CUT FLOWERS AND FOLIAGES

Edited by James E. Faust and John M. Dole

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Cut Flowers and Foliages

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Contents

List of Contributors vii

Preface ix

Acknowledgments xi

1 The Global Cut Flower and Foliage Marketplace 1
James E. Faust and John M. Dole

2 Major Cut Flowers 48
James E. Faust and John M. Dole

3 Cut Foliages 150
James E. Faust and John M. Dole

4 Specialty Cuts 191
John M. Dole

5 Irrigation and Fertilization 224
Raul I. Cabrera

6 Diseases and Disease Management 258
Melissa Muñoz, Elizabeth Cieniewicz and James E. Faust

7 Biological Control of Pests 316
Henry Wainwright

8 Postharvest Management 342
John M. Dole and James E. Faust

Index 369

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Preface

Cut flowers bring us joy, bring us solace, and bring life into our homes and workplaces. In most cultures around the world, cut flowers mark the key events of our lives in ways that nothing else can. Cut flowers also bring economic prosperity to millions of people and are an important economic driver in many countries. From the employees of large multinational companies to the innumerable local farmers, people around the world depend on cut flowers for their livelihoods and to support their families.

The breadth and depth of the cut flower and foliage industry will be apparent in Chapter 1 'The Global Cut Flower and Foliage Marketplace'. The ability to move cuts easily by air, sea and land has allowed the industry to expand across the globe. We highlight countries with the highest levels of production and use, but recognize that many other countries have interesting stories to tell. In this chapter we also diagram the increasingly diverse and complex ways that flowers are marketed and travel from the growers to the final customers and provide comments on the future of the cut industry.

In Chapter 2 'Major Cut Flowers' we profile the production and postharvest handling of 15 species. These species include the most economically important cut flowers, but also a few that illustrate the diversity of production systems.

Chapter 3 'Cut Foliages' recognizes the increasing importance of foliages to the industry. Foliages have moved from being just the background on which cut flowers can shine to being an important partner to flowers in the design and economic worlds of cuts.

The stunning diversity of cuts is illustrated in Chapter 4 'Specialty Cuts'. Once the realm of a few major species, the cut industry now encompasses hundreds of species grown for their flowers, foliage, and decorative stems and fruit.

In any highly competitive industry, it is important for businesses to operate at a high level. The next three chapters focus on the significant details of production. Chapter 5 'Irrigation and Fertilization' provides producers with the key information needed to grow high-quality crops. Chapter 6 'Diseases and Disease Management' and Chapter 7 'Biological Control of Pests' provide us with critical information to protect the health and quality of cuts from the many pests.

Finally, Chapter 8 ‘Postharvest Management’ walks us through the steps by which we harvest, process, store, treat and transport cuts. The retail world is highly competitive, with cut flowers competing for consumer attention and dollars, and long-lasting cuts are needed to provide customers with a positive experience.

Acknowledgments

First of all, we would like to thank our fellow authors, Raul I. Cabrera, Elizabeth Cieniewicz, Melissa Muñoz and Henry Wainwright, for all of their work and ideas. Their contributions to this book have immeasurably improved it, and we appreciate their willingness to devote their precious time to writing chapters.

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We also want to thank the many researchers who published their work on cut flowers from which we were able to cite and draw information. As fellow researchers, we understand the joy of doing good work, and we thank them for focusing on cut flowers to the benefit of the cuts industry.

We thank Will Fontanez for creating the three beautiful world trade route figures in Chapter 1 that communicate more information than is possible with words.

As researchers, our ability to address the needs of the cut flower industry requires funding, and the American Floral Endowment and the Association of Specialty Cut Flower Growers Research Fund have been generous in their financial support of our laboratories for many years. For this opportunity to pursue our research ambitions, we are extremely grateful.

Finally, we thank CABI and its editors, Rebecca Stubbs, Ali Thompson and Emma McCann, for working with us to provide you with a high-quality, informative book that we hope you enjoy.

1

The Global Cut Flower and Foliage Marketplace

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INTRODUCTION

Flowers play a significant role in the lives and traditions of people around the world. Across diverse cultures, the primary uses of flowers are amazingly similar: gift-giving, religious ceremony, the celebration of significant life events such as birth, marriage and death, and decorating living and work spaces with a piece of nature. The ephemeral nature of flowers and their intrinsic beauty mean they are ideally suited to communicating the importance of life, love and the transient nature of time.

For centuries, enterprising businesses have commercialized the production of flowers in every region of the world to meet the demands of the local marketplace. As globalization has encompassed the world economy, flower production has become an international, multi-billion-dollar industry. Flowers that were once solely produced on local farms surrounding population centers are now transported by air and sea across continents, allowing flower production to migrate to lands with more favorable climates and labor situations. Today, the flowers are grown on family-owned, small farms that supply local markets or they can be grown on a production unit within multinational, vertically integrated companies that supply international supermarkets. Whichever the case, the economy of flowers helps to lift the living standards of the people cultivating these lands.

The retail marketplace continues to evolve. The conventional retail florist shops strive to hold on to their market share while supermarkets offer the convenience of purchasing bouquets along with one's groceries. Direct-to-consumer (online) marketing is gaining momentum as consumer purchasing trends evolve. Yet the market dynamics of each society is unique as cultures adapt to technological innovation and the ever-changing marketplace.

The variety of flowers available to consumers has never been larger. Breeders help to drive new enthusiasm for flowers through the development

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and introduction of novel colors and forms. Creative horticulturists, florists and entrepreneurs never cease to seek out and find beauty in unique flora across the globe and develop these novelties for commercial use. To the chagrin of many horticulturists, the use of dyes and paints transforms cut flowers and foliage into design components that nature never intended but to which consumers do respond.

The global cut flower industry is a dynamic and exciting environment. This chapter will describe the evolving geographical distribution of the cut flower world as well as the trends that are driving the industry in new directions and creating new opportunities for enterprising, hard-working horticulturists. All the while the industry is developing more sustainable production methods that demonstrate environmental stewardship and social responsibility to the workers that cultivate and harvest the flowers.

GEOGRAPHY OF CUT FLOWER MARKETS

Note: Production statistics throughout this chapter are primarily derived from International Association of Horticultural Producers (2019a), while import/export data are primarily extracted from International Trade Centre (2019).

Export markets

The annual global value of cut flower and foliage exports exceeds US$10 billion, and three markets account for over 90% of all imports: (i) Europe (US$5.79 billion); (ii) the USA and Canada (US$1.66 billion); and (iii) Japan (US$0.36 billion) (Fig. 1.1).

These three markets dominated the world economies throughout the 20th century, and most of the cut flowers at that time were supplied by domestic growers; however, in recent decades rising labor and energy costs and improved transportation and cold-chain management systems have driven production to developing countries in equatorial regions. Today, the list of leading exporting nations is dramatically different than the past century. Five equatorial countries (Colombia, Ecuador, Kenya, Ethiopia and Malaysia) now account for 35% of world cut flower exports, and this percentage is growing annually (Fig. 1.2).

It must be noted that the international trade in flowers is a complex web of logistics and relationships, so it can be difficult attributing the export and import sales numbers to the appropriate countries. For example, the sale of Kenyan flowers may be executed by a broker in Germany, arrive at a Belgian airport, be driven to the Netherlands, sold through the Dutch auction and shipped to Denmark. Ideally, Kenya would be documented as the exporter and Denmark the importer, but that may not be the case. The sale may be recorded by one or more intermediaries; thus, import and export reports should be viewed with a degree of caution. Similarly, domestic sales are not reflected

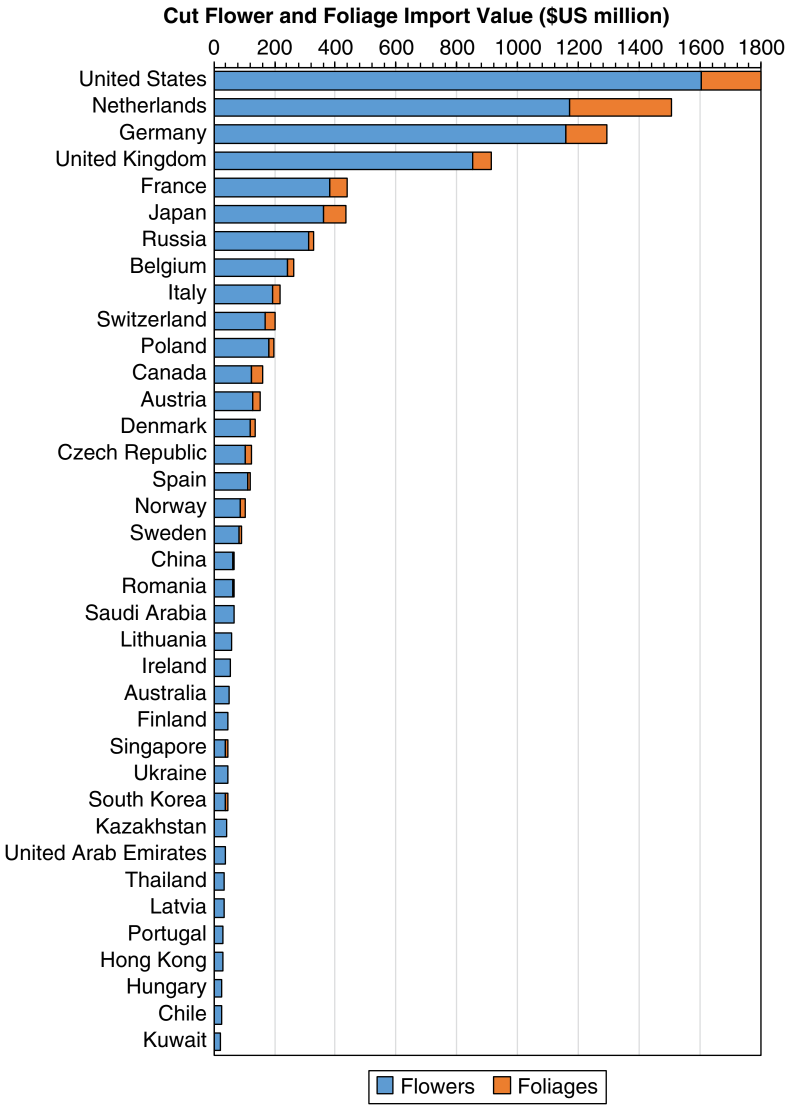

Fig. 1.1. Annual cut flower and foliage import value for the top 37 countries. (From International Trade Centre, 2019.)

in import/export numbers, so Figs 1.1 and 1.2 are not indicative of cut flower and foliage production for any given country.

The 21st century has seen many countries expand their production of cut flowers for the export market. Ten of the top 25 ranked exporters had minimal or no exports just 20 years ago (Table 1.1). Over the same time, export sales of some countries have declined significantly, e.g. Israel, South Korea, Spain and

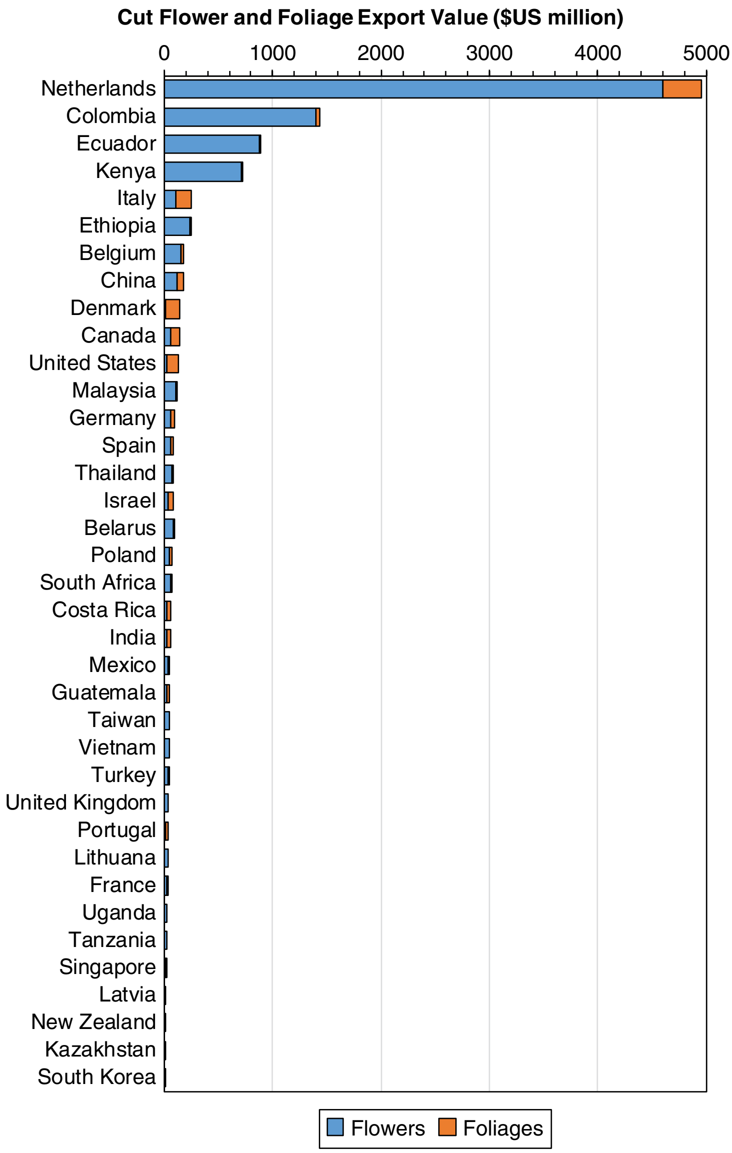

Fig. 1.2. Annual cut flower and foliage export value for the top 37 countries. (From International Trade Centre, 2019.)

the USA. Still other countries experience ups and downs but have seen no clear growth trend in recent years, e.g. Costa Rica, Guatemala, India, Italy, Mexico, Singapore and Thailand.

Table 1.1. Cut flower export countries emerging in the 21st century. (From International Trade Centre, 2019.)

Exporting country	Cut flower export value (US$ million) 2001	2009	2019	Current world ranking (2019)
Ethiopia	0	131	241	5
China	5	54	119	7
Malaysia	12	71	113	8
Belarus	0	0	82	10
South Africa	12	26	56	15
Poland	2	21	48	16
Taiwan	8	16	46	18
Vietnam	5	13	46	19
Turkey	8	24	36	22
Lithuania	0	27	30	24

Emerging markets

For the three main import markets in Europe, North America and Japan, per capita flower consumption is relatively flat and there is little expectation of further expansion of those mature markets. On the other hand, China is viewed as being the next big opportunity for market growth. With a population of 1.4 billion and rapid growth in personal wealth, the large exporting countries are looking to China as the driver of market expansion in the coming decades.

Domestic markets

Export values can be somewhat misleading as they do not reflect production for domestic markets. Many countries have tremendous domestic sales while their exports lag behind. The value of domestic markets is often not reported, so reliable comparisons cannot easily be made. However, some countries report their production area dedicated to cut flowers and foliage, which may or may not be differentiated. Also, production area might be broken down into field production versus protected cultivation. Production area does not easily translate into productivity, because some greenhouse production sites might be highly productive for 12 months each year, while some outdoor production areas might be highly seasonal and relatively low yielding. Nonetheless, production area values do highlight the large domestic markets that do not appear in the international trade statistics. For example, India and China report production areas that dwarf many leading export nations (Fig. 1.3). Similarly, Mexico exports only US$35 million annually while the production area occupies over 12,000 ha. In contrast, Colombia exports US$1.5 billion annually with a production area of just 7700 ha.

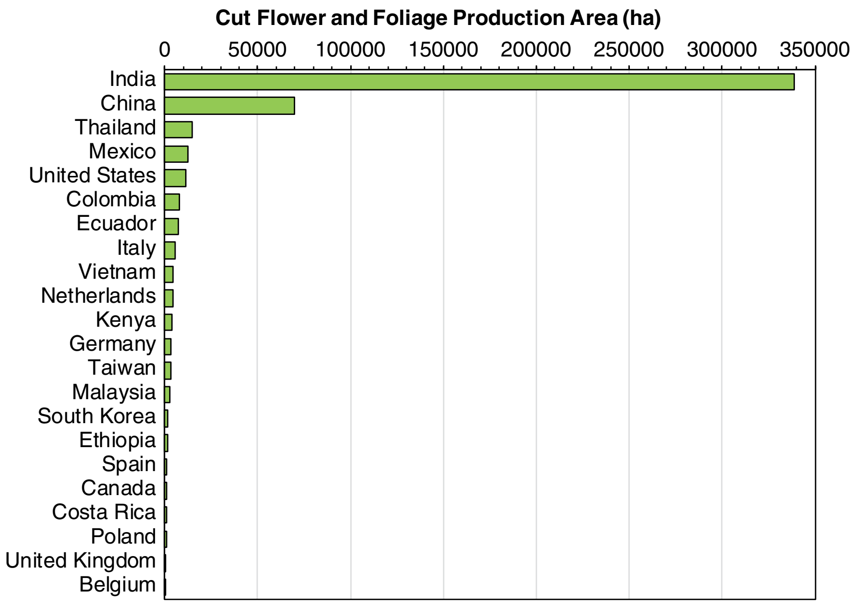

Fig. 1.3. Cut flower and foliage production area (ha) for the top 22 countries. (From International Association of Horticultural Producers, 2019a.)

FACTORS DRIVING THE LOCATION OF CUT FLOWER PRODUCTION

The economic development of the 21st century has brought about the continued migration of cut flower production from Europe, North America and Japan to developing countries often located in equatorial regions in South America, Africa, and Asia, thus creating a truly global marketplace for cut flowers. The locations that have proven to be successful exporters of cut flowers are driven by numerous factors that include the following.

Photoperiod

Countries located in equatorial regions benefit from having a similar photoperiod throughout the year. For short-day flowering species, such as chrysanthemums, the naturally occurring 12-h photoperiods result in flower initiation and development, while photoperiodic lighting with electric lamps is provided during periods of vegetative growth. For long-day flowering species, such as gypsophila, the natural day length results in vegetative growth, and flowering can be stimulated any month of the year by providing photoperiodic lighting.

Thus, photoperiod management is much less complicated at the equator compared with higher latitudes where the photoperiod is in a state of continual fluctuation throughout the year.

Photoperiod can create advantages in the southern hemisphere where growers can compensate for their distance from the large northern hemisphere markets by being able to produce flowers of certain species during the 'off-season' when domestic production in the northern hemisphere is curtailed. South Africa, Australia and New Zealand have successfully used this approach for many years.

Light

Latitudes from 0 to 20° N or S experience relatively high light levels throughout the year, as described by the daily light integral (DLI) (Fig. 1.4), and cut flower growth and yield is closely tied to this measure. While wet and dry seasons cause moderate fluctuations in light levels due to cloud cover, the variation is considerably less than that in higher latitude locations, which may experience a three- to fivefold difference in DLI from winter to summer.

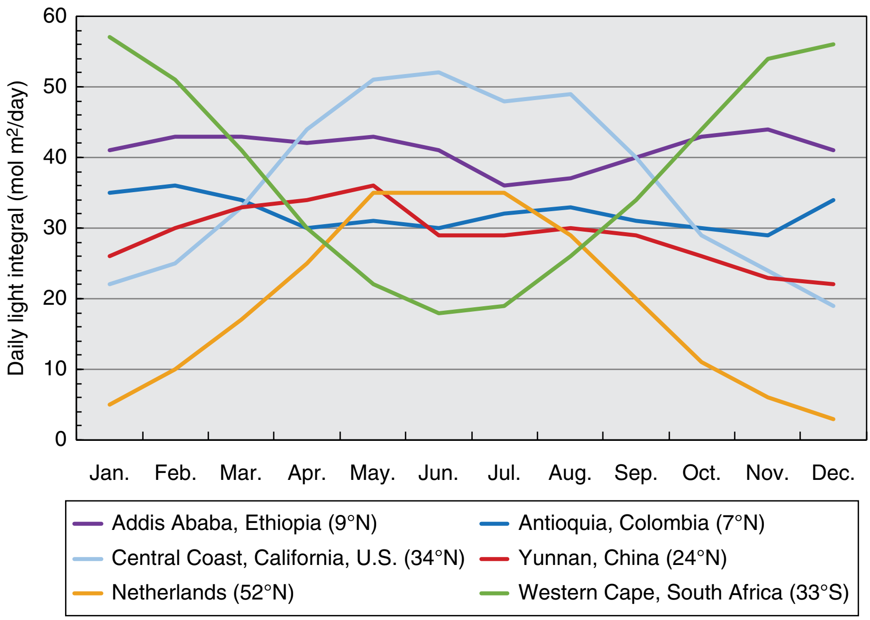

Fig. 1.4. Average monthly daily light integrals (DLIs) for six major cut flower production locations. Latitudes are in parentheses. (From Suntracker Technologies, 2020.)

Temperature

Cut flowers can be broadly categorized into two temperature-response groups: temperate and tropical species. Species that have evolved in temperate climates perform well in locations with moderately warm days (20–30°C) and cool to moderate nights (10–20°C). The ideal 24-h average daily temperatures are 20–24°C. Temperate-climate species include the major cut flower species such as roses, chrysanthemum, carnation and gerbera daisy as well as the 'summer flowers'. Temperate climates usually occur at locations between 30° and 55° N or S. However, temperate climates are also available at high-elevation locations in otherwise tropical and subtropical locations between 0 and 20° N or S. Examples include: the Colombian savannah, the Pichincha region of Ecuador, the Great Rift Valley of Kenya and Ethiopia, the Central Highlands of Guatemala and the Cameron Highlands of Malaysia. The elevation in these regions is typically 1400–2700 m above sea level.

The second temperature category is the tropical species that are heat-loving plants. Tropical species require high average daily temperatures of 25–35°C to develop at a high rate. Tropical climates consist of day temperatures from 30–40°C, while night temperatures are 21–28°C. Tropical cut flower species include dendrobium orchid, anthurium and heliconia. Many cut foliage species are also tropical.

Currency exchange rates

Countries with relatively strong currencies are at a disadvantage in exporting their products to countries with weaker currencies. Strong currencies trade at a higher rate than weaker currencies, resulting in greater buyer power for the strong currency. However, similar products from countries with strong currencies are more expensive than those from countries with weak currencies, which can lower or negate profit margins. Thus, countries with relatively weak currencies have a distinct advantage in developing export markets. The strength of national currencies is obviously outside the control of growers, but growers are inevitably affected by these forces that can ultimately create or destroy export markets. Additionally, when one's currency gains market strength, importers have an advantage competing in the country's domestic market.

Labor cost and availability

Labor is the single largest expense for cut flower growers, and automation is lacking for most cut flower production, harvesting and processing tasks. Finding skilled agricultural labor in developed nations has become exceedingly difficult. One option is hiring migrant workers from neighboring countries;

however, the political forces influencing migration policies can create significant challenges and insecurity. For these reasons, many businesses have moved production to developing countries with a large agricultural work force willing to work for relatively low wages. Eventually, as the local economies in these countries become stronger, limited availability of low-cost labor once again begins to challenge the profitability of businesses and producers look for the next locations for future business development. As more countries develop their economies, the wage and labor differentials will decrease, thus reducing the significance of this factor and motivating the development of automation systems.

Governmental incentives

Governments can create incentives to attract businesses to build new facilities in their countries and to create jobs and economic opportunities for their citizens. No country has proven more successful at this in recent years than Ethiopia. Ethiopian cut flower exports have grown from US$0 in 2001 to US$241 million in 2019. Nearly all of these businesses originated in the Netherlands and nearly all of the exports (81%) go to the Netherlands. The incentives have included generous tax benefits and exemption from export customs duties.

Free-trade agreements

International agreements between countries to remove trade barriers, such as tariffs, can create advantages in the marketplace for labor-intensive, agricultural businesses located in developing countries. These agreements serve as a means to promote development and encourage international cooperation. In the cut flower industry, free-trade agreements between Andean countries and the USA have helped to generate a healthy and vigorous industry in Colombia. In this case, the cut flower industry in the USA has been a casualty of the agreement. Many American growers have ceased operation or have had to turn to other crops to avoid bankruptcy. The lack of a domestic agricultural workforce in the USA and restrictions to the migration of agricultural workers from other countries may have resulted in a similar outcome over time.

Transportation systems

Large-scale international export requires reliable air and/or sea transportation options. Road systems allow distribution to neighboring countries, but they are usually limited markets. Air freight is the current transportation option for the majority of international cut flower shipments. Air freight typically requires

1–2 days to arrive at the importing location. Successful air transport requires planes bringing goods to the exporting country so that planes are available for filling up with flowers on their departing flights. Otherwise, it can be expensive to fly empty cargo planes into a country so that flowers can be exported. Sea transport is the rapidly developing third option, which has the advantages of having a smaller carbon footprint than air freight and a lower cost. The downside is the additional transport time, which limits the number of species that can be shipped via this method. Currently, sea shipments from South America to the USA require 7–10 days, while shipping flowers from South America by boat to the Netherlands takes 12–16 days, and shipping to East Asia takes 23–40 days. Major species, such as rose, chrysanthemum and carnation, can withstand these durations while maintaining a 7-day vase life. The proximity of the cut flower production area to the nearest seaport can make this option more or less attractive for some countries.

Cold-chain management

Maintaining cold postharvest environments (1–4°C) from the packing house to the end consumer is vital to providing the consumer with a flower with an adequate vase life. Growers can control the temperatures to which the flowers are exposed from harvest to delivery to the airport. Coolers and refrigerated trucks are essential. However, thereafter the businesses are dependent on the airport and freight companies to maintain the cold chain.

Airport logistics and proximity

Successful exporting countries have invested in cooler facilities at their airports that benefit all of the growers. This has required industry groups to initiate efforts to influence local policy makers. Insufficient airport facilities are often a major limitation in countries that have yet to forge a strong export industry.

The major commercial cut flower production areas must be located in close proximity to airports, which is needed to minimize shipping time and maintain good product vase life. Production areas that have had good success developing their export market in recent years are invariably located close to a cooperative airport that has worked with growers to develop efficient logistics and a strong cold-chain management system.

GLOBAL PRODUCTION AND MARKETS

This section contains a description of the major cut flower species grown and sold internationally followed by descriptions of the production and markets by continent and country. Note that the country descriptions within each continent are ordered by relative size of the cut flower industry.

Species

The popularity of cut flower species varies with culture and tradition; however, the major species tend to have a high demand in every market. Roses are clearly the dominant cut flower species worldwide. The rankings will vary, but chrysanthemum and carnation are always near the top of the rankings, while gerbera, lily, tulip, alstroemeria and gypsophila are generally in the next tier. Figure 1.5 provides the quantity and pricing for 21 species sold at the Royal FloraHolland auction in the Netherlands. Of course, tulip sales are uniquely high at this location. Design trends, creative marketing programs and skilled plant breeding contribute to the ebb and flow of market demand. For example, carnations and gladiolus may acquire the stigma of being old-fashioned flowers, while peony and lisianthus gain market momentum. The country-by-country discussion that follows in this chapter highlights the major species produced in each country. Chapters 2, 3 and 4 describe the production methods for the major and specialty species of cut flowers and foliage.

