breeds and varieties, their aptitude for

Fig. 17.4. A well decorated exhibit of a Grand Champion pen of market rabbits at a local county youth fair. (Courtesy of the Webb family)

handling rabbits, their fairness in making decisions, their desire to be helpful to the exhibitors and to interested spectators, and their willingness to put in long hours to expedite the show. After a class has been placed, they should take pleasure in answering questions and explaining their reasons for making certain placings.

In North America and Asia, almost all rabbit shows are sanctioned by the American Rabbit Breeders Association. The ARBA *Standard of Perfection* is the basis of the judging system. The standard for each ARBA-recognized breed includes the minimum and maximum allowable weights and a system of points unique to each breed based on body type, fur and wool, color, markings, head shape, bone density, and even eye shape. Animals are judged by comparison to find the one that comes closest to the ideals set forth in the *Standard of Perfection*.

Judging is performed by ARBA-licensed judges. These individuals have held continuous membership with the ARBA for five consecutive years, received the endorsement of 20 adult ARBA members, passed a rigorous written and oral examination, apprenticed under eight ARBA judges at sanctioned shows, and held an ARBA registrar license. An ARBA registrar is the prerequisite license to a judge license, and permits an individual to officially register rabbits with the ARBA by means of physical inspection, pedigree authentication, and tattoo certification. An applicant for a registrar license must have at least three consecutive years of membership with the ARBA, receive endorsement of 20 adult ARBA members, pass a written and oral examination, and apprentice with three ARBA judges and one registrar.

Registering Rabbits

The American Rabbit Breeders Association maintains a registration and recording system. Purebred rabbits can be registered with the ARBA only by a licensed registrar of that association. The registrar examines the rabbit to be registered to make sure it is free of all defects that would render it disqualified in a sanctioned show, including whether its variety is recognized by the ARBA. The registrar also weighs the rabbit to be sure it is within the proper weight range for its breed, ensures the rabbit is at least six months old, and inspects the required three-generation pedigree for breed purity and completeness. If, after checking, the registrar finds the animal is qualified according to the ARBA standards, they will fill in the registration application, stating the breed, sex, variety, name of the rabbit, date of birth, and body weight. The registrar may opt to add their subjective remarks, and finally conclude by attaching a copy of its three-generation pedigree before submitting these documents to the ARBA office for final authorization. There is a number

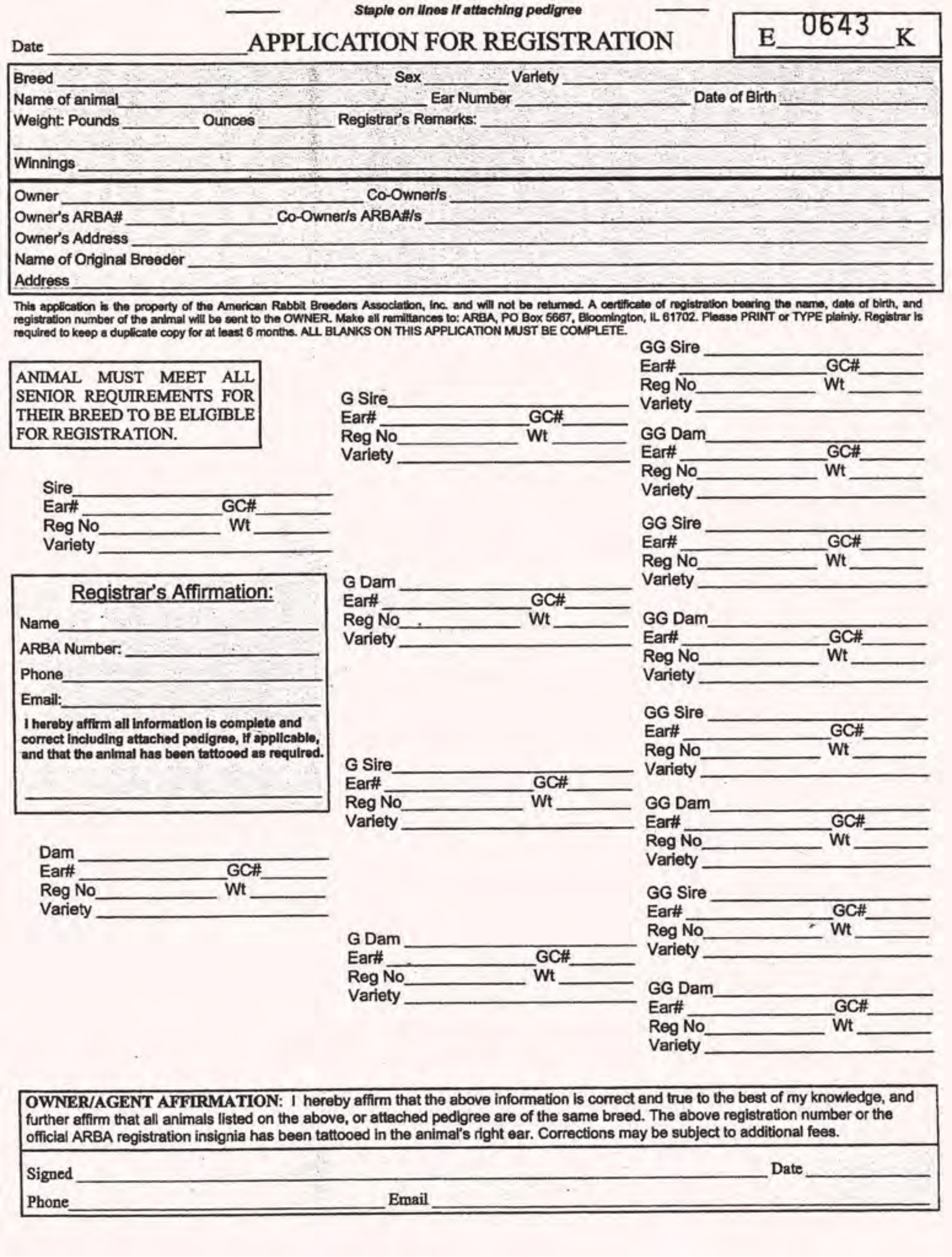
Fig. 17.5. The rewards of showing rabbits include trophies for prize-winning animals. (Courtesy of D.J. Harris)

in the top right-hand corner of the registration application which the registrar will tattoo into the rabbit's right ear. Alternatively, the registrar may tattoo the symbol ® in the right ear to indicate that the animal has been registered. The left ear is reserved for private ear numbers supplied by the breeder.

The registration applications (Fig. 17.6) are in triplicate; the original is mailed to the ARBA by the registrar, the duplicate acts as a receipt and is given to the owner of the rabbit being registered, and the triplicate is kept by the registrar to be used in case the original becomes lost.

If the ARBA finds the application to be correct, it processes a certificate of registration (Fig. 17.7), checks the registration number that appears on the pedigree, and affixes the proper merit seal. If the sire and dam are registered, a red seal is affixed; if the sire and dam and the grandsires and granddams are registered, a red and white seal is affixed; if all 14 ancestors shown on the pedigree are registered, a red, white, and blue seal is affixed. This is the merit system and shows how many generations are purebred, free of defects, and represent the standards of the breed. Registrations may be transferred between ARBA members by sending updated ownership information and a small fee to the ARBA office (Fig. 17.8).

A registration is also valuable to a breeder because a rabbit's lineage will be forever archived by the ARBA should a breeder lose his or her records. Registered rabbits are also eligible to receive Grand Champion status after earning three legs (certificates). Legs are earned by rabbits winning their class, variety, color group, breed, Reserve In Show, or Best In Show. ARBA members seeking Master Breeder Status must prove their success over time, and one of these measures is by breeding rabbits who earn Grand Champion status.



Staple on lines if attaching pedigree

Date

APPLICATION FOR REGISTRATION

E 0643 K

Breed Sex Variety
Name of animal Ear Number Date of Birth
Weight: Pounds Ounces Registrar's Remarks:
Winnings

Owner Co-Owner/s
Owner's ARBA# Co-Owner/s ARBA#/s
Owner's Address
Name of Original Breeder
Address

This application is the property of the American Rabbit Breeders Association, Inc. and will not be returned. A certificate of registration bearing the name, date of birth, and registration number of the animal will be sent to the OWNER. Make all remittances to: ARBA, PO Box 5667, Bloomington, IL 61702. Please PRINT or TYPE plainly. Registrar is required to keep a duplicate copy for at least 6 months. ALL BLANKS ON THIS APPLICATION MUST BE COMPLETE.

ANIMAL MUST MEET ALL SENIOR REQUIREMENTS FOR THEIR BREED TO BE ELIGIBLE FOR REGISTRATION.

Sire
Ear# GC#
Reg No Wt
Variety

Registrar's Affirmation:

Name
ARBA Number:
Phone
Email:

I hereby affirm all information is complete and correct including attached pedigree, if applicable, and that the animal has been tattooed as required.

Dam
Ear# GC#
Reg No Wt
Variety

G Sire
Ear# GC#
Reg No Wt
Variety

G Dam
Ear# GC#
Reg No Wt
Variety

G Sire
Ear# GC#
Reg No Wt
Variety

G Dam
Ear# GC#
Reg No Wt
Variety

GG Sire
Ear# GC#
Reg No Wt
Variety

GG Dam
Ear# GC#
Reg No Wt
Variety

GG Sire
Ear# GC#
Reg No Wt
Variety

GG Dam
Ear# GC#
Reg No Wt
Variety

GG Sire
Ear# GC#
Reg No Wt
Variety

GG Dam
Ear# GC#
Reg No Wt
Variety

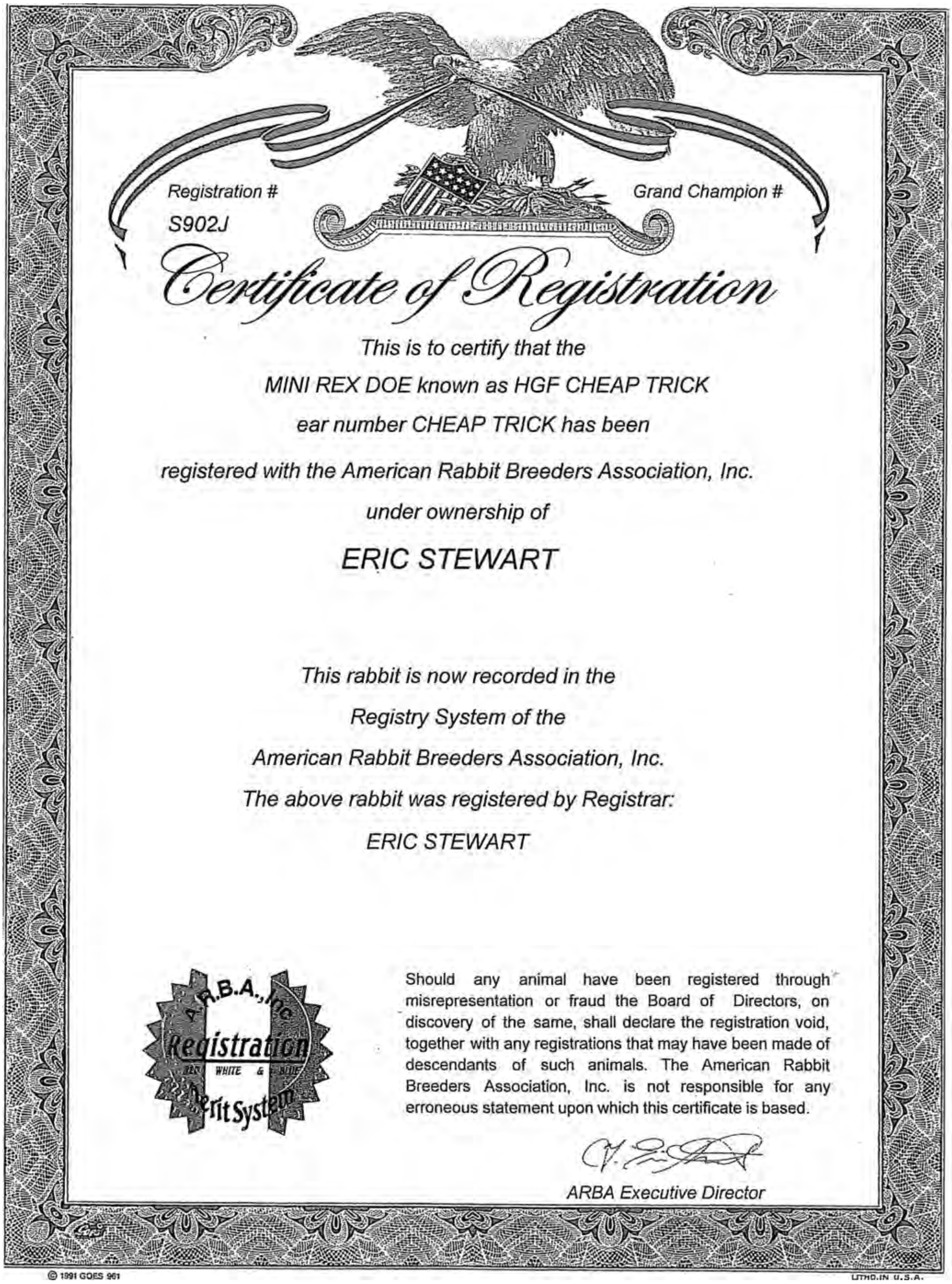
GG Sire
Ear# GC#
Reg No Wt
Variety

GG Dam
Ear# GC#
Reg No Wt
Variety

OWNER/AGENT AFFIRMATION: I hereby affirm that the above information is correct and true to the best of my knowledge, and further affirm that all animals listed on the above, or attached pedigree are of the same breed. The above registration number or the official ARBA registration insignia has been tattooed in the animal's right ear. Corrections may be subject to additional fees.

Signed Date
Phone Email

Fig. 17.6. Application for registration. (Courtesy of the American Rabbit Breeders Association, Inc.)



Registration #
S902J

Grand Champion #

Certificate of Registration

This is to certify that the
MINI REX DOE known as HGF CHEAP TRICK
ear number CHEAP TRICK has been
registered with the American Rabbit Breeders Association, Inc.
under ownership of

ERIC STEWART

This rabbit is now recorded in the
Registry System of the
American Rabbit Breeders Association, Inc.
The above rabbit was registered by Registrar:
ERIC STEWART

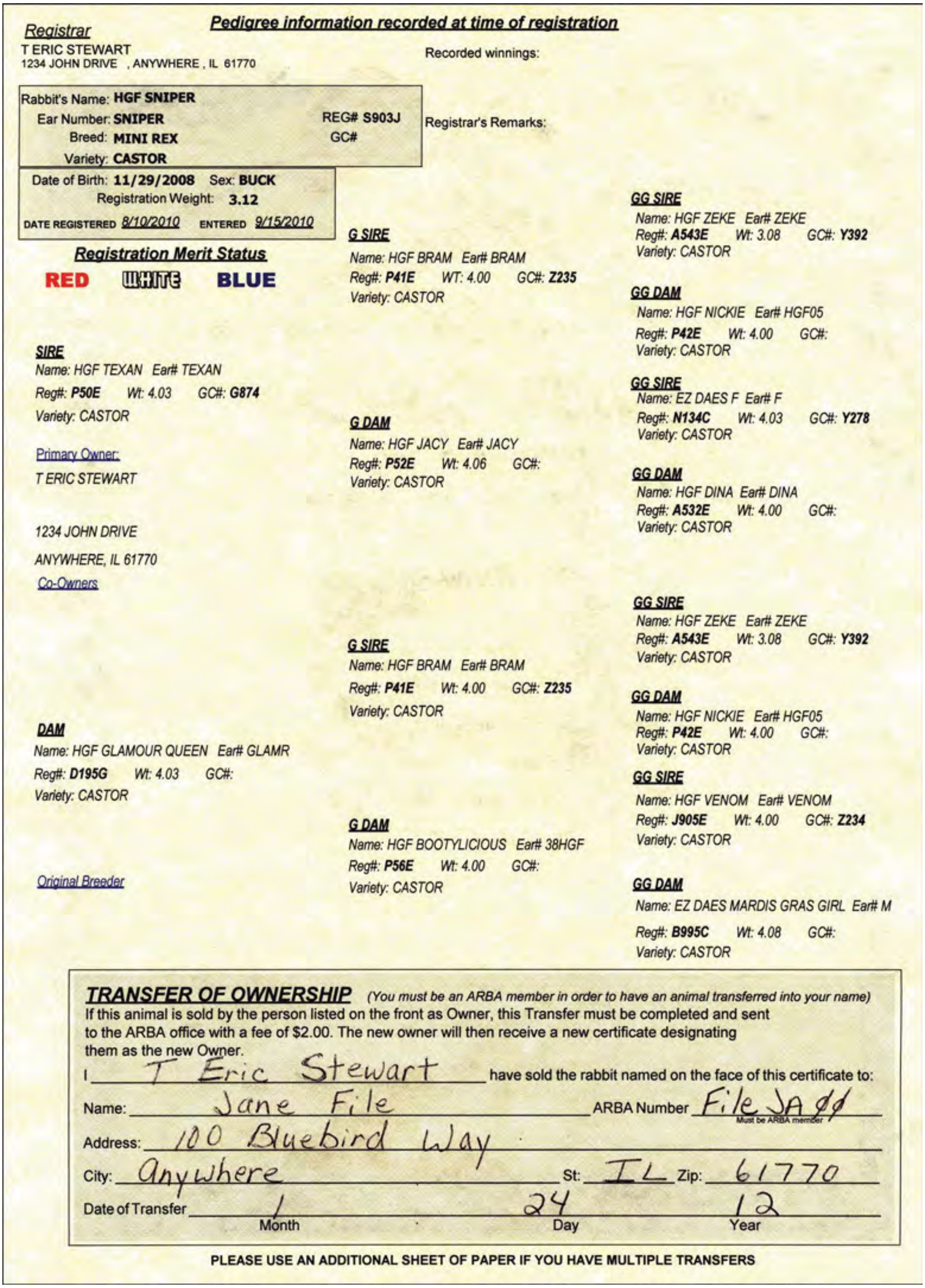
Should any animal have been registered through misrepresentation or fraud the Board of Directors, on discovery of the same, shall declare the registration void, together with any registrations that may have been made of descendants of such animals. The American Rabbit Breeders Association, Inc. is not responsible for any erroneous statement upon which this certificate is based.

ARBA Executive Director

© 1991 GOES 961

LITHO.IN U.S.A.

Fig. 17.7. Front of the rabbit registration certificate. (Courtesy of the American Rabbit Breeders Association, Inc.)



Pedigree information recorded at time of registration

Registrar
T ERIC STEWART
1234 JOHN DRIVE , ANYWHERE , IL 61770

Recorded winnings:

Rabbit's Name: **HGF SNIPER**
Ear Number: **SNIPER**
Breed: **MINI REX**
Variety: **CASTOR**
REG# **S903J**
GC#

Registrar's Remarks:

Date of Birth: **11/29/2008** Sex: **BUCK**
Registration Weight: **3.12**
DATE REGISTERED 8/10/2010 ENTERED 9/15/2010

Registration Merit Status

RED **WHITE** **BLUE**

SIRE
Name: HGF TEXAN Ear# TEXAN
Reg#: **P50E** Wt: 4.03 GC#: **G874**
Variety: CASTOR

Primary Owner:
T ERIC STEWART

1234 JOHN DRIVE
ANYWHERE, IL 61770

Co-Owners

DAM
Name: HGF GLAMOUR QUEEN Ear# GLAMR
Reg#: **D195G** Wt: 4.03 GC#:
Variety: CASTOR

Original Breeder

G SIRE
Name: HGF BRAM Ear# BRAM
Reg#: **P41E** WT: 4.00 GC#: **Z235**
Variety: CASTOR

G DAM
Name: HGF JACY Ear# JACY
Reg#: **P52E** Wt: 4.06 GC#:
Variety: CASTOR

G SIRE
Name: HGF BRAM Ear# BRAM
Reg#: **P41E** Wt: 4.00 GC#: **Z235**
Variety: CASTOR

G DAM
Name: HGF BOOTYLICIOUS Ear# 38HGF
Reg#: **P56E** Wt: 4.00 GC#:
Variety: CASTOR

GG SIRE
Name: HGF ZEKE Ear# ZEKE
Reg#: **A543E** Wt: 3.08 GC#: **Y392**
Variety: CASTOR

GG DAM
Name: HGF NICKIE Ear# HGF05
Reg#: **P42E** Wt: 4.00 GC#:
Variety: CASTOR

GG SIRE
Name: EZ DAES F Ear# F
Reg#: **N134C** Wt: 4.03 GC#: **Y278**
Variety: CASTOR

GG DAM
Name: HGF DINA Ear# DINA
Reg#: **A532E** Wt: 4.00 GC#:
Variety: CASTOR

GG SIRE
Name: HGF ZEKE Ear# ZEKE
Reg#: **A543E** Wt: 3.08 GC#: **Y392**
Variety: CASTOR

GG DAM
Name: HGF NICKIE Ear# HGF05
Reg#: **P42E** Wt: 4.00 GC#:
Variety: CASTOR

GG SIRE
Name: HGF VENOM Ear# VENOM
Reg#: **J905E** Wt: 4.00 GC#: **Z234**
Variety: CASTOR

GG DAM
Name: EZ DAES MARDIS GRAS GIRL Ear# M
Reg#: **B995C** Wt: 4.08 GC#:
Variety: CASTOR

TRANSFER OF OWNERSHIP *(You must be an ARBA member in order to have an animal transferred into your name)*
If this animal is sold by the person listed on the front as Owner, this Transfer must be completed and sent to the ARBA office with a fee of $2.00. The new owner will then receive a new certificate designating them as the new Owner.

I T Eric Stewart have sold the rabbit named on the face of this certificate to:

Name: Jane File ARBA Number File JA 00 (Must be ARBA member)

Address: 100 Bluebird Way

City: anywhere St: IL Zip: 61770

Date of Transfer 1 (Month) 24 (Day) 12 (Year)

PLEASE USE AN ADDITIONAL SHEET OF PAPER IF YOU HAVE MULTIPLE TRANSFERS

Fig. 17.8. Registration transfer form on the back of the rabbit registration certificate. (Courtesy of the American Rabbit Breeders Association, Inc.)

Further Reading

American Rabbit Breeders Association, Inc. 2020. *Official Guidebook to Raising Better Rabbits and Cavies*. ARBA, P O Box 400, Knox, PA.

American Rabbit Breeders Association, Inc. 2020. *Standard of Perfection 2021–2025*. ARBA, P O Box 400, Knox, PA.