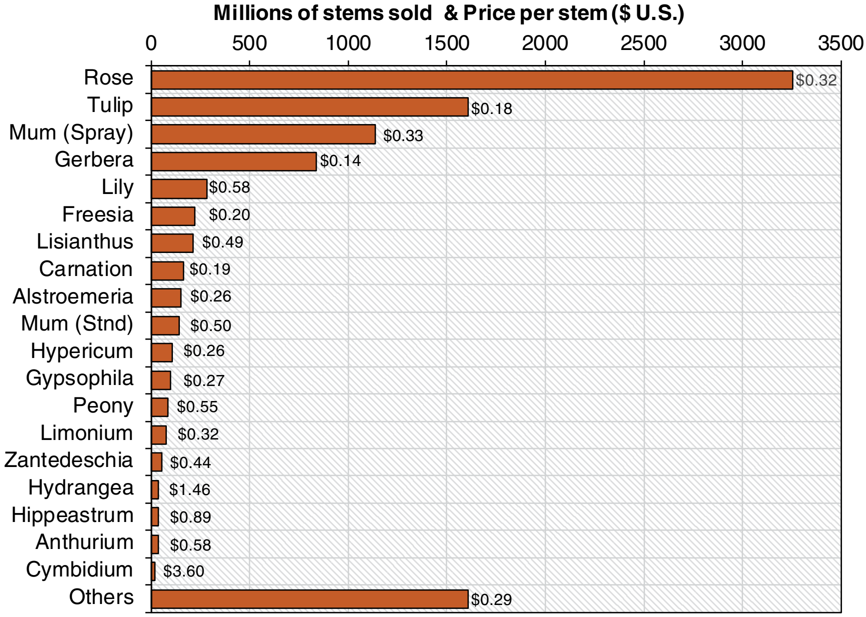

Fig. 1.5. Quantity and pricing for 19 species sold at the Royal FloraHolland in 2018. Quantities include clock (auction) and direct sales, while prices are for clock sales only. (From International Association of Horticultural Producers, 2019a.)

Europe

The European cut flower market accounts for nearly 70% of world imports. Fourteen of the 17 largest cut flower importing countries are in Europe (Fig. 1.1), and the Netherlands resides at the epicenter of the flower trade. In addition to having a large market, Europe has significant greenhouse and field production; although domestic production of the major cut flower species has declined owing to increasing imports from countries with better year-around climates and lower costs of production. Nevertheless, European countries annually import US$5.8 billion while exporting US$5.0 billion (International Trade Centre, 2019).

Europe benefits from a high per capita consumption of flowers and plants. Switzerland leads with US$160 per person, followed by Germany at US$122 (Fig. 1.6). The main sales holidays include International Women's Day (March 8) and Mother's Day (second Sunday in May), while many Europeans have a culture of purchasing flowers to brighten up the home on a regular basis. The wide availability of high-quality, economically priced flowers contributes to the market success of the cut flower industry. The market channels include retail flower shops, street vendors, supermarkets and garden centers. Retail flower shops account for 60–75% of cut flower sales in most European countries, while supermarkets are the primary market outlet in the UK accounting for ~50% of sales (International Trade Centre, 2019).

The Dutch market has historically been driven by the auctions where >12 billion plants and flowers are sold annually, serving as an international marketing hub. Royal FloraHolland operates auctions in Aalsmeer, Naaldwijk, Rijnsburg and Eelde. The auctions function as a cooperative where >4000 members are required to sell to the auctions and the auctions are obliged to

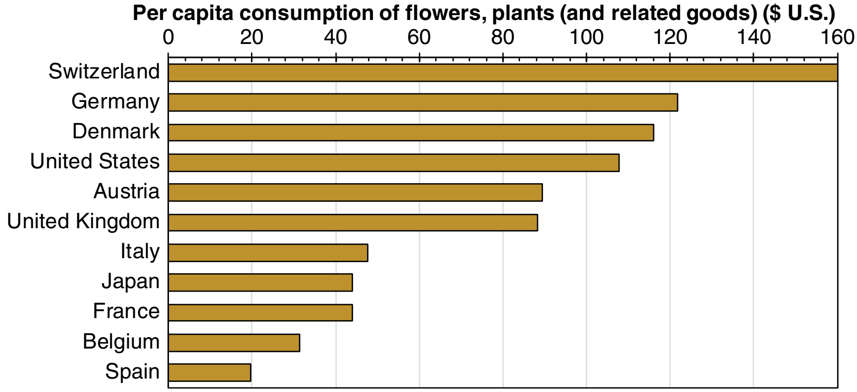

Fig. 1.6. Per capita consumption of flowers, plants and related goods. (From International Association of Horticultural Producers, 2019a.)

sell all of the members' flowers. The auctions receive flowers from within the Netherlands and from across the world. The vast assortment of species offered for sale in the auctions is almost beyond one's imagination.

The incredible volume of product moving through the Netherlands allows for logistics efficiencies that are not available anywhere else in the world (Fig. 1.7). Flowers move through the warehouse on trolleys that are brought into the auction room for bidders to purchase. A clock located at the front of the room starts at a high price and then drops until a buyer in the audience stops the clock and purchases the lot at the price indicated on the clock. The rapid processing of sales allows for >100,000 transactions per day.

The auction allows growers to specialize their production facilities and focus on growing monoculture crops that can be sold to many different buyers while not having to hire marketing personnel. Historically, buyers needed to come to the auction, but the Internet now allow buyers to work from offsite locations. Up to 1000 transactions are made per hour while also allowing buyers to inspect the product directly. The auction provides logistics for product transfer between buyers and sellers while acting as a gatekeeper for participation of buyers and growers, thus authenticating participants. Order tracking and payment occurs daily. Buyers benefit from having a wide range of supply and quality assurance, while sellers have a global sales opportunity, a transparent pricing system and payments that are settled quickly.

The auction is not without its disadvantages. Product must physically go through the auction, which translates into additional transport costs and time.

Fig. 1.7. One of the clock rooms at the FloraHolland auction. (Photo: J. Dole.)

Handling by multiple parties is required, which creates an additional chance of damage and the additional time can negatively impact vase life. Prices tend to decrease through the day, so the order of sale is handled through a lottery to provide an equal market opportunity for growers. Additional marketing costs in the range of 10–20% of the selling price are charged for moving product through the auction. These costs include commission, bucket rental, handling fees and promotional costs. Trolley fees and phytosanitary inspection are also part of the auction expenses. These additional costs can prohibit participation of foreign growers with small volumes or low-value flowers.

In recent years, the marketing trend has been for the supermarkets and retail chain stores to purchase flowers directly from the growers. Direct sales describe the process where product is sold and transported directly from the greenhouses to the wholesaler. This process circumvents the auction and reduces the auctions' influence. A similar event previously occurred with the Dutch vegetable auctions that were once very popular, but disappeared in the 1980–1990s owing to the increasing popularity of direct sales from wholesalers to supermarkets (Wijnands, 2005). Today, supermarkets account for 70–90% of greenhouse vegetables sold, while flowers range from 14 to 64%. The Internet has allowed flower farms around the world to make sales directly with European markets more frequently while avoiding the auctions; however, the enormous assortment of flowers available at the auction is still a very attractive enticement to buyers. The market evolution demonstrates the dynamic nature of the cut flower industry, which is continually seeking to improve efficiencies and offer products to consumers at competitive market prices.

While the market remains strong across Europe, production has been in a slow decline as developing countries improve production quality and volume. The East African countries of Kenya and Ethiopia have become leading suppliers to Europe, and the South American countries of Colombia and Ecuador continue to increase their European, North American and Asian sales (Fig. 1.8). These four countries account for nearly a quarter of all imports to Europe.

Netherlands

Since the 1970s, the epicenter for cut flower production and importation has been the Netherlands; however, peak production was reached in the early 2000s and it has declined since then. The greenhouse production area for the major cut flower species has declined from 2809 ha in 2008 to 1640 ha in 2018. A concomitant decrease in the number of cut flower growers has also occurred, from 1674 in 2010 to 830 in 2018. Despite the fact that major production areas are shifting to equatorial countries, nearly one-half of all cut flower exports continue to come from the Netherlands (Fig. 1.2).

Roses account for the largest production area in the Netherlands (230 ha in 2018), although this is half of what it was 10 years prior (583 ha in 2008). The reduction has primarily occurred in small-bud rose production, which now occurs in Kenya, while the Dutch growers maintain market share in the

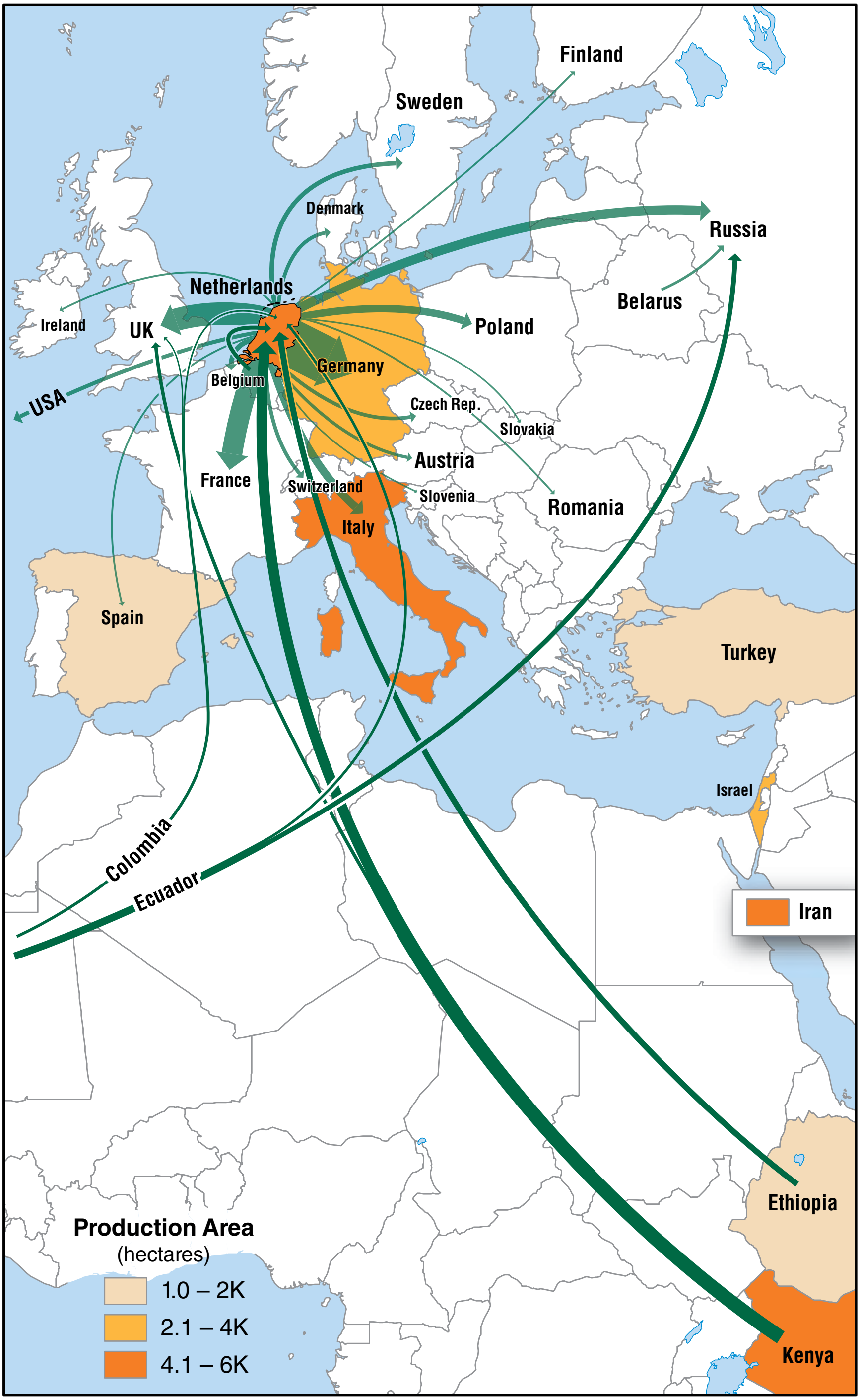

Fig. 1.8. *Continued*

large-bud roses that are produced in a highly efficient manner (2.5 million stems/ha) and achieve good prices. Other major cut flower crops produced under protection include chrysanthemum, gerbera, hydrangea, lily and orchids. The Netherlands has large-scale outdoor production of several species, including peony (940 ha), gladiolus (120 ha), lily (90 ha) and chrysanthemum (90 ha).

The Netherlands remains the primary source for breeding, technology and greenhouse innovation worldwide and cut flower exports are valued at over US$4.6 billion annually, while the imports are valued at US$1.2 billion. Kenya is the largest supplier of cut flowers to the Netherlands at US$384 million, followed by Ecuador (US$182 million), Colombia (US$102 million) and Ethiopia (US$100 million) (Fig. 1.8). The neighboring European countries of Belgium, France, Italy, Germany, Portugal, Spain, Turkey and the UK account for an additional US$286 million in imports.

Germany

The major production regions in Germany include North Rhine-Westphalia, located in western Germany along the border with the Netherlands, which has 1312 ha in production (42% of the total production area for the entire country), and Baden-Wurttemberg and Bavaria, which are located in the southern portion of Germany and together contain 879 ha of production (28% of the country's total). Outdoor production represents 90% of the total production, and the outdoor production area is increasing while the production area under protected cultivation declines (down 30% since 2004). Important outdoor crops include geophytes (gladiolus, narcissus and tulip) and peonies, while lilies are greenhouse-grown. Imported flowers, valued at US$1.16 billion, far exceed production for export (US$65 million). Nearly 90% of imports come from the Netherlands. Germany has its own flower auctions (Landgard and Veiling Rhine-Maas).

Italy

Italy is the eighth largest flower exporter in the world and supplies 1% of the global market, although cut flower production is trending downward owing to competition from Africa and South America. The cut foliage sector located primarily in Tuscany and Liguria is on the rise, and Italy is the second largest cut

Fig. 1.8. Continued.

Trade patterns for cut flowers in Europe, Africa and the Middle East. The magnitude of exports/imports is indicated by the relative width of the arrows. Sales volumes of US$70 million are the minimum threshold for displaying trade routes. Countries are highlighted in different colors based on their cut flower and foliage production area. Note that a country may have a large production area but most of those flowers are sold in domestic markets and not exported, thus no arrows are shown exiting the country. (From International Trade Centre, 2019.)

foliage exporter in the world, accounting for over 10% of world foliage exports. The major foliage crops are eucalyptus and ruscus, while other important foliage crops include asparagus fern, aspidistra and pittosporum. Important flowering/fruiting fillers are genista, gypsophila, mimosa (*Acacia* spp. and hybrids) and viburnum.

Campania and Liguria are important cut flower production regions, while production in Apulia is increasing. Carnation, chrysanthemum, gerbera, lily, ranunculus and rose represent 70% of Italian production or 1.7 million stems (MIPAAF, 2014/2016). The total production area is 5834 ha, and production is evenly divided between open-air and protected cultivation. The typical farm in Italy is quite small at <1 ha in area (ISMEA, 2015), and cut flowers and foliage are primarily sold through florists (65%) and street vendors (25%) (MIPAAF, 2014/2016). Ninety percent of the country's total imports (US$173 million) come through the Netherlands, and the majority of the exports (US$111 million) go to the Netherlands, Germany and France (M. Beruto Regflor, January 2020, personal communication).

Spain

The Andalusia region in the south of Spain accounts for 35% of the country's cut flower production. The total export market is US$58.8 million, and the Netherlands (48%) and Portugal (16%) are the largest trading partners. Rose and carnation are the largest crops. Protected cultivation is used for 900 of the 1270 ha of production. The total acreage used for cut flower production is down by 26% since 2010. Imports total US$109 million with 70% of the flowers coming from Ecuador and Colombia.

UK

Exports from the UK total US$41 million, with the Netherlands (40%), USA (24%) and Ireland (20%) being the largest markets. Cut flower production for fresh and dried cut flowers covers 413 ha. The largest crops include: alstroemeria, chrysanthemum, stock, lisianthus, forced bulb crops (daffodil, lily and tulip) and field bulb crops (daffodil and gladiolus) (Hanks, 2018). Imports are valued at US$659 million, with 70% coming from the Netherlands, 10% from Kenya and 7% from Colombia. Supermarkets are much more popular for distributing flowers in the UK compared with the rest of Europe and account for just over half of all flower sales.

Belgium

Belgium is the sixth largest exporter of cut flowers in the world and accounts for US$150 million or 3% of the global market. The Netherlands is the largest (69%) recipient of Belgian flowers, while 24% goes to France and 8% to the UK. Roses are the main crop and occupy half of the country's greenhouse space. The area under production has been in decline for the past decade owing to competition from African and South American producers. Imports total US$220 million, with the largest volume coming from the Netherlands (49%), Ethiopia (26%), Israel (16%) and Kenya (5%). Some imports arrive via air freight into the Belgian airport because of the lower pricing compared with Schiphol, the Netherlands' main airport. Then, the flowers are immediately transported to the Netherlands for sale and distribution.

Belarus

Belarus produces US$70 million in cut flowers annually that are almost entirely exported to Russia. Flowers to the value of over US$300 million are imported, the majority of which come from Ecuador (47%), Italy (18%), Kenya (15%) and Colombia (7%).

Africa

The 21st century has seen Africa develop into a world leader in cut flower production with Kenya and Ethiopia leading the way. The high elevation, equatorial climates in these countries have proven to be exceptional for the standard cut flower species grown in greenhouses and for summer flowers grown under shade or outdoors. Since the domestic market is small, African growers have utilized the Dutch auctions as their primary marketing pathway (Fig. 1.8).

Kenya

Cut flower production began on the shores of Lake Naivasha in the 1980s and has grown to the extent that Kenya is now the fourth largest exporter in the world and cut flowers are one of the leading agricultural export crops throughout Africa. Today, the flower industry is the largest employer in the country, and Kenya exports US$575 million in flowers annually, which represents 7% of the global market. One-half of the product is delivered to the Netherlands, while US$95 million goes to the UK. Kenya supplies 35% of cut flower sales for the entire European Union and is also a leading supplier to the Middle East with US$40 million in sales. The Dutch auctions are used as a marketplace for Kenyan flowers and provide market stability, while the growth of direct markets in Europe offers better prices. Using both marketing pathways reduces the overall risk for growers.

Kenya's cut flower export value has risen 60% over the past decade, and production land covers more than 4000 ha. Roses claim 84% of exports and other mainstream crops such as carnations are produced by large operations, while small shareholders focus on summer flowers such as ammi, eryngium, gomphocarpus (syn. asclepias), hypericum, molucella, ornithogalum, papyrus, rudbeckia and scabiosa.

The main production region surrounds Lake Naivasha in the Great Rift Valley. Significant production also occurs in highland areas surrounding

Nairobi including Kiambu, Thika and Athi River as well as at the base of Mt. Kenya, near Nanyuki. The elevation in these regions ranges from 1900–2600 m above sea level.

Challenges that face Kenyan production include poor-quality roads and traffic that create uncertainty and interrupt efficient logistics. Also, competition with local communities for water resources in the Lake Naivasha area is a source of conflict, and irregular rainfall patterns exacerbate this issue. The Nairobi airport has been modernized, and the logistics for cold-chain management are quite good, although high freight costs and insufficient cargo space in peak periods create additional challenges. Sea container shipment to Europe has potential and is being explored. The Kenya Flower Council (KFC) provides the industry with lobbying efforts and promotes environmental and socio-economic standards through their sustainability standards (International Association of Horticultural Producers, 2019b).

Ethiopia

The Ethiopian cut flower industry emerged in the early 2000s and has rapidly grown to be the fifth largest international exporter of cut flowers. Currently, the exported flowers are valued at US$197 million with 81% of the product going through the Dutch auctions. The production area exceeds 1700 ha with roses being the dominant crop (~80% of greenhouse area). Other important crops include carnation, eryngium, gypsophila and hypericum. The main production area is in the highlands (1600–2500 m elevation) surrounding Addis Ababa.

Flower growers have been attracted to Ethiopia by low labor costs and government incentives that have offered generous tax benefits and exemption from export customs duties. Much of the growth has been generated through Dutch investment starting in 2004 (Melese and Helmsing, 2010).

South Africa

South Africa exports cut flowers to the value of US$55 million annually to many locations in the world, including Europe (Netherlands, UK and Germany), Asia (Japan and China) and the Middle East (Saudi Arabia and United Arab Emirates). The southern hemisphere location allows South Africa to target off-season markets in the northern hemisphere for crops such as cymbidium orchid and eucalyptus. Imports primarily arrive from Kenya.

South African production is divided into two sectors: non-indigenous and indigenous species. Non-indigenous species, such as carnation, chrysanthemum, gypsophila, lily, limonium and rose, are grown under plastic or shade in the northern provinces, and specialty flowers, such as delphinium, dianthus, ferns, ornamental grasses and sunflower, are frequently grown from seed. The non-indigenous flowers are primarily sold in the domestic market. The Multiflora Flower Market operates an auction system in Johannesburg (Louw, 2020a).

Fig. 1.9. Flower arrangement using South African native species. (Photo: J. Dole.)

The production of indigenous species focuses on three main genera: *Protea*, *Leucospermum* (pincushions) and *Leucadendron* (Fig. 1.9). The indigenous species are primarily grown (wild and cultivated) along the Western Cape coastline in the southwest. Approximately 36 million stems are sold annually. Proteas are the main export crop accounting for ~80% of exports, and king proteas are the most popular. Approximately 8 million protea stems are sold alone and in bouquets. Leucadendrons are cultivated for flowers (cones), but are wild-harvested for foliage. Fynbos is a term used to describe bouquets of indigenous species that are popular in UK supermarkets (Louw, 2020b).

Other unique indigenous species include: *Erica* (heather), *Brunia*, *Phylica* (featherhead) and *Serruria* (blushing bride). An additional 36 million stems of foliage greens and grasses are sold. The greens include *Brunia*, *Erica*, eucalyptus, and Geraldton wax, while the popular grasses or grass-like species are bell reed, rekoala, restio and *Typha* (cattail, bullrush) (Louw, 2020c).

Tanzania

Cut flower production began in Tanzania in the 1980s and has continually grown but not to the same extent as in neighboring Kenya. The current export value is US$17 million/year. While the climate is similar to Kenya, Tanzania has had a less conducive business environment, and the air transport logistics and cold-chain management facilities have been lacking. Most farms are located near Kilimanjaro International Airport, yet most of the cut flowers are trucked to Nairobi and flown out of Jomo Kenyatta International Airport owing to the higher reliability and higher capacity of cargo flights. A total of 65% of exports go to the Netherlands, while Switzerland, the UK and Norway provide significant markets. Rose and chrysanthemum are the major crops (Mwase, 2015).

Middle East

The arid lands of the Middle East limit the development of a significant cut flower export industry. Aside from Israel, the Middle East is primarily an import market. Kenya and the Netherlands are the largest suppliers of the US$200 million in annual imports to the region, and Saudi Arabia (US$60 million), United Arab Emirates (US$48 million), Kuwait (US$23 million) and Qatar (US$15 million) are the main recipient nations. Large domestic production occurs in Iran, which produces nearly 3 billion stems annually on 1800 ha of farmland (Shirdelian, 2017).

Israel

Israel has been a leading innovator in irrigation technology and an important producer of cut flowers for many decades; however, competition from South America and Africa has resulted in a significant decline in production. Currently, Israel exports US$41 million, which is half of the value from 10 years ago. The majority of exports are marketed through the Netherlands, while the USA, Canada and Japan are also significant markets. Rose, gerbera and carnation represent ~40% of production. In the 1980s, Israel exported 450 million roses per year, but roses are no longer exported. Specialty or ‘summer’ cut flowers are grown for Europe during the winter months, including anemone, caryopteris, craspedia, gypsophila, limonium, ornithogalum, peony, ranunculus, scabiosa, solidago, sunflower, veronica and wax flower. Leucadendron, ruscus and barley (leaves removed to display the green seed heads) are also important foliage crops. Many of the specialty flowers are produced outdoors or with minimal protected cover. Desalinated water is commonly used. Israel continues to be an important contributor to the cut flower industry through breeding and new plant introductions.

North America

North America (the USA, Canada and Mexico) is the second largest world market for cut flowers accounting for US$1.7 billion or ~20% of the world market while exporting just US$125 million or 1% of the world cut flower exports. The North American Free Trade Agreement (NAFTA) signed in 1994 effectively eliminated tariffs on agricultural goods between the USA, Canada, and Mexico, which opened up trade within the continent. Figure 1.10 shows the major cut flower trade routes in the Americas. The width of the arrows is proportional to the export value.

USA

The USA is the largest single cut flower importing country, with a value of US$1.6 billion. Imports from Colombia and Ecuador have more than doubled

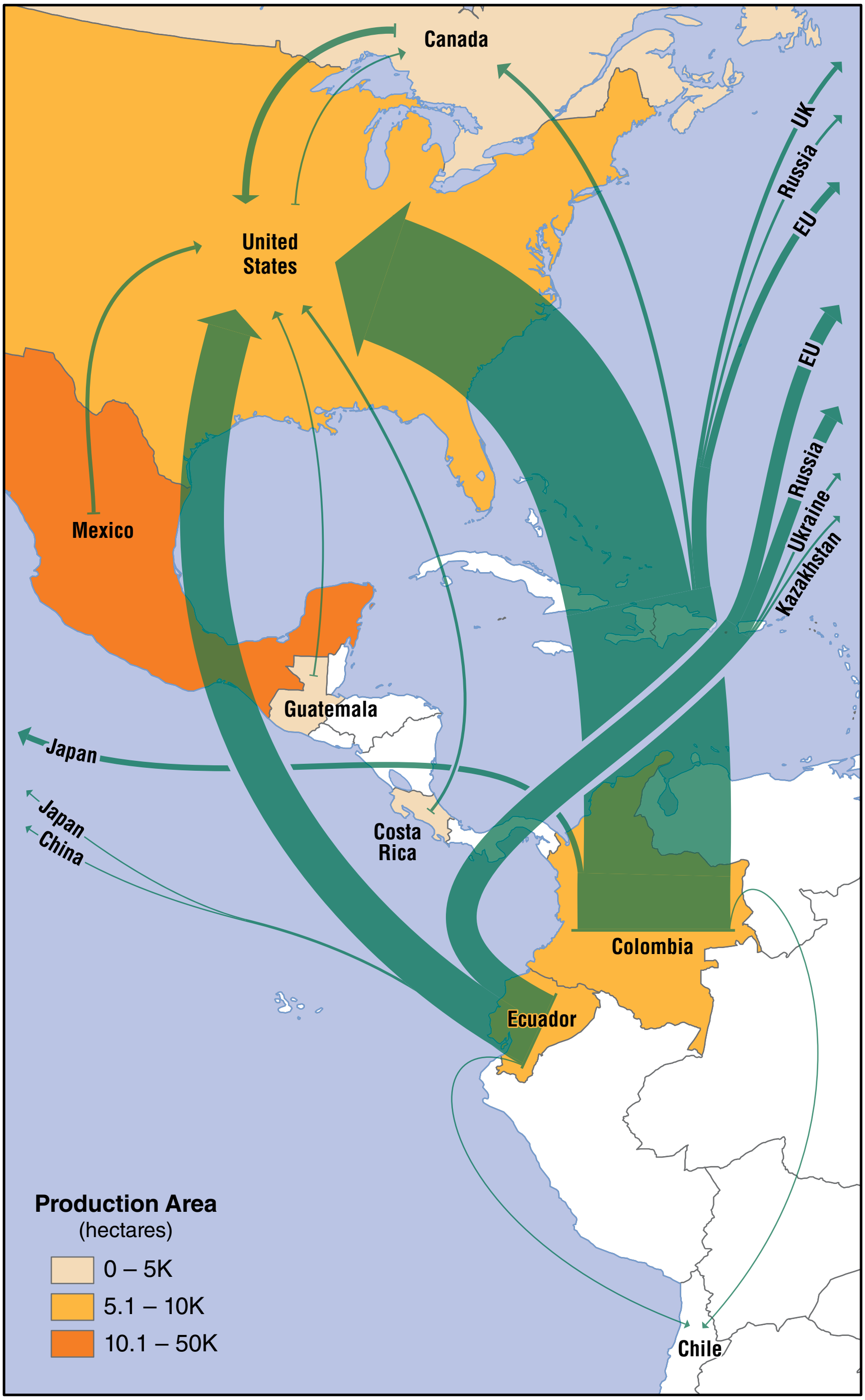

Fig. 1.10. *Continued*

in the past decade and account for 80% of all imports. South American production was initially spurred by the Andean Trade Preference Act of 1991, which encouraged Colombia and Ecuador to reduce drug-crop cultivation by fostering duty-free trade in alternative agricultural products such as cut flowers. Some 80–90% of floral imports arrive through Miami, Florida, where flowers make up ~40% of the total cargo handled at Miami International Airport. Importation of flowers from Canada and Mexico is also on the increase and accounts for 7% of imports. The USA imports US$70 million in cut foliage from Canada, which is its largest foliage supplier.