18

Pet Rabbits

Introduction

Rabbits can be very good pets under the right conditions. Rabbits are curious, highly social animals. When housed indoors in contact with humans and other pets, a rabbit's unique personality appears, ranging from boisterous to affectionate to shy (Fig. 18.1). Unlike dogs, personality does not depend on breed and all rabbit breeds can make good pets. However, each rabbit is an individual whose personality should be matched with the family's lifestyle. Young children should be discouraged from picking up or carrying a rabbit as the struggling rabbit can scratch or nip, causing injury to the child or injury or possible death to the rabbit if it is dropped or squeezed too hard. It is very important to select only healthy rabbits as pets.

As babies, rabbits may like to be cuddled, but as they age, they may lose this desire and instead may nip or scratch when handled. For this reason, an adult rabbit makes a better pet than a young one. Its mature personality is known, and the new owner will not be surprised by the behavioral changes that arrive with adolescence, a period from about three months to one year old. Most rabbits lose their aggressive behavior around eight months old, and a well-cared-for rabbit will live seven years or more. Thanks to their increased longevity, adult rabbits make fine new pets.

Pet rabbits seem to live longest when housed indoors. Many outdoor pet rabbits are not as closely watched for health problems and are susceptible to predators and temperature extremes. Rabbits are highly susceptible to heat stroke. In addition, they lack adequate socialization. Socialization is key if a rabbit is to be a successful family pet.

Most rabbits do best when given restricted freedom and should be caged when not supervised. Several hours of exercise each morning or evening are sufficient, because rabbits tend to sleep at night and during midday. Only a very well-trained rabbit should be given unlimited freedom and be provided an open cage as a home base. If children are present, the cage becomes an even more important retreat for the rabbit. The rabbit's cage should be large enough that the animal can fully stretch out. Wire and wood-framed wire cages both work well. Do not use aquariums or other enclosures with solid walls, because these can trap heat and reduce air circulation. A wire-bottomed cage should have a board, a throw rug, or a towel to protect the animal's feet. Cardboard can also be used. Large wire dog crates (107 to 122 cm or 42 to 48 in) or puppy exercise pens make excellent cages that are easily cleaned. Providing a wooden or cardboard box with a large hole cut into the side gives the rabbit a place to hide inside or lounge on top. In all

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Fig. 18.1. Rabbits can be good indoor pets if properly trained. (Courtesy of Susan Smith)

cases, playthings such as cardboard tubes or pieces of untreated pine wood should be provided to satisfy chewing needs. Rabbits may also enjoy playing with hard plastic or metal baby, cat, or bird toys.

The rabbit's run area must be protected to minimize chewing damage. Electrical cords should be pinned against a wall or wrapped with sturdy plastic protectors, and carpets should be protected by small throw rugs or woven-mat squares. Furniture chewing can be discouraged by polishing the wood with lemon oil containing hot peppers or rubbing plain soap on it. Various house plants, such as *Dieffenbachia* (Fig. 18.2) are toxic to rabbits. All plants should be placed where the rabbit cannot chew on them.

House Training

A rabbit can usually be easily litter trained. A cat litter pan can be located in one corner of the cage. Placing a small quantity of hay in the litterpan will reinforce good litterbox habits, as rabbits frequently eat and urinate in the same location. The litterpan should be large enough for the rabbit to fit comfortably and sufficiently tall to keep urine inside the litterpan when the rabbit lifts its tail to urinate. The litter pan should be changed often, as the rabbit will soil other places if the litter pan is too smelly. Cleaning the pan with vinegar eliminates white calcium buildup and reduces accumulated odors. Suitable litters include hardwood shavings, compressed sawdust pellets, and recycled paper pellets. Clay cat litter, wheat or oat hulls, or corncobs should not be used if the rabbit likes to eat the litter. Softwood shavings such as cedar and pine can cause liver dysfunction and should be avoided. A litter pan outside the cage may also be necessary.

Fig. 18.2. *Dieffenbachia*, also known as dumb cane, is a poisonous houseplant to which rabbits should not have access. (Courtesy of Milagro Berhane)

Litter training is often more successful if the animal is spayed or neutered. Male pet rabbits should be neutered to prevent urine spraying, reduce odors, and stop sexual behavior toward other animals. Female pet rabbits should be spayed because of their high susceptibility to uterine cancer. Some studies find the incidence of such cancer to be as high as 78% in female rabbits over six years old. The risk increases with age. Unspayed females can also be aggressive in defending their territory, boxing and biting hands that enter the cage. Spaying usually stops this problem. The operation should be performed by a veterinarian experienced in rabbit medicine. The rising popularity of pet rabbits means that more veterinarians now are trained in this surgery. Male rabbits can be neutered as young as three months old or when the testicles descend. Female rabbits can be spayed as young as four to six months old; it is important to remove both the ovaries and the uterus to reduce the risk of uterine and breast cancer.

The best companion for a pet rabbit is a second rabbit (Fig. 18.3). Both partners must be neutered or spayed for pairing to succeed. Experience has shown that it is best for a rabbit to "select" its companion, due to issues of dominance. This need likely reflects the domestic rabbit's origins in the extensive warrens and social hierarchies of the ancestral European rabbit. Male–female pairs are easiest to match although male–male and female–female pairs are also successful. Size, age, and breed are seldom relevant. A rabbit will often experience "mourning" when its partner dies. Neutered rabbits often get along with other pets, such as cats or dogs. A cat that is not a hunter and a rabbit frequently become friends and spend time lounging together. Similarly, a rabbit and a dog get along well if the dog understands that the rabbit is part of its pack. However, a rabbit and a dog should never interact except under human supervision.

Nutrition

The nutritional requirements of pet rabbits are lower than those of production or show rabbits. Adult pet rabbits should be fed a maintenance diet rather than a diet designed for growth or pregnancy. The major nutritional problems facing pet rabbits are obesity, gastroenteritis, and improper tooth growth. To reduce these risks, restricted amounts of commercial rabbit pellets should be fed to adults. Several feeds are now made specifically to promote rabbit longevity in the home or laboratory setting. These pellets contain lower levels of protein (less than 14%) and calcium (between 0.6 and 1.2%) and are high in fiber (more than 20%). Smaller rabbits need more calories per kilogram of body weight than larger rabbits. This is because their increased metabolism and shorter gut length reduce their efficiency in extracting nutrients from the diet. Feeding guidelines are shown in Table 18.1.

Fig. 18.3. Rabbits are social animals and enjoy the companionship of a partner. Size and breed do not matter, but both must be neutered for pairing to succeed. (Courtesy of Susan Smith)

A cup of pellets weighs about 125 g (4.4 oz). The actual amount necessary depends on the individual rabbit's metabolism, level of activity, and the pellet's caloric content.

Fresh vegetables are important and low in calories. For each kg or 2.2 lbs of body weight, pet rabbits can be fed 1/2 cup daily of mixed vegetables, such as radish leaves, parsley, basil, carrots and carrot tops, broccoli stems and flowers, mustard or turnip greens, dandelion greens, dark green lettuce, chopped celery, kale, and spinach. High starch vegetables (e.g., corn, peas, and beans) should be avoided because they can cause overgrowth of cecal bacteria and cause enteritis. Leaf crops with a high moisture content and low fiber can cause diarrhea, so they should be fed in limited amounts. Iceberg lettuce is especially bad in this respect. Treats or pellets containing seeds, nuts, dried corn, or beans should be avoided because they are too calorie-rich or because their poor digestibility can lead to cecal impaction. Healthy treats include small amounts of fresh fruit (especially bananas and apples), raisins, dried cranberries or blueberries, or dried rolled oats. Treats can be used to monitor appetite and to reward good behavior. Nutritional supplements, such as vitamins and salt blocks, are usually unnecessary for pet rabbits. Fresh water should always be

Table 18.1. Daily feed allowances for pet rabbits. (Courtesy of Susan Smith)

Body weight (kg)	Daily allowance (teacup)
1–2 (2.2–4.4 lb)	¼
2–3 (4.4–6.6 lb)	½
3.0–4.5 (6.6–9.9 lb)	½–¾
4.5–6.0 (9.9–13.2 lb)	¾–1

available. Open, heavy ceramic crocks are preferred to water bottles as they encourage drinking and flushing of urinary calcium, and are less likely to be turned over.

Plenty of grass hay is essential for good pet rabbit health. Hay propels fur through the gut and thus reduces the risk of cecal impaction and gastroenteritis. Rabbits chew hay using a side-to-side grinding motion. Because the molars grow constantly, this motion keeps the molar surfaces in correct alignment and reduces the risk for molar overgrowth. Hay also satisfies the rabbit's need to chew and helps in litter training. Grass hays, such as timothy, brome, orchard, and seedless oat, should be fed. Mixed grass hays are also acceptable and give the rabbit a chance to "forage" and help prevent fussiness over food. Legume hays, such as alfalfa and clover, should be avoided for pet rabbits because these are too rich in protein and calcium. The high protein can lead to problems with an overproduction of cecotropes, which in turn leads to the growth of undesirable bacteria in the cecum. The excess calcium can cause urinary bladder sludge. However, because hay is so important for stabilizing the gut flora, feeding a clover-based hay is preferable to feeding no hay at all. Straw is not a good substitute for grass hay because of its poor nutrient content, poor palatability, and low digestibility.

Health

More pet rabbit owners are investing in veterinary care to treat disease, and new treatments are being discovered for common health problems. Upper respiratory infections are often highly contagious but frequently respond to antibiotic therapy following a culture and a sensitivity assay by a veterinarian. Wry neck (torticollis, head tilt) often responds to antibiotic therapy but can require up to a month of treatment before remission occurs. The same signs as those of wry neck can be seen in a variety of parasitic infections, so a differential diagnosis is necessary before treatment is started.

Gastrointestinal stasis is common in pet rabbits but can be treated when caught early. A constant supply of hay is the best way to reduce risk. Problems are most frequently caused by overgrowth of undesirable microbes within the cecum. This can be caused by a poor diet or can be a secondary response to an underlying health condition. Rarely, it is caused by physical blockage of the gut with fur or other ingested matter such as carpet fibers. Rabbits ingest fur while grooming but, unlike cats, cannot cough up the fur. Ingested fur must be expelled through the intestinal tract. The long fibers of hay can help ingested fur to exit the digestive tract. The occasional use of a flavored petroleum laxative can help expel fur, especially during a heavy molt. Pet rabbits should be groomed frequently to minimize the amount of fur ingested and to reduce fur within the house.

An early symptom of gut stasis is small, hard fecal pellets. Eventually the rabbit stops eating and defecation ceases. A rabbit reaching this stage can die in as little as 24 hours. Immediate veterinary care is essential. Radiographs are recommended to aid diagnosis. An impacted cecum can sometimes be felt by palpation. Gastrointestinal stasis, with the associated gas build-up, can be heard by listening with a stethoscope. Loud gurgles mean excessive gas build-up. Total lack of sound can mean complete stasis. Treatment may include oral or intravenous fluids and electrolytes to rehydrate the gut, drugs to induce gut motility, and heat lamps or an incubator to treat for shock. Force-feeding of moistened, ground pellets or vegetable mash may be helpful if the blockage is not complete. Mechanical agents that break foam into bigger gas pockets may alleviate some symptoms. Proteolytic enzymes, such as papain, may break up the mucus holding the blockage together, allowing the fur to pass through the gut. However, the proteolytic enzymes cannot digest the fur itself. They will not help if the stasis is not caused by a blockage. Some drugs, such as oral cholestyramine, may prove helpful in absorbing the microbial toxins associated with enterotoxemia before the toxins are absorbed into the body. As a last resort, surgery can be performed to remove the impacted material. However, surgery cannot be used to treat gastrointestinal stasis when there is no blockage to remove.

Rabbits that have recurring bouts of gut stasis or enterotoxemia should be tested for intestinal parasites and for conditions such as Tyzzer's disease, *Encephalitozoon cuniculi,* and coccidia. Rabbits that are homozygous dominant for the English spotting white gene (EnEn) may produce soft, enlarged feces and have recurring bouts of gut stasis due to a hereditary loss of gut nerve function. All these conditions may benefit also from the dietary changes mentioned below.

Another digestive problem is overproduction of cecotropes (night feces). This can lead to fecal smearing on the legs and perianal region and to a need to bathe the rabbit frequently. As stated earlier, this overproduction is often due to an excess of dietary protein, which in turn leads to growth of undesirable bacteria in the cecum. Reducing dietary protein by switching or withholding commercial pellets or by eliminating leguminous hays often solves the problem. Some rabbits exhibit a similar sensitivity to carbohydrates in the diet, and removal of high carbohydrate foods, such as carrots, will help. Replacing all feeds with palatable hay for three days also will help restabilize the cecal flora, as will feeding the rabbit cecal pellets from a healthy rabbit. Diet-linked enterotoxemia is more readily prevented and treated in pet rabbits than in production situations because of the lower nutrient needs and the ability to individualize treatments.

The greater longevity of pet rabbits has led to an increased incidence of urinary and kidney problems. Kidney or bladder stones can occur because rabbits excrete most of their excess calcium through the urine. The basic pH of rabbit urine causes calcium salts – calcium carbonate and phosphate – to precipitate in the bladder or kidneys. The salts can be seen as cloudiness in the urine, or the precipitates can be detected by X-ray. The precipitate can be flushed from the kidney and bladder by administering subcutaneous fluids. In severe cases, stones can be surgically removed. Rabbits with high urinary calcium or a history of kidney problems should be fed a low calcium diet (no leguminous hays, reduced or no commercial pellets) to lessen the kidney burden. The calcium intake should never drop below the minimum requirement of 0.6%. Bacterial bladder infections or *Encephalitozoon cuniculi* damage to kidneys may aggravate the problem and underlying infections should be treated appropriately.

Pet rabbits can also have problems with calcium deficiency. They are often fed rabbit foods from pet stores that include a mixture of pelleted feeds, rolled grains, breakfast cereal, dried fruit, and other “treats.” Rabbits are selective eaters and may consume the treats and ignore the pellets. In this way, they may select a low calcium diet. Some reports show a widespread incidence of poorly calcified teeth and bones in pet rabbits caused by their selective eating habits in which they select palatable but low calcium ingredients (e.g., seeds and dried fruits) from feed mixes. To overcome this, pet rabbits should be given small portions to encourage consumption of all the ingredients and be provided greens and good quality hay. If the diet is inadequate in vitamin D, there should be daily exposure to natural daylight to ensure provision of vitamin D.

In the United States, pet rabbits do not need vaccinations. In regions or countries where myxomatosis and rabbit hemorrhagic disease are endemic, vaccinating companion rabbits against these diseases may be prudent. No vaccines against myxomatosis or rabbit hemorrhagic disease are approved for use in the United States.

All pet rabbits should receive a yearly veterinary check-up, which ought to include examination of the ears, eyes, gastrointestinal tract, and teeth. The rabbit may require mild anesthesia to properly view the rear molars for spurs and overgrowths which can cause eating or digestion problems or even a complete cessation of eating. Older rabbits should also be given a blood test to assess liver and kidney function.

For rabbits with malocclusions (buck teeth), front teeth can be trimmed periodically using a dental drill or removed surgically in extreme cases. Drooling may indicate spurs or mismatch of the molars. The molars can be easily smoothed using dental drills under mild anesthesia. Clippers should never be used because they can crack the tooth and create an avenue for oral infection by cecal microbes.

Toenails should be checked for trimming bimonthly.

Many veterinarians are uncomfortable in treating rabbits, but references to experienced pet rabbit veterinarians can be obtained from the many pet rabbit specialty lists that are active on the Internet. In addition, many useful books on pet rabbit care and management can be found on the Internet.

While the increasing interest in rabbits kept as pets has led to advances in their health and nutrition, it has also led to many rabbits being purchased by people who do not understand their pets' special needs. Each year, thousands of rabbits are abandoned at animal shelters across the United States. With companion rabbits now living seven years or more, it is important that every pet owner receive adequate information about their new housemate. Armed with such knowledge, the owner will be rewarded with a mischievous personality that will provide many years of affection and pleasure.

Further Reading

Anon. *Caring for Your Pet Rabbit*. American Rabbit Breeders Association, Knox, PA.

House Rabbit Society, 148 Broadway, Richmond, CA 94804–1912, Telephone (510) 970–7575. HRS maintains an informative website available at: http://www.rabbit.org and publishes the *House Rabbit Journal*.

Martin, S. 2014. *The Everything Pet Rabbit Handbook: Your Ultimate Guide to Pet Rabbit Ownership, Training, and Care*. Createspace Independent Publishing Platform.

19

Animal Welfare

Since the turn of the new century, there has been increasing concern by the general public for the welfare or rights of animals used for production purposes, kept as pets, or used in research. A number of groups have been formed with various objectives ranging from ensuring that animals are kept in suitable situations to the extreme of trying to block all animal use for food, pets, or research. There are several objectives of the animal rights movement, and several modes of action. Some of the major issues involved include the raising of animals in confinement, "factory farming," vegetarianism, and "animal rights" of the same type as human rights, including the right not to be killed. The modes of action of activists include non-violent activities, such as picketing livestock meetings and rabbit seminars, becoming vegetarians or vegans, and writing letters to newspapers and magazines (Fig. 19.1). Unfortunately, violent activities have also occurred, including attacking confinement livestock enterprises, releasing the animals, and burning or otherwise destroying the facilities; and threatening to inject meat and eggs in stores with cyanide and other poisons (and actually doing it in a few cases) to stop people from consuming animal products. These criminal activities represent a serious threat to the livestock industry, including commercial rabbit production. The annual American Rabbit Breeders Association Convention has been picketed by animal rights demonstrators, protesting against various aspects of rabbit raising, including keeping and transporting rabbits in cages. Other targets have been stores selling rabbit meat and rabbits as pets.

Yet another more recent and growing public concern is that raising livestock for food, in general, is harmful to the planet, particularly due to environmental pollution and waste of natural resources. On a seemingly daily basis, social media criticizes the livestock industry over several contentious issues, typically involving sensational language that includes alarming figures that are not based on scientific evidence. Hence, for any one or more reasons, the development by the food industry of alternative, plant-based food products is now becoming widely accepted.

It has been suggested by some people that modern techniques of animal husbandry are cruel and inhumane. Confinement raising of livestock (beef cattle in feedlots, poultry in cages, swine in pens, etc.), particularly where large numbers of animals are kept, has been called "factory farming," with the animals used as machines. Rabbit raising has been criticized because rabbits are kept in cages. Large-scale commercial rabbitries have been the subject of criticism, with claims that the rabbits are used as "meat machines" with no regard for the quality of life that the animals experience. As with any issue, there are two sides. Technically,

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Fig. 19.1. Animal rights advocates picketing a rabbit seminar. (Courtesy of Bill Cramer, (Courtesy of Allen Mesick)

it is true that commercial rabbits are "meat machines." The function of a commercial rabbitry is to produce meat (or wool or fur) as efficiently as possible, with the idea of generating a profit from this activity. The animals are not pets, and they are subject to the normal processes of culling or removal from the herd because of poor productivity. This does not mean that commercial rabbit production is inhumane.

Two issues specific to rabbits are the charges that keeping rabbits in cages is inhumane and that intensive or post-partum breeding, in which does are kept in a continual state of pregnancy, is inhumane or cruel.

There is a tendency for some people, particularly those with an urban background who may not have had much contact with animals, to think that animals are just like people. This notion is referred to as anthropomorphism. Anthropomorphism ascribes to animals the same feelings and sensations experienced by humans. Since a human would not want to spend his or her life in a cage, it might be assumed that a rabbit might not want to either. It is possible, however, that a rabbit is content to be in a cage, free from the need to be concerned about predators, availability of food, etc. How does one determine whether a rabbit is content or not in a cage? This is an area where objective techniques are needed to measure stress. Inhabiting a stressful environment causes changes in hormonal secretion, such as elevations in blood levels of adrenal hormones. Behavioral studies are also useful to elucidate whether or not a rabbit is content. For example, does a rabbit display any abnormal behaviors such as irregular appetite and fur pulling of rabbits in adjacent cages (i.e., the latter can be a sign of boredom). There is much interest in such research to evaluate objectively how animal husbandry or management techniques affect the quality of life of livestock.

The "Easter Bunny Syndrome" is a clear example of anthropomorphism. It is common for people to regard the rabbit as a cute, cuddly, inoffensive creature. However, rabbits are not little people, dressed up in little suits and having names like Flopsy, and Mopsy. R.M. Lockley, in his book *The Private Life of the Rabbit,* describes the reactions of others to pets he had as a child. If he let his pet rat crawl out of his sleeve, his sisters would react with horror and disgust. If he brought out his pet rabbit, "There were oohs and ahs and a plea to be allowed to cuddle the animal." Being cute by human standards does not make an animal any more or less desirable as an agricultural animal. If it is a legitimate activity to raise beef cattle, sheep, chickens, and pigs for food, it is also legitimate to raise rabbits.

Intensive breeding of rabbits, in which the doe is rebred within 48 hours of kindling, has been called cruel and inhumane or unnatural by animal welfare groups. This is another example of anthropomorphism. Probably not many women would want to experience constant pregnancy and lactation! What about a rabbit? A female rabbit is genetically programmed to be in constant gestation. The fertility of does is very high immediately after kindling. The normal sexual behavior of the wild rabbit is that the doe rebreeds within two days of giving birth. When her litter is about 28 days old, she abandons it and digs a new nest in the burrow, where she has her next litter a few days later. The process is repeated throughout the spring and summer seasons. If the repeated pregnancies become a stress, or if nutrition is inadequate, either conception fails or the litter is resorbed *in utero*. Thus, if a domestic rabbit is stressed by being bred post-partum, she will simply fail to conceive or will resorb the fetuses. Why should the normal breeding behavior of wild rabbits become cruel or inhumane when used with domestic rabbits?

A complete understanding of rabbit behavior, along with objective means of assessing stress, will be necessary to ensure that our systems of rabbit husbandry are the best that can be provided to optimize both production and animal welfare. It is reasonable to assume that any system that adversely affects the animal's welfare will also reduce its productivity. However, even with sound scientific evidence that shows the rabbits are not stressed, it should be understood that this will still not be acceptable to certain animal rights groups. As the adage goes: "You can't please everyone". This is the reality of the animal rights situation.

Rabbit raisers must always bear in mind that they have a responsibility to their animals. They must provide all the needs of the rabbits, including suitable housing; clean, fresh feed in adequate amounts; clean, fresh water in clean containers; and freedom from disturbing outside influences and predation. Today's rabbits are very different from their wild ancestors and, because of selective breeding by farmers, are often unable to exist without human care. Since humans have created this dependence, it is their responsibility to provide proper care. In some cases, such care or practices may be distressful. For instance, rabbits are tattooed for identification, calves are castrated to prevent injuries from fighting, and tails of pigs are docked to prevent other pigs from biting at them. The operations are distressful but often less so than the consequences if they are not carried out.

When such distressful procedures are to be done, care must be taken to help reduce the effects on the animals and their subsequent production. Livestock producers should aim to reduce the stress on the animals and the workers as much as possible. They should also ensure that the procedures are carried out in such a manner that neither the animals nor the workers are injured. This entails knowing how to do the job and having the proper equipment to confine the animals and doing the job as smoothly and quickly as possible. The role of the veterinarian is also paramount to ensure that animals receive necessary treatment when needed.

It is also important in day-to-day management to ensure that conditions in the rabbitry are as non-stressing as possible (Fig. 19.2). In some rabbitries, the rabbits become highly excited and nervous when people enter, in others there is little response, and in some the rabbits come to the front of their cages to see what is going on. The rabbits in the last group are the ones that are likely to be most productive and least stressed. How do they get this way? It is basically due to good livestock production skills. These are very hard to define or to teach, but it is easy to tell whether people are good livestock producers when they are working with their animals. Do they view their animals as just objects without personalities or do they talk to them and treat them as individuals? This does not mean that their animals are pets, but it does mean that they work with them as individuals and are concerned for their individual welfare as well as for their productivity. In fact, the two go together, as productivity is generally increased in those rabbitries operated by good livestock producers.

The animal rights issue is not likely to go away in the near future. Those interested in

Fig. 19.2. The natural role of prolific small animals, such as rabbits and field mice, is to serve as a food source for animals higher in the food chain. Domestic rabbits have a much less stressful life than wild rabbits, which are constantly under threat of attack by predators. (Courtesy of D.J. Harris)

raising rabbits should give serious consideration to the charges of the animal rights activists and ensure that their animal housing and management systems are consistent with the welfare of their animals. They should be prepared to provide the other side of the story to the news media. Activists are often well educated and articulate and create a good impression in interviews on TV and with the press.

It is also important that representatives of the rabbit industry be articulate and present their side in a rational manner. There are three general responses that could be made to the animal rights movement. The first is to take no action and hope that the issue will go away. The second is to become indignant and to shout counterclaims and to ridicule the activists. The third, and obviously most promising, is to respond with positive, reasoned educational programs to extol the virtues of meat and animal production, the positive aspects of the relationships between farmers and their animals, and in sustainably being good stewards of the environment in producing highly nutritious food.

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20

Rabbits for Family and Small Farm Development

In these times when we often hear reference to "family values" and "food safety", the rabbit can make a positive contribution. Today, many families are concerned about the source and safety of the food that they purchase for consumption, especially as a result of the recent global Covid-19 epidemic. From a family development standpoint, small-scale rabbit production offers many advantages. The space required to operate a small-scale rabbit unit (fewer than 10 does and 1 buck) is small (see Fig. 4.4). This makes production possible on a farm or in the backyard of a home located within city limits (if no animal restriction ordinances exist). At the outset, the goal of the rabbit operation should be clearly established (e.g., meat, show, or pets). The entire family can share in the daily responsibilities, such as feeding, management, record keeping, butchering, and marketing. If meat production is the main enterprise goal, the team approach can make this a rewarding activity – for example, when nutritious and healthy homegrown meat is served on the family dinner table (Fig. 20.1).

Rabbit raising is an excellent learning or educational activity for children. Home lessons in rabbit biology (e.g., behavior, reproduction, and growth and development) can attract a child's keen interest (Fig. 20.2). Parents often like rabbits because they are easy to handle, they do not make noise, they stay clean and are relatively odorless, and they are not a large drain on the family budget. Moreover, a child learns responsibility and basic animal care skills. This is especially true when litters are born on a regular basis. Children who learn responsibility and who are actively engaged in such meaningful life skill projects are less likely to turn into couch potatoes! FFA, 4-H, and other youth projects involving rabbits may effectively enhance community development as well. Farm-fresh rabbit meat is becoming more popular at local farmers' markets.

Senior family members can likewise play a special role. For example, Grandpa can take pride in sharpening his skinning knife and in telling old rabbit hunting tales while demonstrating traditional skills in dressing out fryers for dinner. Grandma can prepare and serve her favorite family recipe, such as Brunswick stew or Hasenpfeffer. In addition, in both small and large operations, rabbit raising offers opportunities for occupational, psychological, or physical therapy for persons with disabilities, for convalescent patients, and for the elderly. Simply owning a pet rabbit may also achieve this purpose.

In small-scale operations, production costs are usually lower. This means that rabbit meat may be less expensive to produce for family consumption. Productivity is usually higher and mortality lower on small farms because of better ventilation, higher quality animal care, and superior management because rabbits receive more individual attention. Cost-reducing measures include feeding homegrown forages and

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Fig. 20.1. A family enjoying a tasty and nutritious rabbit meat meal. (Courtesy of S.D. Lukefahr)

Fig. 20.2. Rabbits are easily handled by children. (Courtesy of S.D. Lukefahr)

garden and kitchen "wastes"; using an existing shed, salvaged cages, and simple feeders and waterers; and sharing labor among family members (as opposed to hiring labor).

As a family farm-based unit, small-scale rabbit production can also be integrated into other agricultural activities, such as organic gardening, worm production (vermiculture), and ornamental or nursery plant production. Small-scale operations can be easily diversified to increase family income. Skins can be tanned, feet made into lucky rabbit's foot charms, manure bagged as "natural fertilizer" or compost, etc. In addition, real opportunities exist to develop local markets (e.g., farmers' markets, restaurants, stores, nurseries, and fish bait shops) for rabbits and their products. These and other economic opportunities will be described in more detail in this chapter.

The purpose of this chapter is to identify various applications of small-scale rabbit production that can favorably impact family and community development and small farm profitability.

Rabbits as a Family Activity

Family food production

Keep the following in mind when considering rabbits as a food production activity for the entire family. One obvious risk is that certain family members (usually children) may become emotionally attached to young rabbits destined for the dinner table. The family should agree to the meat production goal before purchasing breeding stock. Once the first litters are produced, avoid giving names to the young rabbits, as this will only make it more difficult later to harvest the fryers. Also, avoid emotive words, such as "babies" and "bunnies," for the same reason. A young rabbit still with the doe is called a kit. After weaning, it is a fryer. A compromise is to name only the mature breeding rabbits, with the understanding that the family will not eat them.

We often hear stories in which children were served what they thought was chicken, only later to be emotionally devastated to find their favorite rabbit ("Flopsy") was missing from its cage. Such strategies are counterproductive. Before purchasing breeding stock, buy rabbit meat from a store or breeder and use it for a family meal. If the family enjoys the meal, this will emphasize the meat production goal.

Another suggestion is to obtain colored rabbits as breeding stock. A nest box containing kits that display a variety of colors is more likely to attract and maintain the interest of children (Fig. 20.3). This may involve the acquisition of either crossbred rabbits of different colors or purebred rabbits of different color varieties. Chapters 3 and 16 provide further information on breeds of rabbits and on coat color genetics.

The number of breeding rabbits to purchase for home meat consumption depends, in part, on the size of the family, the desired frequency of rabbit meals, and the breed of rabbit used. Medium-sized breeds are recommended because they tend to produce larger litters and faster growing fryers with larger carcasses than the small breeds. They consume less feed and require less cage space than the giant breeds. Purchase breeding stock from a reputable breeder of commercial meat rabbits who selects for production traits. Avoid obtaining rabbits from pet stores, flea markets, and fancy breeders.

A 1.8 to 2.3 kg (4.0 to 5.0 lb) live fryer (usually 8 to 10 weeks of age), when dressed, will provide a meal for a family of four to six. Let us assume that a family wants to consume rabbit meat once a week. For backyard production, one breeding cage will accommodate a doe that can produce six litters in a year. A conservative figure for an average litter size at market age is five fryers. Thus, total annual production is 30 fryers. The family will therefore need two does to produce 60 fryers per year. (Of course, a larger family will require more does.) Since there is little need to keep a buck for only two does, one option is that a buck be borrowed from a local source. If a two-doe operation is maintained, only two additional cages will be needed to accommodate growing fryers and an occasional doe replacement. Under backyard conditions, a doe will produce for 2 or 3 years.

The family will have to decide how to divide the various chores involved in rabbit raising. One approach is for all family members to participate in all activities. Another approach is for children to take turns in feeding and cleaning (e.g., brushing cages, and sanitizing feeders and waterers).

A parent should supervise critical activities, such as matings, recording of breeding and kindling dates, nest box placement and early litter care, and harvesting. Very young children should probably not be present during butchering. The word "harvesting" is currently being used with all species to make the process

Fig. 20.3. Nine rabbits from a single litter all have different coat colors. (Courtesy of S.D. Lukefahr)

less repugnant to children and other sensitive people.

A freshly dressed carcass should be rinsed thoroughly and properly bagged or wrapped for freezing unless the meat is for immediate consumption. Rabbit meat should be stored in a freezer no longer than one year.

Youth development

Perhaps the greatest potential and reward for rabbit production as a family activity is in youth development. FFA and 4-H youth projects involving rabbits are very popular. The American Rabbit Breeders Association also has many youth activities. In some states, a 4-H rabbit project is one of the most popular activities among younger club members, mainly because rabbits are easier to handle and less expensive to raise than most other livestock species. A rabbit project is ideal for youth living in rural and peri-urban areas. The children learn basic responsibility and animal management skills that can lead to other projects and be applied to other life situations. Children also learn how to participate in meetings and in meaningful community events, demonstrate leadership, participate in teamwork activities, keep useful records, follow rules, and practice proper skills and etiquette in showing their animals.

At the community level, families usually cooperate to organize rabbit shows. Youth gain knowledge from the valuable comments the judge makes about their rabbits. Business leaders may also show their support by purchasing meat rabbits from children who earned top placings. In many cases, the family deposits the show earnings into a college account and does so for several years. Such project experiences are made even more rewarding when rabbits are raised at home on a year-round basis. For more information, interested families can contact their local extension agent.

Rabbits have also often been used as biological models for youth science projects. For example, one actual experiment involved four litters in which individual kits were weighed just before and after nursing. This intervention was possible because litters can easily be separated from their does and allowed to nurse only once in 24 hours (which is normal doe behavior). The student reviewed the literature on the subject, took photographs, and made charts showing growth curves for individual kits from does that reared small or large litters and from does that were excellent or poor milkers. The rabbit science project took top honors. Before starting such projects, leaders should check with science fair organizers to be sure that animal welfare requirements involved with using live animals are met.

Other benefits

In numerous cases, rabbit operations have benefited persons with disabilities, convalescent patients, and the elderly as a source of occupational, psychological, or physical therapy. Some cases have simply involved individuals enjoying the comfort and company of pet rabbits. Other cases have involved individuals who, because of their disability or for health reasons, cannot operate equipment or machines, do any major lifting, or stand for long periods. Such individuals have raised rabbits with great pleasure as a hobby or even as a business. While certain management activities (e.g., feeding and litter inspection) need to be done daily, the schedule is flexible, allowing the work to be carried out any time of the day. Other activities, such as matings and nest box placement, could, with a breeding management schedule, be distributed throughout the week.

However, as stated elsewhere in this book, persons considering rabbit production as a business after retirement should proceed with extreme caution. Some commercial advertisements have lured retired individuals into raising rabbits as a “get rich quick” business. Unfortunately, some people have lost their entire life savings as a result of such deceptive promotions.

Integrating Rabbit Production on the Family Farm

Integration involves the combination of rabbit production with other farm enterprises. A small-scale rabbit enterprise fits easily into small-farm management, increasing both food supply and income. There are many examples of rabbit integration that can benefit small-farm families. One simple model of integration would be the combination of rabbit raising with gardening. Integration would involve the recycling of rabbit manure as compost into the garden soil, while vegetable "wastes" from the garden would be fed to the rabbits. Reduced costs would result from less use of chemical fertilizer and commercial rabbit feed. In fact, during dire economic times this model has been used in the United States and in developing countries to directly engage poor families in the battle against hunger and poverty. For low-cost, small-scale production systems, the book by Lukefahr (2010), *Developing Sustainable Rabbit Projects*, serves as a resourceful guide.

The basic goal of integration is to increase food yields while minimizing costs. Some examples of integrative models are rabbit production with cultivation of fish, honeybees, fruits and vegetables, trees, and worms. Another advantage of integration is that general agriculturists, field workers, and/or extension agents who have basic knowledge in food production and experience in rural agricultural development can provide valuable assistance to small-farm families. Models described in this section will focus on production methods that are suitable for small farms, not just in the United States, but also around the world. The models will also emphasize those practices that enhance and safeguard the environment.

To reduce feed costs, high-quality forages can be planted in rows. For example, previous studies conducted at Texas A&M University-Kingsville (see the references found in the Further Reading section) involved the feeding of lablab and sweet potato forages to growing fryers. Lablab is a tropical legume (also called tropical alfalfa). These two species are an excellent source of protein, are highly palatable, and contain no known toxins. The harvesting schedule involved harvesting forage from one row each week, and not returning to the same row for three weeks to allow time for regrowth. For sweet potato forage, only the last one-third of the vines bearing leaves were harvested. This way, the growth of the tubers was not compromised. Forage was dried by sunlight for 24 hours to increase the dry matter content so as to make the forage more nutritious, and it was fed by free choice (Fig. 20.4). Further, in the lablab study an energy supplement consisted of mini-molasses blocks, while in the sweet potato study the tubers were fed as an energy supplement. Salt blocks with additional minerals were also provided.

Aquaculture is the production or farming of fish. In some countries, rabbits or other livestock have been raised in sheds, pens, or hutches (made of inexpensive building materials) placed either adjacent to or directly over fishponds (Fig. 20.5). Animal manure drains or falls into the water and fertilizes the ponds, increasing algae and other microbial production. Many species of fish, such as tilapia ("tropical perch"), subsist on algae as their

Fig. 20.4. A rabbit consuming sweet potato forage by free choice. (Courtesy of S.D. Lukefahr)

Fig. 20.5. A rabbitry constructed over a fishpond in Africa. The rabbit manure fertilizes the pond, producing growth of algae and other microorganisms that feed the tilapia fish. (Courtesy of S.D. Lukefahr)

main food source. Some studies involving simple animal manure fertilization have shown that fish harvest yields are more than doubled at little or no cost. A recommended stocking rate is 10 to 15 mature rabbits per 100 square meters (1,076 square feet) of pond area. This stocking rate will provide 10 kilograms (4.5 pounds) of rabbit manure per week. An integrated rabbit–fish enterprise could increase family income, especially if local markets exist for fish.

Apiculture is the cultivation of honeybees. When bees are managed and honey is harvested (using basic equipment and proper safety measures), beekeeping can be a fascinating activity for the family. Certain strains of bees (e.g., Italian) are more docile than other commercial strains. Increased plant pollination activity by bees results in increased fruit and(or) crop yields. When plants are pollinated by bees and fertilized with rabbit manure, the yields can be even greater. More food is produced at lower cost for family consumption, and more income is generated. Information on getting started with bees and on markets for honey may be obtained from your local agriculture extension office or from a member of a local bee club or association.

Part of horticulture involves food plant production (e.g., fruits and vegetables). Horticulture can also include the production of flowering plants that can be grown in combination with rabbit production to further increase farm income (see Fig. 12.2). As previously mentioned, the combination of rabbit raising and gardening is a popular practice on small family farms. Rabbit manure also helps to improve the condition of clay and sandy soils by enhancing water-holding capacity, providing a medium that aids in rapid plant growth, and minimizing runoff and erosion. However, like all animal manures, it should first be composted. Plant yields can be increased further if compost from rabbit manure is applied, especially if it has been converted into humus by red worms. This type of functional integration is illustrated in Fig. 20.6. This figure is used as a broad guide for farmers in developing countries but can be applied in part to almost any agricultural enterprise.

Fresh produce for which rabbit manure was used as compost may attract customers because it was "naturally grown." One study conducted in New Mexico demonstrated the integration of rabbits, catfish, red worms, and vegetables in greenhouses. The rabbits' diet was supplemented with greens from vegetables, and rabbit manure was either used for growing worms that were fed to catfish or used as compost for growing vegetables. Production costs were reduced, and profits were increased. If surplus rabbit manure or compost is available, it can be bagged and sold.

An alternative to feeding rabbits in conventional cages is allowing rabbits to graze forage. Rabbits raised in this way are called pastured rabbits. One method involves raising rabbits in bottomless wire pens that are regularly moved after the grass or grass–legume forage plot has been sufficiently grazed and before digging or burrowing activity occurs (Fig. 20.7). Feeders (supplying a supplement, such as limited commercial pellets) and waterers are typically placed inside the grazing pens. The penned rabbits are usually fryers, which are less likely to mate or to display aggressive behaviors, such as fighting and fur chewing. One benefit is that the forage is fertilized as the rabbits graze. One obvious risk is predation, although a proper pen design can limit this risk. Consumers may be attracted to the more "naturally" produced meat.

Rabbit production can be integrated with the growing and harvesting of trees. Rabbit manure made into compost has been used by plant nursery and greenhouse businesses. Rabbit manure and urine can be collected and directly applied around tree bases. Besides fertilization and erosion prevention, one advantage is that rabbit manure, which is relatively odorless, does not support maggot growth when applied to well-drained or sandy soils. Trees that have forage suitable for rabbit feed (for example, *Leucaena*, Mulberry (*Morus*), and *Gliricidium*) can be grown near the rabbitry, and the manure can be used to grow the trees that feed the rabbits.

Vermiculture is the raising of worms. An older child might show an interest in the management and harvesting of red worms grown in rabbit manure as an alternative or supplemental allowance activity. Generally, worms require higher moisture levels than the rabbits, so it is preferable to rear the worms in special beds outside the rabbitry. Initially, the worms

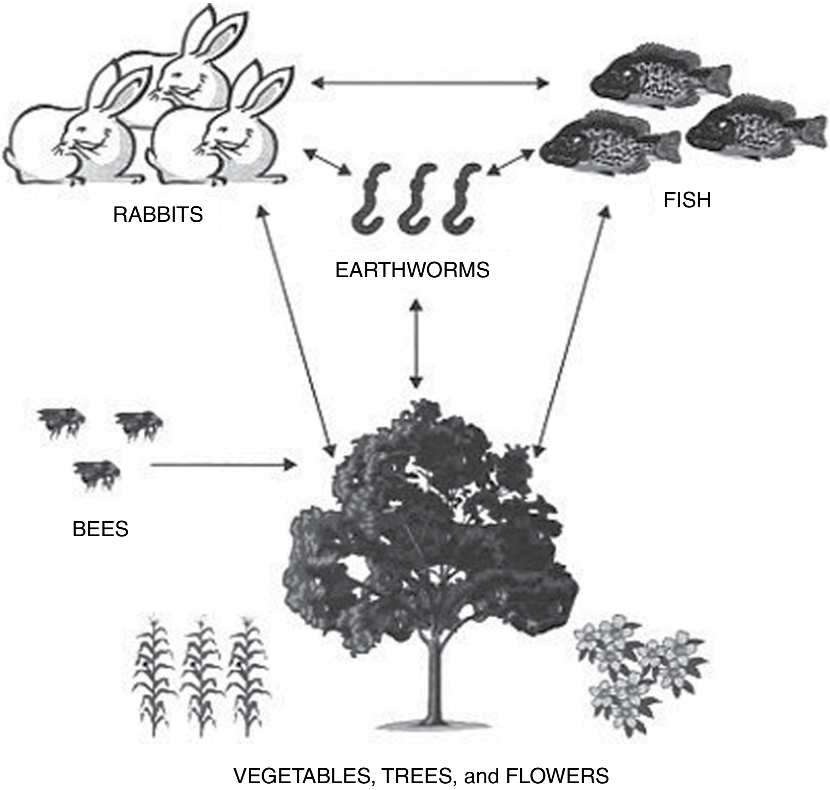

Fig. 20.6. Functional integration. Note that each unit complements the others by increasing food production at little cost on a small farm. (Courtesy of S.D. Lukefahr)

Fig. 20.7. Pastured rabbits grazing grass as forage. (Courtesy of J.I. McNitt)

can be obtained from other rabbitries or commercial red worm farms. The red worms can be counted or weighed, placed in containers with peat moss, and sold to fishers or fishing bait stores. Basic business and entrepreneurship skills are learned through this experience. As with any new business, it is important to start small and expand as the demand grows. Red worms have also been fed to other livestock as a protein source. In Colombia, one study observed satisfactory growth performance in broiler chicks fed diets in which soybean meal was partially substituted by live red worms. Although live red worms could be fed to poultry or swine, they would need to be processed into dried worm meal before being fed to other livestock. A useful book on worm production is by Mays (see the reference in the Further Reading section at the end of the chapter).

Diversifying Rabbit Production on the Family Farm

Diversification involves the utilization of rabbit by-products (e.g., skins, feet, and manure). In a small-scale rabbit enterprise, diversification increases economic opportunities. In other words, while meat may be considered the main product, various by-products can be developed and sold to generate additional family income. The main limitation for diversification is time, but this is where family labor comes in. Diversification produces a more intensive rabbit production enterprise because more labor is involved. However, in many cases, the operation may consist of fewer than 20 does. The key is to start small and stay small. Overproduction without expanding markets has been the cause of many failed family businesses.

As stated previously, colored rabbit breeding stock is recommended to enhance youth interest. Tanned colored hides or items such as rabbit's foot charms, toys, dolls, quilts, blankets, and garments have sales potential. Markets include curio, hobby, and souvenir shops and fairs, bazaars, and famers' markets (Fig. 20.8). Fresh hides are usually salted and dried on wood or wire stretchers and then stored until tanned. A number of tanning methods or recipes may be used, as described in Chapter 24 and in other books, such as *Tan Your Hide!* by Hobson (see the reference in the Further Reading section). Be aware that some methods will remove the fur from the skin. The preferred method is a simple one that yields satisfactory results with minimal costs and labor.

Fig. 20.8. Rabbit skins made into quality garments and handbags. (Courtesy of S.D. Lukefahr)

Manure from rabbits is popular for use in gardens and flower beds. The manure can either be made into compost or be mixed with potting soil. Your local county extension agent or a search on the Internet can provide specific information about proper composting methods. Some families have sold bagged rabbit compost as "natural fertilizer" to their neighbors or even to greenhouse or nursery businesses. Others have made sales by advertising commercially.