The US cut flower market is largely dominated by two holidays: Valentine's Day (February 14) and Mother's Day (second Sunday in May) (Fig. 1.11). Supermarkets are the main suppliers of bouquets throughout the year, while the traditional florist shops focus on providing flowers for special events such as weddings and funerals. More than most countries, flowers are marketed through a broad array of channels and outlets, many of which are direct from the producer to the consumer. See the 'Connecting Producers and Customers' section for a list of business types.

Cut flower and foliage production increased from 571 million to 672 million (2012–2017); however, the outdoor production area for cut flowers has decreased by 30% since 2002, while no change has occurred in the area under protected cultivation. California is the leading state for cut flower production and accounts for 66% of the annual US production; however, rose production has been cut in half in the past 10 years (since 2008). Production of alstroemeria, carnation and chrysanthemum has nearly ceased entirely. Tulips are the largest cut flower crop (173 million stems) followed by gerbera, lily, gladiolus and iris. The USA exports only US$22 million in cut flowers, which mostly go to Canada, and those numbers are on the decline. In contrast, the USA is the fourth largest cut foliage exporter (US$107 million) of which leatherleaf fern grown in the subtropical Florida climate is the largest crop.

Currently, ~80% of the cut flowers consumed in the USA are imported, while ~20% are supplied by domestic producers. Like Europe, the USA is considered to be a mature market with relatively little expectation of an increase in per capita consumption. The availability and cost of labor are major limitations to future growth for US growers (International Association of Horticultural Producers, 2019b).

Fig. 1.10. Continued.

Trade patterns for cut flowers in North, Central and South America. The magnitude of exports/imports is indicated by the relative width of the arrows. Sales volumes of US$10 million/year are the minimum threshold for displaying trade routes. Countries are highlighted in different colors based on their cut flower and foliage production area. Note that a country may have a large production area but most of those flowers are sold in domestic markets and not exported, thus the arrows exiting the country may be relatively small. (From International Trade Centre, 2019.)

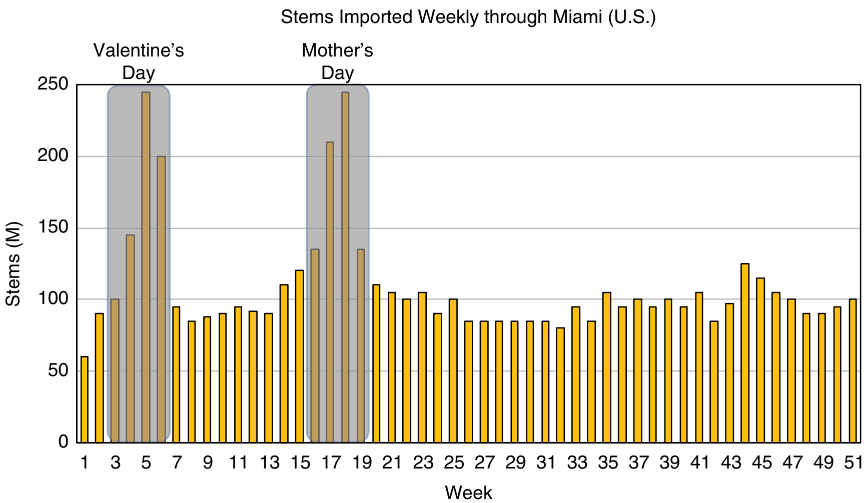

Fig. 1.11. Number of stems (millions) imported weekly through Miami International Airport, USA, the primary port of entry for imported cut flowers and foliage. (From National Administrative Department of Statistics, cited in Diaz Ceron, 2018.)

Despite these challenges, the number of specialty cut flower producers has been increasing rapidly. As cut flower imports soared in the USA, specialty cut flower producers initially found a niche growing a wide array of novel species or those that did not ship well. More recently, the popularity of locally supplied agricultural products has resulted in renewed interest in specialty cut flower production. The Association of Specialty Cut Flower Growers (ASCFG) reports that membership increased from approximately 500 in 2014 to more than 2400 in 2021. Specialty cut flower producers tend to be particularly entrepreneurial, with many selling to florists, designers, wholesalers and grocery stores, while others sell directly to the final customer through on-farm sales, farmers' markets, marketing cooperatives, design/event operations, community-supported agriculture and subscriptions, and online.

Specialty cut flowers include a wide assortment of seasonal annual, perennial and woody plants harvested for their flowers, seed pods, fruit, foliage and decorative stems. A recent tally indicated that over 240 species are being grown commercially (Dole *et al.*, 2017). In a survey that included Canadian producers, the top ten specialty cut flowers were zinnia, peony, snapdragon, sunflower, dahlia, lisianthus, cockscomb, sweet William, ammi and cosmos, in order of percentage of producers growing the crop (Loyola *et al.*, 2019). Specialty cut flowers are commonly produced in the field or under tunnels in the spring and summer, hence the common label of 'summer flowers'; however, many are harvested in the fall and winter or are greenhouse-grown.

Canada

Canada imports US$126 million in cut flowers annually, of which 84% is grown in Colombia and Ecuador. On the production side, Canada exports US$64 million, which nearly entirely goes to the USA. Tulips and gerbera (317 million stems) are the major crops. Ontario and British Columbia are the provinces with the largest production. Canada's specialty cut flower industry is similar to that previously described in the USA and is also increasing rapidly.

Mexico

Mexico has a long history of cut flower production. Montezuma, the ruler of Mexico in the 1500s, was responsible for the world's first botanical garden, and legend has it that he so loved fresh flowers that long-distance runners transported flowers every day from farms in the countryside to his residence in Mexico City. Today, Mexico exports US$39 million, which mostly goes to the USA. Protected cultivation is utilized on 1500 ha. The dominant crop is roses, which has nearly doubled over the past decade. In the open, 10,000 ha is used for cut flower production. Gladiolus, chrysanthemum and marigold are the major species, while chamaedorea palm is the major cut foliage crop, some of which is harvested from the wild. Only about 5–10% of Mexico's flowers are exported, so Mexico is considered to be an emerging producer with the potential to capture a greater share of the US market (International Association of Horticultural Producers, 2019b).

South and Central America

Colombia

Colombia's high-altitude climate located along the equator provides high light and moderate temperatures throughout the year, which is ideal for cut flower production of temperate-climate species. Additionally, fertile volcanic soils and a large labor force have been beneficial. Consequently, Colombia has experienced a continual rise in flower production over four decades (Fig. 1.12). Today, Colombia supplies 15% of the global cut flower market while exporting US$1.5 billion annually to North America, Europe and Asia. The country enjoys a well-established infrastructure and strong connection to markets. Colombia has a particularly strong market presence in the USA, Canada, UK and Japan. Production primarily occurs in two departments (regions): Cundinamarca near Bogotá is 2600 m above sea level and accounts for 65% of the country's production, and Antioquia near Medellín is 2100 m above sea level and accounts for 33% of the production. Because of the elevation differences,

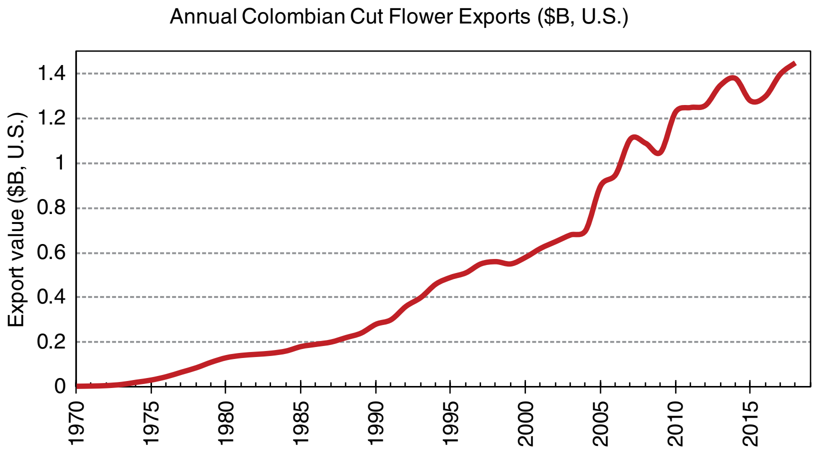

Fig. 1.12. Annual cut flower exports from Colombia. (From National Administrative Department of Statistics, 2019.)

Antioquia is slightly warmer than the savannah region near Bogotá, so more chrysanthemum, gerbera and hydrangea are grown near Medellín, while rose, carnation and alstroemeria are the main crops grown near Bogotá. Tropical cut flowers and foliage are grown at lower and warmer elevations, such as around Cali.

The floral industry is celebrated in Medellín with the annual Feria de las Flores, the Festival of Flowers, with the highlight being a parade of silleteros, who carry elaborate floral displays (Fig. 1.13). The origin of this tradition is that the indigenous peoples of the Andes carried on their backs the Spanish colonial rulers seated on saddles (silletas). The people now carry flowers instead to celebrate their cultural history and their pride in the local flower industry.

In total, production covers 7665 ha in cut flowers and foliage. Rose is the largest crop (of which 75% goes to the USA), carnation is second, followed by chrysanthemum, alstroemeria and hydrangea. Gerbera and orchid are trending downward. Cut foliage exports have increased ten fold over the past decade up to US$12.5 million. Major foliage species are ruscus (165 ha) and cocculus (99 ha).

Most product is delivered via air freight, but sea transport is gaining in popularity. Sea transport to the eastern USA and Europe leaves from the Atlantic port in Cartagena, while shipments to Asia leave out of the Pacific port in Buenaventura (International Association of Horticultural Producers, 2019b).

Asocolflores is a non-profit association of flower growers and exporters that promotes the Colombian floral industry. Florverde is a social and environmental code developed to drive improvement of human resources management, professional training, occupational health/welfare, integrated pest management, waste management and emissions control.

Fig. 1.13. The annual Feria de las Flores (the Festival of Flowers) in Medellín, Colombia is highlighted with a parade of silleteros, who carry elaborate floral displays on their backs as a celebration of the local flower industry. (Photo: J. Dole.)

Ecuador

Similar to Colombia, Ecuador benefits from a high-altitude climate along the equator that produces ideal growing conditions every month of the year. Ecuador exports US$851 million in cut flowers, which represents nearly 10% of the global market. While the USA is the largest customer, Ecuador has historically had a strong market in Russia, Kazakhstan and Ukraine that accounts for ~25% of its exports; however, the recent economic decline in Russia and tariffs assessed by the USA have caused Ecuador's exports to be flat in recent years. Canada and Europe continue to be strong markets. Roses account for 80% of the 6133 ha of greenhouse production, and over 3 billion stems are sold per year. Ecuador has created a worldwide brand for producing large-bud and long-stem roses. In open production, gypsophila and hypericum are the major species, covering 1376 ha. The main production area is in Pichincha (75% of the country's total) followed by Cotopaxi (20% of the country's total) (International Association of Horticultural Producers, 2019b).

Sea transport is becoming more important in Ecuador for a couple of reasons. First, the production areas are located relatively close to the shipping ports. Second, air freight costs can be higher than in neighboring Colombia owing to fewer incoming cargo planes being available for flying product out of the country. Guayaquil is the primary sea port for Ecuador, and a smaller portion departs from Manta.

Costa Rica

Costa Rica exports US$63 million in cut flowers (47%) and foliage (53%), the majority of which goes to the USA. Important foliage crops include cordyline, aralia and ferns. Tropical flowers include anthurium, calla lily, gingers (*Alpinia*, *Curcuma*, *Zingiber*), heliconia and strelitzia. Flower production is most common on the lowland Atlantic side of the country. The total production area covers 850 ha.

Guatemala

Guatemala exports US$48 million in cut flowers (42%) and foliage (58%), the majority of which goes to the USA. The diverse geography creates many unique microclimates appropriate for growing a wide range of ornamentals (Fig. 1.14). Flower and leatherleaf fern production are focused in the Central Highlands (1500 m elevation), while tropical foliage is grown at lower elevations, including asparagus fern, fatsia and fishtail palm.

Asia and Pacific

With a population of 4 billion people, Asia is the region with the most significant market growth potential in the coming decades owing to the anticipated high economic growth rates and rapidly rising standard of living. Currently,

Fig. 1.14. Mayan women selling cut flowers and petals on the steps of Iglesia de Santo Tomás in Chichicastenango, Guatemala. (Photo: J. Faust.)

the Asian cut flower market approaches US$6 billion and 40 billion stems, and demand for cut flowers is expected to increase by 80% through the 2020s.

Export figures are just US$700 million, which does not reflect the scale of Asian cut flower production. Half of those imports are accounted for by Japan alone (Fig. 1.15). The export numbers are skewed because China and India have enormous markets that are currently satisfied with domestic production. eCommerce is also expanding rapidly in Asia and already accounts for significant cut flower sales.

Japan

Japan has historically had significant domestic cut flower production: 4 billion stems grown by 60,000 growers account for US$1.7 billion in domestic sales. Japan has also benefited from relatively high consumer consumption (US$31/person/year). Japan's large latitudinal range of temperate and subtropical climates allows for cultivation of a wide range of flowers produced over multiple seasons. Chrysanthemum represents one-third of the domestic production. The Japanese market is concentrated on ceremonial occasions such as weddings and funerals. Soft, pastel colors are the predominate color in the domestic market. Flower retail shops remain popular, but supermarket sales

Fig. 1.15. *Continued*

are growing. Retailers primarily purchase flowers from numerous private auctions located across the country rather than from wholesalers. Home delivery and online purchases are increasingly popular.

While the Japanese market has not experienced significant growth over the past decade, Japan remains the dominant importer in the region (US$364 million). Imports are led by carnation (56%), chrysanthemum (16%) and rose (18%), while gentian, matthiola, ranunculus, scabiosa, sunflower and sweet pea are also popular. Malaysia (US$85 million), Colombia (US$79 million), China (US$45 million), Taiwan (US$38 million), Vietnam (US$34 million) and Thailand (US$21 million) are the largest cut flower suppliers to Japan, and eight or more countries list Japan as their most important market. Japan has plant quarantine officers located in exporting countries providing pre-inspection, which results in low levels of rejection and allows for rapid customs clearance (Ministry of Agriculture, Forestry and Fisheries, 2017). Japan continues to be a leading location for breeding of ornamental plants.

China

China's cut flower industry focuses almost entirely on domestic production and consumption, so export and import reports reveal little about the enormity of the industry. Domestic production occupies ~70,000 ha and accounts for US$1.9 billion in sales, while only US$120 million of flowers are exported. An estimated 2 million small growers sell direct to local markets. Production is centered in Yunnan province, which provides a diverse geography yielding tremendous climatic variation for a range of flower species. For example, within Yunnan province, the Kunming region has climatic conditions similar to the Savannah in Colombia, while the Xishauangbana region has a tropical climate resembling the Central Plain of Thailand. Valentine's Day is the largest market holiday, while the Qixi festival, Mother's Day, Teacher's Day and National Day are also important dates for gifting flowers. Weddings are the most important events for florists. eCommerce is gaining in popularity, with RoseOnly and PandoraFlora being among the leading online retailers. Rose, lily and carnation account for 50% of online sales. Other important species include eucalyptus, gerbera, gypsophila, hydrangea, lotus, peony, platycodon and sunflower (Xia *et al.*, 2006).

Fig. 1.15. Continued.

Trade patterns for cut flower exports/imports in Asia. The magnitude of exports/imports is indicated by the relative width of the arrows. Sales volumes of US$10 million/year are the minimum threshold for displaying trade routes. Countries are highlighted in different colors based on their cut flower and foliage production area. Note that a country may have a large production area but most of those flowers are sold in domestic markets and not exported, thus the arrows exiting the country may be relatively small or non-existent. (From International Trade Centre, 2019.)

Great anticipation surrounds the future growth of cut flower sales owing to the large domestic population of 1.4 billion consumers, a relatively low per capita flower consumption (14 stems/person/year) and a rapidly increasing standard of living. The import value of cut flowers increased by 395% through the 2010s. China is the emerging market that international suppliers of cut flowers are hoping will drive market growth through the coming decades. Sea transport from South America and Africa is anticipated to be used to supply flowers for the growing demand. Several issues need to be dealt with if China is going to become interconnected with the global supply chain for flowers. Recognition of plant breeders' rights will be required by breeders to willingly sell new genetic introductions into the Chinese market. Cooperative trade agreements, phytosanitary regulations and the interconnectedness of trade logistics are also limitations that need to be addressed (International Association of Horticultural Producers, 2019b, c).

India

The cut flower industry in India has been driven by the domestic demand of its 1.3 billion inhabitants. India has over 80,000 cut flower producers and the acreage for cut flowers and foliage reportedly covers over 330,000 ha. The largest production areas include Jammu and Kashmir, Kerala, Karnataka and West Bengal. Most of the production is in open fields that focus on traditional flowers, such as chrysanthemum, jasmine and marigold, which account for two-thirds of the production. These species are marketed loose and are measured by mass, which reaches 2 million metric tons (t) annually. Loose flowers are used for religious offerings and are made into garlands and wreaths that are used in places of worship, weddings and for social occasions (Fig. 1.16). Loose flowers, such as marigold, jasmine and crossandra, are also used as adornments for women's hair (gajra veni). Large-scale consumption of flowers occurs throughout the country during religious festivals. Increasing urbanization and Western influence are indicated by the primary markets for cut flowers, which include Valentine's Day, anniversaries, birthdays, Friendship Day, Mother's Day and Father's Day.

African marigold is the most popular flower and is grown in all regions of the country and accounts for >70,000 ha. Often, the seed has been produced in local communities for many generations. Jasmine and tuberose are popular for their scents. White chrysanthemums are also popular and primarily sold in October through December when jasmine and tuberose are not available (Dadlani, 1998).

Cut flower production in India has been viewed as a potential high-growth industry. Therefore, the industry has desired to shift from traditional flowers for the domestic market to higher valued cut flowers for export. The export foliage market has experienced steady growth and is now valued at US$38 million, while the export flower market value has stood at ~US$20 million throughout the 2010s. The USA and UK are the largest importers of Indian flowers. The

Fig. 1.16. Pakistan and India share their love of flowers, especially loose flowers that can be threaded into spectacular floral garlands. (Photo: J. Dole.)

main export flower crops are rose, orchid and gladiolus. A strong tissue culture industry exists for the export of young plants, which also benefits domestic producers of carnation and gerbera.

Malaysia

Malaysia is an emerging cut flower producer and important regional exporter. Current export values have leveled off at US$113 million after a period of rapid expansion at the beginning of the 21st century. Over half of the exported flowers go to Japan, while other important markets include Thailand, Australia and Singapore. Road transport is used to deliver to Singapore and Thailand while air freight is used for the Japanese and Australian markets.

Peninsular Malaysia has two main production areas. The hot, humid, tropical lowlands in Johor focus on orchids (*Dendrobium*, *Aranda* and *Mokara*) and anthurium, while temperate-climate flowers (carnation, chrysanthemum and rose) are produced in the Cameron Highlands in Pahang. The total production area is 2640 ha. The main regional competition comes from Thailand and Vietnam. Some of the main challenges for growers are land ownership (most farms are on leased land), and most agricultural products, such as fertilizers and pesticides, must be imported. A shortage of labor is also a concern for future growth of the industry. The import market is relatively small (US$8 million) and is primarily supplied by China and India (Jong *et al*., 1998; International Association of Horticultural Producers, 2019b).

Thailand

Thailand has had a consistently strong export market of US$70–80 million throughout the 2000s. The main markets are the USA, Japan, Vietnam, China and Italy, and the main crop is dendrobium orchid. Orchid production covers over 5000 ha, which produces 46,000 t of flowers. Orchid production is mainly in the Central Plain, which includes Bangkok and its nearby provinces. *Dendrobium* is the major orchid produced, while *Mokara* and *Vanda* are also important genera. Thailand has over ten tissue culture laboratories, which facilitate domestic production and are a source of young orchid plants for export.

Total flower production covers 14,000 ha and includes jasmine, marigold, crown flower (*Calotropis*), pandanus palm and lotus (Fig. 1.17). Urbanization and growth of the industrial sector have created labor shortages for Thai growers. Workers are frequently brought from Myanmar and Cambodia for greenhouse work. Thailand has a significant import market (US$36 million) that is primarily supplied by Malaysia and Indonesia (International Association of Horticultural Producers, 2019b).

Taiwan

Taiwan's cut flower industry is valued at nearly US$600 million, while exporting US$46 million of flowers that are primarily sent to Japan. Oncidium orchids are responsible for 90% of exports. Cut flower production covers 3000 ha

Fig. 1.17. Street vendors in Bangkok, Thailand, displaying garlands of marigolds and jasmine and buckets of cut lotus stems. (Photo: J. Faust.)

and the major crops are anthurium, chrysanthemum, gladiolus, lily and rose. Carnation, gerbera, heliconia, lisianthus and tuberose are also valuable crops. Cut flowers are primarily produced in the central part of Taiwan. A public wholesale auction system exists for domestic sales. Domestic demand for flowers has paralleled the country's strong economic development. Imports are valued at just 4 million, half of which comes from Colombia (Lee, 2014).

Vietnam

The export market is US$43 million, which represents a 250% growth rate over the past decade. The predominant market is Japan while China and Australia are also significant. The focus is primarily on roses, chrysanthemum, gladiolus, orchid, carnation and lily. Production covers 1500 ha and is mainly by small producers. The Red River Delta region dominates production, while there is growth in the Central Highlands of Lam Dong Province (Dalat). Production is mostly in open fields and under shade structures. Imports are primarily from Thailand (US$13.5 million of US$15.5 million). This represents a threefold increase over the past decade as personal income has been improving and the population is moving to major cities. Flowers play a key role in Buddhist culture. Lunar New Year, International Women's Day and other religious celebrations drive flower consumption.

South Korea

Cut flower production in South Korea steadily declined during the 2010s. The area under production (1300 ha) and the number of farms are half of their recent numbers as cut flower growers change production to vegetables. Exports are down nearly 90% and are currently valued at US$10 million. Japan is the only significant export market.

For Korean growers, the major crops are carnation, chrysanthemum, gerbera, gypsophila, lily and rose, while alstroemeria, calla lily, freesia, gladiolus, lisianthus, snapdragon, stock and statice are also important crops. Gyeonggi, Gyeongsangnam and Chungcheongnam are the provinces with the largest production area.

While exports and production are declining, the import market has grown ten fold to US$36 million over the past decade. The majority of imports are from China, Colombia and the Netherlands. Carnation, chrysanthemum, orchids, rose and tulips are the largest import species. Per capita consumption has remained surprisingly very low (<US$4/person) despite the rapid increase in personal income. A large portion (80%) of flower consumption is for ceremonial occasions such as weddings and funerals and for use by hotels. Chrysanthemums are the flower of choice for funerals, while carnations are popular for Parent's Day and Teacher's Day (Ministerie van Landbouw, 2019).

Australia

Cut flower production in Australia approaches 2 billion stems/year and is valued at US$261 million. The domestic market drives sales, while exports (US$4 million) are primarily to Japan. Australia has 435 ha of production under protection and 5000 ha in the open. Over the past decade, the production area has increased by 40% while the number of producers has been cut in half. Most production occurs in Victoria and New South Wales. Native woody perennial species have been developed into floriculture crops, such as banksia, eucalyptus, kangaroo paw, koala fern, leucadendron, scholtzia, stirlingia, thryptomene and waxflower. The import market of US$51 million has leveled off in recent years after experiencing rapid growth from 2008 to 2014. Primary suppliers include Kenya, Malaysia, Ecuador, Colombia, China, Vietnam and Thailand.

New Zealand

New Zealand exports US$12.4 million in cut flowers but this number has been on a steady decline since 2007 owing to international competition, poor exchange rates with the Japanese yen and improved cymbidium orchid production in the Netherlands. Japan and the USA are the largest markets. Cymbidium orchids are the largest export crop, while calla lily, hydrangea and peony are also popular. New Zealand's southern hemisphere location is an advantage in the global market as it allows for off-season markets in the northern hemisphere, especially in Japan (Ratnayake, 2016).

CONNECTING PRODUCERS AND CUSTOMERS

The global cut flower industry is characterized by its diversity – hundreds of species, a rainbow of colors and multiple ways to sell the same flower (single-species bunches, bouquets, arrangements and more) – leading to one of the most complex distribution systems of any product in the world. The distribution systems can be divided into two main categories based on whether or not there are intermediary businesses between the producers and the final customers. The major of flowers sold in the world flow through pathways with one or more intermediaries, especially in North America, Europe and eastern Asia. Direct sales account for a smaller percentage of sales in most developed countries.

A select set of countries produce the majority of the world's flowers, including Colombia, Ecuador, Ethiopia, Kenya and the Netherlands. Except for the Netherlands, flower production for export dwarfs that for domestic use in those countries.

Many of the remaining countries around the world either have relatively little flower production and sales or most of it is handled through domestic production. Countries such as India, Nigeria and Pakistan have large populations with growing middle-class populations where demand for flowers is increasing. Currently demand in those countries is primarily met through domestic production, but increasingly through imported flowers as well.