One advantage of rabbit manure is that it can be directly applied to soil supporting growing plants without the undesirable "burning" effect observed with poultry and other manures. This assumes that the manure used has not been saturated in urine. However, it should be emphasized that rabbit manure, like all animal manures, has low fertilizer value in comparison to commercial chemical fertilizers that are far more concentrated in certain critical elements (e.g., nitrogen, phosphorus, and potassium). Nonetheless, rabbit manure does contribute important organic matter and some elements that can improve soil properties such as water-holding capacity and permeability for root growth. At the same time, it provides a medium that supports beneficial microorganisms, worms, and insects.

Manure can be collected in pits beneath rabbit cages to culture worms – a practice known as vermiculture (Fig. 20.9). Typically,

Fig. 20.9. Commercial red worms cultured in rabbit manure. (Courtesy of D.J. Harris)

the worms are commercial red worms (red wigglers; in colder climates nightcrawlers can be used), which reproduce and grow well in the rabbit manure. Besides the manure, the worms require adequate shade, moisture, and protection from predators (e.g., fire ants). Interestingly, many rabbit producers have had higher gross sales from worms sold as fishing bait than from meat rabbits. Families can get started in vermiculture by contacting a rabbit raiser who has worms for sale. A rabbit–red worm enterprise is also an example of integration, which was covered in more detail in the previous section.

Market Development

In small-scale operations, opportunities exist for "cottage industry" market development and economic benefits. In some European countries, the rabbit meat industry continues to be dominated by traditional small-scale subsistence producers who maintain fewer than 50 breeding does. Consumers usually drive to a farm or a farmers' market to buy rabbit meat directly from the farmer. This activity has become more popular as a result of the Covid-19 global pandemic. Because of favorable economies of scale, small-scale rabbit production is a popular microenterprise. To some extent, similar scenarios are found in the United States.

Local farmers' markets should be developed to sell surplus meat and by-products from small-scale operations. As opposed to sales from commercial operations, sales from local small-scale rabbit operations can be more competitive with other meats. This is because of lower production, processing, and transportation costs (especially in U.S. states that have no rabbit meat inspection laws). A thumb figure is that small producers should establish their own local markets within a diameter of 150 miles. There are marketing advantages as well, such as eliminating intermediate marketing stages (i.e. the "middleman") and lowering transportation costs for local and niche marketing of rabbit fryers.

Markets should be created and expanded gradually. Contact your state department of agriculture for information about any meat inspection laws that might pertain to rabbits. In some states, rabbit meat can be sold as long as the producer sells less than 1000 rabbits annually. Because of the Covid-19 pandemic, federal and state inspection requirements have been curtailed to encourage local food production even without inspection. At farmers' markets, some producers sell live rabbits, which bypasses the meat inspection issue altogether.

If existing restrictions or regulations do not pose a barrier, the local marketing strategy might first be developed to involve, for example, meat sales to neighbors. Later this could be expanded to involve sales to community stores and restaurants (Fig. 20.10). Alternative markets, such as auctions and farmers' markets, might also be pursued. A good marketing tool for the family business is to supply rabbit recipe and nutrition information sheets and free meat samples to customers (see Chapters 23, 24 and 25).

Another justification for the local market development approach is the extreme difficulty in making commercial inroads into the meat marketplace. Despite the nutritional qualities and health attributes of rabbit meat, this difficulty exists because of the highly competitive nature of the food business, as well as pressure from animal rights groups. The poultry and swine industries continue to expand and integrate to minimize production costs. This limits the prospect of rabbit meat becoming a competitive commodity. Moreover, American consumers' demand for meat has stabilized. This stimulates even greater competition among the beef, goat, sheep, pork, and poultry industries and makes market entry by a new commodity very difficult.

The very high cost of rabbit production (mostly due to the cost of commercial feed) and the labor-intense nature of the business (10 hours of labor per doe per year) explains the high retail costs of rabbit meat in food stores and in "white tablecloth" restaurants. It also explains the categorization of rabbit meat as a specialty or luxury product. As previously stated, a small-scale and integrated rabbit enterprise that is managed as a family activity offers opportunities to reduce some of the production costs while increasing profits by selling directly to consumers.

Fig. 20.10. Promoting rabbit meat at a local business. (Courtesy of S.D. Lukefahr)

In time as demand increases, sales can expand to other areas or regional businesses. It should be emphasized that the rabbit enterprise should be expanded gradually only in proportion to the increased market demand and in relation to the willingness of the family members to take on further responsibilities.

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21

Rabbit Production in Developing Countries

In recent years, rabbit production has made a favorable impact in developing countries. Typically, rabbits are raised in small numbers (fewer than 10 does) in simple, inexpensive, easily constructed cages and provide a family with a source of fresh meat on a year-round basis (Fig. 21.1). They are raised on forages grown in plots, forbs or weeds, tree leaves, waste fruits and vegetables, and by-products, such as corn bran and rice bran. Much of the labor for feed collection and care is provided by the family. Because of their small size, a few rabbits don't require much feed. On the other hand, buying and feeding a beef animal might be prohibitively expensive; moreover, the farm may be too small anyway to support a cow. In addition, the small carcass of the rabbit is consumed in one or two meals, so meat storage isn't required. There are few religious prohibitions against the consumption of rabbit meat.

Rabbit production fits in well with integrated small farming systems that are common in many developing countries. Usually, a village family might have a small tract of land available (less than 1 hectare or 2.5 acres) for a garden and a plot of rice or corn and might raise a few animals, including chickens, goats, and perhaps rabbits . The animal manure is used in the garden or grain field, while the crop by-products and plant residues left over from harvest are fed to the animals. Rabbits can be a very useful component of such a system. Most of the world's population is fed by the output of small farms such as just described. With the rapidly increasing human populations of most developing countries, there is less and less land available per family, and the need for intensive, efficient production increases. Labor is usually abundant, so the high labor intensity of rabbit production is not a detriment.

As a brief global overview, in Africa it is evident that rabbit research activities are greatest in Egypt and Nigeria, where several rabbit scientists are employed at universities. Research topics vary considerably. Other countries with active rabbit research involvements include, for example, Algeria, Benin, Cameroon, Ghana, Kenya, South Africa, and Tunisia. In Asia, China is not a developing country. Instead, in Cambodia, Indonesia, Laos, Malaysia, the Philippines, and Vietnam there is a great interest in both rabbit research and project development. In these select countries, there are universities with active rabbit research programs where the research topic of nutrition is commonly investigated. In Latin America, rabbit research activities have been particularly noted in Argentina, Brazil, Cuba, Mexico and Peru involving studies on many topics. Also, major rabbit conferences have been held in these countries. Rabbit projects have been developed in the countries mentioned above, and in many others not mentioned.

Most of the general procedures of rabbit production are the same, regardless of where the animals are raised, so only aspects unique to

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developing countries will be discussed in this chapter. Additional information is provided in the book by Lukefahr (2010), *Developing Sustainable Rabbit Projects* (see the Further Reading section at the end of the chapter for details).

Cages and Equipment

Most people in developing countries who raise rabbits as a source of protein do not have much money. Therefore, it is very important that the equipment be simple, be easily constructed, and involve few if any purchased materials. Simple rabbit hutches or cages can be constructed of local materials, such as clay or concrete blocks, wooden boards, split bamboo, and raffia palm (Fig. 21.2). Bamboo cages are in some respects superior to wire cages. A bamboo or raffia palmwood floor gives more support to the feet than a wire cage bottom, so problems with sore hocks are minimized (Fig. 21.3a,b). Feeders can be constructed from clay or from a large stem of bamboo. Cans, tins, glass bottles, and other items can be used as well. Mangers for forage feeding can also be made from local materials, such as bamboo, clay, or wood, and can be incorporated into the structure of the cages. Watering crocks can be made of clay or concrete. In many cases, where large amounts of greens are fed, less drinking water may be required, but it is still a good practice to always provide water. In some countries (e.g., Cameroon, Haiti, and Vietnam), it is a common practice not to provide any water when diets composed of freshly harvested greens are fed (Fig. 21.4).

Fig. 21.1. A typical village rabbitry in Indonesia constructed of bamboo. The rabbits are fed green forage. (Courtesy of S.D. Lukefahr)

Feeding and Management

Generally, rabbits raised for home meat consumption in developing countries, especially in

Fig. 21.2. A backyard rabbitry in Poland constructed from a variety of discarded but suitable materials. (Courtesy of S.D. Lukefahr)

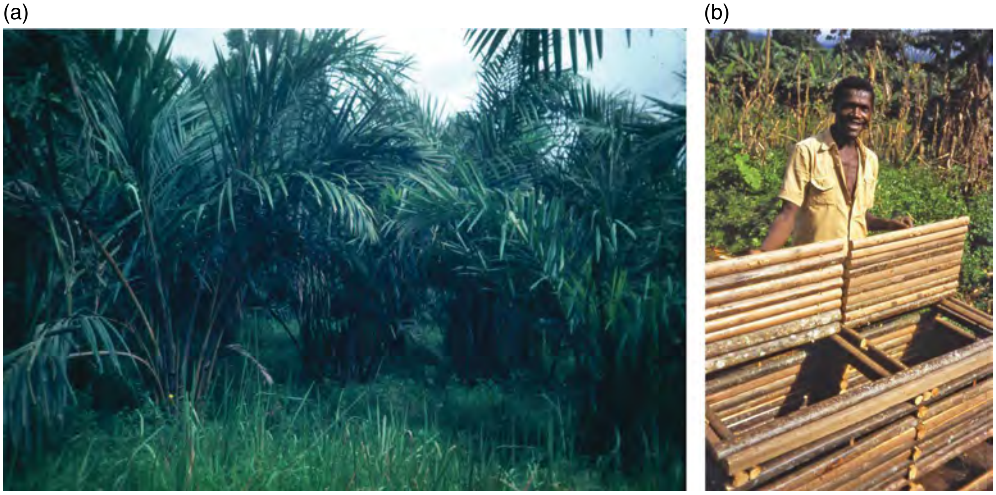

Fig. 21.3. The raffia palm (a) grows in West Africa. It is used for building rabbit hutches and cages (b) in many African countries. (Courtesy of S.D. Lukefahr)

Fig. 21.4. A traditional practice in Vietnam is not to provide water to rabbits on a fresh forage-based diet although this practice is discouraged. (Courtesy of S.D. Lukefahr)

tropical regions, will be fed a forage-based diet supplemented with by-products, such as rice bran and garden wastes. A wide variety of forages may be used, varying from country to country depending upon local crops and vegetation available. Crop residues, such as cassava and peanut leaves and sweet potato vines, are quite suitable, as are leaves from leguminous trees, such as Mulberry (*Morus*) and *Leucaena*. The composition of some typical tropical feeds is given in Table 21.1.

In countries where rabbit production is being seriously explored and promoted, one of the first priorities should be the evaluation of local forages. In most cases, forages will provide the bulk of the diet, although supplements will still be needed. According to the table, many forages have high moisture content. Wilting or drying of harvested forage in open sunlight on racks or over fences for several days reduces the moisture content. For example, in studies conducted at Texas A&M University-Kingsville, drying sweet potato leaves and vines for four days reduced the moisture content from about 90% to only 10%, thus increasing the nutrient intake for rabbits since they can consume more feed that has a lower moisture content.

Supplementary energy and sometimes protein feeds, such as a moist mash prepared from rice and corn bran, cottonseed and palm kernel meal, bean curd, or other by-products, should be used. Kitchen or table scraps can also be fed if available. The addition of molasses promotes palatability, provides energy, and retards feed spoilage. The level of production that can be achieved with this type of a feeding system in arid or tropical environments is about half of what is achieved in temperate countries with rabbits fed commercial pelleted diets. However, this level is economically justified and makes a meaningful contribution to family food production.

Many tropical forages are deficient in minerals. Those minerals most likely to be lacking

Table 21.1. Composition of selected tropical feedstuffs (wet weight or "as fed" basis[1])

Feedstuff	Dry matter (%)	Crude protein (%)	Crude fiber (%)
Arachis hypogaea (peanut)			
Fresh forage	37	4.4	8.6
Hay	91	10.6	23.7
Seeds with shells	93	22.0	19.6
Seeds without shells	95	28.4	2.8
Artocarpus heterophyllus (jack fruit)			
Fresh leaves	16	2.0	3.2
Brachiaria decumbens	17	1.8	6.0
Cajanus cajan (pigeon pea)			
Fresh forage	23	5.0	6.5
Seeds	86	18.9	7.6
Cenchrus ciliaris (buffel grass)	20	2.2	6.4
Centrosema pubescens (butterfly pea)			
Fresh forage	20	4.6	6.2
Chloris gayana (Rhodes grass)	20	2.0	6.4
Coconut meal (copra)	88	22.7	12.3
Desmodium intortum (tick clover)	17	2.8	5.0
Digitaria decumbens	18	2.0	5.8
Dolichos lablab	19	4.9	4.9
Gliricidia sepium	25	6.4	3.3
Ipomoea batatas (sweet potato)			
Tubers	31	1.7	1.3
Foliage	22	2.8	5.9
Leucaena leucocephala	29	6.5	4.2
Manihot spp. (cassava)			
Tubers	35	1.6	1.3
Foliage	26	5.2	5.5
Melinus minutiflora (molasses grass)			
Fresh forage	33	1.4	12.9
Musa spp. (banana)			
Fresh fruit	24	1.1	0.5
Skins (peelings)	16	1.0	1.6
Leaves	16	1.0	3.8
Oryza sativa (rice)			
Rice bran	86	11.9	10.0
Rice hulls	86	3.3	37.2
Panicum maximum (guinea grass)	24	2.1	8.0
Pennisetum purpureum (napier grass, elephant grass)	16	1.7	5.8
Pueraria phaseoloides (tropical kudzu)	21	4.5	4.5
Saccharum officinarum (sugarcane)	28	0.9	8.2
Sesbania grandiflora	17	4.3	3.0
Setaria sphacelata	20	1.9	6.3
Stylosanthes guianesis	24	3.7	7.5
Tripsacum laxum (Guatemala grass)	27	1.7	8.9

[1] To convert the values in Table 21.1 from the "as fed" basis to the dry matter basis, multiply the protein or fiber contents by 100, and divide by the percentage dry matter. For example, for Musa fruit (banana), the protein content on a dry matter basis is: $\%CP = (1.1 \times 100) \div 24 = 4.58\%$. Forage composition values were obtained from multiple literature sources.

are calcium, phosphorus, sodium, cobalt, copper, iodine, selenium, and zinc. Fluorine, manganese, and selenium are sometimes present in toxic amounts. Tropical soils are often highly leached, infertile, and acidic. These conditions tend to result in low mineral levels. The use of trace mineralized salt and calcium–phosphorus supplements in rabbit feeding is recommended. At the village level, this may be somewhat difficult to achieve and may call for extension programs and other forms of assistance in making these supplements available to subsistence farmers. Some farmers effectively use dried and ground bone meal.

In many situations, it may be possible for farmers to use commercially prepared chicken, pig, or cattle feed (called "mash" or "concentrate", which is usually not pelleted) supplemented with green feeds as their rabbit diet. As long as adequate fiber from forage is provided, this may be an adequate feeding program. Commercially prepared rabbit feeds are very uncommon in developing countries, whereas rations formulated for other more major types of animal species are more readily available. The cost of purchased feed can be justified only when strong markets for rabbit meat exist.

In many arid and tropical countries, rabbits have been raised for a long time. The local rabbits are usually small, colored, have slow growth rates (20 instead of 40 grams per day), and have low reproductive rates (4 instead of 8 litters per doe per year). It is reasonable to expect that they might be better adapted to the arid and tropical environments than imported breeds, such as the New Zealand White. Genetic studies are urgently needed to assess breed differences in adaptability and the potential for using crossbreeding programs involving local and imported breeds. In many cases, adapted local breeds or crosses are the most appropriate stock for small-farm families under subsistence (poor) conditions.

Special Problems in Tropical Rabbit Production

Heat stress

An obvious problem for rabbit production in the tropics is heat stress. Rabbits have a Mediterranean origin and are not particularly well adapted to areas with hot, arid, or humid conditions. Nevertheless, they have been successfully raised in areas with these conditions. Several procedures can be used to minimize heat stress. In a hot environment, rabbits should be provided with an unlimited supply of clean, cool water. In large rabbitries, buildings can be constructed to gain a "chimney effect" (Fig. 21.5) to provide cooling. A rabbitry can be situated under the shade of trees and located to maximize air movement. The area around the cages can be soaked with water during the hottest part of the day for the evaporative cooling effects. The use of indoor/outdoor units as described in Chapter 4, "The Rabbitry and Its Equipment," might be a way of providing a cooler microclimate. In arid countries, such as Egypt and Tunisia, rabbits are sometimes kept in deep, underground tunnels, where the temperature is considerably lower (Fig. 21.6). Farmers should have a breeding objective of selection for longer ears as this will allow their rabbits to better maintain normal body temperatures (thermoregulation; Fig. 21.7). In many tropical countries, there are regions of higher elevations (highlands) where the temperatures are quite moderate and ideal for rabbit production. Breeding and selection programs and the incorporation of local breeds into the gene pool should be a feasible means of increasing the adaptability of the animals to arid or tropical conditions.

Fig. 21.5. A rabbitry in Louisiana constructed with roof vents to aid air movement by the "chimney effect." (Courtesy of J.I. McNitt)

Zoonoses

A zoonosis is a disease of animals that can be transmitted to humans. When rabbit raising is proposed in areas where it has not been practiced, the question of potential zoonoses is often raised. Tularemia is the disease most often mentioned. It is named for Tulare, a county in California where the disease was first described. Tularemia is a disease of rodents and lagomorphs and is transmitted by the bites of fleas, flies, ticks, and lice. It may be acquired by humans from handling infected animals. The disease, caused by a bacterium called *Francisella tularensis*, is characterized by inflammation of the lymph glands, headache, chills, and a high fever. The disease has been contracted by people handling infected wild rabbits. However, it has not been a significant hazard with domestic rabbits and should not be a matter of concern. Of course, rabbits, like any mammalian species, can carry rabies.

Fig. 21.6. Rabbits in Tunisia in a pit 2 m (6.6 ft) underground. The rabbits dig tunnels laterally from the bottom where they stay cool during the day. Feed is given above ground. (Courtesy of A. Finzi)

Fig. 21.7. A rabbit with large ears allows it to maintain body temperature more efficiently to prevent heat stroke. (Courtesy of S.D. Lukefahr)

Tsetse fly

In many African countries, the tsetse fly (*Glossina palpalis* and G. *morsitans*) is a severe impediment to livestock production (Fig. 21.8). This fly bites animals and sucks blood, causing irritation. It is a carrier of a protozoan of the genus *Trypanosoma*, which causes the disease trypanosomiasis. The initial stages of the disease in humans involve fever, chills, headaches, and vomiting, followed by enlargement of the lymph glands and anemia. Later, the central nervous system is involved, producing sleeping sickness, characterized by lethargy and prolonged sleeping, and finally causing death. Domestic animals, including rabbits, also contract the disease. In rabbits, infection causes poor growth and poor feed utilization. An experiment in Nigeria indicated that feeding infected rabbits a diet containing 250 parts per million copper sulfate virtually eliminated the detrimental effects of the parasite and reduced the parasite count in the blood. Thus, by using copper sulfate as a feed additive, the tsetse fly problem in rabbits

Fig. 21.8. A female tsetse fly (*Glossina morsitans centralis*) feeding on the ear of a rabbit. Tsetse flies are vectors for the *Trypanosoma* protozoan, which causes sleeping sickness. (Courtesy of J.S. Scott)

can apparently be overcome. Another method of avoiding the problem would be to cover the rabbit cages with mosquito netting. Because of their small size and confinement housing, rabbits would be easier to protect from the tsetse fly than grazing animals, such as cattle, and thus could become an important source of meat in tsetse-infested areas.

Rabbits as Pests

There has been some concern that if rabbit raising is introduced into a country as an agricultural activity, some animals may escape and become pests. The well-known example of Australia is always cited. Wild rabbits have caused tremendous damage in Australia (Fig. 21.9). It is well to bear in mind that these are wild rabbits – European wild rabbits – and not domestic rabbits. The domestic rabbit has not become feral and a pest anywhere, except on a few small islands where there were no predators. The domestic rabbit is an easy target for predators. Domestic rabbits are usually completely or partially white, making them more conspicuous to predators than wild rabbits. They are more compact and less agile, making them less likely than wild rabbits to be able to evade or escape from predators. When domestic rabbits are chased, they tend to squat down and hide rather than run away. Wild rabbits have never made a foothold in the tropical areas of Australia. There is virtually no likelihood of domestic rabbits becoming pests in tropical countries. The abundance of predators, the high human population density in many areas (with the resultant decimation of wildlife from overhunting), and the basic limitations of the adaptability of rabbits to hot, humid environments are all impediments to success of the domestic rabbit in the wild.

Fig. 21.9. One of the rare instances in which domestic rabbits have become pests. European rabbits (*Oryctolagus cuniculus*) were introduced by sailors as a source of food on the isolated Macquarie Island off the coast of Australia. The rabbits have since completely denuded it, causing serious erosion losses. Note the exposed roots of the tree. (Courtesy of W.R. Sobey)

Agencies Involved in International Development of Rabbit Production

The potential and recent impact of rabbits and other "microlivestock" in developing countries has been widely recognized. A number of agencies involved in international development have incorporated rabbit raising into their programs. Some of the American agencies include the Peace Corps, CARE, Heifer International, World Neighbors, and a variety of church organizations. Volunteers working for the Peace Corps live with villagers in developing countries, providing assistance and training, for example, in food production, water supply, energy development, nutrition and health education, and reforestation. Many of the Peace Corps and CARE projects include rabbit raising for food. Heifer International is a private organization, based in Little Rock, Arkansas, that promotes community development through sustainable livestock production and small farming in developing countries. As one of its first major projects, the organization provided heifers, donated by American dairy farmers, to farmers in Europe following World War II. The program has been expanded to encompass all types of livestock as well as aquaculture, gardening, and crop and forestry production in about 125 countries. Rabbit production and guinea pig production are of increasing interest to Heifer International. Many churches have aid programs and have missionaries located in developing countries that are involved in self-help food production projects. Increasingly, rabbit production is being encouraged for home food production.

Many other developed countries have programs in less developed countries that incorporate rabbit production. France has programs in Africa, the Caribbean, and Mexico. The Food and Agriculture Organization (FAO) of the United Nations has a rabbit program. Germany has had rabbit projects in such countries as China, Kenya, and Thailand. Australia has supported work in Indonesia. The Tropical Development and Research Institute of Great Britain has been prominently involved in rabbit production. There are many others. Professional journals that promote rabbit research activities in developing countries include *Livestock Research for Rural Development* and *World Rabbit Science*.