Producer to customer – via intermediates

No one firm can produce all of the different product types. No one location has the appropriate climate to produce all of the different species. Thus, three types of operations have developed to bring together flowers from all over the world, including local flowers, into one place for business customers: flower markets, wholesale florists and auctions (Fig. 1.18). With the former, the flower market provides facilities and operational guidelines to producers who sell their flowers directly to other businesses. Wholesale florists and auctions take control of the product, make the sales and pay the producers.

Importers and brokers facilitate the movement of flowers from the producers to the aggregation firms and sometimes directly from growers to large retailers (Fig. 1.18). Importers move the flowers physically from producing countries to where they are sold, while brokers link producers with customers but do not physically handle the flowers.

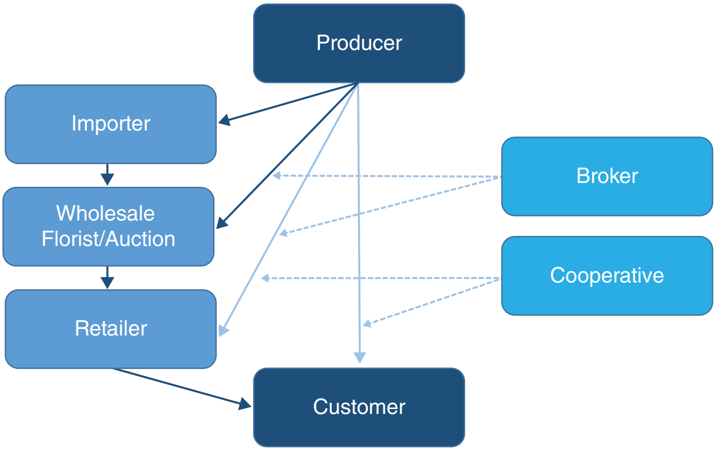

Fig. 1.18. Multiple pathways for distribution of flowers from producers to the final customers. Dashed lines indicate transactions that are facilitated, but product is not handled. Dark lines indicate pathways for the majority of cuts sold worldwide.

In many parts of the world, the majority of flowers are sold to the public through a variety of retailers, including retail florists, street vendors, designers, bouquet makers, box and club stores, grocery stores and online vendors. Cut flower producers that sell flowers through intermediaries tend to be medium to large in size. The cost of marketing for the producers is relatively low, but each intermediary must make a profit. Hence, the price/stem for the producers is often low and the profit is made on volume. One estimate for imported flowers shows that exportation adds 20% to the price, shipping adds another 20%, import/wholesale adds 15% and the retailer adds 45%. Retail florists provide much customer service, with lesser service provided by the box, club and grocery stores to relatively low service by the online retailers.

One category of firms, marketing cooperatives, do not easily fit into the above distribution pathways. Marketing cooperatives have developed to serve as both aggregators and retailers. The cooperatives bring together growers to share marketing costs and increase the range of products available. The cooperative might sell only to other business, only to the public or both avenues.

Importers

Importers move the flowers from international production areas to countries importing the flowers. They handle the logistics of the import/export process, navigating customs regulations among the various countries. To be imported, flowers need to be pest-free and may be discarded or fumigated if pests are found. Miami is the major entry point for flowers coming into the USA, handling close to 90% of the volume, and is the home base for many of the US flower importers. The Netherlands handles most of the flowers for Europe through Amsterdam. Various other major cities are the gateways to other countries.

Brokers

Flower brokers connect producers with business customers. The product is shipped directly to customers and the broker does not actually take possession of the product at any time. Brokers provide customers with one-stop access to a broad range of products from various producers. Brokers receive a commission on the total sale or a box charge based on the specifics of the shipment (box, type of flowers and numbers of stems). Some producers, importers, auctions and wholesale florists also provide broker services.

Wholesale firms/florists

Wholesale florists physically bring together a broad range of flowers from all over the world providing business customers with the convenience of one-stop shopping. In addition to flowers, wholesale florists provide hard goods, flower foods and other floral supplies.

Auctions

Floral auctions are large-scale aggregators providing an avenue for dozens to hundreds of growers to sell their products to other businesses. Floral auctions traditionally use a reverse auction process, such that the price starts at a high level and quickly drops. Customers stop the process ('the clock') at the price they want to pay. If demand is high, prices are high and the reverse occurs if prices are low. More information on auctions can be found in the 'Europe' section above.

The largest floral auction, indeed, the largest floral business in the world is Royal FloraHolland, located in Aalsmeer, the Netherlands, handling an immense volume of flowers from all over the world. Smaller auctions are also located in Naaldwijk, Rijnsburg and Eelde, the Netherlands. The United Flower Growers is the largest flower auction in North America, based in Vancouver, British Columbia, and Ota Shijo, based in Tokyo, is Japan's largest flower auction and the third largest in the world.

Flower markets

Flower markets provide space for producers to sell their products to other businesses. Some flower markets also provide limited access to the general public for sales directly to consumers. Markets provide the organizational structure to manage the market and promote sales. Most major European and Asian cities have flower markets. Some of the major flower markets include:

- New Covent Garden Flower Market, London, largest wholesale market in the UK (includes fruits and vegetables).
- Sydney Flower Market (Australia's largest flower market), mostly business-to-business but general public allowed for a limited period of time (Fig. 1.19).

Fig. 1.19. One can find an amazing array of cut flowers, stems, fruit and foliage at flower markets such as the Sydney Flower Market. (Photo: J. Dole.)

- New England Flower Exchange (formerly Boston Flower Exchange), only business-to-business.
- San Francisco Flower Market, only business-to-business.
- Bangkok Flower Market, mostly business-to-business, but general public allowed later in the day.
- Laitai Flower Market, Beijing, largest market in northern China, both business-to-business and general public.

Marketing cooperatives

Marketing cooperatives are groups of producers banding together to share marketing, sales and distribution of their flowers. By working together, cooperatives can increase the diversity of products offered and serve more and larger customers. A number of cooperatives have been established in North America, and the model is being tried elsewhere. Marketing cooperatives sell only to businesses, to the general public or, more commonly, to both.

Retail florists

In addition to selling flowers and design services, retail florists provide an array of floral products. Many florists serve as agents for national floral wire services that collect the orders from customers and transmit them to local florists for fulfillment. Some florists provide a broad range of services, while others specialize in various types of events or customers, such as corporations, entertainment or high-end consumers.

Street vendors

These are small operations that typically sell bunches and bouquets of cut flowers. They differ from retail florists in that they do not provide design services. They might be located in city markets, as discussed below, but are often scattered around cities in high-traffic areas. Street vendors are most common in large cities, especially in Europe and East Asia.

Designers

Floral designers can work for retail florists, bouquet makers, online vendors or other retailers. Other individual designers provide design services, but not through any physical business location. Generally, they focus on events, especially weddings, or everyday flowers for businesses and wealthier consumers. Designers tend to be located in the larger cities where there are enough clients to support their businesses.

Bouquet makers

The companies buy flowers from producers to create and sell bouquets that are then sold to large retail customers such as box, club and grocery stores. Bouquet makers are often sited close to the producers in the major flower-producing countries or in ports of entry, such as Miami, where flowers from various producers can be consolidated.

Box and club stores

These large retailers sell cut flowers as part of a broad range of consumer products. The firms tend to focus on maintaining low prices, and thus provide limited customer service. Competition among the various box and club stores can be intense, leading the purchasing agents from each chain of stores to work closely with producers and bouquet companies to provide unique products to their customers. Box and club stores are most common in North America, Europe and East Asia, but are increasingly expanding into large cities in many countries around the world.

Grocery stores

Grocery stores are similar to box and club stores in that the floral products are only a subset of products sold. More latitude exists among grocery stores regarding prices as some focus on keeping prices low while others compete on selection and customer service. As with box and club stores, grocery store chains are similarly competitive, and there is a strong desire to provide unique products. Grocery stores along with box and club stores are collectively known as mass-market retailers.

Online vendors

Today, most businesses have an online presence to assist with marketing and customer management, whether they be other businesses or the general public. However, some businesses sell their products exclusively online using flowers purchased directly from producers. The businesses rely on shippers to deliver their products to the final customers.

Producer to consumer – direct

The simplest distribution system is direct from the producer to the final customer though on-farm sales, city and farmers' markets, marketing cooperatives (as previously mentioned), design/event operations, community-supported agriculture and subscriptions, and online sales. Producers selling directly to the general public tend to be small to medium sized. The closer a firm is to the final customer, the greater the control over prices, which usually means that producers are able to set prices as needed to make a profit. Producers also have greater latitude to adjust production more quickly as they see sales increasing or decreasing for individual products. However, these firms bear all of the marketing and sales costs; thus, prices need to be relatively high to accommodate those costs.

On-farm sales

On-farm sales encompass a broad range of operations. The simplest system is a roadside stand, which can vary from a small shed near the road to a fully developed store that sells a broad range of agricultural products including flowers. U-pick operations have long been popular with fruit production, especially strawberries, raspberries and blueberries, and occasionally include cut flowers. The most extensive operations are agri-tourism, where cut flower production and sales are part of an overall farming experience for visitors, including animals, children's areas, tours and educational displays.

City and farmers' markets

For centuries, flowers have been sold at markets, usually in city or town centers, around the world. Producers bring their products to one central location and sell directly to the public. Such markets often include a broad range of products from fruits, vegetables and flowers to virtually anything used in daily life.

Farmers' markets are a subset of the city markets and typically found in North America. They tend to focus on agricultural products and minimally processed foods. Many farmers' markets are only seasonal, whereas city markets are open year-round. Many farmers' markets also limit vendors to only sell what they produce and, thus, are typically very local. Markets have an administrative structure that manages the market, determines who can sell at the market and what types of products can be sold.

Farmer florists

Farmer florists grow flowers and provide floral design services. Some use only the flowers they produce while others will purchase flowers as needed from other producers or intermediaries. These businesses tend to be small, local, and proficient at using the web and social media for marketing purposes.

Community-Supported Agriculture (CSA) and subscriptions
As the name suggests, a community of customers support the business by pre-purchasing flowers to be delivered weekly or biweekly for a set number of weeks during the growing season. Subscription services are similar, but the payments are made monthly and customers typically have more floral options from which to choose.

Online
As with the intermediary online businesses indicated above, most direct-to-consumer businesses have an online presence to assist with marketing and customer management. An increasing number of firms are completely online with all of their business conducted electronically and the flowers shipped directly to customers.

GLOBAL TRENDS

Industry consolidation

Business costs, such as labor and transportation, are increasing at a faster rate than prices. This situation results in lower profit margins. Small- to mid-sized cut flower growers often struggle to maintain profitability if they are not able to find a market niche. Larger operations benefit from economies of scale and the ability to invest in automation to improve production and transport efficiencies. Opportunities for expanding the markets in developed countries are also limited. These forces are driving industry consolidation. Larger businesses are merging or buying smaller businesses, resulting in fewer, larger growers. For example, Colombia now has three firms that each exceeds 800 ha of production over many farms (the average individual farm size is ~25 ha).

Consolidation actually creates opportunity for small farms located in the major markets in North America and Europe. Consumers who are looking to find novel seasonal products grown by local farmers are generating considerable growth. Domestic farms also supply large international bouquet makers with seasonal products that can be incorporated into their mixed bouquets to complement the major imported cut flower species while adding distinctiveness and seasonality to the bouquets.

The net effect is a bifurcation of the cut flower industry into large, vertically integrated, international businesses that supply the major species through the major market channels and the small businesses that supply the floral needs of the local, domestic market. Both segments of the industry rely on their creativity and horticultural skills to adapt to societal and technological changes while profitably meeting the ever-changing needs and desires of the consumer.

Distribution pathways

Modern markets are on the rise while traditional market pathways decline. The traditional market route has focused on the auctions and/or florist shops. Meanwhile, direct sales between the grower and the wholesaler are on the rise and are bypassing the auctions. Supermarket sales are also on the rise and are challenging the florist shops. Direct-to-consumer sales are also growing. For example, Internet sales in the USA now account for 15% of stem sales, while farmers' markets and CSAs provide seasonal variation in the flower supply and tap into the increasing demand for locally grown agricultural products.

International transport

Sea transport is gaining momentum as a more environmentally friendly means of internationally transporting flowers owing to its smaller carbon footprint compared with air freight. Additionally, sea transport offers more competitive transportation costs for South American and African growers trying to supply the European and Asian markets, most notably China. Many of the major cut flower and cut foliage species can be successfully shipped via sea transport; however, the postharvest challenges created by the extended transit time are significant. The biggest postharvest challenges are botrytis and bent neck (insufficient hydration or excess water loss). The huge risks associated with product failure intensify the need for farm-level implementation of best management practices. Sea transport remains a small fraction of total international transport, but it is growing annually as producers learn how to manage the logistics of growing and supplying products with a reliable vase life to the end consumer.

Phytosanitary obligations

Exotic pests and diseases pose an ecological threat to the import nation and a financial threat to the exporting businesses. Phytosanitary permitting and certification systems are in place to address these issues, but small errors or failures translate to potentially huge consequences. These systems also add cost and time for international transport. In the future, countries that act cooperatively and develop reliable and efficient oversight methods are at a tremendous advantage for economically exporting/importing product.

Sustainability

Sustainability continues to rise to the forefront of important issues destined to drive the future success of the cut flower industry. Certification systems and eco-labels provide market incentives for growers to improve production practices for the betterment of the workplace, the environment and the local community. These programs require growers to make and document progress toward implementing sustainable practices that encompass the following:

- Reduce chemical usage, including insecticides, pesticides, herbicides, soil fumigants, etc.
- Reduce carbon generation, particularly with regard to fuel consumption for heating or cooling greenhouses and for transporting product from the farm to the consumer.
- Reduce water usage through improved irrigation methods, such as drip irrigation and hydroponic systems.
- Increase environmental protection, including containment of fertilizer runoff.
- Promote and protect the biodiversity surrounding farms.
- Increase social responsibility, which may include the following: maximum weekly work hours; maternity leave; facilities and flexibility for nursing mothers; freedom from workplace harassment; improved terms of employment, e.g. non-discriminatory hiring practices, no forced labor, no child labor; worker training and professional and personal development; the right to freedom of association and participation with trade unions; and worker safety training and equipment.
- Increase support for projects that benefit local communities, such as food-security programs, daycare centers, and housing subsidies.

Popular programs include MPS (Milieu Programma Sierteelt), GlobalGAP, Rainforest Alliance, FairTrade and Veriflora. Participants have to make a significant commitment of time and resources to succeed in meeting the certification requirements. Record keeping, audits, interviews and inspections by independent overseers are integral to documenting progress toward sustainability goals. These certification programs may be required to sell into some countries, markets and auctions.

Individual countries have developed their own programs to promote sustainable practices specifically for cut flower growers while also branding their products. Examples include Flor Verde (Colombia), Flor Ecuador, and Carbon Reduction Resources and Opportunities Toolkit (CaRROT) (KFC).

REFERENCES

Dadlani, N.K. (1998) Cut flower production in India. In: *Cut Flower Production in Asia*. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/3/ac452e/ac452e04.htm#bm04 (accessed 18 August 2020).

Diaz Ceron, W.A. (2018) Analisis de las Oportunidades del Sector Floricultor Exportador Colombiano Frente a las Actuales Condiciones del Mercado en Costa Rica. Thesis, Fundacion Universidad de America, Bogotá-Colombia.

Dole, J., Stamps, B., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. American Society for Cut Flower Growers Press, Oberlin, Ohio.

Hanks, G. (2018) A Review of Production Statistics for the Cut Flower and Foliage Sector. The National Cut Flower Centre. Agriculture and Horticulture Development Board, Holbeach St. Johns, UK, pp. 1–135.

International Association of Horticultural Producers (AIPH) (2019a) *International Statistics Flowers and Plants (ISFP)* 67, 1–212.

International Association of Horticultural Producers (AIPH) (2019b) *Production and markets, the future of ornamentals*. Available at: http://aiph.org/wp-content/uploads/2019/08/AIPH-IVP-Report2-2019.pdf (accessed 18 August 2020).

International Association of Horticultural Producers (AIPH) (2019c) *Understanding the Chinese market, The demand for ornamentals*. Available at: http://aiph.org/wp-content/uploads/2019/09/AIPH-IVP-Report-Understanding-the-Chinese-Market.pdf (accessed 18 August 2020).

International Trade Centre (ITC) (2019) Trade map. Available at: https://www.trademap.org/tradestat/Country_SelProductCountry_TS.aspx (accessed 18 August 2020).

ISMEA (Istituto di Servizi per il Mercato Agricolo Alimentare) (2015) Tendenze Piante e Fiori. Available at: http://www.ismeamercati.it (accessed 17 December 2020).

Jong, L.H., Ridzuan, M., Saad, M. and Hamir, N.A. (1998) Cut flower production in Malaysia. In: *Cut Flower Production in Asia*. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/3/ac452e/ac452e06.htm#bm06 (accessed 18 August 2020).

Lee, H.-J. (2014) The development and expansion strategy for Taiwan's floriculture industry. FFTC-AP Agricultural Policy Platform. Available at: http://ap.fftc.agnet.org/ap_db.php?id=357&print=1 (accessed 18 August 2020).

Louw, M. (2020a) The flower industry in South Africa. Available at: http://southafrica.co.za/the-flower-industry-in-south-africa.html (accessed 18 August 2020).

Louw, M. (2020b) Exports and markets of indigenous flowers. Available at: http://southafrica.co.za/exports-and-markets-of-indigenous-flowers.html (accessed 18 August 2020).

Louw, M. (2020c) Indigenous cut-flowers of South Africa. Available at: http://southafrica.co.za/indigenous-cut-flowers-of-south-africa.html) (accessed 18 August 2020).

Loyola, C., Dole, J.M. and Dunning, R. (2019) North American specialty cut flower production and postharvest survey. *HortTechnology* 29, 338–359.

Melese, A.T. and Helmsing, A.J.J. (2010) Endogenisation or enclave formation? The development of the Ethiopian cut flower industry. *The Journal of Modern African Studies* 48, 35–66.

Ministerie van Landbouw (2019) The Korean flower market – focusing on cut flowers. Ministerie van Landbouw, The Hague, the Netherlands, pp. 1–11.

Ministry of Agriculture, Forestry and Fisheries (2017) Current status of flowers and plants in Japan. Available at: https://www.maff.go.jp/e/policies/agri/attach/pdf/index-5.pdf (accessed 24 March 2021).

MIPAAF (Ministero delle Politiche Agricola Alimentari e Forestali)(2014/2016) Piano Nazionale del Settore Florovivaistico. Available at: https://www.politicheagricole.it (accessed 17 December 2020).

Mwase, D.E. (2015) Performance of floriculture industry in East Africa: what lessons can Tanzania learn from Kenya. *Asian Business Review* 5, 20–27.

Ratnayake, I. (2016) The experiences of New Zealand floriculture export producers in the changing international market: what can be done to strengthen the sector's capabilities? Master's Thesis, Auckland University of Technology.
Shirdelian, A. (2017) Iran's flower industry blooming. *Financial Tribune* 4 December. Availableat:https://financialtribune.com/articles/economy-business-and-markets/77330/iran-s-flower-industry-blooming (accessed 17 December 2020).
Suntracker Technologies (2020) DLI calculator. Available at: https://www.suntrackertech.com/dli-calculator/ (accessed 18 August 2020).
Wijnands, J. (2005) Sustainable international networks in the flower industry. *Scripta Horticulturae* 2, 1–92.
Xia, Y., Deng, X., Zhou, P., Shima, K. and Teiceira da Silva, J.A. (2006) The world floriculture industry: dynamics of production and markets. In: Teiceira da Silva, J.A. (ed.) *Floriculture, Ornamental and Plant Biotechnology* (vol. IV). Global Science Books, UK. pp. 336–347.

2

Major Cut Flowers

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INTRODUCTION

Hundreds of species are produced commercially for their beautiful flowers, foliages, stems and fruits. The most important species vary with the countries where they are produced and the countries where they are sold. Owing to the impossibility of covering all cut flowers species in this book, we have selected the highest value species from the major production regions as well as a few other species to represent the diversity of production systems. For example, we have included gladiolus, peonies and sunflowers to represent outdoor production of geophytic, perennial and annual species, respectively, although it should be noted that all three are also grown under cover in some situations. Entire books have been written on orchid production, but owing to space limitations we had to select only one, dendrobiums, to represent this fascinating and diverse family of plants, most of which are grown in warm climates under cover. Two species, gypsophila and statice, used as fillers in bouquets and arrangements, have been included. Although filler flowers may not be as glamorous as some of the other flowers covered in this chapter, they are an important part of the cut flower industry. Finally, ranunculus represents a number of species that are widely grown in unheated or minimally heated tunnels. For more complete listings of species being grown, check out Chapters 3 and 4.

ALSTROEMERIA

Scientific name: *Alstroemeria* × *hybrida*
Common names: Peruvian lily, lily-of-the-Inca
Native to cool, subtropical locations in the Andes Mountains in South America (Peru, Brazil and Chile). The flowers display six long, curved stamens positioned in front of three freckled or streaked petals that sit in front of three solid-colored sepals resulting in a bilaterally symmetrical presentation. Alstroemeria is a

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monocot with parallel leaf venation. The leaves turn upside down so that the bottoms of leaves face upward. Plants grow 1–2 m tall.

Production started in Europe in the 1960s and gained great popularity throughout the 20th century. Considerable hybridization has been done in recent decades, primarily in the Netherlands, to combine the best features of various species. The resulting modern varieties have improved heat tolerance, year-round production and excellent vase life.

Market

Alstroemeria flowers lack fragrance, and are frequently used as filler flowers in mixed bouquets. The flowers tend to have a longer vase life than the leaves. In mixed bouquets, alstroemeria are one of the longer-lasting flowers. Stems range from 60–90 cm long and contain three to seven flowers per stem. Stem diameter is ~7 mm.

Cultivars and related species

- *Alstroemeria* has a nearly limitless selection of flower colors and shades including white, pink, red, yellow, salmon, orange, green, lavender, purple and bicolors. Most varieties have an orchid, butterfly- or lily-like appearance, and narrow-petaled, spider forms are also available. The three petals are freckled or streaked in various shades of red, burgundy, brown, purple and black.
- *Alstresia* and *Florinca* are spray-type alstroemeria that have branching at the top of each stem resulting in dozens of small flowers per stem. The flowers lack pistils, stamens and pollen. The stems are harvested with the first flowers already open, which allows the vase life to be up to 3 weeks. Productivity ranges from 180–220 stems/m^2, which is slightly lower than with other alstroemeria.

Production practices

Alstroemeria are propagated by division or tissue culture. Rhizomes are planted in ground beds under protected cultivation (Fig. 2.1).

Two rows are planted per 1-m-wide bed providing 30–60 cm spacing within rows and 35–50 cm between rows. The result is a plant density of three to four plants/m^2. During the first 2–4 months of establishment, the photoperiod is ≤12 h, the air temperatures are 16–18°C and soil temperatures are 13–16°C (Fig. 2.2). Short days and low temperatures promote shoot development

Fig. 2.1. A retractable roof greenhouse is used on an alstroemeria crop to allow for higher light levels (DLI) while rainfall or excessive winds are not a concern. (Photo: J. Faust.)

from the rhizome. Cool temperatures result in slower growth but yield higher-quality stems and fewer 'blind' shoots, i.e. shoots lacking flowers, while warm soil temperatures (>18°C) and low light will increase the number of blind shoots owing to a lack of sufficient carbohydrate levels to support flower development. Slightly warmer temperatures are tolerable if light levels are high. The emerging shoots take 6–8 weeks to flower. During this time, straight stems are maintained by placing a layer of 20 × 20 cm mesh netting every 50 cm of crop height, resulting in three or more layers (Fig. 2.3). The rhizomes branch underground, but the vertical shoots emerging from the rhizomes do not form lateral branches.

Alstroemeria have a series of complicated environmental requirements for maintaining high-quality flowering stems throughout the year. Figure 2.2 demonstrates the temperature, photoperiod and light quantity (DLI) requirements for shoot production and flowering. Considerable variation exists among cultivars, but in general, alstroemeria are facultative long-day plants (critical night length is 12–14 h) that require relatively cool temperatures for year-round production. Plants go dormant under cold temperatures (<5°C) and flower poorly at warm temperatures (>20°C). Soil temperatures are particularly important because the plants are grown from rhizomes. Flower

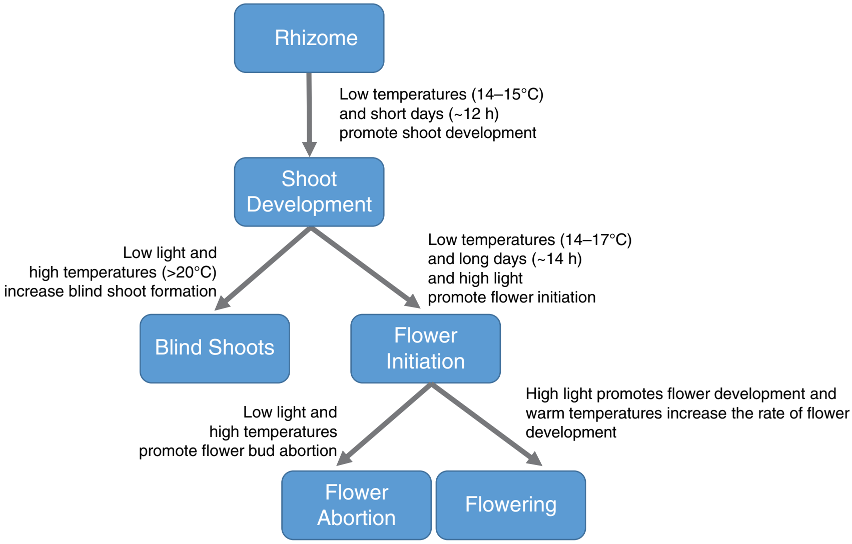

Fig. 2.2. Description of the conditions required for shoot and flower development of alstroemeria. (From Heij, 2002 and HilverdaKooij Plant Technology, n.d.)

Fig. 2.3. Netting is used to support cut flower crops. Alstroemeria is pictured here. (Photo: J. Faust.)

initiation is promoted by low temperatures (14–16°C), long days (≥14 h) and high light. Under these conditions, fewer nodes will appear on the stems below the terminal flowers. Once flowers are initiated, high light promotes the development of those flowers while warmer temperatures (up to 20°C) speed the rate of flower development, i.e. reduce the time to open flower. The goal is to maximize light while minimizing its effect on soil temperature as soil temperatures should be <18°C. Shade should be applied to the greenhouse structure if air temperatures exceed 30°C.

The stringent environmental requirements for alstroemeria production make this crop challenging to grow at high-latitude locations having large seasonal variations in temperature, photoperiod and light levels. Temperate locations, such as the Netherlands, must provide heat in the winter and must have the capacity to maintain cool summer temperatures. Circulation of cool water through underground tubing is beneficial for moderating soil temperatures. Supplemental lighting is also beneficial during low-light winter conditions. High-elevation, equatorial regions benefit from having moderate temperatures and high light levels year-round, thus soil cooling is not necessary.

The relative humidity should be 65–85%. Higher humidity causes weak leaves, taller stems and more disease pressure. Lower humidity makes the plants more susceptible to leaf scorch on sunny days particularly after a period of cloudy days. Overhead misting can be implemented to cool the canopy and reduce leaf scorch. Carbon dioxide provided at 600–1000 ppm increases fresh weight and shoot number (Anonymous, n.d.).

Alstroemeria cultivars produce 200–270 stems/m^2/year and upward of 450 stems/m^2 can be achieved with greenhouse heating and supplemental lighting. A total of 60–80% of the stems will be rated top quality. Maximum production is not reached until after the first year. Most cultivars will yield good flower quality for 3–5 years.

Pinching and canopy thinning (stem removal) are critical for maintaining yield and quality over multiple years. Until the canopy is mature and full, low-quality (thin) stems are pinched to maintain leaf area, which is necessary to keep soil temperatures relatively low. Once the canopy is full, low-quality stems and blind stems are removed to improve air circulation, lower canopy humidity and improve light penetration. Typically, the mature stems that are not cut for sales are allowed to senesce before removal. This allows the nutrients in the stem to be translocated to the rhizome to support future shoot production.

Productivity can be managed by counting the number of young shoots (up to 10 cm tall) per m^2 to verify that plants are making new shoots. Pinching and stem removal can performed to create flushes of flowers for holiday markets.

Irrigation and nutrition

Alstroemeria can be grown on a wide range of soils, but organic matter may be added at a rate of 2–5 m^3/100 m^2 to improve the nutrient holding capacity and soil structure (Lozano, n.d.). Consistently moist soils are ideal and periods of wet or dry should be avoided. Soils can be disinfested by steaming at 70°C for 1 h.

The most common nutrient deficiencies are due to iron, manganese and magnesium. Iron and manganese deficiencies appear as chlorosis of the young, immature leaves. These deficiencies are most often associated with high soil pH (>7.0), so reducing soil pH provides a longer-term solution than increasing the rate of iron and manganese application. Magnesium deficiency appears as interveinal chlorosis of the older leaves. This can be corrected with 100–200 ppm Mg applications of magnesium sulfate.

Leaf yellowing during production can also occur when root health is poor after periods of high productivity, low light or excessive fertilization. Plants recover more slowly when soils are cold (10–12°C) and wet.

Table 2.1 shows the concentration of macronutrients for drip irrigation of alstroemeria crops. Additional weekly spray applications of calcium (500 ppm) may be beneficial to improve tissue resistance to botrytis blight, especially under high-humidity conditions.

Major pests

The major pests include: aphids, thrips, spider mites, slugs, caterpillars, whiteflies and nematodes (*Pratylenchus bolivianus* and *Pratylenchus penetrans*). Pythium root rot can be a problem in wet soils, while rhizoctonia stem rot can occur in warm environments. Botrytis blight can occur, especially on flowers, as well as powdery mildew, stemphylium leaf and flower spot, and bacterial soft rot. Several viruses are problematic for alstroemeria including tomato spotted wilt virus, alstroemeria mosiac virus, alstroemeria streak virus, alstroemeria carla virus, cucumber mosaic virus, lily symptomless virus and iris yellow spot virus.

Table 2.1. Nutrient solution for macronutrients in drip irrigation of alstroemeria. Higher rates are delivered during periods of high productivity when temperatures are cool, while lower rates are provided during periods of lower productivity when the climate is warmer and water demand is higher. The electrical conductivity of the nutrient solution should be ~1.6–2.3 dS/m. (From Lozano, n.d.; Heij, 2002.)

Macronutrient	Concentration	
	ppm	mM
N	154–196	11–14
P	25–40	0.8–1.3
K	156–235	4–6
Ca	100–140	2.5–3.5
Mg	36–60	1.5–2.5

Postharvest management

Stems are harvested for local markets when four or five flowers are open, and for export markets when the first flower starts to open and the buds display 50% color. Stems can be pulled except when rhizomes are not well established, which will require them to be cut. Harvest occurs two to four times per week depending on the time of year and the rate of plant development. Alstromeria can cause dermatological responses in some individuals.

Alstroemeria are ethylene-sensitive and leaf yellowing is the primary symptom. Several postharvest products are used to prevent leaf yellowing by reducing ethylene responses (silver thiosulfate (STS) and 1-methylcyclopropene (MCP)), reducing carbohydrate depletion (gibberellic acid (GA) and cytokinins) and increasing carbohydrates available (2–4% sucrose). STS, hormones and sugars are added to the pre-packaging bucket solution prior to storage or shipping. Stems are stored wet in buckets at 2–4°C for 2–3 days or dry at 1–2°C and 80–90% relative humidity for 5–7 days. Alstroemeria can be shipped via sea transport. With good postharvest procedures, vase life is 2–3 weeks and the flowers typically outlast the foliage (Dole *et al.*, 2017).

REFERENCES

Anonymous (n.d.) Growing information alstroemeria cut flower. Available at: www.alstroemeria.com/sites/default/files/Growing%20Information%20Alstroemeria%20Cut%20Flower.pdf (accessed 1 August 2020).

Dole, J.M., Stamps, R., Carlson, A., Ahmad, I. and Greer, L. (2017) Alstroemeria. In: Laushman, J. (ed.) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers, Oberlin, Ohio, p. 86.

Heij, G. (2002) Alstroemeria literature survey: a review of 10 years of Dutch applied research. Applied Plant Research BV, Glasshouse Horticulture Research Unit, Wageningen, Naaldwijk, the Netherlands.

HilverdaKooij Plant Technology (n.d.) Cultural instruction alstroemeria. Available at: www.hilverdakooij.com/media/files/teelthandleidingen/en-Cultural-instruction-Alstroemeria.pdf (accessed 1 August 2020).

Lozano, E. (n.d.) Alstroemeria cultivation guide. Available at: www.academia.edu/7073638/Alstroemeria_grow_esp (accessed 26 August 2020).

CARNATION

Scientific name: *Dianthus caryophyllus* and hybrids
Common names: clavel, dianthus
Native to the northern Mediterranean region, carnations have been cultivated for centuries. Large-scale production began in the mid-1800s. Currently, carnations are the third largest cut flower worldwide. Over recent years,

carnation production has been moving from Europe to South America and Africa. Colombia has >1000 ha of carnation production and is the largest exporting country. Other important carnation exporters include the Netherlands, Turkey, China, Spain, Italy, Kenya and Ecuador. Production is also on the rise in Ethiopia and Morocco.

Carnations are herbaceous perennial plants with opposite leaves that enclasp the stem, creating a thickened node. The individual leaves are flat, linear and green to gray-blue. Wild-type carnations contain five petals, while cultivated varieties have numerous petals in a 'double' flower. Flowers are born solitarily with a large terminal flower and smaller axillary flowers positioned down the stem. Carnation flowers contain eugenol, which is responsible for the clove scent. Fragrance is correlated with poor vase life, however, so fragrance has mostly been lost in commercial cultivars through the breeding process.

Market

Carnations are among the most recognizable flowers by consumers around the world. This familiarity has been somewhat detrimental as the public often perceives them as an old-fashioned flower and a common component in low-cost bouquets. However, recent promotional campaigns and creative breeding programs are rejuvenating the carnation's image (Fig. 2.4).

High-quality carnation stems must be free of shrunken flowers, woody stems and crooked necks. Standard flowers must be free of axillary buds and are sold in bunches of 20 stems. Carnations are graded by stem length and flower opening (ripeness). Sprays must have at least three 'bloomable' buds, no sign of the removed terminal flower and no excess shoots. Sprays are sold in bunches of 10 stems and are graded by the number of 'bloomable' buds (those likely to open for the customer).

Peak productions vary throughout the year in different locations, e.g. Dutch production peaks in April and May, Spain peaks from April to July, Colombia peaks in October and Kenya has its highest volumes in November through March (Center for the Promotion of Imports, n.d.).

Cultivars and related species

- *Standard* carnations possess one large (7–12 cm diameter) flower on an individual stem and axillary flower buds are removed. Red, white and pink are traditional colors, while shades of yellow, orange, green, salmon, peach, violet, burgundy and fuchsia expand the color palette. New breeding has introduced 'antique' shades of dusty rose, mauve and peach that have added a modern touch to this traditional flower. Additionally, genetically modified blue pigmentation has been added to carnations (Office of

Fig. 2.4. Examples of breeding for new flower colors and patterns within carnation. (Photo: J. Faust.)

the Gene Technology Regulator, 2006). This has been accomplished by inserting genes from petunia that produce the pigment delphinidin, an anthocyanin. A large assortment of bicolors and flecked petals in striped and picotee patterns are available.

- *Spray* carnations consist of a flush of small (3–5 cm diameter) axillary flowers that develop on each stem after the terminal flower bud is removed. The array of colors and bicolors is similar to that available in the standard form. Single-flower forms, i.e. one array of petals, are available in spray cultivars. Spray carnations are more frequently used in bouquets.
- *Petite spray* carnations are a newer form that have numerous, exceptionally small (<3 cm diameter) flowers.
- *Novelty dianthus*: *Dianthus barbaratus* (sweet William) stems produce a round umbel containing dozens of five-petal flowers. Many bicolor white, pink, red and deep red patterns are available. A bright lime-green, ball-shaped barbatus type displays dense tufts of frilly green sepals that can be used as a long-lasting unusual green filler in bouquets (Fig. 2.5).

Production practices

Carnations are propagated by tissue culture to create clean stock, and breeding programs germinate seeds as part of the hybridization and selection process. Shoot-tip cuttings are used for multiplying plant numbers for cut flower production. Once harvested, cuttings can be stored for several weeks at 0°C. Rooting hormone (500 ppm indolebutyric acid (IBA) or 500–1000 ppm

Fig. 2.5. Green ball-type dianthus provides a unique new color and architectural component in mixed bouquets. (Photo: J. Faust.)

naphthaleneacetic acid (NAA)) is applied to the base of the stem prior to insertion into the propagation medium. The medium must be fumigated or pasteurized unless soilless substrate is used. Cuttings will be rooted and ready for transplant after 3 weeks when the temperature of the propagation medium is maintained at 26–28°C.

Carnations should be transplanted into growing beds or containers at a height that matches the top of the propagation medium with the height of the soil or growing medium. Care must be exerted to avoid planting too deeply. Carnations are grown under protected cultivation in ground beds or in hydroponic systems. Most new plantings are done in hydroponics to improve control of *Fusarium* wilt. Plants are planted with four to six rows across a 1-m-wide bed, and individual plants placed at 15–20 cm spacing (25–45 plants/m^2). Three to four layers of netting support the weak flowering stems. The first layer of netting has 7.5–10 cm squares, and the area increases with each layer so that the uppermost layer has 15 × 15 cm squares.

The primary stem of the transplants is pinched above the fifth to sixth node pair, and the emerging lateral shoots can receive an additional pinch 7 weeks later. GA3 (100 ppm) can be applied at first pinch and when laterals are 8–10 cm long to promote flowering and stem length. Flowering starts 4 months after planting and continues for 1–2 years before the crop is replanted.

Carnations are facultative long-day plants that flower year-round, but flower better during long days. In temperate climates located at higher latitudes, photoperiodic lighting (>13 h/day) is provided for 14–21 days during winter months to promote flowering. Long-day conditions also increase internode length while producing few nodes and faster flowering. In equatorial locations, photoperiod does not need to be manipulated to produce year-round flowering. Carbon dioxide-enriched air (500–750 ppm) can increase yield by 10–30% (Jawaharlal *et al.*, n.d.). Ideal day temperatures are 18–24°C, while night temperatures are 10–15°C. Relative humidity should be near 70–80%.

Standards are disbudded by removing the small axillary buds below the terminal flower. Unwanted lateral stems must also be removed when they are 2–3 cm long. The terminal flower is removed for spray flowers. Flowers are harvested every 2 days. Stems are harvested at the tight-bud stage to the paint-brush stage for long-distance shipping. Flowers are allowed to open to the semi-open stage for short-distance or local markets. The cut flower yield is ~8–12 stems/plant/year, which translates into 250–350 stems/m^2/year (Jawaharlal *et al.*, n.d.).

Calyx splitting is the most common physiological disorder. It is thought to be caused by fluctuating environmental conditions. Also, temperatures <10°C produce extra petals that cannot be held by the calyx, causing it to split open. Plant nutrition is also a possible causal factor. Low nitrogen, high ammonium-nitrogen and low boron are all thought to contribute to the development of calyx splitting.

Irrigation and nutrition

Water application will vary with the growing medium, but a water volume of 4–5 l/m^2/day has been reported. High-frequency irrigation has been used to increase flower stem strength, stem diameter and weight, flower diameter, vase life and yield (Aydınşakir *et al*., 2009).

The target electrical conductivity of a hydroponic nutrient solution is 1.5–2.0 dS/m, and the composition of nutrients is shown in Table 2.2.

Boron deficiency is associated with flower bud deformation, calyx splitting and excessive branching of the flower stems, so additional boron may be necessary (Jawaharlal *et al*., n.d.).

Major pests

Fusarium wilt (*Fusarium oxysporum* f. sp. *dianthi*, race 2 and *Fusarium redelens* f. sp. *dianthi*) is a soil-borne fungus that causes shoot wilting, discoloration of leaves and brown streaks on vascular tissue in stems. Poor drainage and high temperatures contribute to the rapid decline. Carnation production is rapidly moving toward hydroponic (soilless) systems to manage this serious problem. Disease-free young plants and stringent sanitation protocols are necessary. Calcium nutrition improves host resistance. Biological control agents, such as *Bacillus subtilis*, *Trichoderma viride* and *Pseudomonas fluorescens*, are useful management tools (Jawaharlal *et al*., n.d.).

Phialophora wilt is a vascular pathogen (*Phialophora cryptogea*) that infects carnations, producing similar symptoms to *Fusarium*. Alternaria leaf spot (*Alternaria dianthi*) is promoted by warm temperatures (>24°C), present in dead plant material. It is spread with splashing water. Botrytis blight creates tan spots on flower petals under high-humidity conditions and when tissues are wetted

Table 2.2. Concentration of nutrients in fertilization solution for carnations. (From Jawaralal *et al*., n.d.; Kazaz *et al*., 2009.)

Nutrients	Concentration	
	ppm	mM
N	115–160	8.2–11.4
P	30–45	1.0–1.5
K	150–225	3.8–5.7
Ca	45–140	1.1–3.5
Mg	7–18	0.3–0.7
Fe	2	0.036
Mn	0.41	0.0075
B	0.21	0.194
Zn	0.19	0.003
Cu	N/A	N/A

by condensation. The related *Alternaria dianthicola* can cause flower blight. Rust (*Uromyces dianthii*) causes pale green blisters and the release of red/brown masses of spores under warm, humid conditions (Jawaharlal *et al*., n.d.).

Pseudomonas caryophylli bacterial wilt is soil borne, so soil sterilization or soilless production systems are necessary for control. Erwinia streak disease causes purple/brown streaks along stems and flowers. Numerous viruses target carnation, including: carnation mottle virus, carnation etched ring virus, carnation vein mottle virus and carnation latent virus. Many others occur, which are listed in Table 6.1 of Chapter 6.

Other diseases that can be significant at times include downy mildew (*Peronospora dianthicola*), leaf and flower spot (*Stemphylium* spp.), flower blight (*Alternaria dianthicola*), root and stem rot (*Rhizoctonia solani*), crown gall (*Agrobacterium tumefaciens*) and aster yellows.

Important pests include: thrips, aphids, spider mites, caterpillars (*Helicoverpa armigera*, bud borer) and nematodes (*Criconemoides* (*Criconemella*) spp., *Meloidogyne incognita*). Numerous other nematodes have been reported on carnations and are listed in Table 6.2 in Chapter 6.

Postharvest management

Carnations have excellent postharvest performance, so they became the first cut flower species in which production moved from North America and northern Europe to equatorial locations, and sea container shipment was proven to be successful. Carnations are ethylene-sensitive, and the primary symptom is petal curl, termed ‘sleepiness’. STS and 1-MCP help to prevent symptoms from developing.

The stage of bud development at the time of harvest varies with the planned duration of storage and shipping method. For long-term storage, standard flower forms are harvested in the tight-bud stage with petals just beginning to appear (star stage). For wholesale markets, standards are harvested with petals emerging but upright. For local markets, the outer petals of the buds are open but not yet perpendicular to the stem. Spray forms are harvested with one to three open flowers, and the remaining buds showing color. Approximately five nodes are left on the stem below the cut to facilitate branching and further stem production.

Harvested stems may be placed in STS solutions in the greenhouse prior to being transported to the cooler. After harvest, stems are precooled at 4–7°C, then they are graded and processed in an ambient-temperature packing house. Lower leaves are stripped off the stems. Stems are placed in a solution containing various possible compounds, such as STS, sucrose (5–10%), cytokinins, a biocide and citric acid (to drop the solution pH to 4.5) for 4 h, before being packed, sleeved and wrapped to prevent physical damage. Alternatively, 1-MCP sachets are placed in boxes to reduce the harmful effects of ethylene gas. Boxes are roughly 122 × 50 × 20 cm, fitting 24–32 bunches of standards or 100 bunches of sprays. Spray carnations do not respond well to STS owing to a lack of uniform uptake.

Boxes are run through forced-air coolers to drive the temperatures down to 0–1°C for storage and shipping. Flowers can be dry stored at 0–1°C for 2–4 weeks. Open flowers are held in buckets (wet storage) at 3–4°C for 1–2 weeks. Buds are less sensitive to ethylene, thus they have a longer storage capacity than open flowers. A high relative humidity (90–95%) prevents desiccation. The vase life is up to 28 days with the use of flower food solutions and anti-ethylene treatments.

REFERENCES

Aydınşakir, K., Özçelik, A., Büyüktaş, D. and Tüzel, I.H. (2009) Quality characteristics of drip irrigated carnation (*Dianthus caryophyllus* L. cv. 'Eilat') under protected conditions. *Acta Horticulturae* 807, 307–312.

Center for the Promotion of Imports (CPI) (n.d.) Exporting carnations to the Netherlands. Ministry of Foreign Affairs. Available at: www.cbi.eu/market-information/cut-flowers-foliage/carnation/netherlands (accessed 1 August 2020).

Jawaharlal, M., Ganga, M., Padmadevi, R., Jegadeeswari, V. and Karthikeyan, S. (n.d.) A technical guide on carnation. Tamil Nadu Agricultural University. Available at: www.agritech.tnau.ac.in/horticulture/pdf/A%20Technical%20Guide%20On%20Carnation.pdf (accessed 1 August 2020).

Kazaz, S., Yılmaz, S. and Sayın, B. (2009) Comparison of soil and soilless cultivation of carnation in Isparta Province. *Acta Horticulturae* 807, 547–552.

Office of the Gene Technology Regulator (2006) Biology of Dianthus caryophyllus L. (Carnation). Australian Government, Dept. of Health and Ageing. Available at: http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/content/carnation-3/$FILE/bioeco-carnation.pdf (accessed 1 August 2020).

CHRYSANTHEMUM

Scientific name: *Chrysanthemum* × *morifolium* (syn. *Dendranthema* × *grandiflorum*)
Common names: chrysanths, chrysanten, mums, pompons
Chrysanthemums are native to China and Japan where they have been in cultivation as ornamentals for centuries. Mums are herbaceous perennials that are produced like an annual crop that flowers in 11–12 weeks from transplant. As a member of the Asteraceae family, the flowers are actually an inflorescence, termed a composite, head or capitulum, consisting of hundreds of individual disk and/or ray florets. Disk florets contain both male and female parts, whereas the showier ray florets contain only female flowers.

Market

Chrysanthemums are in the top three cut flowers sold internationally. They are extremely popular in Japan where they have been cultivated since the

17th century. Japanese growers have also taken a unique approach towards year-round flower forcing. While most of the world produces mum flowers throughout the year by implementing strict photoperiod schedules, the Japanese have taken an approach that works more closely with nature. They have bred and selected cultivars that naturally flower at different times of the year owing to their differing photoperiod requirements for flower initiation and development (Kawata, 1969).

Cultivars and related species

Cultivars are categorized by product form, flower color, flower type, flower diameter, response time, vigor, *Fusarium* tolerance and vase life. Individual growers may produce as many as 200 cultivars throughout the year to provide an array of products targeting different markets, holidays and events.

The three product forms for chrysanthemum are:

- *Standard/disbud*: a large, solitary flower (up to 14 cm diameter) is displayed atop each stem. Axillary flower buds located below the terminal flower are removed (disbudded) as they become large enough to roll out without damaging the stem. Expandable nets may be placed over individual flowers to protect them during harvest, processing and shipping.
- *Spray*: the terminal flower bud is removed to allow axillary flowers to develop uniformly. The individual flowers are 3–9 cm in diameter. A stem may contain 7–12 potential flowers.
- *Santini*: spray-type chrysanthemums with numerous tiny blooms. The individual flowers are 2–5 cm in diameter, and a stem may have 15–30 flowers. Santini typically are available in single and pompon forms.

Hobbyists categorize mums into as many as 13 flower types, but commercial growers tend to utilize just six main categories, although distinct lines between the categories can be blurred owing to extensive hybridization.

- *Single/daisy* – classic daisy appearance with one to multiple (semi-double) rows of ray florets around the perimeter, surrounding a central section of green/yellow, disk florets. Flowers 5–9 cm in diameter.
- *Anemone* – similar to the single/daisy form except that the florets in the center of the flower are shortened ray florets that resemble a pincushion in the center. Flowers 5–9 cm in diameter.
- *Decorative/cushion* – a double-flower form with florets that are progressively shorter toward the center of the flower. The petals in the center of the flower are incurved (curved inwards) while the petals on the outer portion of the flower are reflexed (curved outwards). Flowers 5–9 cm in diameter.
- *Pompon/button* – shortened petals in double-flower form creating a small, globe-like flower that has a button-like appearance. Flowers 3–4 cm in diameter.
- *Spider* – long, tubular ray florets that terminate with a hook or coil, creating a fireworks- or spider-like display. Flowers 8–14 cm in diameter.

The color categories for chrysanthemum include: yellow, white, red, purple, pink, orange, green and bicolor. In reality, mums are available in innumerable tones, tints and shades of these colors, which allows growers to target specific markets and holidays throughout the year. For example, pastel shades are popular during spring, while gold, orange, maroon and bronze are popular in the autumn. Green flowers are marketed for Saint Patrick's Day. White cultivars are particularly versatile since they can be painted or dyed any color imaginable.

Production practices

Chrysanthemums are relatively easy to propagate and grow, thus market prices are relatively low. The production systems tend to be relatively low-investment, low-tech facilities located in favorable climates; however, highly automated facilities are also utilized in Europe. These systems eliminate hand labor with the exception of cutting harvest prior to propagation and cut flower harvest at the end of the production cycle. All tasks in between have been eliminated, from sticking cuttings to transplanting rooted cuttings to transporting plants to and from the greenhouses.

Propagation begins with tissue culture for the purpose of supplying clean, virus-free plants to stock plant producers. Stock plant production is mostly done by specialists in equatorial locations. These growers supply unrooted cuttings for the international market and/or for their own in-house production locations. Shoot-tip cuttings are 5–7 cm long, and the lower one to two leaves may be removed. Older production systems harvest suckers (shoots emerging from below the soil) as propagation material. Hormone (IBA) dips and foliar sprays promote adventitious root formation.

Rooted cuttings are transplanted to ground beds. Hydroponic systems are equally effective, but their implementation has been limited by the high capital expenditure required. Cultivars with high *Fusarium* tolerance may be required in locations where that soil-borne pathogen has been present.

Spacing varies from 64–100 plants/m^2 for standard mums and can be as low as 32 plants/m^2 for sprays that receive one or two pinches during the vegetative stage (Fig. 2.6). The decision for spacing depends on the local economics. Where labor is more expensive or less available, it is most economical to plant at a higher density while minimizing the amount of labor required to grow the crop. This approach also minimizes the crop time, which can allow up to four crops per year from a single greenhouse bed. In other situations where labor is more available and production efficiencies are less vital, the grower may choose to transplant fewer plants but spend more time and labor on each plant, e.g. pinching the plants once or twice. The appropriate-sized netting (10–15 cm^2) is used to support the stems as they grow.

Fig. 2.6. Chrysanthemum crop in a greenhouse. (Photo: J. Faust.)

Plant growth regulators can be used to promote or inhibit stem elongation. Daminozade (2500–3000 ppm) may be applied two to four times to reduce stem elongation and improve leaf color. GA (50–150 ppm) may be applied multiple times to promote stem elongation when needed.

Chrysanthemums are short-day plants with respect to flowering. Long days are provided during stock plant production, propagation and the first few weeks after transplant to maintain the plant in a vegetative state. Compact florescent lamps and white LEDs have replaced incandescent bulbs for providing long days. The light intensity delivered to crop should be >2 µmol·m^2/s (~10 footcandles or ~108 lux, however conversions depend on light source) to prevent flower initiation. Lighting can be provided as day-length extension or night interruption. The critical night length is 13–14.5 h, depending on the cultivar. Long days are typically provided for 3–5 weeks or until the shoots are 20–50 cm tall. Then short days are provided for the remainder of the crop to initiate and develop flowers. In equatorial locations, the natural day length of 12 h is sufficient for flowering, so lighting is used to provide long days and then natural day lengths are used for the short-day period. Cultivars are rated by their response time. This is the time from the start of short days until flower. Modern cultivars of cut flower mums tend to fall into the 7–9-week response time categories, although it must be noted that these times are under optimal temperatures, while warmer or cooler temperatures will slow the rate of flower development, resulting in longer response times. Under optimal conditions, a mum crop can be produced in as little as 11 weeks (3 weeks of long days + 8 weeks of short days). This would allow for a single bed to produce four crops per year.

The desired range of temperatures is 16–25°C, with 18–22°C being optimal. Carbon dioxide concentrations up to 600–900 ppm benefit plant growth. Relative humidity should be between 60 and 85%, while >90% should be avoided, since this environment produces soft growth and increases the potential for fungal and bacterial pathogens to infect the crop (Kumar *et al.*, 2007).

Crown buds are a term used to describe flower buds that fail to develop. This phenomenon occurs when the temperature and photoperiod conditions have been met for flower initiation but not for flower development. Hence, a flower bud forms but does not mature into a normal flower.

Excessively high temperatures (>25°C) can cause some double-flower cultivars to develop as semi-double, i.e. the ray florets in the center of the flower revert to disk florets. Sunscald can also appear on standard flowers during hot temperatures and high light. The damaged petals will eventually turn brown and become desiccated.

For long-distance shipping, standard forms can be harvested in the bud stage (5 cm diameter or greater) and then opened with bud-opening solutions (Dole *et al.*, 2017). Bud opening solutions improve hydration, which helps to increase bud opening and avoid bent neck and flower wilting. Stems should be placed in the solution for 1–2 h at room temp or overnight at 1–3°C. For local markets, standard mums are harvested when fully open or the outer row or two of ray florets are fully open and perpendicular to the stem. Single-flower types should be harvested before pollen appears on the outer row of disk florets.

Spray forms should be harvested when most petals on the most mature flowers are still upright. Typically, sprays contain three to six open flowers and more to come. Flowers will continue to open after storage and transport. Spray anemone types should be harvested when outer ray florets are open, but interior ray florets have not started to elongate. Spray decorative types should be harvested when the centers of the oldest flowers are fully open.