It is increasingly evident to these development agencies and to government officials in developing countries that small animal species, such as rabbits, may have much to offer in the race to match food production with human population expansion. In fact, in recent times rabbit projects have been developed in response to emergency crises in the aftermath of natural disasters. For example, the earthquake disasters in Haiti in 2010 and in Nepal in 2015 killed thousands of people and left many more homeless. Rabbit projects were introduced to farm family victims. Following village-level training, families were provided with loans to purchase supplies and to acquire breeding stock and were provided with critical follow-up supervision. Within 6 months, families were already benefitting from meat consumption, manure for their gardens, and increased income (Figs 21.10 and 21.11). In some cases, the income generated allowed families to pay tuition costs to send their children back to school. Rotary International, the U.S. Agency for International Development and the World Rabbit Science Association, in addition to local (non) governmental organizations, were involved in these disaster relief projects.

Fig. 21.10. A group of trained rabbit farmers in Haiti. (Courtesy of M. Kaplan-Pasternak)

Fig. 21.11. A woman in Nepal who used rabbit manure compost for her vegetable garden. She also operated a small restaurant where rabbit meat was served. (Courtesy of S.D. Lukefahr)

The success or failure of rabbit production schemes hinges on several factors. For success, it is very important that there be strong support from the government of the country. In some countries, such as Ghana, China, and Mexico, strong government support has been given. It is important to work with, rather than bypass, existing institutions, such as extension and veterinary services, research centers, and government programs. Unless the local agencies are directly involved and supportive, they may react negatively and sabotage a project to make it fail, or the project will not be actively supported after the development agency leaves. Success of a program of which they are not a part can be construed as a failure for them or a threat to them. Local protocols and chains of command must be recognized and respected.

Ultimately, the success of a project hinges on the involvement of the community and the farmers. Ideally, it should be a community-based project and even the community's idea to initiate a rabbit project. In other words, the whole community accepts the idea of raising rabbits for food and income and even selects their best farmers for training by the program staff. In addition, farmers must be genuinely interested, or else failure is assured. Unfortunately, improving the nutritional status of one's family is not usually considered of sufficient importance to get involved in something new. Village farmers in developing countries, like people everywhere, are interested in making more money so that they can buy consumer goods to improve their standard of living. For an American, this often means a home in the suburbs, many electrical appliances, one or more automobiles, and so on. For a villager in one of the developing countries, it may mean a cell phone, transistor radio, and a motorbike. For a rabbit project to succeed, rabbit raising must put money in the farmers' pockets. Coincidentally, but of course importantly, rabbit raising also provides meat for the table and improved nutrition. Programs based solely on the idea that you should raise rabbits because they are good for you and your family are unlikely to succeed.

It is of paramount importance that adequate training and follow-up supervision be provided. This requires a project leader or coordinator with a sound basic knowledge of rabbit production and with considerable practical experience. Many rabbit projects in developing countries have failed because a qualified rabbit expert was not involved. Production, disease, or nutritional problems may develop during the early part of a project, the rabbits may die, and the project may be abandoned, whereas if adequate expertise had been available, the problems might have been detected early and readily overcome. A rabbit production expert who has had experience in an environment similar to that of the project should be involved early in the design stage of the project. The focus should be to seek out and train rabbit farmer leadership at the village level. A year or more of close supervision will be required to adequately train these village leaders, who can then take on the responsibility of training other farmers in the village. Once a core of well-trained and experienced rabbit raisers has been established, the project becomes self-perpetuating as other villagers learn from the successful rabbit raisers. People should be trained not only how to raise rabbits but also how to use them to improve small farms through integrative measures.

A very important part of the training program should be the provision of instruction on harvesting rabbits and preparing dishes for home consumption. A good way to begin a program in a village is to prepare some rabbit meat using recipes for local meat dishes and have a party. Once the people have consumed rabbits, they generally are eager to begin raising them.

Fig. 21.12. (a, b) In some regions of Africa, rabbits are cooked like “bush meat” over an open fire, with the hide left on. The hair is burned off, and the skin consumed as part of the meat. (Courtesy of J.I. McNitt)

Too often, rabbit development schemes have failed because the people have not learned how to butcher and cook rabbit meat. The method of preparation of rabbit dishes reflects the specific cultural habits of different parts of the world. In Africa, for instance, it is common to cook “bush meat.” This refers to a variety of small animal species hunted in the “bush,” which are then eviscerated and cooked on stakes over an open fire (Fig. 21.12a, b). The hide is left on. The fire burns off the hair, but the skin remains as part of the cooked meat.

In many respects, the future of rabbit raising appears to be brightest in developing countries, where maximum efficiency of food production is urgently needed.

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22

Angora Wool Production

Leslie Samson

Angora rabbits produce high-quality fiber that is used worldwide in garment manufacture. They are unique among rabbit breeds due to their ability to produce a renewable textile material that can be harvested without harm to the animal. Angora underwool fiber has small diameter and chambers (Fig. 22.1) that give the wool excellent insulation properties and warmth without much weight. The naturally insulating structure of Angora fiber impedes the escape of body heat. It also readily transmits moisture so that garments feel dry.

These properties are especially useful in providing warmth and comfort to persons with joint diseases. Therapeutic clothing, such as elbow and wrist warmers, as well as Angora blend undergarments, has been appreciated in Europe for many years (Fig. 22.2). Angora is popular as a fashion textile material because it is a renewable material. It can be spun, knitted, woven, and felted to create high-end gloves, socks, and garments (Figs 22.3 and 22.4).

China is the main source of the raw Angora wool in world commerce, providing about 90% of the world production. Other major producers of Angora wool have included India, Argentina, Chile, Germany, France, and Hungary. It should be mentioned that mass-media exposure of even isolated cases of poor care and management practices (animal welfare) involving the raising of Angora rabbits in one country can have a ripple effect on plummeting international markets and(or) discouraging the acceptance by buyers of rabbit wool.

An alternative strategy to large-volume raw-wool operations has been the development of cottage industries run by either individuals or cooperative ventures. Angora growers harvest their own fiber, process it and offer value-added goods from the farm gate directly to end-use buyers. In this manner, they can control product quality while maintaining respectable profit margins. Most of the Angora wool produced in North America is either hand-spun, marketed to hand-spinners, or custom mill-spun. In 2004, the I.A.G.A.R.B. (International Association of German Angora Rabbit Breeders) established a successful volunteer co-op that offers both yarn and finished goods. Wool product buyers should be educated not only on the amazing qualities of Angora wool, but also on how rabbits are raised with good care and management that involve humane methods of wool harvesting.

Angora wool differs from sheep wool in several respects. The underwool component of Angora rabbit fleeces, which comprises the bulk of the fiber, is very fine with an average diameter of about 8 to 10 microns. It has a low density of about 1.15 to 1.18 grams per cubic centimeter as compared to values of 1.33 for sheep wool and 1.50 for cotton. This gives Angora garments a feeling of being very light but warm.

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The characteristic halo or fuzzy nap distinctive in garments made with a high percentage of Angora, is formed by the escape of guard and awn hairs, or "spike" from the twist of the yarn. Fashion industries prefer the drama created by the almost fur-like texture of hairy Angora garments. By contrast, Angora fiber with low hair content is a good choice for therapeutic and intimate apparel.

As with all follicle-grown fibers, Angora wool is covered in scales. Ideally, the scales would be smooth, which creates a silky "hand" to the wool. In the most extreme case, as in fiber from Satin Angora rabbits, the wool scales are so tight that they take on a reflective quality. The opposite characteristic would be protruding scales, which give the wool a dull, chalky look and a dry hand. This kind of wool coat is especially prone to matting on the rabbit, resulting in diminished yields of usable fiber. Raw Angora wool will lose an average of 7–9% of its weight to normal dirt and oils after washing. By contrast, the heavy lanolin content of a skirted Merino sheep fleece accounts for a loss of 50% of raw weight after it has been scoured.

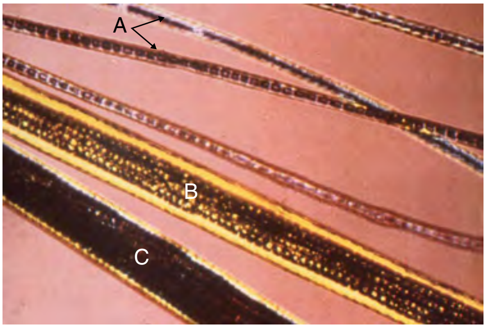

Fig. 22.1. Angora rabbit wool showing (A) underwool with single rows of medullary cells, (B) guard hair with a thick cortex, and (C) an awn hair tip with a thin cortex and numerous medullary cells in series. (Courtesy of Dr Robert Brusenbach)

Compared with sheep fleece, raw Angora looks snowy white and feels clean to the touch. Handspun Angora yarns and garments must be washed, however. During normal grooming, the rabbit deposits minute amounts of saliva on its wool coat. The saliva contains the antigen AG1, which causes allergic reactions in susceptible people.

Wool Coat Growth

The recessive mutation, (l), extends the normal coat length of 2 to 3 cm (0.78 to 1.18 in) for

Fig. 22.2. Knee-warmers available for sale in Germany. (Courtesy of P.R. Cheeke)

Fig. 22.3. North American milled yarn, socks, and hand-knitted gloves. (Courtesy of Leslie Samson)

Fig. 22.4. Felted coat of 50% Angora and 50% Merino made by the author of this chapter. The Angora wool was of a lower quality but was still useful to produce a high-end garment. (Courtesy of Leslie Samson)

short-haired rabbits to 10 cm (3.93 in) for commercial varieties of Angora rabbits. Selective breeding and specialized management of show rabbits have increased coat lengths to more than 20 cm (7.87 in).

The wool coat architecture of an Angora rabbit contains the same fiber types as normal short-haired rabbits. Hairy fibers provide strength and structure to the coat while wool fibers create protective insulation. Intermediate fiber types transition between hair and wool. Primary follicles grow guard hairs (Figs 22.5–22.8). These fibers are the backbone of every lock of the wool coat. Guard hairs are the longest component of the wool coat and they have the largest diameter. By 90 days, the guard hairs are commonly 9.5 cm (3.74 in) long.

Surrounding each guard hair are specialized follicles, which produce the next layer of coat, the awn hairs. Awn hairs differ from guard hairs in their length and in their internal structure. If the guard hairs are 9.5 cm (3.74 in) long, then the awn hairs would measure approximately 8.75 cm (3.44 in). Awn hairs terminate in a flat tip. Typically, awn hairs have a slight wave and thinner cortex compared to the straight guard hairs.

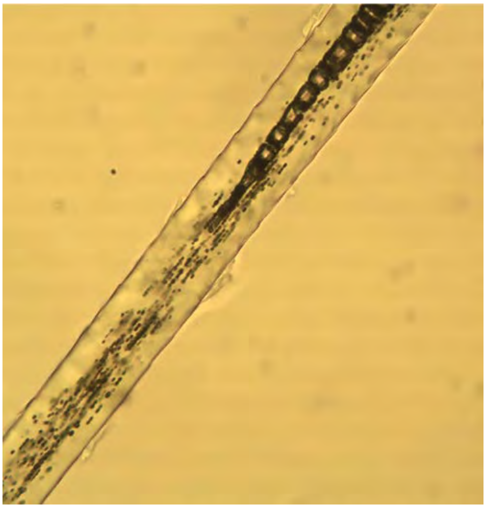

Fig. 22.5. Follicle root of a guard hair from an agouti-colored Angora rabbit. Note the pigment grains and how they form into medullary cells. (Courtesy of Leslie Samson and Susan Wiley)

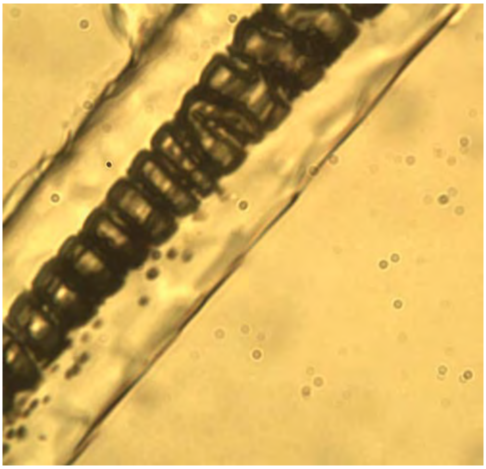

Fig. 22.6. The same fiber from the previous figure that shows a division of medullary cells. (Courtesy of Leslie Samson and Susan Wiley)

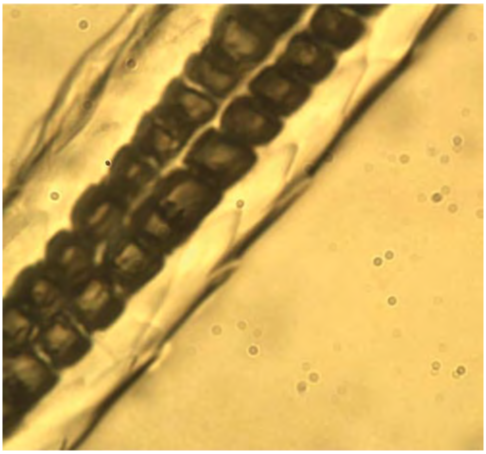

Fig. 22.7. The same fiber as the two previous figures, in which thesingle row has now divided into two distinct rows of cells. Also note the cuticle scales. (Courtesy of Leslie Samson and Susan Wiley)

Grouped near each awn hair are groups of follicles, which produce awn wool and underwool fibers. The next layer of coat, at 8 cm (3.15 in), is formed by awn wool fibers. These fibers bridge between the hairy components that stand protectively above the bulk of the coat and the underwool. Like underwool, awn wool contains single medullary cells and is crimped. However, like awn hair, each awn wool fiber terminates with the characteristic flat awn tip.

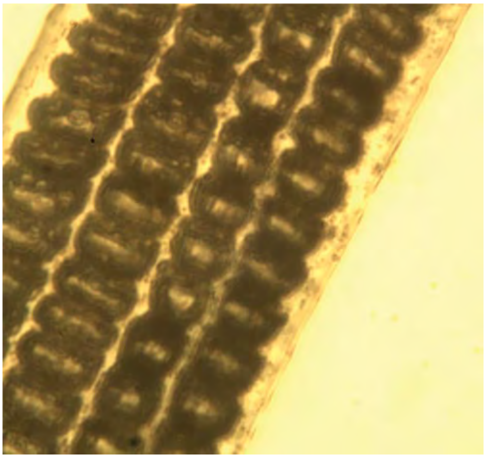

Fig. 22.8. The medullary cells continued to split into four distinct rows. Note pigment grains inside the cells and throughout the cortex of the fiber. A similar mechanism of division produces the under-wool clusters. (Courtesy of Leslie Samson and Susan Wiley)

The underwool, at 7.5 cm (2.95 in), is the softest and the most insulating portion of the rabbit's coat. Together with the awn wool, underwool makes up approximately 70–90% of the weight of the fleece, depending on the Angora breed.

The under-wool follicles begin as single follicle roots. As the fibers develop, they will divide into several more fibers, which appear as clusters connected by a single root. In low yield types of Angora rabbits, the clusters will contain less than ten fibers. High production wool rabbits will produce over 40 fibers per cluster. These specialized follicles explain the differences in coat density between individuals and breeds. Short-haired rabbits also produce under-wool clusters from single follicles. Textile industry standards determine the length of the coat by measuring the underwool. The underwool length is referred to as the “staple”. Staple length is a vital factor defining the grade and value of Angora.

Wool production of Angora rabbits is influenced by a variety of factors such as genetics, nutrition, water quality, and environmental temperature. Females produce about 20% more wool than males. Castrated males produce 10–12% more than breeding bucks. Over a three-month harvest interval, the wool grows an average of 2.5 cm (1 in) per month. Angoras reach their peak of wool production between 18 and 36 months of age. After three years of age, wool yields and reproduction abilities begin a rapid decline. Heavy wool yields may cause heat stress on animals. This can be an issue concerning the raising of Angora rabbits as projects for low-income farmers in tropical developing countries.

Wool Yields

Objective genetic selection is crucial in the improvement of wool density and texture. Angoras in Germany have been selected for high yields of usable wool for many years. Wool characters tend to be quite heritable, which results in noticeable response to selection (see Chapter 15 – Genetic Selection for Herd Improvement). An annual yield of 2232 g (4.92 lbs) of wool for a doe was recorded in 1990. Since then, many more rabbits have tested yields in excess of 2300 g (5.07 lbs).

Angora rabbit foundation stock was imported to North America from Germany, as well as other European sources, from the mid-1980s to the early 2000s. Prior to 2003, generations of breeding stock out of the imported Angoras were selected based on subjective criteria such as how thick a coat felt rather than the actual weight. Production fell from a high of 1745 g (3.84 lbs) to an average of 1000 g (2.20 lbs) per year.

When Angoras from imported lines were managed in a recordkeeping system similar to European models, wool yields improved. This has been attributed to a data-based, performance selection process and improved nutrition. Wool testing is also a valuable tool for evaluating the efficacy of different feed formulas. In 2008, I.A.G.A.R.B. performance tests set North American wool records at 2284 g (5.0. lbs) for albino wool and 2004 g (4.41 lbs) in 2011 for black Angora wool.

Average annual yields for A.R.B.A, (American Rabbit Breeders Association) recognized breeds, the French and English Angoras, range between 250 and 550 g (0.55 and 1.21 lbs). Wool production for the A.R.B.A. Giant Angora ranges between 750 and 1200 g (1.65 and 2.64 lbs). Satin Angoras are genetically distinct from other Angoras. The combination of both the Angora and Satin genes results in a wool with an unmistakable silk-like luster. Annual yields tend to be quite low at about 150 to 350 g (0.33 and 0.77 lbs).

Management

For the most part, Angora rabbits are cared for in the same manner as the normal coated breeds, but there are a few special considerations for optimal wool production.

Although Angora rabbits will survive on regular rabbit's feeds, a good quality, corn-free ration with enhanced levels of the amino acids methionine and cysteine will increase wool yields. Daily access to roughage like low protein grass hay will reduce the incidence of wool block. A daily ration of 225 ml (1 cup) is generally sufficient for an Angora rabbit. Check the condition of the rabbit and note the amount of flesh over the ribs and back. Adjust the ration accordingly.

Feed-to-wool conversion is an important issue for anyone concerned with the financial viability of an Angora rabbitry. Based on a daily feed intake of 170 g (6 oz), one Angora will consume 62 kg (137 lbs) of feed in one year, If an Angora produces 500 g (1.10 lbs) of wool in one year, about 30 kg (66 lbs) of additional feed will be needed, or 120 kg (264 lbs) of additional feed if it produces 2000 g (4.41 lbs). Cost ratios can be calculated by dividing the price of three months of feed by the weight of the wool produced during that period. Values for graded wool can be compared to production costs.

Angora rabbits have been selected for their wool-producing abilities, not their reproductive capacities. Consequently, they tend to breed less readily, to kindle less successfully, and to lose condition to lactation more quickly than commercial meat rabbits. A litter size of six to eight kits is manageable for most Angoras.

It is a good practice to harvest the wool from a doe prior to breeding. The stimulation of handling, which occurs during wool removal, will increase the doe's receptivity to the buck. By the time the doe kindles, her wool will have regrown about 2.5 cm (1 in). This short wool, which she will pull for her nest, is less apt to tangle around the necks or limbs of the kits than is the wool of a long-coated Angora rabbit. If the kindling doe has a coat longer than 4 cm (1.6 in), clip the nest wool into little bits and replace it in the nest. No matter the length of the doe's coat when she kindles, it is advisable to re-clip her belly wool in order to improve access for the kits to her teats. Blood-stained wool in the does vent area may attract flies. To prevent fly strike, clip or clean the doe's vent postpartum.

Angoras will benefit from a cage size of 72 × 91 cm (30 × 36 in) or larger. Extra space will help to maintain the health of the rabbit and the condition of the wool coat.

Wool Block (Gastric Stasis)

Wool block is the common term for a type of gastric stasis caused by the swallowing of coat fibers during normal grooming. The wool fibers are indigestible and collect in the stomach. The accumulated fibers work like a net, which traps and combines with feed in the rabbit's stomach. In time, the wool and food form a matted mass known as trichobezoar or hairball (see Fig. 10.25) that is too large to move out of the stomach. Unlike cats, rabbits are not able to cough up hairballs. Fortunately, wool block rarely develops in rabbits on a regular 90-day shearing schedule. The risk of wool block increases with the length of time the coat is left on the rabbit. The first indication of blockage is that the rabbit will refuse to eat. A decrease in the size of droppings is another sign of abnormal digestion. Droppings strung together by strands of wool are evidence that hairs are in the gut. A gentle palpation of the stomach just under the ribs will reveal the size the trichobezoar. A large wool block will feel firm and heavy. A smaller blockage may feel like an irregular golf ball. In an advanced case, the rabbit will sit in a hunched position and become listless. As food cannot pass from the stomach into the intestines, the animal may die of starvation if immediate action to break down the hairball is not taken.

Pineapples contain a digestive enzyme called bromelain. Papayas contain papain. Either enzyme will help digest the feed caught in the trichobezoar. Oral administration of 4 ml (cc) of fresh pineapple or papaya juice twice a day will help to dissolve the blockage. Digestive enzyme tablets containing bromelain and papain may be crushed and mixed with water. These are often more effective than fresh juices and are more convenient as they are shelf stable. Offer hay or succulent green feeds like parsley or cilantro to push the hair through the rabbit's system.

On occasion, a small blockage may become lodged in the intestine causing an infection and eventual necrosis of the surrounding tissue. By the time a diagnosis can be made, the condition of the rabbit is often too compromised for any successful intervention. Surgical removal of a trichobezoar rarely has a good outcome as the rabbit is generally too weak and dehydrated to withstand anaesthesia.

Prevention of wool block is much easier than its treatment. Timely wool removal is the best way to avoid this troublesome condition. Good grass hay and green foods like dandelions, carrot tops and parsley will provide cleansing roughage. During the last month of a 90-day harvest schedule, diligently watch the rabbit's appetite and stools for changes.

Equipment for Grooming and Wool Harvesting

1. A table, waist high, with a 30 × 60 cm (11.8 × 23.6 in) top. It should have casters so it can be turned easily, and it should be covered with carpeting to prevent the rabbit from slipping.

2. A brush, or slicker brush with single steel bristles set in rubber for brushing and removing foreign material from the wool.