Mum stems are harvested by grasping the stem and then pulling the entire plant out of the soil and cutting. Leaves are stripped from the lower third, although if leaf necrosis is a problem, additional leaf removal may be necessary to prevent this problem from shortening vase life. During processing, sprays are cut to 50–80-cm lengths, while standards are cut to 80–100 cm.

Irrigation and nutrition

Irrigation ranges from 7.5 to 10 l/m^2/day, which is delivered over multiple irrigation events per day. A typical fertilizer recipe is shown in Table 2.3. The same concentration can be applied throughout the cropping cycle; however, the volume

Table 2.3. A typical fertilizer recipe for a constant liquid fertilization program. The electrical conductivity of the fertilizer solution is typically in the range of 2.0–3.0 dS/m.

	Concentration	
Nutrients	ppm	mM
N	170–200[a]	12–14
P	30–60	1–2
K	200–220	5.1–5.6
Ca	100–130	2.5–3.2
Mg	40–60	1.6–2.5
Fe	2–3	0.036–0.054
Mn	1–3	0.018–0.055
B	1	0.09
Zn	0.5	0.0076
Cu	0.5	0.0078
Mo	0.1	0.001

[a]90% $N–NO_3$, 10% $N–NH_4$.

of solution applied needs to increase as leaf area increases. For ground beds, soil should be amended annually with organic matter, e.g. rice hulls or compost.

Major pests

Fusarium and white rust are the major pathogens, and white rust is a quarantine pathogen in some countries. Soil solarization to 50°C is used to reduce fusarium. A number of other diseases can occur including botrytis blight, powdery mildew, itersonilia petal blight, stemphylium leaf and flower spot, alternaria leaf spot, pythium root rot, phytophthora root and stem rot, bacterial wilt and soft rot, aster yellows and crown gall.

Several viruses can infect chrysanthemums. See Table 6.1 in Chapter 6 for a complete list of possible viruses.

Thrips are the primary insect pest, but mites and aphids can also cause challenges. Several nematodes can be problematic including *Aphelenchoides*, *Pratylenchus* and *Meloidgyne* spp.

Postharvest management

The major limitations to vase life are the failure of flower buds to open, leaf chlorosis and leaf necrosis. In general, the flowers tend to have longer vase life than the foliage. Chrysanthemum flowers are not ethylene-sensitive, but ethylene can cause leaf yellowing.

Following harvest, if the stems are not going to be immediately packed, they are placed in a postharvest field solution (Fig. 2.7). After processing and

Fig. 2.7. Harvest of chrysanthemum stems. (Photo: J. Faust.)

prior to packaging, stems should be placed in a pulse solution containing 2–4% sucrose for up to 24 h. Stems should be recut every time they are placed into a new solution in the postharvest environment. Leaf chlorosis can be addressed through the use of cytokinins, e.g. benzyladenine (10 ppm), in the pre-packaging bucket solution.

Storage at 0–1°C can be done 2–4 weeks prior to shipping. The further that the flower is developed at the time of harvest, the longer it can be stored. After storage of budded stems, stems should be recut and and placed in bud-opening solution containing 2–3% sucrose at 15–20°C for 16 h (Reid, 1997). Retail shops use hydration solutions to promote water uptake.

Leaf necrosis is a recent phenomenon that results in the leaves turning black and becoming desiccated after only a few days in the final vase solution. Cultivar sensitivity varies widely with green-flowered cultivars being the most sensitive. The cause of leaf necrosis is not yet understood.

REFERENCES

Dole, J.M., Stamps, R., Carlson, A., Ahmad, I. and Greer, L. (2017) Chrysanthemum. In: Laushman, J. (ed.) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers, Oberlin, Ohio, pp. 164–165.

Kawata, J. (1969) Year-round production of chrysanthemums in Japan. *Japan International Research Center for Agricultural Sciences* 4, 23–27.
Kumar, R., De, L. and Baiswar, P. (2007) Production of chrysanthemum under greenhouse condition. In: *Advanced Technologies for Production of Commercial Flower Crops under Greenhouse Condition*. Indian Council of Agricultural Research-National Research Centre for Orchids, Pakyong, Sikkim. pp. 40–44.
Reid, M.S. (1997) Ornamental produce facts: chrysanthemum, florist mum. Available at: postharvest.ucdavis.edu/Commodity_Resources/Fact_Sheets/Datastores/Ornamentals_English/?uid=11&ds=801 (accessed 1 August 2020)

DENDROBIUM ORCHID

Scientific name: *Dendrobium* × *hybrida*
Common name: dendrobium
The genus *Dendrobium* includes over 1000 species of epiphytic orchids that are native throughout south, east and Southeast Asia and the Pacific islands. Breeding efforts and commercial production are concentrated in Southeast Asia, particularly Thailand, and Hawaii, so dendrobiums are often thought of as plants to be grown only in high-temperature, high-humidity, tropical climates; however, dendrobium species include a wide range of ecotypes that are even adapted to subtropical and temperate climates, so great opportunities exist to further hybridize dendrobium species.

Dendrobium cultivars grown for cut flower production possess erect, cane-like stems (pseudobulbs) that grow from the base of the pseudobulb grown during the previous growing season (sympodial growth). In the wild, the plants climb by clinging to trees and rocks with their aerial roots. In commercial production, the plants are grown in highly porous, gravel-like substrates or in coconut husks attached to concrete blocks or pillars.

The leaves (10–14 cm long × 3–5 cm wide) appear alternately up the cane. The inflorescence is a raceme, but the industry refers to them as spikes or sprays. Spikes emerge from the leaf axils near the terminus of the cane. Each plant produces 5–10 spikes/year as they mature over multiple years, and each spike holds 5–15 flowers.

Market

Dendrobium sales account for 70–80% of US$500 million global cut flower orchid market (Cheamuangphan *et al.*, 2013), and Thailand is the largest producer (Thammasiri, 2015), while other leading countries include the Netherlands, Taiwan, Singapore, Malaysia and the USA (Hawaii).

Dendrobium are sold as flowering stems and as individual flowers, which are used for garlands and are considered to be a lei flower in Hawaii. The wide range of flower colors, sizes and forms available as well as their good vase life account for the strong market demand. The most common dendrobium cut flowers are shades of pink and purple, while Thai cultivars include yellows, reds and greens. Additional variation is created through the dyeing of white and bicolor (white and pink) flowers.

Cultivars and related species

Thousands of hybridized cultivars exist with a range of colors, including purple, pink, white, red, yellow, green, orange and bicolor. Important dendrobium species are pictured and described by De *et al.* (2013).

Flower sizes are graded as: small (<5 cm), medium (5–7.5 cm) and large (>7.5 cm). The spikes are 30–50 cm long and are graded as: small (30 cm spike, 4–5 open flowers), medium (40 cm spike, 6–8 open flowers, large (45 cm spike, 8–10 open flowers) and extra-large (50 cm spike, >10 open flowers) (De *et al.*, 2005). Cultivars can also be categorized based on their temperature responses, e.g. cool (10–24°C), intermediate (14–26°C) and warm (16–30°C).

Production practices

Dendrobium can be propagated from seeds, offshoots (keikis), division of pseudobulbs and from cane cuttings (10–12 cm with three nodes) placed in a moist propagation medium. Thai cultivars are tetraploids that are clonally propagated via tissue culture (Fig. 2.8). In this system, one young pseudobulb can produce 10,000 plants in 1–2 years. Thai breeding has relied more heavily on *Dendrobium phalaenopsis*, which provides large, fully shaped flowers. Hawaiian cultivars are amphidiploid (double diploid) and are primarily propagated by seeds. Hawaiian breeding has relied on *D. phalaenopsis* and *Dendrobium gouldii*, which provide higher spike yield, spike length, flower numbers per spike and postharvest longevity (Leonhardt and Sewake, 1999).

Crop flower crops are planted at a density of 37,000–54,000 plants/ha in shade houses (galvanized steel greenhouse structures covered with shade cloth, Fig. 2.9). Shade cloth can consist of one layer of 25% light reduction or two layers (one permanent layer of 25% shade and one retractable layer of 50% that is used only in the middle of the day). Polyethylene coverings may be needed in areas of high rainfall (>10 cm/month). Too much light will cause leaf yellowing, sunburn and stunting. Excessively low light will produce dark green leaves and poor flowering (Naik and Bharathi, 2012).

Excellent ventilation is essential for dendrobium production, and the relatively humidity must stay above 50%. Misting may be required during sunny and hot days to maintain adequate humidity in the plant canopy. Optimal day

Fig. 2.8. Tissue culture propagation of Dendrobium orchids in Thailand. (Photo: J. Faust.)

temperatures are 24–29°C, while night temperatures are kept above 18°C. Cooler temperatures reduce productivity.

GA (50–200 ppm) alone or in combination with benzyladenine (10–25 ppm) can be used to improve spike length and number (De *et al.*, 2013).

Thai dendrobium have peak flowering in February through May, while Hawaiian dendrobium peak in June through November. For long-distance markets, spikes are harvested when 30–40% of the flowers are open. Proper postharvest bucket solutions will be needed for the buds to fully open. Stems can be harvested with 75% open flowers for local markets.

Fig. 2.9. Dendrobium flowers growing in shade houses in Thailand. (Photo: J. Faust.)

Irrigation and nutrition

Since dendrobium orchids are epiphytic plants, they must be grown in or on extremely porous substrates and be provided relatively low fertilizer rates via a constant liquid fertilization program. Foliar feeding is also a common technique for use with epiphytic orchids, while controlled-release fertilizers are beneficial in areas with high rainfall. Dendrobium have seasonal growth cycles, e.g. a vegetative phase is followed by a flower initiation phase, followed by a flowering phase. Thus, the fertilization program is also altered seasonally. Little fertilization is needed during flower initiation. Moderate fertilizer rates with a low N:K ratio are used during flowering, and the higher fertilizer rates with a high N:K ratio are used during the vegetative growth phase. Nutrient management can be monitored and managed with foliar testing (Table 2.4).

The primary substrate for dendrobium is coconut husks and fiber blocks. Cocofiber lasts for several years but, as it decomposes, aeration decreases. Thus, the plants must be replanted to avoid a poor drainage situation. Alternatively, the plants can be established in cocofiber mounted on concrete blocks or posts (Fig. 2.10). Gravel or volcanic rock screened to 3–6 cm can be used to create raised beds or to fill containers. Watering and misting under benches also improves humidity. Keep in mind that overwatering can cause far more damage than underwatering for this crop, and excessive nitrogen will make the leaves darker green but will be deleterious to growth and flowering.

Table 2.4. Sufficiency ranges for foliar nutrient analysis of dendrobium. Collect leaf samples from the third mature leaf of a matured cane (pseudostem) or the third most recently matured leaf on an immature cane that has produced at least six mature leaves. (From Leonhardt and Sewake, 1999.)

Nutrient	Sufficiency range
Nitrogen	1.45–1.90%
Phosphorus	0.15–0.22%
Calcium	1.75–2.40%
Magnesium	0.40–0.80%
Sulfur	0.15–0.50%
Iron	50–150 ppm
Manganese	30–100 ppm
Zinc	50–150 ppm
Copper	8–15 ppm

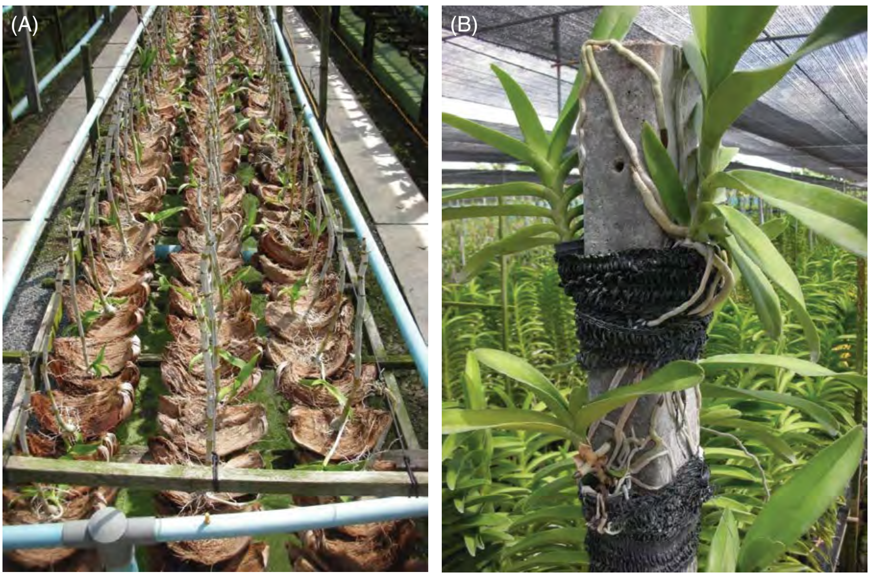

Fig. 2.10. Dendrobium orchids established on coconut husks (A) and attached to concrete posts (B). (Photos: J. Faust.)

Major pests

Leonhardt and Sewake (1999) and Naik and Bharathi (2012) provide thorough discussions of the major pests (aphids, ambrosia beetles, black weevil, caterpillar, mealybug, blossom midge, orchid weevils, plant bugs, scale, shoot borer, spider mites, thrips, whiteflies, birds, mice, slugs and snails), fungal organisms (*Botrytis*, *Alternaria*, *Cercospora*, *Colletotrichum*, *Exserohilum*, *Bipolaris*, *Colletotrichum*, *Phyllosticta*, *Fusarium*, *Phytophthora*, *Pythium*, *Rhizoctonia*, *Pseudocercospora* spp.), bacteria (*Pseudomonas* and *Erwinia* spp.), viruses (Cymbidium mosiac virus (CyMV) and Odontoglossum ring spot virus (ORSV)) and nematodes (*Apthelenchoides*). Stemphylium leaf and flower spot has also been reported as well as many additional viruses (see Table 6.1 in Chapter 6) and at least one nematode (*Meloidogyne*).

Postharvest management

The vase life for dendrobium spikes is 2–3 weeks. Spikes harvested during hotter months are reported to have a shorter vase life. The primary limiting factor for vase life is the disruption of water absorption owing to bacterial contamination of cut stems. Dendrobium are also harvested as loose flowers for garlands, leis and for decorating food (Fig. 2.11).

Dendrobium are ethylene-sensitive, so flower petal abscission can damage shipments if proper handling techniques are not used. Ethylene is a naturally occurring plant hormone that is produced following pollination of the flower or as a result of wounding and handling during and after harvest. Ethylene damage results in droopy flowers or transparent flower petals that have dry patches or are discolored. In severe cases, flower abscission occurs.

Fig. 2.11. Loose dendrobium flowers are harvested for decoration and adornment. (Photo: J. Faust.)

To prevent ethylene perception 1-MCP can be used during shipping. Ethylene scrubbers, such as potassium permanganate ($KMnO_4$), do not work well, in general, for densely packed shipping boxes. However, sachets or packaging materials that contain ethylene scrubbers may be useful for dendrobium because the lack of leaves and the relatively low product density may allow for sufficient air movement for the scrubber to reduce the ethylene concentration in the box.

Spikes can be placed in field postharvest bucket solutions immediately after harvest or can be transported dry (out of water) to coolers if the transport logistics are efficient. Dendrobium are chilling-sensitive, so the minimum cooler temperatures range from 5 to 10°C, depending on the duration of time spent in the cooler. For example, 10°C is acceptable for storage periods >4 days, 8°C is acceptable for 2 days and 5°C is acceptable for 1 day (Leonhardt and Sewake, 1999). The first sign of chilling injury appears as darkening of the labellum (lip or landing pad for pollinating insects), then progressive discoloration occurs in the sepals/petals or bud.

After processing, stems are placed in a pre-packaging solution, a.k.a. pulse solution, where they are treated with an anti-ethylene compound, an acidifier and a biocide. The lack of leaves on flowering spikes results in low transpiration (water uptake) and lack of carbohydrate supply, thus supplementing sucrose in solutions is critical. Sucrose (6%) and benzyladenine (25 ppm) have been reported as beneficial (Naik and Bharathi, 2012).

Prior to packaging the base of the spikes are placed either in a water vial with a postharvest solution or in contact with moistened cotton that has been dipped in biocide and wrapped in polyethylene film with rubber bands to prevent desiccation (De *et al.*, 2015).

Spikes can be stored for 10–14 days under ideal conditions (10°C and 90–95% relative humidity). After transport to the wholesale distributor, the stems are placed in a storage/transport solution containing a biocide, an acidifier and sucrose. A similar solution is used at the retailer for display and/or bud opening. The sucrose levels are typically higher in this display/vase solution than in the storage/transport solution.

REFERENCES

Cheamuangphan, A., Panmanee, C. and Tanusuchat, R. (2013) Value chain analysis for orchid cut flower business in Chiang Mai. *Business and Information* July 7–9.

De, L.C., Barman, D., Medhi, R.P., Chhetri, G. and Pokhrel, H. (2013) Production technology of dendrobium. Technical Bulletin No. 13. National Research Centre for Orchids, Sikkim, India.

De, L.C, Pathak, P., Rao, A.N. and Rajeevan, P.K. (2015) Post-harvest management of cut flower of commercial orchids. In: De, L.C. (ed.) *Commercial Orchids*. DeGruyter Open, Warsaw, pp. 250–269.

Leonhardt, K. and Sewake, K. (1999) Growing Dendrobium Orchids in Hawaii, a Production and Pest Management Guide for Hawaii Growers. College of Tropical Agriculture and Human Resources, Univ. of Hawaii at Manoa.
Naik, S.K. and Bharathi, U. (2012) Production Technology of Dendrobium Cultivation. ICAR Research Complex for Eastern Region Research Centre, Ranchi, India.
Thammasiri, K. (2015) Current status of orchid production in Thailand. *Acta Horticulturae* 1078, 25–33.

FREESIA

Scientific name: *Freesia* × *hybrida*
Common name: freesia
Freesias are frost-sensitive, herbaceous perennial plants grown from corms. The flowers are produced on one-sided, leafless racemes and are perhaps the most fragrant of all cut flower species. The funnel-shaped flowers consist of six tepals. The foliage appears in sword-like fans, similar to other members of the iris family (Iridaceae). Freesias originate from East and South Africa.

Market

With a broad range of colors (Fig. 2.12), strong wiry straight stems and light fragrance, freesia is one of the world's most popular cut flowers. It has consistently ranked among the top five flowers sold at the Royal FloraHolland Auction (Hanks, 2018). Freesia is also grown as a potted flowering plant for indoor use and as a garden ornamental in suitable climates.

Fig. 2.12. Fragrant freesias are available in many colors. 'Pink Glow' is shown here. (Photo: J. Dole.)

Cultivars and related species

Hundreds of cultivars are available ranging in color from white to pink, rose, purple, yellow and orange. Single and double flowers and bicolors are available with a different colored throat, usually yellow or orange. Flower stem length varies from long in cut flower cultivars to short in those grown for potted plant production. Fragrance can also vary with the cultivar, with it generally being the strongest in yellow cultivars (Wongchaochant *et al*., 2005). Interestingly, approximately 10% of people may not be able to smell freesia fragrance, owing to a genetic mutation that leaves them unable to perceive β-ionone, one of the major scent constituents of freesia (Wooding, 2013). Newer varieties have been bred to be more tolerant of warm soil temperatures.

Production practices

Freesias are greenhouse-grown from corms, purchased from large-scale producers, typically in the Netherlands. Corms are produced in both the northern and southern hemispheres to supply fresh corms year-round.

Commercial corms are stored at 30°C for at least 3 months (programmed) to flower rapidly after planting (De Hertogh, 1996). After the corms arrive from the supplier, they should be planted immediately. If planting is delayed, corms should be stored at 13°C for no more than 3 weeks.

Corms (4–7 cm circumference) are planted at 96–120/m^2, with the tighter spacing (approximately 2.5 cm apart) during high light times of the year, and the wider spacing (approximately 5 cm apart) during low light periods. Corms are planted about 5 cm deep as measured from the base of the bulb. The substrate should have a pH of 6.5–7.2, be well drained and free from fluoride. Freesia can be produced in ground beds or in trays, and one to three layers of netting are often used to prevent stems from leaning and curving.

Freesias grow best in high light and at cool temperatures between 13 and 16°C (Fig. 2.13). In cool climates, freesias can be produced year-round. However, in warmer climates, freesias are produced primarily in the winter as warm substrate temperatures above 16°C will prevent flowering. A soil cooling system can be used to maintain proper soil temperatures, but this is increasingly not profitable. Newer varieties have been bred to be more tolerant of warm soil temperatures. Supplemental carbon dioxide at 1000 ppm can improve plant quality (Doorduin, 1990).

Corms sprout within 2 weeks of planting, and flower harvest will occur as quickly as 95 days after planting at warm times of the year to as long as 126 days during cool times. The harvest period lasts approximately 4 weeks. Supplemental lighting for 16 h/day is sometimes used to improve flower quality (Doorduin, 1992), especially in the winter, but economics may prevent its use.

Fig. 2.13. Bed of freesia plants. Note side vents in greenhouse for passive cooling. (Photo: J. Dole.)

Freesia plants can be reflowered, but the process is generally not cost-effective and plants become increasingly prone to virus infection. If practiced, irrigation reduction should begin approximately 6 weeks after final flowers are harvested. Dig and store plants at 25°C for 2–3 weeks in an area with excellent air circulation to finish drying the plants down. Then remove corms and cormlets and place them at 30°C to prepare them for replanting or at 2°C to hold for long-term storage (Imanishi, 1993). Cormlets can be planted as well and will produce a flowering-sized corm within a year.

Irrigation and nutrition

Plants should be kept moist but not wet to avoid root and corm rot. Freesias produce contractile roots that pull corms deeper into the substrate, making it more likely that overwatering will occur. Allowing plants to wilt when the flower spikes are forming will result in crooked stems. Avoid use of water with fluoride, which can cause foliar tip burn that might progress toward the middle of the leaves with greater exposure. Drip irrigation works best as that avoids water on the foliage, which can cause disease and result in the plants leaning over.

Freesias have a moderate fertilizer requirement. One recommendation calls for 200 ppm N from 20-20-20 every other week (De Hertog, 1996). Avoid ammonium-based fertilizers owing to the cool growing conditions.

Major pests

Aphids and thrips are the most problematic insects, with the latter being especially difficult to control. Viruses cause the most serious diseases. Unfortunately, many different types of viruses (bean yellow mosaic, cucumber mosaic, freesia sneak, tobacco rattle) are known to infect freesia, with symptoms typically including foliar mottling, streaked or brown flowers and reduced plant vigor (Dreistadt, 2001; Bobev *et al.*, 2013). Be sure to purchase freesia corms from reputable sources and be aware that the spread of viruses in a production greenhouse will limit reuse of the corms for multiple crops.

Botrytis can damage the flowers, and wilt and corm rot are caused by a number of organisms: *Fusarium oxysporum* f. sp. *gladioli*, *Rhizoctonia* sp., *Erwinia* sp. and *Stromatinia gladioli* (Dreistadt, 2001). Rust (*Uromyces transversalis*) has also been reported on freesias.

Postharvest management

Stems are harvested for wholesale use when one or two florets are puffy and just starting to open (Dole *et al.*, 2017). If harvested when too immature, buds will not open properly; however, treatment with carbohydrates will increase bud opening. Flowers sold for local use can be harvested when more developed with the first flower open and two to three more buds showing color. Flowers should last 7–10 days.

Stems should be treated with flower foods containing carbohydrates to increase the number of buds opening. Very high rates of sugars, from 4 to 20%, have been used experimentally as pulse treatments to increase bud opening, flower size and color.

Freesias are ethylene-sensitive with the most common symptoms being shortened vase life of open florets and lack of bud opening (Spikman, 1986; Zencirkiran, 2010). Treatment with STS or 1-MCP prevents bud abortion.

Cut stems can be stored dry at 0–1 °C and 95% relative humidity for less than a week or in water at 1–2 °C for a week. Treating stems with either 1-MCP or STS will increase vase life after storage (Dole *et al.*, 2005). Ship in water, if possible.

REFERENCES

Bobev, S.G., Taphradjiiski, O.I., Hammond, J. and Vaira, A.M. (2013) First report of *Freesia sneak virus* associated with foliar necrosis of *Freesia refracta* in Bulgaria. *Plant Disease* 97, 1514.

De Hertogh, A.A. (1996) *Freesia* cut flowers. In: *Holland Bulb Forcer's Guide*, 5th ed. International Flower Bulb Centre, Hillegom, the Netherlands, pp. C59–C63.

Dole, J.M., Fonteno, W.C. and Blankenship, S.L. (2005) Comparison of silver thiosulfate with 1-methylcyclopropene on 19 cut flower taxa. *Acta Horticulturae* 682, 249–256.

Dole, J., Stamps, R., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers Press, Oberlin, Ohio.

Doorduin, J.C. (1990) Effects of CO2 and plant density on growth and yield of greenhouse freesias. *Acta Horticulturae* 268, 171–177.

Doorduin, J.C. (1992) Effects of photosynthetic lighting on freesia grown for winter flowering. *Acta Horticulturae* 325, 85–90.

Dreistadt, S.H. (2001) *Integrated Pest Management for Floriculture and Nurseries*. University of California Division of Agriculture and Natural Resources, Publication 3402, Davis, California.

Hanks, G. (2018) A Review of Production Statistics for the Cut Flower and Foliage Sector. The National Cut Flower Centre, Agriculture and Horticulture Development Board (AHDB), Holbeach St. Johns, Lincolnshire, UK.

Imanishi, H. (1993) Freesia. In: De Hertogh, A. and Le Nard, M. (eds) *The Physiology of Flower Bulbs*. Elsevier, Amsterdam, pp. 285–296.

Spikman, G. (1986) The effect of water stress on ethylene production and ethylene sensitivity of freesia inflorescences. *Acta Horticulture* 181, 135–140.

Wooding, S. (2013) Olfaction: it makes a world of scents. *Current Biology* 23, PR677–PR679.

Wongchaochant, S., Inamoto, K. and Doi, M. (2005) Analysis of flower scent of *Freesia* species and cultivars. *Acta Horticulturae* 673, 595–601.

Zencirkiran, M. (2010) Effects of 1-MCP (1-methylcycloprene) and STS (silver thiosulfate) on the vase life of cut *Freesia* flowers. *Scientific Research and Essays* 5, 2409–2412.

GERBERA DAISY

Scientific name: *Gerbera jamesonii* and hybrids
Common names: gerbera daisy, African daisy, transvaal daisy
Gerbera daisies are native to South Africa. Modern breeding was initiated in the 1890s in England. Current breeding efforts are concentrated in the Netherlands. High susceptibility to several pests and diseases makes gerbera one of the more challenging cut flower crops to grow, and, in particular, the postharvest disorder called stem bending makes gerbera one of the more challenging cut flowers to ship and market. Nonetheless, the beauty of the flowers and the amazing array of available colors, sizes and forms continue to make gerbera a popular choice among consumers.

Market

Gerbera are the fifth largest cut flower species marketed through the Dutch auctions, accounting for 5.7% of sales, which includes nearly 1 billion stems (CBI Market Intelligence, 2016).

Cultivars and related species

Hundreds of cultivars provide a broad palette of red, pink, yellow, orange, purple, white, cream, light green and bicolor flowers. As a member of the Asteraceae family, the inflorescence consists of various combinations of ray and disk florets displayed in a head or capitulum atop a leafless stem or scape. In the industry, the inflorescence is termed a flower. Gerberas can be classified into the following sizes and forms:

Sizes are based on flower diameter:

- standard (10–13 cm)
- mini (5–9 cm).

Flower forms are differentiated by variations in ray and disk florets:

- *Standard/single* flowers comprise a single row of non-overlapping ray florets around the outer perimeter that surround an 'eye' composed of yellow/green or dark red/brown/black disk florets.
- *Semi-double* flowers consist of multiple rows of overlapping ray florets surrounding yellow/green or dark red/brown/black disk florets.
- *Crested double* flowers consist of multiple rows of overlapping ray florets and inner rows of shortened (crested) ray florets surrounding yellow/green or dark red/brown/black disk florets.
- *Fully crested double* flowers consist of multiple rows of overlapping ray florets, inner rows of shortened (crested) ray florets and no disk florets.
- *Fully double* flowers have relatively long and numerous ray florets throughout the inflorescence, resulting in a somewhat rounded, three-dimensional appearance.
- *Spider/quill* flowers possess all ray florets in fine-textured/narrow petals. Inner rows of ray florets progressively diminish in size. They are available in mini and standard sizes.

Some cultivars are specifically marketed as 'pollen-free', which is desirable for cleanliness in the consumer environment.

Production practices

Cut flower gerbera cultivars are mainly propagated by tissue culture, and almost exclusively grown under protected cultivation. As young plants, they are particularly sensitive to water sitting on the surface of immature leaves, which then become distorted as they expand. Extreme care must be exercised during transplant as planting too deeply causes crown rot and delayed or distorted flowers. Spacing is at 30–40 cm, and flowers are supported by an individual layer of netting.

The ideal temperatures average 24°C during the day and 15°C at night with an average daily temperature of 20–21°C. Excessively high temperatures (>32°C) will cause missing petals (ray florets) in the flower. Relative humidity should be maintained between 70 and 85%. Flowering is not affected by photoperiod, but long days do promote leaf elongation.

Production can be done in ground beds or in hydroponic substrates; however, yields are 20–30% higher in hydroponic substrates, and the percentage of Grade A stems is also higher (Fig. 2.14).

Yield varies with the flower form. Standard cultivars produce 240–360 stems/m^2/year in substrate, while spider standards yield a lower 220–300 stems/m^2/year. The yield of mini flowers is quite a bit higher at 450–650 stems/m^2/year.

Standard flowers are harvested at 60–75 cm stem length, while minis produce 50–70 cm stem lengths. To provide the longest vase life, single flowers are harvested when the two outer whorls of disk florets show pollen (Reid, 2004). Cut stems are immediately placed in a field postharvest bucket solution in the greenhouse before being transported to the packing house. These solutions help to reduce the bacterial population, improve flowering opening and decrease wilting. Standard/single flowers are harvested when two outer rows

Fig. 2.14. Greenhouse-grown, hydroponic gerbera crop. (Photo: J. Faust.)

of disk florets in the eye have begun to open and are showing pollen. Stems are harvested by twisting and pulling them away from the crown. The bottom 10 cm of the stem is then cut off to improve water uptake. Green plastic tubes may be placed around the stem to reduce stem bending. Gerbera stems are packed individually to avoid flower damage and are often suspended in a cardboard sheet so that the stems hang freely.

Irrigation and nutrition

Gerbera production is largely moving to hydroponic systems owing to the higher yields and improved disease management in soilless systems. Khalaj and Kanani (2018) recommend nutrient solutions based on cut flower yield and vase life (Table 2.5).

Several nutritional deficiencies are particularly problematic with gerbera. Magnesium deficiency is displayed by interveinal chlorosis of the mature leaves. Iron deficiency appears as whitish-yellow immature leaves. Boron deficiency is expressed with numerous distorted leaves. Boron applied at a rate of 0.25 ppm in a constant liquid fertilization program should prevent this disorder. Note that leaf distortion is also promoted by water sitting on immature leaves as mentioned above. Manganese toxicity can occur when the soil or media pH is low (<5.5). The symptoms appear as black/bronze spotting on older leaves.

Table. 2.5. Nutrient concentrations for nutrient solutions used on gerbera daisy. The electrical conductivity of the solutions will be 1.45–1.50 dS/m. (From Khalaj and Kanani, 2018.)

	Concentration	
Nutrients	ppm	mM
N	120–170	8.5–12.0
P	37	1.2
K	164–215	4.2–5.5
Ca	120–160	3–4
Mg	24	1
S	42	1.3
Fe	2	0.035
Mn	0.16–0.27	0.003–0.005
B	0.32–0.38	0.030–0.035
Zn	0.20–0.26	0.003–0.004
Cu	0.05–0.06	0.0008–0.001
Mo	0.10	0.001

Major pests

Thrips are a tremendous challenge in daisy type flowers, like gerbera, where innumerable hiding places exist for this cryptic pest. Media drenches with entomopathogenic nematodes have proved to be a valuable management tool since thrips pupate in the soil or media where they become prey.

Whiteflies, mites and leaf miners specifically target leaves, not flowers. Since the leaves are not shipped with the flowers, the symptoms are not as devastating as they are with potted gerberas. Thus, a low population of these pests can be tolerated; however, large populations will reduce plant growth and yield, so providing adequate control is required. Whiteflies can proliferate on the undersides of leaves where they can be difficult to target with spray applications. The reduction in neonicinoid-based pesticides has made whiteflies more challenging to control. In dry climates, mites can become a nuisance. This includes two-spotted, broad and cyclamen mites. Leaf miners are more easily controlled than whiteflies and thrips, but occasionally they escape detection and become problematic. Fungus gnat larvae feed on roots and stem, which can weaken plants and make them more susceptible to pathogens.

Several pathogens create problems for gerberas. *Phytophthora cryptogea* (collar rot) creates an infection at soil surface, resulting in yellow leaves before wilting occurs on the entire plant. Pythium, fusarium wilt, rhizoctonia root and stem rot, and sclerotinia crown and root rots can be a problem resulting from poor irrigation management.

Botrytis blight targets the disk florets and the flower receptacle (the green calyx that subtends the flower head), while the showy ray florets are less susceptible. Itersonilia is a relatively new and unknown pathogen that targets gerbera. The initial symptom is a small, dark spot on the foliage that can be easily confused with several other foliar fungal diseases. Stemphylium can cause similar leaf and flower spots.

In terms of bacteria disease *Pseudomonas* can be a problem. Unfortunately, gerberas are susceptible to a number of viruses (see Table 6.1 in Chapter 6).

Powdery and downy mildew attacks foliage and flowers. Improved circulation, humidity control and burning sulfur can improve control of powdery mildew. Nematodes (root-knot nematode, spiral and others) can create problems in soil-based production systems.

Postharvest management

Freshly cut gerbera stems should be placed in field postharvest bucket solutions while still in the greenhouse. The solution contains a biocide to control the high bacterial count that can occur on the flower stems of gerbera. Also, an acidifier is added to the solution to improve water uptake and reduce the risk of dehydration.

Individual flowers are placed in cardboard trays and trays and suspended in solutions to keep stems straight. The stems are then dry shipped in the cardboard sheets. Interestingly, hydration is provided more for the stem than the flower, since more water is lost through the stems than the flowers themselves. Petal wilting at the end of the vase life is a signal that senescence is beginning.

Stem bending, termed bent neck, is the major limitation to vase life. It is defined as the abrupt bending/folding/collapse of a stem 5–15 cm below the flower prior to flower senescence. The cause of bent neck has been a widely studied phenomenon. Results suggest several key factors. Vascular blockage in the bottom 5 cm of the cut stem owing to bacteria can cause water loss and weakening of the stem (Yan, 2016). Thus, biocides applied in the postharvest bucket and vase solutions reduce bent neck. Harvesting too soon, before the stem has matured and hardened sufficiently, can also create weakened stems. Stems can snap owing to the weight of the flower head when the stem has inadequate stem wall thickening and low mechanical strength (Perik *et al.*, 2012). Sucrose (2–4%) in the shipping/storage bucket solution can alleviate bent neck owing to the improved lignification of vascular bundles in sclerenchyma cells (Yan, 2016). Stems may be placed in plastic tubes to physically prevent stem bending regardless of the cause. Ultraviolet irradiation (UV-C, 200–280 nm) has also been shown to reduce botrytis blight (Darras *et al.*, 2012), which can target the base of the receptacle. Vase life benefits from a 24-h pulse immediately after harvest with a solution of calcium chloride (25–50 mM, 1000–2000 ppm Ca), 2.5% sucrose and citric acid buffer to maintain a pH at 3.5 (Perek *et al.*, 2014).

Gerbera are generally considered to be ethylene-insensitive. Dry storage at 1°C is possible for 4 days, but gerbera are not recommended to be stored for more than 7 days, thus sea transport is not an option.

REFERENCES

CBI Market Intelligence (2016) CBI trade statistics: cut flowers and foliage. Ministry of Foreign Affairs. Available at: https://www.cbi.eu/sites/default/files/market-information/trade-statistics-cut-flowers-foliage-2016.pdf (accessed 25 August 2020).

Darras, A.I., Demopoulos, V. and Tiniakou, C. (2012) UV-C irradiation induces defence responses and improves vase-life of cut gerbera flowers. *Postharvest Biology and Technology* 64, 168–174.

Khalaj, M.A. and Kanani, M. (2018) Flower longevity and quality attributes of gerbera cut flower affected by different nutrient solutions. *Journal of Applied Horticulture* 20, 247–252.

Perik, R.R.J., Razé, D., Harkema, H., Zhong, Y. and van Doorn, W.G. (2012) Bending in cut *Gerbera jamesonii* flowers relates to adverse water relations and lack of stem sclerenchyma development, not to expansion of the stem central cavity or stem elongation. *Postharvest Biology and Technology* 74, 11–18.

Perik, R.R.J., Razé, D., Ferrante, A. and van Doorn, W.G. (2014) Stem bending in cut *Gerbera jamesonii* flowers: effects of a pulse treatment with sucrose and calcium ions. *Postharvest Biology and Technology* 98, 7–13.

Reid, M.S. (2004) Ornamental produce facts: gerbera, transvaal daisy. Postharvest Center, University of California. Available at: postharvest.ucdavis.edu/Commodity_Resources/Fact_Sheets/Datastores/Ornamentals_English/?uid=17&ds=801 (accessed 1 August 2020).

Yan, Y. (2016) Effects of some preservative solutions on vase life in *Gerbera jamesonii*. MSc Thesis, Massey University, New Zealand.

GLADIOLUS

Scientific name: *Gladiolus* × *hortulanus* (hybrids)
Common names: gladiolus, glad
Gladiolus is an herbaceous perennial produced from corms. The flowers appear on a one-sided spike. Individual flowers comprise six tepals that form a funnel-shaped perianth. The foliage appears in sword-like fans. One shoot and one flowering stem are produced from each corm. Commercial hybrids primarily originate from at least eight different species from South Africa, although the 300+ *Gladiolus* species can also be found in Mediterranean Europe and Asia.

Market

The gladiolus has remained popular for many years, particularly in northern hemisphere countries and Southeast Asia. In the United States, Canada and many other temperature climate locations, the gladiolus was a locally grown summer field flower, popular as dramatic single-stem bunches in homes or as part of large funeral displays. In time, the image of large glad spikes as a funereal flower led to decreased sales. However, the recent emphasis on local production has led to a resurgence. In warm climates, Zones 8–10, gladiolus can be treated as a perennial, but large-scale production generally relies on re-planting corms annually.

Gladiolus remains very popular in Southeast Asia, especially in Pakistan and India, and white is the most popular color in those countries. In India, gladiolus is one of the most important cut flower species grown along with marigolds, roses and tuberoses.

Cultivars and related species

With hundreds of cultivars available, almost any color can be found in gladiolus from pure white to yellow, orange, red, rose, pink, purple and all shades in between (Fig. 2.15). While blue is absent, blackish maroon or purple, brown and even green-flowered gladiolus can be grown. Most striking are the

Fig. 2.15. Gladiolus are available in a stunning array of colors and combinations of colors. (Photo: J. Dole.)

stunning multi-color gladiolus, often with different colors in the throat or on the edges of the petals.

Large-flowered gladiolus are most commonly grown, but smaller flowered cultivars are available as well. The smaller gladiolus are easier to use in small arrangements and mixed bouquets. Small-flowered gladiolus can be grown at higher densities, making them more amenable to tunnel or greenhouse production. The American Gladiolus Council has set up the following classification system for flower diameter:

- miniature: <6 cm
- small: 6–9 cm
- medium: 9–11 cm
- large: 11–14 cm
- giant: >14 cm.

In addition, the International Flower Bulb Centre presents the following categories:

- Large-flowered: florets ≥10 cm across and spikes ≥75 cm long. Generally used only for cut flower production and sold as single-species bunches.

- Small-flowered: florets averaging 7 cm and flower stems between 65 and 75 cm long. Often used for mixed bouquets but also for potted flowering plants.
- Nanus: florets 5–10 cm across and short stems. Used as potted flowering plants.

Gladiolus cultivars are categorized by the number of days to flower after planting:

- very early (VE): <70 days
- early (E): 70–74 days
- early midseason (EM): 75–79 days
- midseason (M): 80–84 days
- late midseason (LM): 85–90 days
- late (L): 91–99 days
- very late (VL): >100 days.

Production practices

Gladiolus is most commonly field-grown in beds or ridges of soil, but can also be greenhouse- or tunnel-grown during the cooler time of the year. In the field, sandy loam soil works best as it is well drained and easily worked when planting and harvesting corms. Avoid heavy soils that do not drain well. If needed, raised beds can be used to improve drainage. Soil pH should be 6.0–6.5.

Flower size is determined by the cultivar, corm size and planting density (Table 2.6). Increasing planting density will increase stem production and profitability up to a point, after which stem quality will be reduced and botrytis issues increase.

If using purchased corms, they should be planted soon after they are received. If planting is delayed, the corms can be briefly stored in a dry, well-ventilated location at 17–20°C. Corms that need to be stored longer should be kept at 2–5°C (International Flower Bulb Centre, n.d.).

Gladiolus is generally planted in rows 30–60 cm apart with the individual corms spaced at 5–15 cm apart within the row. Corms may also be planted

Table 2.6. Corm size and recommended planting density for gladiolus. (From International Flower Bulb Centre, n.d.; USDA, 1997.)

Corm size (cm)	USDA size designation	Corms/m^2
6/8	#4 (medium)	60–80
8/10	#3 (medium)	50–70
10/12	#2 (large)	50–70
12/14	#1 (large)	30–60
14+	Jumbo	30–60

in double rows, approximately 15 cm apart. Larger corms will produce longer stems and more leaves and flowers/stem with fewer days to shoot emergence and flowering (Uddin *et al.*, 2002; Kareem *et al.*, 2013). Large operations usually use planting machines.

Corms are planted 5–15 cm deep, with the deeper planting on lighter, sandy soil. Planting corms deeper in the soil will help reduce stem lodging, but may delay shoot emergence by a few days. The latter will become less of an issue as the soil warms up in the summer. Be sure to rotate plantings on a 2–3-year schedule to reduce the likelihood of diseases.

It can be challenging to maintain a continuous supply of high-quality cut gladiolus. Generally, warm temperatures in the summer will decrease crop time (e.g. 110–120 days at 12°C, down to 60–70 days at 25°C), large corms will flower earlier (e.g. 12/14 corms will flower up to 3 weeks earlier than 8/10 corms) and deeper planting may delay flowering. In addition, the various cultivars each have their own crop time and are categorized as early, mid or late flowering. To maintain continuous supply, corms will have to be planted every 1–4 weeks, depending on the market and climate.

Planting can start on or near the last day for frost. Be aware of the cold soil temperatures, less than 13–15°C will delay emergence and, if very cold, promote rotting. Clear plastic sheeting can be laid on the soil after planting to warm up the soil and promote rapid shoot emergence, at which time it is removed. This process is most efficiently used when growing gladiolus in beds.

For winter production in mild climates, artificial long-day lighting will increase stem quality and length and reduce the incidence of flower blasting (abortion). Long-day lighting can be provided as a 4–5-h day extension or as a 2–4-h night interruption with 2-4 $\mu mol/m^2/s$ at the plant level (Armitage and Laushman, 2003). Planting large corms helps to overcome the negative effects of low light.

Gladiolus can also be grown in greenhouses or tunnels, the former providing more control over the environment during the late fall, winter and early spring. Maintaining high light intensity and temperature control is particularly important when growing gladiolus under cover. Wider spacing and larger corms can be used to compensate for the reduction in light. As with the field, clear plastic sheeting can be laid on the soil after planting to warm up the soil and promote rapid shoot emergence, at which time it is removed. Be sure to use cultivars specifically listed as suitable for growing under cover. Netting is often used in greenhouse production, but not in field production.

Some growers dig and reuse corms. During harvest, be sure to leave some foliage, four leaves is recommended, on the stems to regenerate a new corm. In such cases, flowers can be harvested with small, curved knives that slide down along the lower leaves to the base of the plant and then cut horizontally to remove the stems. Harvest the corms after the foliage has started to turn yellow or after the first frost (Armitage and Laushman, 2003). Dig corms, cut off foliage near the corm and spread corms on screen trays or bulb crates to provide excellent ventilation. Do not exceed four layers of corms. Cure the corms at 24–29°C for 10–15 days to allow the corms to dry and any wounds to callus.

Gladiolus stems are harvested one of three ways:

- Pull up entire plant, bunch and trim to length, removing the corms. Works best with loose sandy loam soils and reduces stem bending.
- Cut off at ground level, bunch and trim to length.
- Cut low on the stem, leaving four leaves for regeneration of the corm, bunch and trim to length.

Irrigation and nutrition

Gladiolus need regular rain or irrigation. Wilting might cause stems to become crooked or flower bud blasting, reducing quality. Plants are most sensitive to water stress immediately after planting and when four to seven leaves have been produced and the flowers are developing (Armitage and Laushman, 2003). Avoid high electrical conductivity water.

Test the soil and amend accordingly. Thereafter, a balanced granular fertilizer, such as 5-10-10 or 5-15-5, should be applied at planting and again about a month later or at the third or fourth leaf stage (International Flower Bulb Centre, n.d.; Armitage and Laushman, 2003). Additional fertilization may be needed in sandy soils, especially if there has been a lot of rain. Apply 7.3–9.8 kg/1000 m^2 N during the season. Divide this rate by the number of applications during the crop cycle.

Fertilizers can also be provided through the irrigation system. Nitrate nitrogen is typically used when the soil is cool and wet and ammonia or urea when soils are warm.

Major pests

Gladiolus are susceptible to a broad range of diseases, including corm rots, bacterial and fungal spots and many viruses. Of the many corm rots, *Fusarium oxysporum*, *Botrytis gladiolorum* and *Stromatinia gladioli* are the most common, with *Fusarium* generally being the most destructive. Control of the disease starts with corm production and digging, and continues with storage, transportation and planting. Dust corms with fungicide and store at 4°C and 70–80% relative humidity. Hot water treatments at 55–58°C can be used to control corm disease (Cohen *et al.*, 1990; Dreistadt, 2001).

The bacteria *Pseudomonas marginata* infects corms and *Xanthamonas* causes water-soaked spots on the leaves.

Fungal leaf spots include *B. gladiolorum*, *Curvularia lunata*, *Curvularia trifolii* f. sp. *gladioli*, *Urocystis gladiolicola*, *Stemphylium* spp. and *Septoria gladioli*

(Dreistadt, 2001; Moorman, 2016). *Uromyces gladioli* and *Uromyces transveralis* cause rust diseases on gladiolus.

Numerous viruses such as bean yellow mosaic, cucumber mosaic, tomato ringspot, tomato spotted wilt and tobacco ringspot infect gladiolus, resulting in small, distorted flowers, abnormal flower coloring and mottled or blotchy foliage (Moorman, 2016). There is no cure for viruses; control the vector to prevent spread and destroy infected plants as soon as they are seen.

Since gladiolus are generally field-grown, they are susceptible to nematodes, especially root-knot nematode (*Meloidogyne*), which can stunt plants and delay flowering. Nematodes are best prevented by planting in uninfested soil.

Thrips are the major insect pest, causing petal distortion and white streaking. *Botrytis* is destructive on the flowers during harvest, storage and shipping, particularly during cold, wet harvesting periods.

Postharvest management

The long spikes with many buds present both postharvest opportunities and challenges. Flowers are generally harvested when the lowest flower shows color as many of the buds should open for the consumer with proper postharvest care. For local sales, stems can be harvested with the lowest two to three flowers open. Flower petals are easily damaged if harvested when one or more flowers are open.

The key to a long vase life with gladiolus is to supply stems with carbohydrates that will encourage continued opening of the buds. The carbohydrates can be applied at a high concentration (20% sucrose) overnight or at a lower concentration (4%) for multiple days. Antimicrobial biocides should be included to reduce bacterial contamination.

Stems can be stored dry at 2–4°C for up to 2 weeks, if pretreated with a 10% sucrose + STS solution for 24 h. Treatment with 1-MCP gas can be used in place of the STS. Either anti-ethylene agent will help protect stems from abortion of the immature flower buds. Stems can be stored in solutions for up to 1 week.

Do not use water containing fluoride. Doing so may lead to transparent flower petal margins, failure of the flowers to open, burning of the flower sheath, marginal leaf scorch and premature wilting (Dole *et al*., 2017).

It is critical to keep gladiolus stems upright at all times. If allowed to lean or if placed horizontal, the tips will turn upwards. When placing in buckets, be sure there are enough stems in the bucket to keep them upright but do not overpack the buckets.

Stems should last 7–10 days in water and up to 14 days when using floral preservatives. Retailers should treat stems with floral preservatives containing sugar upon receipt.

REFERENCES

Armitage, A.M. and Laushman, J.M. (2003) Gladiolus. In: *Specialty Cut Flowers*, 2nd edition. Timber Press, Portland, Oregon, pp. 297–303.

Cohen, A., Barzilay, A. and Vigodsky-Haas, H. (1990) Hot-water treatment tolerance in gladiolus cormels and their state of dormancy. *Acta Horticulturae* 266, 495–503.

Dole, J., Stamps, R., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers Press, Oberlin, Ohio.

Dreistadt, S.H. (2001) *Integrated Pest Management for Floriculture and Nurseries*. University of California Division of Agriculture and Natural Resources Publication 3402.

International Flower Bulb Centre (n.d.) Gladiolus as cut flowers. Available at: https://edepot.wur.nl/167428 (accessed 11 January 2020).

Kareem, A., Khan, A.M., Rehman, S.U.R. and Afzal, I. (2013) Different corm sizes affect performance of *Gladiolus grandiflorus* cvs. Red Majesty and Early Yellow. *Advances in Zoology and Botany* 1, 86–91.

Moorman, G.W. (2016) Gladiolus diseases. PennState Extension. Available at: https://extension.psu.edu/gladiolus-diseases (accessed 15 December 2019).

Uddin, F., Rahman, M., Rabbani, G. and Mannan, A. (2002) Effect of corm size and depth of planting on the growth and flowering of gladiolus. *Pakistan Journal of Biological Sciences* 5, 553–555.

United States Department of Agriculture (USDA) (1997) United States standards for grades of gladiolus corms (bulbs). Available at: https://www.ams.usda.gov/sites/default/files/media/Gladiolus_Corms_Standard%5B1%5D.pdf (accessed 11 January 2020).

GYPSOPHILA

Scientific name: *Gypsophila paniculata*
Common names: gypsophila, gyp, baby's breath
Gypsophila is an herbaceous perennial species native to the Mediterranean and Eastern Europe well known for its cloud-like display of numerous, small, white or pink flowers used as filler in floral arrangements. The inflorescence is a panicle, the narrow, lance-shaped foliage is rather sparse and the flowering stems are leafless. Ecuador is a leading international supplier.

Market

Gypsophila has been a traditional filler matched with roses; however, in recent years it is beginning to be marketed by itself in arrangements. Dyes provide variety and allow designers to create the perfect color to fit the décor or event.

Gypsophila is sold in bunches of 25; however, the grading process is often based on mass, not stem length, since mass reflects the degree of branching within the inflorescence. Stem mass ranges from 10–35 g/stem. The inflorescence can be broken down into various lengths needed for arrangements of all sizes. The flowers are mildly fragrant, but this is not always perceived positively. Flowers are easily dried.

Cultivars and related species

Cultivars are categorized based on individual flower size, e.g. small (5–7 mm), medium (8–10 mm) and large (11–13 mm). White flowers dominate the selection, but pink are also available. Dyes are the preferred method of achieving different flower colors. The individual flowers can be flat and have semi-double appearance or contain numerous petals in a double-flower form than creates full, rounded flowers. The inflorescence can provide a dense and robust display or an open and loose display. Strong, erect and well-branched flowering stems are desirable.

Cultivars are also rated on yield and tolerance to soil-borne diseases. Breeding efforts aim toward reducing day-length sensitivity and reducing the duration of the production phase, i.e. the time to return a new crop of flowers following the previous harvest.

Production practices

Tissue culture is the primary means of propagation. Bud micro-cuttings are grown at 23°C and 16-h photoperiods (Lopez and Gonzalez, 2006).

Production occurs in full sunlight field situations as well as under protected cultivation in tunnels. Shade cloth may be required to manage temperatures during tunnel production. Outdoor plantings are done during winter months, while greenhouse crops can be planted any time of year. Tunnels allow rain to be kept off the plants; however, the high-humidity conditions inside the tunnels also allow for some pathogens to thrive.

The plants go through two or three flowering cycles per year, termed flushes, and remain productive for 2–3 years (Lopez and Gonzalez, 2006). Planting density is five to eight plants/m^2 (35–45 cm spacing between plants) in 1-m-wide beds with 0.5-m aisles. Two layers of netting are needed to support the flowering stems.

Gypsophila are obligate, long-day plants, meaning that long days (>12–24 h) are required for flowering. Optimal flower quality and length occur with 16–18-h photoperiods (Kusey *et al.*, 1981). A total of 50–60 consecutive long days are required (Hicklenton *et al.*, 1993). Photoperiodic lighting is used to force plants when the natural day length is <13 h. Cyclic lighting that provides one-third light on and two-thirds light off is effective for creating long-day conditions. Twelve nodes are needed for a plant to perceive the long-day signal.

After transplant, commercial crops will typically have 20 nodes present in the rosette on new plantings before long days are provided. This occurs ~3–5 weeks after transplant. Following flowering, plants are pruned at 2–3 cm above ground level, then long days are provided whenever the next flush of flowers is desired. Plants are typically forced to flower ~3–4 months after planting or pruning.

Far-red light needs to be part of the spectrum of the photoperiodic lighting. Fluorescent lamps cannot be used for photoperiodic lighting of gypsophila since they lack far-red light.