3. A pair of sharp scissors, similar to those used by barbers.

4. Electric clippers, especially if wool is to be removed from a large number of animals.

5. A ruler to measure the length of the wool.

6. A container for each grade, placed within easy reach so the wool may be graded at the time it is removed from the animal and put into the proper receptacle for storage.

The ideal number for a wool harvest schedule is 90 days. The fiber length at 90 days will reach an average of 9 to 10 cm (3.54 to 3.94 in). Coincidentally, this is an optimal length for the construction of a stable, non-shedding yarn. Most Angoras will hold their coats for 90 days. Depending on climate, management and genetics, some will continue to resist shedding up to 120 days, others may "blow" their coats at 75 days. Because wool block is a potentially fatal condition, the appearance of loose wool on the rabbit and in its cage is always an indication of harvest time.

Healthy adult rabbits that are free of mites require little grooming, provided they are clean and the wool is removed every 90 days. If the coat is allowed to grow for a longer period some fibers will shed and fall back into the coat. These loose fibers tangle with the existing coat to form webs, which will later tighten into hard matts.

The presence of a waxy-feeling dandruff over the rump and hips of a rabbit is evidence of an infestation of *Cheyletiella parasitivorax* or fur mites. The feeding actions of these mites damage fibers and irritate the skin of the rabbit. In advanced cases, raised lesions will appear like colonies of scabby mounds on the back of the rabbit.

Harvesting wool from a rabbit with mites is time consuming for the manager. The oily wool, skin flakes, and scabs will clog electric clipper blades. Plucking will cause bleeding to skin already damaged by the mites. Routine brushing of Angora rabbits with a mite-contaminated brush will distribute the parasites over the entire body of each animal groomed. A routine sub-cutaneous injection of Ivermectin™ will eliminate mites. For best results, every animal in the rabbitry should be treated at the same time. Regular washing and disinfecting of equipment will reduce the spread of mites.

Removal of Wool

Young Angoras should be sheared or clipped at weaning and subsequently every 90 days. Ideally, records of graded wool production would follow the performance of each rabbit over its lifetime.

There are two methods of removing wool from adult Angora rabbits: plucking or shearing. When either method is performed with care, rabbits are unharmed. Shearing employs electric clippers and(or) scissors. Plucking may be done with a plucking knife or simply by hand. The method of harvest will affect the regrowth of the coat to such an extent that the rabbitry manager may manipulate the texture of the replacement coat to a considerable degree. When a wool coat is removed by plucking, the next coat will regrow with a high percentage of hair type fibers. A shorn coat will replace itself with a high percentage of underwool. Because most of the coat pigment is carried in the hairs, a shorn wooly coat will appear lighter in color than will a hairy, plucked coat.

Through selective breeding, wool coat growth may occur in stages or in one synchronized flush. This is a very important distinction as it determines the most appropriate method of wool removal, which in turn influences fiber end use and value. When an Angora grows its coat in non-synchronous stages, one will typically see one layer of coat that measures 3 cm (1.18 in), another layer at 6 cm (2.36 in) and sometimes a third coat at 9 cm (3.54 in) in length. The layers of coat are very easy to see in agouti Angoras as the awn tips, which define the top of each layer will be colored golden brown. When one blows into this type of coat, "rings" of gold will contrast with the blue-grey background of the fiber shafts. Wool coats that grow in stages are not suitable for shearing as the shortest and longest staple lengths will be mixed. This presents a significant grading problem as fibers less than 3 cm (1.18 in) in length will increase processing losses and shedding during garment wear.

In order to remove only the longest layer, non-synchronous wool coats are best suited to plucking. When the entire coat grows at the same time, it has only one staple length. Synchronized coats are best removed by shearing.

Plucking

Plucking is a traditional harvest method still in use in France. In part, this harvest method is responsible for the dramatically spiky, fur-like quality associated with premium Angora garments from France. The method for coat removal in France begins with a special ration containing Lagodendron™, a systemic depilatory, which is fed to the rabbit four days before plucking. In order to minimize stress on the rabbit, plucking sessions are spread out over a number of days. On the first day, all of the wool on the lower half of the flanks of the rabbit is removed by grasping a tuft of wool between the thumb and the edge of a plucking knife. The knife has dull, serrated edges, which help to grip the fibers. Because the depilatory product has had time to cause a "break" in the coat, the fibers come away relatively easily. Over the period of a week, sections of wool are removed until only the top of the back is covered with a cap of protective wool. As soon as enough wool has regrown, the last of the coat is removed.

When no depilatory product is used, care must be taken to remove small amounts of wool at a time. To avoid the development of wool block, the longest wool is usually removed in one session by pulling tufts between the thumb and index finger. A shorter layer of coat should be present before the longest layer of coat is pulled from the rabbit. The repetitive action of pulling tufts of wool from the rabbit is particularly stressful to the wrist and thumb joints of the person performing the task.

Shearing or clipping

The objective in shearing is to remove as much prime wool as possible and as quickly as possible without degrading the quality of the fiber or stressing the rabbit.

There is no one right way to shear a rabbit. Every owner will have his or her preferred method. If you are using scissors, before closing the blades, turn them so that they are perpendicular to the skin of the rabbit. If the blades are parallel to the skin of the rabbits, there is a danger of catching the delicate skin and cutting it. As long as the blades are at right angles to the skin, it will not be possible to hurt the rabbit. Adjust the angle of the scissors with the contour of the rabbit's body.

There are several methods for limiting the movement of the rabbit during shearing. Some people prefer to use a device for tying it, while others choose to simply hold the rabbit on their laps. Placing the rabbit on a shearing table is also effective. As you gain experience, you will become proficient and devise the method that works best. Eventually you should be able to remove the wool safely from a rabbit in 15 to 20 minutes.

To prepare a rabbit for either shearing with clippers or scissors, part the wool along the backbone (Fig. 22.9). Begin removing the wool in narrow swaths from the rump to the head, following the contour of the body until all of the wool is removed from one side (Fig. 22.10). Repeat the procedure on the other side.

For removing the wool from under the neck and from the forelegs, restrain the rabbit by gently holding its ears and raising its body so that the front feet just touch the table (Fig. 22.11, upper). Then, turn the rabbit over on its back on the table, and securely hold it by the fold of skin on the back of the neck to remove the coat on the thighs and on the belly (Fig. 22.11, lower). Care must be taken not to injure the teats. Figure 22.12 shows a rabbit shorn with electric clippers. In Fig. 22.13, a shorn rabbit sits above its graded wool from a 90-day clip.

Care of Shorn Rabbits

A shorn rabbit will need protection from temperatures lower than 10 °C (50 °F) until its coat is about 2 cm (0.80 in) long. It is important to compensate for the removal of the long,

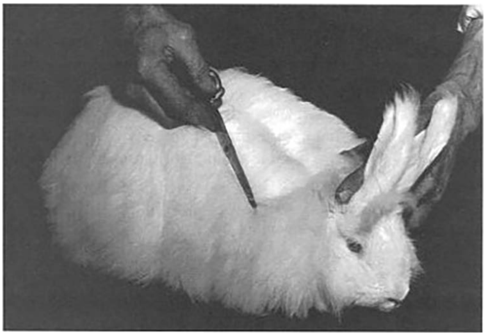

Fig. 22.9. Preparing an Angora rabbit for shearing. (Courtesy of USDA)

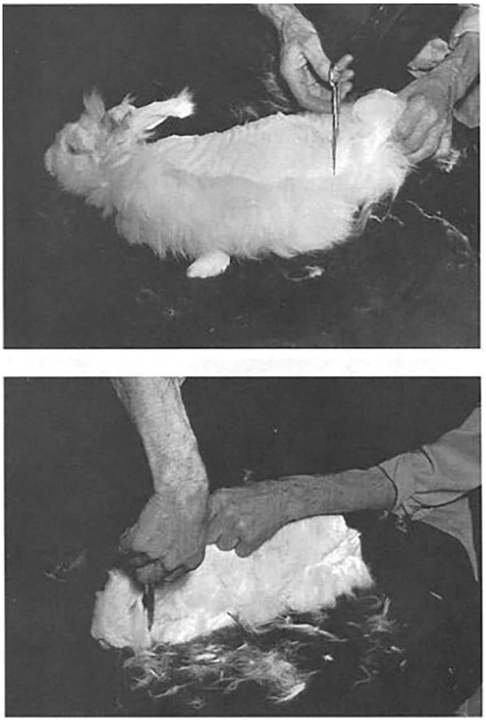

Fig. 22.10. Shearing an Angora rabbit (see also Fig. 22.11). (Courtesy of USDA)

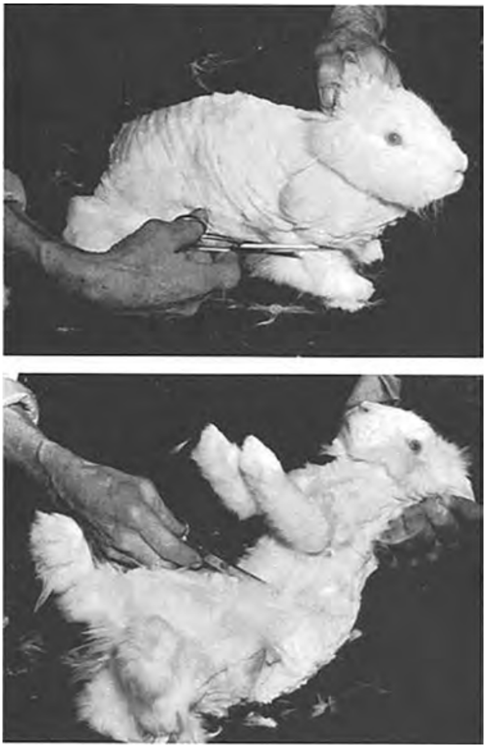

Fig. 22.11. Shearing an Angora rabbit (continued from Fig. 22.10). (Courtesy of USDA)

Fig. 22.12. An Angora rabbit being shorn with electric clippers. (Courtesy of P.R. Cheeke)

insulating Angora coat to which the rabbit had become accustomed. Ideally, in regions where the winters are especially severe, the shearing schedule should be timed to avoid the harshest weather. Housing shorn rabbits in a warm room is the simplest way to protect them. In a large rabbitry, groups of Angoras can be shorn and rotated through the warm room.

If the temperature dips below 7 °C (45 °F), additional measures should be taken. A simple coat made of thick polar fleece can be fitted over the rabbit until 2 cm (0.80 in) of wool has regrown (Fig. 22.14). Warming electric lights can be placed on the top of the rabbit's cage so the heat is directed at the rabbit. A cold rabbit will sit under the light, which will warm the blood in its ears. Cages should be stuffed with insulating material such as clean straw. A wooden nest box lined with straw is another option.

Electric shears remove the wool just above the skin. Clipping with scissors, however, offers more control over the length of coat left on the rabbit. It is easy to leave 1 cm (0.40 in) of wool on the rabbit when cutting against the natural grain of the coat. If you need to leave 2 cm or more on the rabbit, cut with the grain.

Pay attention to the rabbit. If it is sitting hunched and its ears are cold to the touch, help it. Continue to adjust its situation until the

Fig. 22.13. An Angora rabbit sits above its graded 90-day wool clip. (Courtesy of Leslie Samson)

Fig. 22.14. Shorn Angora rabbit in a protective coat. (Courtesy of Leslie Samson)

rabbit looks comfortable. It is often advisable to double the rations for newly shorn Angoras until they regrow 2 to 3 cm (0.80 to 1.20 in) of wool.

Grading and Storing Angora Wool

1. Prime Angora white or colored – staple length 6.5–9.0 cm (2.5–3.5 in). Prime wool is clean, free of all matts, dandruff and foreign matter. It is suitable for either hand-spun or mill-spun premium yarns.
2. Angora seconds white or colored – staple length 2.5–6.5 cm (1–2.5 in). Seconds are clean, free of all mats, dandruff and foreign matter. Seconds may be spun into yarn if enough sheep wool is included in the blend to hold the short Angora in the twist of the yarn. Three-ply yarns are a good choice to secure this grade.
3. Angora shorts white or colored – staple length < 2.5 cm (<1 in). Angora shorts have limited use as they are prone to processing fly and shedding. It can be useful to keep a supply of short Angora in the rabbitry for replacement nest wool.
4. Clean webby or matted wool can be hand-spun into premium novelty yarns or used in felting.
5. All stained and unclean wool, free-falling or matted should be discarded.

Wool from rabbits less than 6 months old is considered "baby wool". It is not generally considered acceptable for spinning, as its diameter is so fine (3 to 6 microns) that it is prone to breaking, shedding, and felting in knitted garments. While such a fine fiber is not ideal for yarn, its natural propensity to matt makes it a good choice for felted end uses.

The manner of storage will depend on the use for the wool. If the wool is intended for sale to hand-spinners, it should be stored in hard-sided containers. Fiber kept in paper or plastic bags has a tendency to shift and tangle. Prime and seconds destined for a spinning mill can be tightly compacted for shipment because machine picking and carding will open and blend the fiber effortlessly.

Store Angora wool, yarn, or finished goods in tightly covered containers with slices of soap made with essential lavender oils. Lavender is an effective alternative moth deterrent that will also create an attractive scent for most people. Mothballs or crystals are often suggested, but they contain the insecticides naphthalene or paradichlorobenzene. These toxins create fumes poisonous for clothing moths. They are also an unpleasant addition to a material intended for wear or sale. Exposure to mothball vapors may cause nausea and headache.

Home-spinning of Angora Wool

Many people hand-spin the wool from their Angora rabbits into yarn and then knit garments from it (Fig. 22.15). Like the fleeces of any fiber animal, textures of Angora wool vary over the body of the rabbit. A homogenous nap in the finished garment can be achieved by mixing all of the prime from a rabbit's coat. For best results, card the blended wool and pre-draft before spinning.

Angora wool is often blended with other fibers to improve specific characteristics of a yarn. Because Angora has little elasticity, the addition of sheep wool lends stretch and rebound to a garment. Silk adds a quality of shine. Including other natural fibers or synthetics in the yarn design reduces the percentage of Angora and production costs.

Because Angora is a warm fiber to wear and relatively expensive to produce, it is advantageous to spin single-ply yarn to at least 183 m per 30 g (200 yards/ounce). When two-plied, the finished yarn will measure 91 m per 30 g (100 yards/ounce). During mill processing, Angora wool is subject to fly, a spinnery term referring to nearly weightless fibers that escape the machinery and float away on air currents during the normal manufacture of yarn. The higher the content of sheep wool in the blended yarn, the lower the production losses to fly will be. The staple length of Angora fibers is also a determining factor in production losses to fly. The ideal length of fiber for spinning is 7–9 cm (2.8 to 3.5 in). As the average fiber length decreases, the percentage of loss to fly increases. Angora wool, yarn and garments should be washed with a mild detergent or shampoo in warm water. Gently soak Angora with as little agitation as possible. Static may be eliminated with the addition of a hair conditioner in the rinse water. Rinse well and dry flat.

Fig. 22.15. Spinning Angora wool. (Courtesy of J.I. McNitt)

Further Reading

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23

Meat Production

Rabbits are raised throughout the world for meat, and the trend in commercial production is toward increasingly larger and more efficient units. In the United States, rabbits are slaughtered when they have attained the desired market weight and condition without regard to the primeness or value of the pelt. In other countries, where feed costs and labor conditions are quite different, rabbits are sometimes fed rations that will cause them to gain at a much slower rate, and each animal is kept until its combined value for carcass and pelt will bring the highest returns. For family food production, a common practice is to keep fryers alive until the family is ready for a meal with rabbit meat. Many prefer the fresh flavor over meat that has been frozen.

Fryers

Fryers comprise more than 85% of the rabbits marketed for meat. Those of the medium breeds that are properly developed and conditioned will average 1.7 to 2.0 kg (3.8 to 4.4 lb) when marketed at approximately two months of age. Carcass yield, or dressing percent, is determined by dividing the weight of the dressed carcass by the weight of the live rabbit. As an example, a 2 kg (4.4 lb) fryer yielding a carcass of 1.1 kg (2.4 lb) would give a dressing percent of 55% ((1.1 ÷ 2.0) × 100 = 55%). Fryer yields of carcasses vary from 50 to 60% live weight, and 75 to 80% of such yields is edible.

There are several factors that affect the dressing percent. Those rabbits that are more physiologically mature and that have been properly conditioned for market yield a higher dressing percent than younger ones. Those with well-sprung ribs and deep chest, carrying the width and depth of the body uniformly from the shoulders to the hips, give a higher carcass yield than narrow, rangy animals. A long, well-developed loin is desirable. When rabbits are properly finished for the market, fat will be deposited over the ribs, along the backbone, in the flanks, and around the tailhead and the kidneys, increasing the dressing percent over that of thin rabbits. In some countries, the head and feet are left on the carcass, so dressing percentages are higher than in the United States. The amount of ingested material in the digestive tract also has a bearing on dressing percent. If the animal has been without food and water for several hours before being slaughtered, with a consequent smaller quantity of material in the digestive tract, the dressing percent will be higher. The breed of rabbit also influences carcass quality. New Zealand Whites, because of their popularity, set the standard for other breeds. Californians tend to finish out at a lighter weight than New Zealand Whites but

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produce a more compact carcass with a higher dressing percent.

The Agricultural Marketing Service of the U.S. Department of Agriculture has established standards for the quality of rabbit carcasses. These are published as AMS 70.300 *et seq*. – United States Classes, Standards and Grades for Rabbits (search on the Internet for "Standards and Grades for Rabbits"). The grades for ready-to-cook carcasses are A, B, and C (Fig. 23.1). This system of grading should make it possible to obtain more meat per pound for the top grades and should act as an incentive for the rabbit producer to produce a superior quality product. In order to be graded, however, the carcasses must be inspected during the slaughter process by inspectors from the Food Safety and Inspection Service (FSIS) of the USDA. Rabbits are not classified as an agricultural commodity, so inspection falls under rules established for voluntary grading services (Title 9, Chapter III, Subchapter A, Code of Federal Regulations, Part 354-Voluntary Inspection of Rabbits and Edible Products Thereof) (search on the Internet for "Voluntary Inspection of Rabbits"). Because this is a voluntary service, there is a charge for inspection that frequently is too expensive for the rabbit processor.

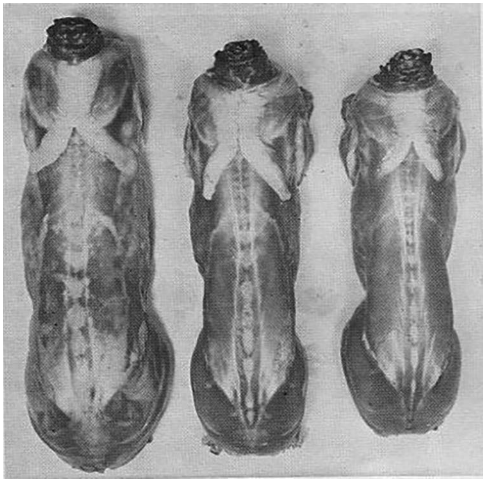

Fig. 23.1. Fryer carcasses left to right: Grades A, B, and C. (Courtesy of USDA)

White pelts are usually worth more than colored pelts, so processors usually pay more for white animals. Also, colored rabbits are less valuable because dark hairs show up on the carcasses, whereas white hairs don't, so more labor is required to produce acceptable fryer carcasses from colored rabbits. Thus, commercial rabbit producers should raise a white breed, such as the New Zealand White, or a white terminal crossbred fryer.

When does and litters are full fed a well-balanced ration, approximately 3 to 4 kg (6.6 to 8.8 lb) of feed will be required to produce a kilogram or pound of weaned fryer at two months of age, counting all feed from when the doe is mated until the litter is weaned (Fig. 23.2). The type of ration has a direct bearing on the quantity needed to produce a pound of gain. The lower the energy content

Fig. 23.2. Feed needed to produce a 2 kg (4.4 lb) fryer using complete pellets. (Courtesy of USDA, with modifications by J.I. McNitt)

of the diet, the greater the amount of feed that will be required per unit of gain.

A current commercial practice when intensive breeding is used is to wean the fryers at four or five weeks of age. This allows a period of recovery for the doe before the birth of her next litter. Milk production has begun to decline by this time (see Fig. 11.7), and the feed is used more efficiently when it is consumed directly by the fryers than when converted to milk by the doe.

Stewers

Most rabbits of more than 3 kg (6.6 lb) live weight are graded as stewers. In most markets, the price paid for these heavier rabbits is considerably less than for fryers. They may not require any conditioning when they are culled from the breeding herd at the end of their period of usefulness and should yield a carcass of 55 to 65% of their live weight. Whether it is economically sound to condition these larger culled rabbits that are not carrying the proper amount of flesh will depend on the cost of feed and the relative market value. Many producers prefer to market them as soon as they are culled from the herd, for it saves labor, cage space, and feed. For family food production, a stewer is ideal for dishes that involve slowly cooked soups and stews such as rabbit and dumplings, rabbit with vegetable soup, and Brunswick Stew. Because of the large size of stewers there are often leftovers for future meals.

Nutritional Properties of Rabbit Meat

Rabbit meat is high in protein and low in fat. It has a low content of saturated fatty acids. It tends to have a low cholesterol content and a low sodium content compared to other meats. Thus, it is a highly nutritious meat and is suitable for special diets, such as those for heart disease patients, diets for the aged, low-sodium diets, weight reduction diets, etc. Nutritional information should always appear on labels where rabbit meat is sold (Fig. 23.3). The nutrient composition of rabbit meat compared to that of other common meats is shown in Table 23.1, and the vitamin and mineral content is shown in Table 23.2.

Fig. 23.3. A package of rabbit meat with nutritional information being sold in Nepal. (Courtesy of Ujjwal Chapagain)

Alternative Systems of Commercial Rabbit Production

For the commercial rabbit industry to become more viable in the United States, it must be economically viable for both growers and processors. Rabbit meat must be competitive in price with other meats. It is unlikely that a significant market based on high-priced rabbit meat can be developed. For the industry to become more competitive, the costs of rabbit raising must be reduced. Reduction in disease losses, improvements in feeding and genetic selection methods, and increased reproductive efficiency must be accomplished. The average number of fryers marketed per doe per year is probably in the range of 30 to 35. In China and in Europe, some producers have achieved levels of 50 to 60 fryers per doe per year. Such

Table 23.1. The nutrient composition of edible fresh rabbit meat compared to other meats.[1]

Nutrient	Rabbit	Chicken	Beef	Pork
Water (g/100 g)	70.8	72.2	69.1	70.5
Protein (g/100 g)	21.3	20.1	19.5	18.5
Fat (g/100 g)	6.8	6.6	9.0	8.7
Calories (kJ/100 g)	618	586	665	639
Saturated fatty acids (% TFA[2])	38.6	32.0	39.5	37.0
Monounsaturated fatty acids (% TFA[2])	32.8	41.0	42.4	44.4
Polyunsaturated fatty acids (% TFA[2])	23.9	25.1	9.5	18.5
Cholesterol (mg/100 g)	45	81	70	61

[1] Wet weight basis.

[2] Percentage of total fatty acids.

Source: Modified from Dalle Zotte, 2002 (see the Further Reading section for full details).

Table 23.2. The mineral and vitamin composition of edible rabbit meat per 100g.[1]

Nutrient	Nutrient quantity
Calcium (mg)	2.7–9.3
Iron (mg)	1.1–1.3
Phosphorus (mg)	222–234
Potassium (mg)	428–431
Selenium (µg)	9.3–15.0
Sodium (mg)	37–47
Vitamin B1, Thiamine (mg)	0.18
Vitamin B2, Riboflavin (mg)	0.09–0.12
Vitamin B3, Niacin (mg)	3.0–4.0
Vitamin B6, Pyridoxine (mg)	0.43–0.59
Vitamin B9, Folic acid (µg)	10.0
Vitamin B_{12} (µg)	8.7–11.9
Vitamin D (µg)	Trace
Vitamin E (mg)	0.16

[1] Wet weight basis.

Source: Modified from Dalle Zotte and Cullere, 2019 (see the Further Reading section for full details).

levels of production in the United States would increase the likelihood of rabbit raising becoming profitable.

Some new systems of rabbit production might be considered. For example, in Europe, breeding programs are much better developed than in the United States. There are several European companies that produce hybrid breeding stock. Generally, a genetics company develops several lines of animals. These lines represent many generations of intense selection for traits involving sophisticated genetic methods. The foundation stock or seedstock farm provides a second unit, the multiplier, with breeding stock of different lines. The multiplier crosses these lines to produce hybrid breeding animals that are sold to rabbit farmers, along with a separate buck line. The farmers then produce rabbits for sale as fryers. They buy all the replacement bucks and does they need, ready to breed. The farmers and the multiplier can't save their own replacements because they don't have the foundation stock. In this manner, the breeding program is tightly controlled, and the farmers have healthy, high-quality bucks and does that produce uniform, rapidly growing fryers.

In large-scale commercial rabbitries, the use of artificial insemination (AI) offers much potential. Advantages of AI include more extensive use of superior sires, labor savings, and the potential for use of cycled production. Disadvantages of AI include decreased conception when compared to natural mating done at the proper time, and increased costs. Breeding of does can be synchronized. On rabbit farms in Europe, barns are filled with several hundred does, all bred on the same day. These does all kindle at approximately the same time. The litters are all weaned the same day. The does are removed and rebred to be used in another barn. The litters are kept in the same cages until market. At 8 to 10 weeks, all fryers are marketed. The empty building is fumigated, and then a new lot of synchronized-bred does is brought in. This is known as an "all-in, all-out" system. It offers advantages in management and disease control.

Another system that may have potential is the fryer finisher. The operator, usually in proximity to a processing plant, buys weanling rabbits and raises them to market age. The rabbit raiser concentrates on the doe herd and does not raise fryers. The finisher has a large number of fryers of the same size and so can feed a series of diets (starter, grower, and finisher) for maximum efficiency. The rabbit raiser feeds only one diet, a doe lactation diet. This system offers the potential of improving the economic efficiency of rabbit production. This system is similar to the practice of vertical integration in the poultry and swine industries. Basically, the company owns and controls all phases of the business. For example, in the poultry industry the company develops the breeding stock and owns the feed mill (including land used to grow crops as feedstuffs) and the processing plant, as well as the business of marketing and distributing the meat products to the retail outlets. This “single-profit center” corporation has many farmers who sign contracts to grow the hatched chicks to market age. The main benefit of this industrial model is low food prices. On the other hand, this model is highly criticized by animal rights and environmentalist groups.

Lastly, an alternative system is small-scale production as described in Chapter 20. Here family labor and on-farm integration practices are key to reduce costs (Fig. 23.4). Sales of rabbit meat occur locally, especially at farmers’ markets. Some businesses develop their own websites and sell directly to consumers via Internet markets. In this model the advantage is that local economies are supported. A possible disadvantage is that the production supply is too low to be sold in the commercial or commodity marketplace.

Fig. 23.4. A delicious rabbit meal served with carrots and broccoli. The vegetables were produced from the family garden where vegetable wastes were fed to rabbits and rabbit manure was made into compost for the garden. (Courtesy of S.D. Lukefahr)

Further Reading

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Dalle Zotte, A., and Zs. Szendro. 2011. The role of rabbit meat as functional food. *Meat Sci.* 88: 319–331.

24

Harvesting and Preparation of Meat and Skins

The first step in harvesting a rabbit is to render it unconscious. This should be done quickly in order to prevent suffering and struggling. One of two methods is generally used – either stunning the animal or dislocating its neck. For the most part, the former method is used by persons with little experience and when speed is not as important as it would be if large numbers of rabbits were to be processed. It consists of grasping the rabbit across the loin with one hand and suspending it head down, then stunning it by a heavy blow at the base of the skull between the ears with the butt end of a skinning knife, a stick, or a small iron rod. In large commercial plants, the rabbits are stunned with an electric stunning knife. In the other method, you would hold the rabbit by its lower hind legs just above the feet in one hand and place the thumb of the other hand on the neck just back of the ears, with the four fingers extended under the chin; then, stretch the animal by pushing down on the neck with the hand. Press down with the thumb, and with a quick movement raise the animal's head and dislocate the neck. This method is suitable only for small rabbits.

Immediately after stunning suspend the animal on a hook, and cleanly cut the jugular vein to ensure the heart keeps beating to provide thorough bleeding so the meat will have good color. A skinning knife with a 12 cm (4.7 in) blade is a convenient size for dressing a rabbit.

Harvesting and dressing out the first few rabbits will take the novice longer than it will after having developed the technique through experience. Commercial butchers can catch the rabbits out of the holding pen, render them unconscious, hang them on hooks, bleed them, cut off the heads, and skin and eviscerate them at the rate of 100 or more per hour.

In suspending a rabbit, insert the hook between the tendon and the bone of a hind leg, just above the hock. Remove the tail and cut off the free hind leg at the hock joint. Cut off the front feet. Then, slit the skin just below the hock of the suspended leg. Insert the skinning knife under the skin on the inside of the leg and open the skin up to the root of the tail. Continue to the hock of the other leg. Carefully separate the edges of the skin from the carcass and pull the skin down over the entire carcass, using the knife to separate the fat from the skin (Fig. 24.1) so the fat will be left on the carcass. When the skin is removed by this method, it is known as a cased skin. If it has commercial value and is to be sold, care must be taken to avoid cutting it, for even small cuts lower its value. This method of skinning a rabbit is very similar to that of dressing wild game.

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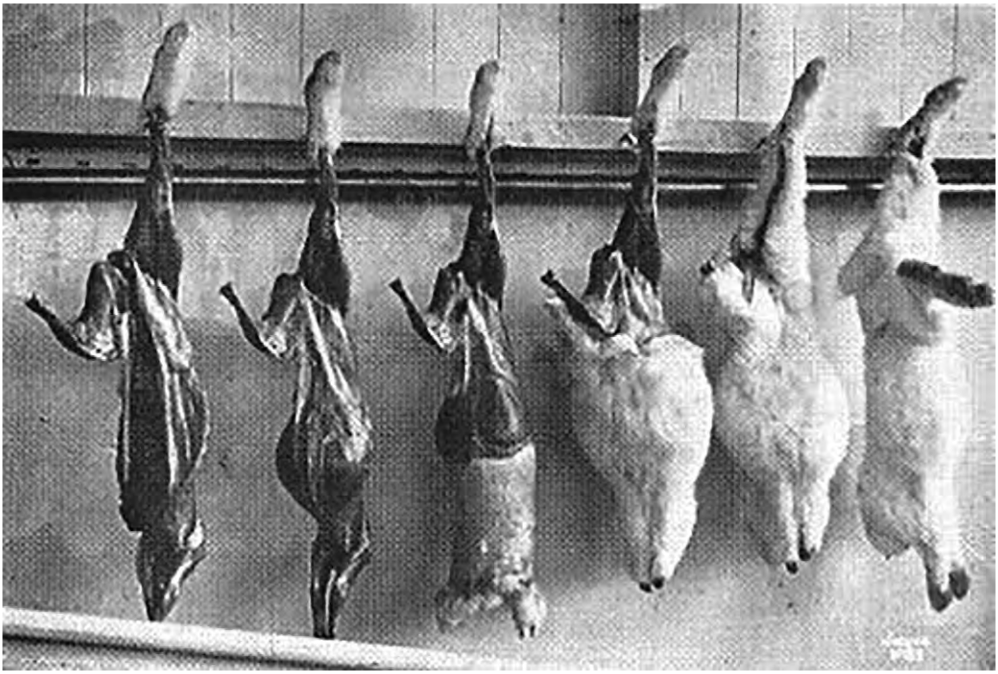

Fig. 24.1. Steps in skinning and removing the internal organs of a rabbit. (Courtesy of USDA)

Meat

After skinning the rabbit, carefully make a slit in the abdominal wall of the carcass along the midline of the belly, cutting from the breastbone to the tail. Remove the bladder whole and take out the entrails. Pinch or cut the gallbladder away from the liver, and leave the heart, liver, and kidneys intact. Spilling the contents of the bladder or gallbladder on the meat will cause bad flavors and may result in condemnation of the entire carcass.

The carcass will draw out of shape if left suspended on the hook. For it to have a more blocky and attractive appearance, it should be shaped up and chilled for 15 minutes and refrigerated for 24 hours before being cut up.

Particular care must be taken to prevent hairs from getting on the carcass, for in addition to being very difficult to remove, they detract from the appearance. Rinsing the carcass in cold water or soaking it in ice water will remove the hairs and blood and will cleanse and blanch the carcass. However, it should not be left in the water for more than 15 minutes because prolonged soaking causes the meat to absorb water. This is considered an adulteration. If small blood clots have formed around the neck, they can usually be removed by brushing.

After chilling, carcasses should be refrigerated for 24 hours before being cut into pieces as shown in Chapter 25. This storage period allows the fat to harden and makes cutting easier. During storage, the carcasses should be wrapped or placed in plastic bags to prevent drying. If freezing, commercial sealable bags should be used suitable for long-term storage (Fig. 24.2). The bags should also be dated. It is recommended to consume the meat before one year has elapsed.

All work in connection with rabbit carcasses should be done in a sanitary manner. If the rabbit meat is to be marketed in cities where health regulations regarding the inspection of slaughtering plants and meat are in effect, or if the meat is to be moved into trade channels where city, county, state, or other inspection is required, the proper health authorities should be contacted for detailed information relating to such inspection. Several excellent videos can be viewed online that show how to butcher a rabbit.

Fig. 24.2. Rabbit meat that is properly bagged and dated. (Courtesy of S,D, Lukefahr)

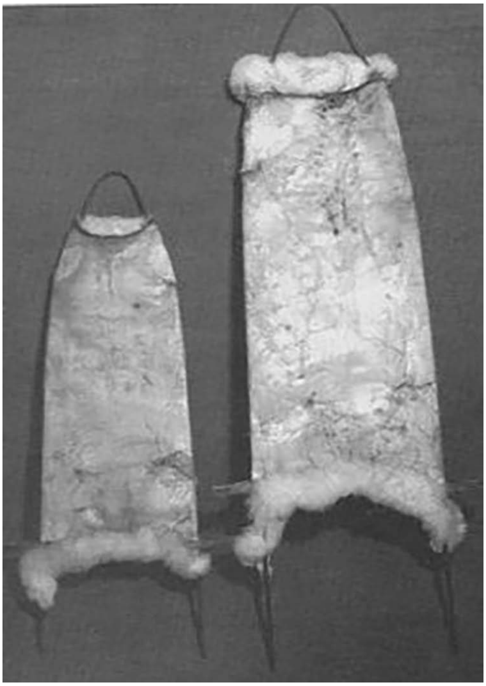

Fig. 24.3. Rabbit skins properly placed on stretchers. (Courtesy of P.R. Cheeke)

Skins

Curing

While the skin is still warm, secure it on a stretcher, with the flesh side out (Fig. 24.3). A No. 9 galvanized wire can be shaped for a stretcher. Two sizes of stretchers should be available, a smaller one for fryer skins and a larger one for mature and medium-size skins. Place the skin on the stretcher, with the two front legs on one side, and pull the ends of the skin down over the stretcher to remove all wrinkles without actually stretching the skin. Fasten the skin from the hind legs to the stretcher with clamp clothespins. Straighten out the folds in the neck skin. Lift up the skin on the front legs so it will not come in contact with the pelt and will dry more readily. Then, hang the skin up for drying. No salt or other preservative should be used in preparing the pelt for marketing. Hang the skin up to dry where it will be protected from sun, flies, and rodents. The following day, examine it to check that the edges are drying flat and that the skin on the front legs is straightened out. Remove any patches of fat, for it will cause the skin to burn and lower the value of the pelt. During periods of low temperature, some artificial heat will be required to dry out the skin. This is accomplished in large slaughtering plants by circulation of warm air through the pelt-curing room.

Tanning skins for home use

Skins that are to be sold should not be tanned before shipment, because fur buyers prefer them in the raw state. If intended for home use, however, the skins may be tanned by the methods described below, but they should not be expected to compare favorably in appearance and pliability with products of a tannery or factory equipped with modern machinery and operated by experienced workers (Fig. 24.4).

Fig. 24.4. Tanned rabbit skins. (Courtesy of S.D. Lukefahr)

The first step in tanning a skin is to get it thoroughly softened, clean, and free from flesh and grease. If it is cased or whole, slit the skin down the middle of the belly and soak it in clean, cool water. Change the water several times.

When the skin is soft, lay it over a pole or board, and work over the skin side with a coarse file or dull knife, breaking up and removing the adhering tissue, flesh, and fat and at the same time working the grease out of the skin. It is useless to start tanning until all the tissue and fat have been removed and the skin has been made uniformly soft and pliable.

The thickness and condition of the pelt determine the length of time a skin must be soaked. Some skins require two or three hours, and others longer. A skin should be soaked until it is soft, but it should not remain wet longer than necessary, as the hair may start to slip. When the skin has been thus treated and is somewhat softened, work it in lukewarm water containing 7 grams of soda or borax per liter of water (1 ounce per pint). Soap added to the water is also helpful in cutting the grease and softening and cleansing the skin. After rinsing the skin thoroughly in lukewarm water, squeeze out the water, but do not wring the pelt. Finally, work the skin in a mild detergent solution, which should remove the last particles of dirt and grease. It is then ready for tanning.

There are several methods for tanning rabbit skins. Directions for using two of the more successful methods – the salt–acid and salt–alum processes – are given below.

Salt–acid process

The salt–acid formula calls for a solution made of 0.5 kg of common salt and 14 g concentrated sulfuric acid to each 4 l of water (4 lbs of salt and 2 oz of sulfuric acid per gallon). Dissolve the salt in the water, and carefully pour in the acid while stirring. Because of the strong acid, this tanning liquor should be made and used in glass or earthen jars or wooden vessels, never in metal containers of any kind. When pouring in the acid, do not inhale the fumes and be careful not to get any of the strong acid on your skin or clothing. As soon as the salt–acid solution has cooled, it is ready for use.

Put the cleaned, softened skin into the solution so that it is entirely covered. Leave it in for one to three days, stirring it frequently. Then, remove it and rinse it in clean, cool water. Next, work the skin for about 10 minutes in a solution of 14 g of borax to 4 l of water (2 ounces per gallon). Rinse again in clean water, and squeeze (but do not wring) as dry as possible. Work the skin a few minutes in the hands by rubbing and pulling. Then, tack it out flat, flesh side up, and apply a thin coating of clean grease or oil and let it dry. Fresh butter, neat's-foot oil, or olive oil will be good for this purpose.

When the pelt is nearly dry but still damp, begin to work it with the hands, stretching it in all directions, working the flesh side over the edge of a board and pulling it back and forth as if shining shoes with a cloth. If the skin is rough, you may smooth it by working it over a sandpaper block, which also helps to make it soft and pliable. Much of the success in producing a soft, pliable skin depends upon this repeated working, which must be done while the skin is drying out and not after it is dry. If the skin is not soft enough when dry, it should be dampened and worked again as before. A final cleaning, accomplished by working the skin in warm, dry hardwood sawdust, is beneficial and will add to the luster of the fur.

Salt–alum process

The salt–alum formula calls for 0.5 kg (1 lb) of ammonia alum (ammonium aluminum sulfate) or potash alum (potassium aluminum sulfate) dissolved in 4 l of water (1 gallon); and 112 g (4 oz) of washing soda (crystallized sodium carbonate) and 224 g (8 oz) of common salt dissolved together in 2 l of water (1/2 gallon). Pour the soda–salt solution slowly into the alum solution while stirring vigorously. Mix the combined solution, as used, with sufficient flour to make a thin paste, first mixing the flour with a little water to prevent lumps.

After cleaning and softening the skin as previously described, tack it out smoothly, flesh side up, on a board. Then, coat it about 3 mm (0.1 in) thick with the tanning paste, and protect it with paper or sacking laid on lightly so as not to come in close contact with the paste. The next day scrape off most of the paste and give the skin another coating. At one-day intervals repeat this application two or three times, depending upon the thickness of the skin. Only thick skins from mature bucks will need as many as three applications. Leave the last coating on for three or four days. Finally, scrape off the paste, work the skin in borax water, rinse, and squeeze it. Stretch and work it over a board in the manner described for the salt–acid process.

The salt–alum process is widely used and is considered slightly better than the salt–acid tannage, although alum-tanned skins often come out stiff and hard and require much working to make them soft and pliable. Many methods and videos on tanning rabbit hides can be found on the Internet.

Further Reading

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Hobson, P. 1977. *Tan Your Hide*. Storey Books, North Adams, MA.

25

Marketing Rabbits and Their Products

Rabbit Meat

In some countries, rabbit meat is a well-established food served regularly at restaurants, hotels, clubs, and hospitals and available throughout the year in stores and meat markets. In addition, in certain countries it is a tradition to raise a few rabbits for meat in backyards as a cottage industry. The general marketing procedure in large rabbit-raising centers is for collection trucks (Fig. 25.1) to cover regularly scheduled routes within a radius of 160 to 320 km (100 to 200 miles), pick up the live animals at the rabbitries, and deliver them to a central processing plant. Some of these processing plants have a capacity of 2,000 to 5,000 rabbits per day (Fig. 25.2). Where there is no established market or in small towns, a person may develop an outlet for the rabbit meat through sales to neighbors and friends. Very satisfactory booths at farmers' markets have also been established.

With any marketing system, the problems involved are dealing with supply and demand, producing a choice-quality product, merchandising it in a form that will appeal to the consumer, and using such methods of advertising as will be most effective in the immediate area where the product is to be offered. Under all circumstances, the rabbit meat should be handled in a sanitary manner. Contact the proper health authorities to determine whether there are any rules or laws covering the inspection of the slaughtering process, the equipment, or the meat.

The 0.8 to 1.0 kg (1.8 to 2.2 lb) fryer carcass lends itself to quick preparation for the table. It may be cut into seven pieces (Fig. 25.3) to meet the requirements of the average family. The larger carcass can be made into 12 servings if the hind legs are cut into two pieces, the loins and back portion of the ribs into five pieces, and the front portion of the ribs and each of the front legs into one serving each.

The presentation of meat products in the most convenient form for the consumer to use is rapidly gaining favor. While the cut-up rabbit carcass in the package has been popular for many years, consumers now desire products that are ready to cook. In some countries, rabbit meat is even sold in microwaveable trays as a complete meal. However, when sold in the carcass form, the cuts, or other rabbit meat products, may be arranged on a pre-pack tray (Fig. 25.4) or be packaged in a plastic bag (Fig. 25.5). The packaging for fryers may be made more attractive by having a picture of cooked rabbit meat and recipes printed on them. Some producers include the name of their rabbitry or some other means of identification to stimulate repeat orders.

It is extremely important that the supply be kept in balance with the demand. If the consumers make purchases and then are unable to

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Fig. 25.1. A collection trailer used to haul fryers to market. Note the scales for weighing each cage of rabbits. (Courtesy of D.J. Harris)

Fig. 25.2. A large processing plant. (Courtesy of Richard Popik)

find the product when they wish to use it again, they may discontinue asking or looking for it.

Today, whole rabbit carcasses have little appeal to the modern consumer, especially considering that most Americans have never eaten meat from domestic rabbits. To be more attractive and more competitive with other meats, rabbit carcasses should be further processed and even cooked as a complete meal. Examples of processed products include breaded nuggets, cutlets, filets or lean strips, rabbit forelegs (the rabbit equivalent of buffalo wings), cube steak, sausage, and barbecue packs. In China, the Kangda Foods Company (headquarters in Qingdao) is the largest exporter of rabbit meat in the world. This company has developed many convenience items that are ready to cook and serve (Fig. 25.6). In fact, the company sets high standards by performing routine, state-of-the-art laboratory analyses to test for possible environmental or microbial contamination. In addition, at international rabbit conferences, a rabbit competition cookoff event among teams of the country's finest chefs is always a highlight (Fig. 25.7).

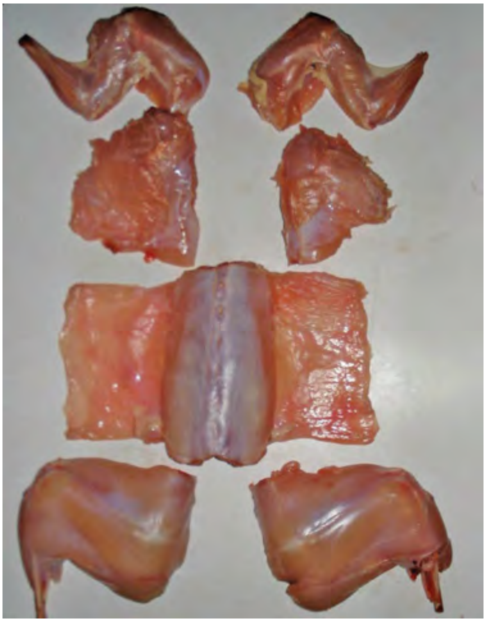

Fig. 25.3. A method for cutting up fryers. (Courtesy of J.I. McNitt)

Quick-freeze units may be placed in a store and packaged rabbits delivered once or twice a week, with the proprietor paying on the basis of the number sold. In contacting a store, restaurant, or hotel, you may stimulate business by giving the proprietor a sample package of meat for his or her own use. This practice is especially popular at local farmers' markets where the producer can develop a direct relationship with the potential buyer.

Freezing dries out the meat and causes it to lose some of its flavor. Because of this, the pieces should be sealed in freezer wrap prior to being placed in a carton and frozen unless the carton is wrapped in a sheet of moisture proof, self-sealing freezer wrap. In either case, the package should be sealed in order to shut out the air. The liver, heart, and kidneys should be put into a small bag before being placed with the rest of the meat, for if these parts touch the other meat they may cause it to become discolored and unappealing. For home use, prepare the carcasses for freezing and storing by wrapping the pieces to keep them from sticking together and to prevent the meat from drying out and losing flavor. Appropriate wrappings include plastic freezer bags or tightly sealed freezer wrapping paper.

With self-service stores, no personal sales skills are involved. Consequently, each item is on its own, and rabbit meat is in competition

Fig. 25.4. Rabbit meat can be used to make sausage products. (Courtesy of J.I. McNitt)

with all other types of meat being offered for sale. If it is to be marketed to advantage, it must be presented in an attractive package and in a manner that will have eye appeal. A price that is too low will be unsatisfactory to the producer; on the other hand, a price that is too high will deter the consumer from purchasing the meat. In many areas, daily newspapers give market reports, and generally in those regions where there are large rabbit populations, marketing services give market reports of the price for live rabbits and often include the retail and wholesale prices for the meat. In arriving at a price, it is a good plan to consider the price of chicken, for it is often used as a measuring stick for evaluating other kinds of meat.

When individual members of a rabbit club do not wish to devote the time and effort necessary to market their products, an excellent

Fig. 25.5. An attractive package of frozen rabbit. (Courtesy of J.I. McNitt)

Fig. 25.6. A convenience, deboned rabbit meat product developed and sold by Kangda Foods Company in China. (Courtesy of S.D. Lukefahr)

Fig. 25.7. A rabbit sushi dish prepared by chefs at a rabbit conference in Malaysia. (Courtesy of S.D. Lukefahr)

opportunity is presented for starting a cooperative similar to those that handle other agricultural commodities. By pooling their products, the members of the club will have a larger supply of rabbit meat available for sale. Generally, arrangements can be made with one of the members to do the processing and selling for all. If this person has time, he or she can pick up the rabbits from the individual rabbitries; otherwise, they can be delivered to the person. Many cooperatives that have begun on a modest scale have developed into sizeable businesses.

During the spring and early summer, when the supply exceeds the demand, the storing of rabbit carcasses may be a problem. Sometimes, arrangements may be made with a cold storage plant to store the surplus. Thus, it can be made available later in the year when the supply is more limited. You can overcome this problem of seasonal distribution by using management practices to ensure steady year-round production and by promoting the demand for rabbit meat (e.g., for barbecues) during the summer, when production is highest.

Rabbit meat is in competition with other sources of meat in the marketplace, and increasingly with non-meat sources of protein. The meat industry in the United States is "mature," meaning that there is little yearly increase in demand. Any inroad made by rabbit meat into the market will be largely at the expense of some other form of meat. Therefore, if consumers are to buy rabbit instead of another meat product, it will have to offer them some significant advantage. Realistically, price is not apt to be an advantage. Rabbit meat, in all likelihood, will be more expensive than poultry and most of the red meats for the foreseeable future. The advantages that rabbit could offer are related to quality and nutritional properties. Because rabbits are fed high-fiber, low-energy diets based on alfalfa meal or other fibrous feedstuffs, rabbit meat is low in fat and is lower than most meats in cholesterol. Rabbits are grown without the use of feed additives, such as antibiotics and hormones. This is not usually for altruistic reasons, but because these additives are not approved by the FDA for use in rabbit feed. This is a potential advertising tool. Chickens and turkeys, for example, are fed quite a number of feed additives. While these are unlikely to be injurious to human health, a common perception is that they might be dangerous. Similarly, rabbits are raised on low-grain diets, which is a desirable attribute to many people who don't believe that animals should be fed grain that could be eaten by people. Rabbit might thus be promoted as "the ecological meat," produced using non-competitive feeds, or the "all-natural meat," produced without the use of feed additives. Presently, sales of organic meats are rapidly rising in popularity. In the U.S. especially, rabbit meat can penetrate the highly competitive marketplace if consumers are well informed and educated about the availability of the "green rabbit", and if it is sold at a reasonable price.

Another potential promotional strategy is to emphasize that rabbits are produced by family farmers. Poultry production in the United States, on the other hand, has become almost entirely consolidated into huge units controlled by industrial concerns, using highly automated "factory farming" techniques. Rabbits are generally grown on small farms and managed by the owners and their families. Some consumers might prefer to purchase a product grown in this manner rather than products produced industrially.

Breeding Stock

The business of selling registered or commercial stock requires substantial ability on the part of the producer, for the animals must be superior in type and production and must appeal to other breeders. It will be necessary to expend considerable time and money to build up a reputation by maintaining detailed performance and pedigree records; exhibiting rabbits at local, county, and state rabbit shows; and(or) advertising in rabbit journals or farm periodicals, including business websites.

Some rabbit raisers produce pedigreed stock, sell their best animals to other breeders, and depend on the meat market as an outlet for those individual rabbits that do not come up to breeding stock standards. The initial investment in pedigreed breeding stock is greater than that in non-pedigreed stock, and more time and labor are required to keep the breeding and production records, etc. However, the asking price for the pedigreed or proven high-performance animals that are to be sold for breeding purposes may more than offset these extra costs.

Other commercial breeders devote their entire time and effort to producing meat for the market. For improving their herds, they buy their breeding stock from those who have developed superior meat-producing animals. Adequate records and evidence of selection for performance traits are essential for the commercial seedstock producer who raises these replacement animals. As the rabbit industry expands, superior hybrid breeding stock may be available to commercial producers, who would not raise their own replacements.

Laboratory Stock

Rabbits are used in a variety of medical research and scientific studies for the benefit of humanity. Many laboratories, hospitals, and universities use them for studying problems relating to nutrition, disease, inheritance of malformations, and effects of new drugs, for diagnosing medical problems, and for producing antisera. Anyone interested in selling rabbits to one of these institutions should contact the person in charge to determine the type or breed of animal preferred, the number used, the prices paid, etc. The requirements will depend on the nature of the problem. For certain types of research work, a specific color of coat is preferred; when laboratory space is limited or the ration to be used is expensive, small breeds or young rabbits are generally desired. In producing antisera, the preference is for large breeds, because large quantities of blood are used.

In addition, a few very specialized laboratory stock producers sell rabbits guaranteed to be free of specific pathogens (SPF), such as *Pasteurella multocida*, coccidia, etc. While lucrative, producing SPF rabbits requires very high standards of production and business management. As it is usually not economical to ship live rabbits long distances, local institutions should be contacted. Medical research is carefully monitored to ensure that humane animal treatment is carried out. Most research and medical laboratories in the United States will buy rabbits only from producers who have a federal license. Licensing is provided by the Animal and Plant Health Inspection Service of the U.S. Department of Agriculture.

Skins

There is little market for rabbit skins. About 85% of the rabbits marketed for meat are sold at two to three months of age, when the skins are small, the leather lacks strength, and the fur mats, appears flat, and has poor wearing qualities. As a result, these skins are often a liability to the processor rather than an asset. Limited local markets may be found for pelts from older rabbits.

If skins are to be stored prior to shipment, they should be kept in closed containers and protected with mothballs or moth crystals. Skins may also be salted for storage. Small shipments may be made by parcel post, larger ones by express or freight. The pelts should be thoroughly dried and then packaged flat in cardboard cartons.

Pharmaceuticals

Pharmaceuticals are derived from by-products of rabbit processing, such as brains, blood, and eyes, that are used for research, testing, and teaching purposes. There are very exacting standards for the animals from which these products are taken and for the techniques used for collection. As a result, prices are high, and many people feel that the rabbit processors are getting rich from these by-products. The markets are very competitive so unless a processor can produce a consistently top-quality product, often requiring specialized equipment and trained personnel, the buyers will go elsewhere. Furthermore, because the markets are so competitive, markets and sales outlets are not freely divulged, so finding new buyers may be very difficult. This is especially true for the new processor. The processor makes increased income from these products, but it frequently barely covers the processing costs.

Angora Wool

In the preparation of Angora wool for shipment by parcel post, express, or freight, each grade should be placed in a separate container. A paper bag about 30 cm (12 in) high will hold a kilogram (2.2 lbs) of wool without being packed too tightly. If the wool is to be stored for any length of time, mothballs or moth crystals in cloth sacks should be placed in the container.

Some rabbit breeders prefer to spin the wool that they produce, which can be made into yarn and knitted garments, either for their own use or for sale. Others prefer to sell their Angora wool to organizations or individuals acting as agents who collect large quantities to be sold to woolen mills. Some of these sell the wool on a commission basis. Cooperative organizations collect the wool from their members, grade it, and sell it to the mills. The movement of the product is somewhat seasonal. Some of these cooperatives make an advance for when they will later receive the wool from the producer, and because this advance helps to pay the feed bill when Angora wool is not moving readily, the arrangement proves quite satisfactory. Individuals or groups may also send wool to mills for custom spinning. The producers can then market the yarn or finished goods themselves.

Fur Crafts

Some people may have a knack for making various products from fur and skins and enjoy making coats, slippers, gloves, toys, such as balls, rabbits, and teddy bears, and a variety of novelties and articles from rabbit fur. This fur craft utilizes a variety of sizes and colors of pelts and lends itself nicely to occupational therapy. It is especially attractive to individuals who enjoy sewing and working with patterns. Skin markets have been developed with some success in lesser developed countries, mostly due to low labor costs (Fig. 25.8).

Fig. 25.8. Rabbit skins used to make a variety of attractive products at a vendor's booth in Mexico. (Courtesy of S.D. Lukefahr)

Pets

In recent years the sales of young rabbits as pets have become a growing activity in certain developing countries (Fig 25.9). Often selling at lucrative prices, pets are frequently sold to allow children who live in larger cities to raise them as pets. A major reason is that, unlike cats and dogs, the neighbors are seldom aware of a pet rabbit next door. Another likely reason is that the cost of feeding is relatively low.

Fertilizers

Some rabbit breeders may be so located that they can market the manure from their rabbitries to nurseries and to individuals for use as a fertilizer on flowers, shrubs, fruit trees, lawns, etc. Rabbit manure is especially easy to incorporate into the soil, is relatively free of noxious weed seeds, and does not burn the plants. When large quantities are available, it is usually sold by the cubic meter (foot) or by the ton. For retail sale in small amounts, the clean fertilizer is dried, ground or pulverized, and sacked. With attractive packaging, it may be profitably marketed in garden stores and supermarkets. However, it should be understood that animal manures do not have the high values of the elements found in chemical fertilizers. For example, some chemical fertilizers

Fig. 25.9. Rabbits being sold as pets by street vendors in Indonesia. (Courtesy of Yono Raharjo)

contain about 20% nitrogen, 20% phosphorus, and 20% potassium. However, animal manures are especially useful as an organic source of material that can improve certain soil properties in the garden, for example, water-holding capacity and organic matter.

Rabbit manure contains about 3.7% nitrogen, 1.3% phosphorus, and 3.5% potassium. The nutrient values of manure from three livestock species are shown in Table 25.1. It should be recognized that these are not fixed values; the composition of manure depends more on the type of ration fed than on the type of animal. It should also be noted that the nutrients in the manure are waste as far as the animal is concerned. The nitrogen in manure comes from dietary protein that the animal didn't utilize. For example, if a sample of rabbit manure has a high nitrogen content, there is something wrong with the ration, causing the rabbit to excrete excessive (and expensive) amounts of nitrogen. Poultry manure is high in nitrogen because chickens excrete uric acid, a very concentrated source of nitrogen. Rabbit manure is high in potassium because alfalfa, a major ingredient in rabbit rations, is very high in potassium.

Table 25.1. The average composition of manure from domestic animal species.

Species	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Cattle	2.9	0.7	2.1
Poultry	4.7	1.6	1.0
Rabbit	3.7	1.3	3.5

Values were obtained from multiple literature sources.

Worms

Many rabbit raisers grow earthworms (usually commercial redworms) in beds of rabbit manure. The sale of worms for use as fishing bait and sometimes for soil enrichment for gardens and flower beds is a way of supplementing the income of the rabbitry. However, the beds should not be located beneath the rabbit cages unless adequate ventilation is provided, because digging to harvest worms will cause the release of ammonia and other noxious gases into the rabbitry. The optimal moisture conditions for raising worms are quite different from those for raising rabbits. Therefore, it is not advisable to put the worm beds in the rabbit building. The high moisture required by the worms may raise the humidity of the rabbitry, causing increased *Pasteurella* problems.

Glossary

Alleles - Two or more versions of a gene.
Amino acids - Basic units of proteins.
Anterior presentation - Normal birth. Front feet and head presented first.
Antibiotics - Compounds used as feed supplements and for combating disease. Produced by molds; inhibit the growth of bacteria.
Antisera - Sera (serums) that contain specific antibodies.
Artificial insemination (AI) - Artificial introduction of semen into the reproductive tract of the female.
Balanced ration - A ration that has the proper proportions of individual ingredients to provide for growth, production, and reproduction.
Barren period - The period during which a rabbit does not conceive.
Breech presentation - Normal birth with hind feet and rump presented first.
Buck - A mature male rabbit used for breeding.
Cannibalism - The practice of a doe eating her young.
Carcass yield - Dressing percent. Obtained by dividing the weight of the dressed carcass by the weight of the live rabbit.
Carrier - An animal carrying a gene for a specific characteristic that may be transmitted to offspring, although it may or may not be apparent in successive generations. Also, an animal with a subclinical level of disease; it may not show signs of disease but can infect others (e.g., a carrier of *Pasteurella*).
Cecotropes - The soft feces produced from the contents of the cecum and consumed directly from the anus.
Cecotropy - See Coprophagy.
Cecum - The blind gut at the head of the large intestine.
Chromosomes - The microscopic rod-shaped bodies in the egg and sperm cells that carry the hereditary factors (genes).
Concentrates - Grains, milled products, and supplements of protein, vitamins, and minerals in the ration.
Conception - The union of ovum and sperm.
Contagious disease - A disease that spreads from one individual to another. A disease that is catching.
Coprophagy - The practice of rabbits consuming some of the droppings (soft, night pellets) directly from the anus. Also called *cecotropy*.

Cubic centimeter (cc) - See Milliliter.
Dam - Mother.
Dewlap - The pendulous fold of skin under a rabbit's neck.
Doe - A mature female rabbit used for breeding.
Dominant characteristic - A characteristic of one parent (normal coat, white fat, etc.) that, when transmitted to offspring, masks a recessive characteristic.
Dressing percent - See Carcass yield.
Embryo - The developing rabbit from the time the fertilized egg is implanted in the uterus until all organs are formed.
Embryo transfer (ET) - A technique in which embryos from a donor animal are flushed from the reproductive tract and introduced into a recipient animal to grow to term.
Estrous cycle - The recurring 14- to 16-day cycle when a doe is more apt to conceive. Also called the heat period.
False pregnancy - See Pseudopregnancy.
Feed:gain ratio - The amount of feed required for one unit of gain.
Felting - The manufacturing of felts from furs of rabbits and other animals.
Fetus - The developing rabbit from the end of organ formation to kindling.
Finish - The desired condition of flesh and coat for market or show rabbits.
Fly back - The prompt and even flowing back of the fur when it is stroked from the tail toward the head of the animal.
Follicles - Small enlargements on the surface of the ovary that contain egg cells. Also the roots of the hair in the skin.
Fostering - Using a doe other than the dam to nurse and develop young.
Fryer - A rabbit kept for meat consumption before the age of 12 weeks.
Full feeding - Supplying a rabbit each day with all the feed it will consume.
Furrier - One who dresses furs or makes or sells fur garments.
Gene - The basic unit in inheritance.
Gestation period - The time from mating of the doe to kindling.
Glossy coat - Smooth, bright, lustrous fur.
Gram - A unit of weight in the metric system equal to about $\frac{1}{28}$ ounce. 453.6 grams equal 1 pound.
Grooming - Removing foreign material or loose fibers from the coat of a rabbit by brushing or rubbing its coat with the hands, proceeding from the head toward the tail.
Hand-feeding - Giving a rabbit the required amount of feed each day.
Heat period - See Estrous cycle.
Heredity - Characteristics inherited from ancestors.
Hopper feeding - Making available to a rabbit a sufficient quantity of feed for several days so the animal may eat as often as it wishes and not be limited to a certain amount.
Hybrid - The offspring of parents of different breeds, varieties, species, or genera.
Impaction - Lodgment of undigested food in the digestive tract.
Inbreeding - Mating closely related animals.
Infectious disease - A disease caused by germs. It may or may not be contagious.
Inter se mating – Brother–sister mating.
Juniors - Developing young from time of weaning until old enough to go into production.
Karyotype - Arrangement of the chromosomes of a single cell, typical of an individual or a species.
Kindling - See Parturition.
Kit (kitling) - A young rabbit from birth to weaning.
Lactation - The secretion of milk.
Limit feeding - Restricting a rabbit's feed intake to an arbitrary level.
Linebreeding - Mating animals with a common ancestor within a breed.
Litter - A number of young born to a doe at one time.
Maintain - To keep an adult rabbit in good condition without its gaining or losing weight.

Malocclusion - A deviation from the proper closing or meeting of the teeth.
Manger - A container for holding hays and roughages.
Mature - Fully developed; adult.
Milk line - The white band on the belly of kits that have just been nursed.
Milligram (mg) - A unit of weight in the metric system. 1000 milligrams equal 1 gram.
Milliliter (ml) - 1 cubic centimeter (cc). 5 milliliters approximate 1 teaspoonful.
Miss - See Pass.
Nick - A mating that produces offspring superior to either parent.
Night feces - Cecotropes. May be consumed at any time of day.
Palpate - To feel through the abdominal wall for developing young in the uterus, for hairballs, and for impaction.
Parity - The number of litters to which a doe has given birth.
Parturition - Kindling. The act of giving birth.
Pass - Failure to conceive and produce young. An infertile mating (a miss).
Pedigree - A record of ancestors.
Pheromone - A volatile hormone produced by one individual that is perceived by and stimulatory to another individual of the same species.
Posing - Placing a rabbit in the most advantageous posture for show.
Predator - A pillaging or destructive animal that kills, maims, or stresses rabbits.
Prepotency - An exceptional capacity to transmit certain genetic characteristics to offspring.
Pressure tank - A tank with a float valve, used with an automatic watering system.
Prime coat - A mature, glossy coat with good fly back and free of loose fur or patches of ingrowing fur.
Prolific - Fertile, reproducing freely, producing large litters.
Protein - A combination of amino acids. Essential in the diet.
Pseudopregnancy - A 17-day period during which a doe may not conceive. May be caused by sterile mating or by other sexual stimulation. The doe experiences physical symptoms and changes in hormonal balance simulating those in pregnancy. Also called *false pregnancy*.
Purebred - An animal that belongs to a recognized breed.
Rabbitry - A place where domestic rabbits are kept; also, a rabbit-raising enterprise.
Random mating - Mating without regard to ancestry.
Recessive characteristic - A characteristic of one parent (woolly coat, yellow fat, etc.) that, when transmitted to offspring, is subordinate to the dominant characteristic of the other parent.
Registration - The official record of a rabbit that has been approved by a licensed registrar.
Restrained mating - Forced mating in which a person holds the doe.
Roughage - Hay, grass, etc.
Scrabbling - Digging feed out of the feeder.
Self - Solid coat color, such as black or chocolate.
Settle – To conceive.
Sexing - Determining the sex of a rabbit.
Sheen - Shininess. See also Glossy coat.
Sire - Father.
Specialty club - A rabbit club that specializes in matters pertaining to one breed.
Standard - The characteristic for a breed of rabbits as set up and approved by a registering organization.
Sterile - Barren or infertile.
Succulent feed - Fresh, green, growing plants containing a large amount of moisture.
Suckling period - The time from birth to weaning.
Superovulation - Use of hormones to induce does to produce extraordinarily large numbers of ova.
Tan - To make into leather.
Tattoo - To make a permanent identification mark in the ear of a rabbit by using a perforating instrument and rubbing India ink into the perforations.

Thermostat - An instrument for automatically controlling the turning on and off of water sprinklers, fans, etc.
Toxic - Poisonous.
Vector - A carrier, usually an insect, that transfers an infective agent from one host to another.
Vulva - The external opening of the female genital organs.
Warrens - Outside pens in which groups or colonies of rabbits may be kept.
Weaning – Removing the young from the doe’s milk.
Weanling (weaner) - A newly weaned rabbit, regardless of intended future use.
Wool - The coat of the Angora rabbit.
Wool block – An indigestible mass of wool swallowed by a rabbit.
Woolliness - A recessive characteristic transmitted to offspring, producing a hair coat that resembles wool.
Xanthophyll - A yellow compound found in plants, conducive to the development of yellow fat in susceptible animals.
Yellow fat - A recessive characteristic intensified in susceptible offspring by the feeding of green feeds.
Zoonosis - A disease of animals that may be transmitted to humans.

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RABBIT PRODUCTION

10th Edition

Steven D. Lukefahr, James I. McNitt,
Peter R. Cheeke and Nephi M. Patton

Rabbits are versatile animals, farmed for their meat and fur, as laboratory and show animals, and also as pets. This well-established book continues to provide an overview of domesticated rabbit production, covering topics such as breeding, management, feeding and health. Now in its fully updated tenth edition, it includes an expanded consideration of important issues such as animal behavior and welfare and sustainable methods of small-scale rabbit production. With chapters relating specifically to international and backyard family rabbit production, pet rabbits, rabbit shows, and angora wool production, this new edition:

- Includes new information on the latest methods of rabbit reproductive management, including applications of artificial insemination, estrous synchronization, embryo transfer, cloning, and molecular genetics;
- Tackles globally prevalent health issues such as mucoid enteropathy (ME), epizootic rabbit enteropathy (ERE) and rabbit hemorrhagic disease (RHD);
- Reviews up-to-the-minute developments such as the impact of the Covid-19 pandemic on food production, opportunities of selling rabbits at farmers markets, organic rabbit meat, raising of pastured rabbits, as well as new projects addressing poverty alleviation and food security.

Providing updates on worldwide production trends, breeds, and figures, as well as use of color photos throughout, this book is an essential resource for anyone involved in rabbit production – from novice to experienced breeders, trainers and managers of rabbit projects, veterinarians and industry professionals.