Ideal temperatures are 25°C day and 15°C night temperature, while plants are sensitive to temperatures <5°C. High temperatures (>25°C) produce shorter floral stems and fewer flowering nodes (Moe, 1988). Cool night temperatures (<12°C) result in vegetative growth even if long days are provided (Shillo and Halevy, 1982); however, GA (150–500 ppm) applied one or two times after pruning and in combination with long days will promote flowering during cool months (Ju *et al.*, 2003). GA does not stimulate flowering under short days. Benzyladenine (BA, 100–300 ppm) promotes flower initiation under long days and seems to substitute for the cold requirement. It has been recommended to expose rooted cuttings to 2°C for 40–55 days, then treat with 100 ppm BA (Doi *et al.*, 1989).

Flowering stems can be harvested when 30–40% of flowers have started to open, but can also be done when just 5% of the flowers are open (Lopez and Gonzalez, 2006). Gypsophila crops will yield 700,000–1,000,000 stems/ha/year.

Irrigation and nutrition

Well-drained soils or substrates are required. The volume of irrigation solution and the concentration of nutrients in those solutions vary with each of the three stages of crop development (vegetative growth, floral initiation and early development, and flowering). Each stage lasts ~20–50 days (Lopez and Gonzalez, 2006). Nitrogen concentration starts at 150 ppm during the vegetative stage and decreases to 100 ppm at the flowering stage. The volume of solution applied is 3–4 l/m^2/day during the vegetative stage and decreases slightly during each crop stage.

Major pests

Major pests include: spider mites, aphids, thrips, whiteflies, leaf miners and caterpillars. Nematodes include: *Heterodera*, *Meloidogyne* and *Pratylenchus*.

Major fungal disease organisms include: *Alternaria*, *Botrytis*, *Erysiphe*, *Fusarium*, *Peronosphora*, *Phytophthora*, *Phoma*, *Pythium*, *Rhizoctonia* and *Sclerotinia* spp.

Major bacterial disease organisms include: *Erwinia*, *Agrobacterium*, *Pseudomonas* and *Rodococcus* sp., as well as aster yellows. The laboratory technique known as polymerase chain reaction (PCR) is used to characterize and identify *Erwinia herbicola* pv. *gypsophilae* (Manulis and Barash, 2003).

Viruses are known to infect gypsophila, especially tomato ringspot and cucumber mosaic.

Postharvest management

The postharvest process for gypsophila is unique compared with other cut flowers. Stems are harvested as the first 5% of the flowers open, and then are placed in a growth room under lights and at warm temperatures to force additional flowers to open (Fig. 2.16). This technique is used to prevent senescence and Botrytis infection of the first open flowers before additional flowers open. Thus, flowers of different ages display a uniformly healthy appearance. Note that gypsophila flowers are ethylene-sensitive.

The growth room consists of 20–22°C temperatures, 40–60% relative humidity and supplemental lighting that provides 10–50 μmol/m^2/s for 24 h/day. The high end of the lighting range allows for flower opening without stem elongation. The stems are placed in a postharvest bucket solution containing a biocide and a high sugar level (~10% sucrose).

Fig. 2.16. Growth rooms are used to open gypsophila flowers prior to shipping. (Photo: J. Faust.)

Alternatively, stems are harvested at 20% open flower and placed in a pre-packaging postharvest solution containing a biocide, an anti-ethylene compound and 5–10% sucrose (Dows *et al.*, 1988). Sugar levels can be adjusted seasonally with lower rates needed during summer months. The storage and shipping environment should be 1–2°C and 90–95% relative humidity. Dry stems reduce the spread of botrytis. Vase life can be expected to be up to 3 weeks with appropriate use of vase solutions.

REFERENCES

Doi, M., Takeda, Y. and Asahira, T. (1989) Effects of BA treatment on growth and flowering of some vegetative lines of *Gyposophila paniculata* L. 'Bristol Fairy' selections as influenced by temperature and shoot-root interactions. *Journal of the Japanese Society for Horticulture Science* 60, 119–124.

Dows, C.G., Jong, J.S., Chang, C., Eun, L.J., Eun, C.G. and Hak, P.B. (1988) Bud-opening treatments to improve Gypsophila quality after transport. *Scientia Horticulturae* 34, 301–310.

Hicklenton, P.R., Newman, S.M. and Davies, L.J. (1993) Night temperature, photosynthetic photon flux, and long days affect *Gypsophila paniculata* flowering. *HortScience* 28, 888–890.

Ju, C.H., Young, D.C. and Byoung, R.J. (2003) Effects of planting date, chilling treatment of liners, growth regulator, and lighting on flowering. *HortScience* 28, 888–890.

Kusey, W.E., Weiler, T.C., Hammer, P.A., Harbaugh, B.K. and Wilfret, G.J. (1981) Seasonal and chemical influences on the flowering of *Gypsophila paniculata* 'Bristol Fairy' selections. *Journal of the American Society for Horticultural Science* 106, 84–88.

Lopez, J. and Gonzalez, A. (2006) In: Teixeira da Silva, J.A. (ed.) The use of photoperiodic lighting in floriculture in Mediterranean conditions: *Gypsophila paniculata.* In: *Floriculture, Ornamental and Plant Biotechnology, Vol.* 1. Global Science Books, London, pp. 276–281.

Manulis, M. and Barash, I. (2003) The molecular basis for transformation of an epiphyte into a gall-forming pathogen as exemplified by *Erwinia herbicola* pv. *Gypsophilae*. In: Stacey G. and Kenn, N. (eds) *Plant-microbe Interactions.* American Phytopathological Society, St. Paul, Minnesota, pp. 19–52.

Moe, R. (1988) Flowering physiology of Gypsophila. *Acta Horticulturae* 218, 153–158.

Shillo, R. and Halevy, A.H. (1982) Interaction of photoperiod and temperature in flowering-control of *Gypsophila paniculata* L. *Scientia Horticulturae* 16, 385–393.

LILY

Scientific name: *Lilium* hybrids
Common name: lily
Lilies include 80+ herbaceous perennial species that are typically propagated by bulbs. The bulbs are formed by a collection of scales that lack an external covering, or tunic. Plants in the *Lilium* genus are often referred to as 'true lilies', since the name lily is frequently used as a common name for plants in other genera. Lilies have been cultivated for centuries as ornamental and medicinal

plants. The large flowers are often fragrant and appear at the terminus of a solitary shoot. Individual flowers comprise six tepals.

Market

Lilies have a long history of cultivation and are one of the most popular flowers in the world. They are grown as garden ornamentals, potted flowering plants and, of course, cut flowers. Lilies are one of the top 5–10 flowers at the Royal FloraHolland auctions in the Netherlands (Hanks, 2018) and are the most important domestically produced cut flower in the United States (USDA, 2016).

Cultivars and related species

Considering how long lilies have been cultivated, it is not surprising that thousands of cultivars are available, in addition to many beautiful species. Those suitable for cut flower production fall into the following groups:

- *Asiatic* (A) – upward-facing, open flowers in a broad range of colors including white, cream, yellow, orange, bronze, pink, rose and bicolors. Cultivars grown for cut flower production are taller than those grown for potted flowering plants.
- *Longiflorum* (L) – *Lilium longiforum* has outward-facing, trumpet-shaped, white, fragrant flowers. Commonly associated with the Easter holiday in many countries, it is grown year-round in some countries and serves as a parent of many hybrids. Cultivars grown for cut flower production have fewer flowers per stem that are more upright-facing and are taller than those grown for potted flowering plants.
- *LA hybrids* (LA) – hybrids between *L. longiflorium* and the Asiatic group with upward- to outward-facing flowers in a broad range of colors. Some have trumpet-shaped flowers, others are more open.
- *Oriental* (O) – large fragrant outward- to slightly upward-facing open flowers in a limited color range of white, pink and dark rose. Many have darker spots on the tepals. Double-flowered types, known as roselilies, have many petals, mild fragrance and no stamens, eliminating problems from the pollen.
- *LO hybrids* (LO) – hybrids between *L. longiflorium* and the Oriental group with fragrant, upward- to outward-facing flowers that are smaller than those of Oriental lilies. These hybrids are among the newest on the market.
- *OA hybrids* (OA) – hybrids between the Oriental and Asiatic groups with mildly fragrant, outward- to upright-facing flowers that come in a broader range of colors than Oriental types including yellow, orange and various bicolors.

- *OT hybrids* (OT) – hybrids between the Oriental and Trumpet/Aurelian groups with large, fragrant, outward- to upright-facing flowers that come in a broader range of colors than Oriental types including yellow, orange and close to true red (Fig. 2.17).

Many species of lilies are grown as garden ornamentals, but most tend to be fairly difficult to use as cut flowers as they have downward-facing flowers. Cut lily cultivars also vary in production time, bud count/stem and height.

Production practices

Cut lily production uses commercially grown bulbs produced in both the northern and southern hemispheres to provide high-quality bulbs year-round. In addition, bulbs are stored long-term at temperatures of −1 to −2°C to maintain cut stem quality during subsequent production. Freezing bulbs prevents premature sprouting and reduces the likelihood of disease. Asiatic and LA hybrids are typically stored at −2°C and the others at −1.5°C. However, bulbs frozen for an extended period will flower sooner, be shorter and have fewer buds. Thus, for off-season production fresh bulbs from the southern hemisphere are best used when available.

Fig. 2.17. The large, fragrant flowers of 'Shocking' make this OT variety especially striking. (Photo: J. Dole.)

Table 2.7. The bulb sizes available for different lily groups.

Group	Bulb size (circumference, cm)
Asiatic hybrids	10–12, 12–14, 14/16, 16–18 and 18+
Longiflorum hybrids	10–12, 12–14, 14–16, 16–18 and 18+
LA hybrids	12–14, 14–16, 16–18 and 18+
Oriental, OT, LO, OA hybrids	12–14, 14–16, 16–18, 18–20, 20–22 and 22+

Bulbs are available in a range of sizes. Large bulbs produce more flowers/stem, longer stems and higher stem weights (Table 2.7). The specific size of bulb to use will depend on the desired bud count/stem, planting density, cultivar, production season, market and economics. For example, cut lilies for bouquets should not have a high bud count and, thus, are typically grown from smaller bulbs.

Bulbs are shipped to producers in crates, with the number of bulbs/crate depending on the size of the bulbs (Table 2.8).

Optimum planting density will be a matter of trial and error for each producer, depending on the bulb size, cultivar, time of year and desired cut stem quality. Tighter spacings can typically be used during high light times, while lower densities can be used at other times (Table 2.9).

Lily bulbs need a cold treatment for 6–8 weeks at 1–2°C for proper flower initiation and development after planting. Suppliers typically provide the cold treatments prior to sending the bulbs to the grower or to freezing the bulbs for long-term storage. However, growers can provide the cold treatment themselves. The optimum precooling temperature and duration vary with cultivar.

Once frozen bulbs arrive, allow them to thaw at 10–12°C until ready to plant. Do not refreeze bulbs again as that may cause damage. If all of the frozen bulbs cannot be planted, it is best not to thaw them and hold below freezing until planting. If bulbs have not been frozen and cannot be planted immediately, they can be held at 0–2°C for 1–2 weeks. Regardless of the original condition, warm temperatures will allow the bulb shoots to start elongating, which might be damaged during planting.

Bulbs are planted with about 8–10 cm of substrate above the bulb. After planting, maintain temperatures of 10–12°C for 2–3 weeks to encourage stem rooting (roots originating from the shoot as compared with roots originating from the base of the bulb). The initial low temperatures will be more practical to provide if bulbs are grown in crates or trays, after which time the temperature is raised to the optimum temperature for production. Asiatic and LA lilies should be grown at 10–13°C night and 17–18°C day temperatures with an average daily temperature of 14–15°C, while Oriental lilies and their hybrids are best grown at 14–17°C night and 18–20°C day temperatures with an average daily temperature of 15–16°C. Soil temperature should be 10–12°C and should not go above 20–25°C.

Table 2.8. The number of bulbs/box for different bulb sizes.

Bulb size	Number of bulbs/box
10/12	500
12/14	400
14/16	300
16/18	200
18/20	150
20/22	100–125
22/+	75–100

Table 2.9. Planting density (bulbs/m²) for cut flowers in northern Europe based on flowering group and bulb size. (From Van den Bos Flowerbulbs, n.d.)

	Bulb size (cm)						
Flowering group	10/12	12/14	14/16	16/18	18/20	20/22	22/+
Asiatic	60–70	55–65	50–60	40–50	35–45	–	–
LA, OA	–	45–55	40–50	35–45	30–40	–	–
Oriental (with small leaves)	–	55–65	45–55	40–50	35–45	–	–
Oriental (with large leaves)	–	–	40–50	35–45	30–40	25–35	25–35
OT	–	55–65	45–55	40–50	35–45	–	–
Longiflorum	55–65	45–55	40–50	35–45	30–40	–	–

Production temperatures that are too high, in general, reduce quality, and increase the likelihood of flower bud abortion or deformities. Production temperatures that are too cold will delay the crop and result in leaf drop and yellowing. During warm times of the year, shade can be used to reduce the air temperature since high temperatures decrease vase life in lilies (Locke, 2010). However, both high temperatures and low light increase the incidence of bud abortion during production, reducing marketability. In such situations, shading can be used to maximize vase life, but planting density should concurrently be reduced to maximize the light interception and reduce bud abortion.

Lilies can be grown in crates, raised ground beds or in the field during the summer. Year-round production takes place in greenhouses and typically uses crate production.

Lilies are tolerant of a wide range of substrates as long as they are well drained. In greenhouses and tunnels, lilies are usually produced in crates filled with peat or coir-based substrates. In the field and under tunnels in some cases, lilies are grown in field soils. Heavy clay soils should be amended with organic matter prior to planting to improve drainage and aeration.

A substrate pH of 6–7 should be used for Asiatic, LA and Longiflorum hybrids, while a lower pH of 5–6.5 is recommended for Orientals and their hybrids. Lilies can be sensitive to high substrate electrical conductivity, which should be 1.0–1.5 dS/m. High soluble salts can damage roots, increasing the likelihood of root rots, as well result in soft growth and marginal leaf necrosis.

Lilies need high light to maintain stem quality and prevent bud abortion (Fig. 2.18). When grown in the winter, plant quality of some cultivars will be improved with supplemental lighting and carbon dioxide.

The crop time from planting until harvest varies with the cultivar, bulb storage duration, production temperature and weather (Table 2.10). Asiatic lilies may flower in as few as 8 weeks in the summer, while Oriental lilies may require almost 20 weeks in late winter/early spring. Table 2.10 shows general crop times for lilies produced in northern Europe.

Lily bulbs are generally used only once and then composted. However, field growers sometimes leave the bulbs in the ground for additional crops. Such plantings will produce marketable flowers for 2 or 3 years, but they will flower all at once, which can make marketing difficult.

Fig. 2.18. Greenhouse-grown Oriental lilies. (Photo: J. Dole.)

Table 2.10. Crop time for different lily groups and seasons (from Van den Bos Flowerbulbs, n.d.).

	Greenhouse period (days)		
Group	Spring	Summer	Autumn/winter
Oriental hybrids	90–135	75–100	80–120
Asiatic hybrids	60–105	60–75	50–90
Longiflorum hybrids	80–110	70–100	70–95
LA hybrids	65–110	70–80	55–95
LO hybrids	75–105	60–90	65–90
OT hybrids	90–125	60–90	90–110
OA hybrids	80–125	60–90	70–110

Irrigation and nutrition

Plants are irrigated as needed to prevent wilting and encourage stem elongation. Overirrigation will increase the likelihood of root and bulb rots. Proper irrigation is especially critical during the first few weeks until the stem roots develop. Note that leaves will often wilt in the middle of hot sunny days, especially after a period of cloudy weather, even when the substrate is well irrigated.

Drip irrigation is preferred to prevent water on the foliage and reduce the likelihood of botrytis, but overhead irrigation is often used from planting until canopy closure. Water should have an electrical conductivity of ≤ 0.5 dS/m. Be sure to use fluoride-free water to prevent marginal leaf burn.

Lilies grown in crates can be fertilized with nutrients through the irrigation system at 250–300 ppm N using a fertilizer with a 2:1 ratio of calcium nitrate to potassium nitrate. Lower nitrogen rates can be used if fertigating continuously. When grown in ground beds or outdoors, apply 5–7 g N/m^2 granular fertilizer using one that has 30–50% water-insoluble nitrogen to provide nitrogen for the entire crop cycle.

Major pests

Major insect pests in the greenhouse include aphids, thrips and bulb mites, of which aphids are generally the most common. Outdoors a variety of other insects can also cause problems, including the voracious lily beetle and grasshoppers. For the specialty cut producers growing lilies as a perennial crop, deer, voles and other rodents can decimate a planting.

Botrytis (*Botrytis elliptica*, *Botrytis liliorum* and *Botrytis cinerea*) can cause brown spots and patches on the foliage and petals. If present at harvest, botrytis can spread rapidly during postharvest in the presence of water and high humidity.

Root and bulb rots can be caused by a number of pathogens, especially *Pythium* and *Rhizoctonia solani* as well as *Colletotrichum* spp., *Cylindrocarpon* *radicicola*, *Fusarium oxysporum* f. sp. *lilii*, *Phytophthora* spp., *Sclerotium rolfsii* and *Sclerotium sclerotiorum* (Horst, 2013). Rust (*Uromyces*) and bacterial soft rot can also occur. Many viruses, such as arabis mosaic, cucumber mosaic, lily mottle, lily streak, lily symptomless, lily X, plantago asiatica mosaic, rosette, strawberry latent ringspot, tobacco necrosis, tobacco rattle, tomato spotted wilt, tulip breaking and tulip X can occur; be sure to buy bulbs from reputable sources. A host of nematodes can also attack the roots or foliage (see Table 6.1 in Chapter 6). Finally, a variety of leaf spots can occur, especially in field production, from various fungal organisms.

Postharvest management

For immediate use, harvest stems with one or two open flowers. For wholesale use, harvest stems with one or more buds well colored and fully formed but not yet open as lily petals are easily damaged during storage and shipping. However, harvesting too immature may mean that buds will not open and color properly.

Vase life should be 10–14 days with proper handling. All buds should open in the vase, if stems are treated with floral preservatives, not stored too long and not subjected to ethylene.

Treat flowers with a commercial postharvest bucket solution. Use products specifically developed for lilies as they generally reduce the leaf yellowing that can occur without the use of floral preservatives or with the use of general flower foods. Various solutions have been used experimentally to increase vase life including 10% sugar pulses. Carbohydrates are needed in the solutions to allow the buds to open and encourage color development of the petals. Commercial bucket solutions augmented with 2.5–5 ppm GA plus cytokinin (benyzladenine) for 20 h extended the vase life and prevented leaf yellowing of Oriental and Asiatic lilies (Ahmad *et al*., 2014).

Sensitivity to ethylene varies from insensitive to very sensitive, depending on the cultivar. Asiatic cultivars appear to be most commonly sensitive. Ethylene exposure results in yellowing of the leaves, failure of buds to open and premature petal abscission. Most sensitive cultivars should be treated with STS or 1-MCP to extend vase life.

Flowers may be stored wet or dry for up to 4 weeks at 0–2°C, if stems are harvested in the bud stage and properly treated before storage. Otherwise, do not store for more than a week. Some lilies, especially Oriental and OT hybrids, are sensitive to cold storage, which can produce bruising-like symptoms on the buds. To prevent damage, if harvesting from a hot greenhouse or field, place stems at an intermediate temperature for a while before placing in a cooler. Don't leave stems too long at the intermediate temperature as vase life might be reduced.

Lily flowers produce a lot of pollen, which can stain clothes. Remove anthers from open flowers before handling and marketing. Pollenless double-flowered cultivars are available. Pollen stains will disappear if clothes are left in direct sunlight for a day.

REFERENCES

Ahmad, I., Dole, J.M. and Favero, B.T. (2014) Pulsing with low concentration gibberellin plus benzyladenine or commercial preservatives affect postharvest longevity, quality and leaf chlorosis of cut lilies and gladioli. *HortTechnology* 24, 560–564.

Dole, J., Stamps, R., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers Press, Oberlin, OH.

Hanks, G. (2018) A review of production statistics for the cut flower and foliage sector. The National Cut Flower Centre, Agriculture and Horticulture Development Board (AHDB), Holbeach St. Johns, Lincolnshire, UK.

Horst, R.K. (2013) Lily. In: *Westcott's Plant Disease Handbook*, 8th Edition. Springer Dordrecht, Berlin, p. 579.

Locke, E. (2010) Extending cut flower vase life by optimizing carbohydrate status: preharvest conditions and preservative solution. PhD Dissertation, North Carolina State University. Available at: https://repository.lib.ncsu.edu/bitstream/handle/1840.16/6166/etd.pdf?sequence=1&isAllowed=y (accessed 22 March 2021).

United States Department of Agriculture (USDA) (2016) Floriculture crops 2015 summary. National Agricultural Statistics Survey, Washington, DC.

Van den Bos Flowerbulbs (n.d.) Lilies as cut flowers and as pot plants. Available at: https://www.vandenbos.com/downloads/content/6636/8d7bb6445a353f0/Lilium%20Forcing%20Guide%20English.pdf (accessed 20 June 2020).

PEONY

Scientific name: *Paeonia* hybrids, primarily derived from *Paeonia lactiflora*
Common names: peony, Chinese peony
Peonies are long-lived herbaceous perennials that are native to Central Asia, and thus are well adapted to temperate climates. The large, mostly fragrant flowers appear just once per year following a dormant, cold period. The compound leaves have nine leaflets with irregular margins. Tuberous roots store energy for the following year's growth. Peonies are relatively slow growing, so plants may require several years to reach peak productivity.

Market

One of the top 20 most commonly traded flowers at the Royal FloraHolland auctions in the Netherlands (Hanks, 2018), peony was ranked second in frequency of production in a survey of the North American cut flower industry, with 75% of respondents growing peonies (Loyola *et al*., 2019). While there is year-round market demand for peonies, production from any one region is limited to only a few weeks. Thus, multiple production sites have developed around the world to supply cut peonies most of the year (Kamenetsky and Dole, 2012).

Cultivars and related species

The long history of peony cultivation has resulted in thousands of cultivars over the years. However, the modern cut peony industry relies on a fraction of those cultivars, many of which have been grown for decades, if not centuries. Cultivars vary in color from white to red and from no to heavy fragrance. A number of flower types are available showing the progression from single flowers to fully double flowers:

- *Single* – dense central cluster of stamens and carpels surrounded by a single row of guard petals.
- *Japanese* – similar to single but anthers are large and the filaments of the stamens are broad, resulting in a more substantial central cluster.
- *Semi-double* – multiple outer rows of petaloids and guard petals surrounding a cluster of stamens and carpels.
- *Bomb* – very large central cluster of petaloid carpels and stamens surrounded by a single row of single guard petals.
- *Full double* – a large mass of petals in which there is little difference between those derived from stamens and carpels and the outer guard petals.

For practical reasons, most cut peonies are in the bomb or full double groups – buds with more petals take longer to open up (Fig. 2.19). However, enterprising growers use cultivars from any of the groups as long as there is a market.

While the flowering period for individual cultivars is generally only 7–10 days, careful selection of cultivars can result in a 4–6-week peony season. Not surprisingly, the peony season is longer in cooler climates and shorter in warm climates. Peony cultivars are categorized by early, mid and late season. One

Fig. 2.19. Bomb and full double peonies are most useful as they have many petals that take longer to open. (Photo: J. Dole.)

of the most commonly grown cultivars is Sarah Bernhardt owing to its large stems, high productivity, large attractive buds and overall reliability.

Production practices

Peonies are generally field-grown in Zones 3–8, but can also be tunnel- or greenhouse-grown in some situations. Tunnels can be used to provide earlier harvests, up to 3–4 weeks earlier. The tunnels are covered with plastic 3–4 weeks before the stems normally start sprouting, which will warm the soil and speed shoot emergence. The plastic is left off the tunnel during most of the winter, especially in warmer growing areas, to ensure that the crop receives sufficient cold to flower properly. Typically, tunnels are constructed over mature plantings. Building a tunnel first and then planting means the tunnel environment will be wasted until the plants mature and can be harvested. Be sure to control botrytis as tunnels are especially conducive to botrytis development.

Plants need proper vernalization during the winter to produce large numbers of long, high-quality stems. Insufficient cold during the winter will result in shorter, small stems or a lack of flowers. The amount of cold needed will vary with the cultivar. Halevy *et al.* (1995) determined that the optimum number of days at 6°C was 40 for most cultivars for shoot elongation and further flower development. Byrne and Halevy (1986) reported that the peony required a minimum of 4 weeks of 6°C to break dormancy and flower, while 6 weeks at 6°C or 1°C maximized the number of flowering shoots. Kamenetsky *et al.* (2003) suggested that 10 weeks at 6°C or 8.6 weeks at 2°C was optimum.

Peonies can be produced in areas without sufficient winter cold or forced early before the plants have received a full cold treatment by digging and cold-treating roots and applying 100 ppm GA3 (Halevy *et al.*, 2002). GA applications at 200–500 ppm can also partially substitute for cold in dormancy breaking, but the GA is not effective if applied prior to flower initiation (Evans *et al.*, 1990; Halevy *et al.* 1995; Cheng *et al.*, 2009). Excessive temperatures, especially night temperatures ≥22°C, during flower development will cause flower bud abortion (Kamenetsky *et al.*, 2003).

Be sure to prepare soil well before planting as these long-lived plants have a commercial life of up to 25 years or more. Test the soil and amend accordingly. Soil pH should be 6.5–7.0.

Dormant roots are used to establish plantings, which are usually made starting in late August through fall, winter or spring, depending on the climate. Generally, fall planting is preferred in most climates. Roots should be large and firm with two to three or three to five visible eyes (shoot buds). Roots with more eyes will be productive sooner but will cost more.

New plantings may produce flowers in the first year but they should not be harvested. Remove the bud and allow the foliage to support the roots and crown for next year's production.

Plants can be planted in single rows with plants 60 cm apart or in double rows that are 45 cm apart with the individual plants spaced 60 cm apart and in a staggered pattern (Fig. 2.20). Plants can be planted into holes in landscape fabric to control weeds. The holes will need to be enlarged as the plants grow. Landscape fabric will also heat up the soil, which might induce a little earlier harvest, but should not be used in warm climates as it will heat up the soil too much, which will reduce the cold available for vernalization and reduce stem length.

Crowns are planted ~5 cm deep. Deep planting will prevent flowering. Crowns can be planted a little shallower in southern climates to allow the roots to be exposed to more cold during the winter, which is needed for proper vernalization.

Support netting is not needed as the stems are sturdy and flowers are harvested at the bud stage when they do not weigh too much. Many resources recommend support but they are generally doing so for plantings being grown in gardens and landscapes when the large heavy flowers open up.

Traditionally, the side buds on peony stems were removed, which results in a larger main flower and makes the stems easier to harvest, process and pack. Side buds should be removed as soon as they can be handled by gently rolling

Fig. 2.20. Field of cut peonies in Chile close to harvest stage. (Photo: J. Dole.)

them out of the leaf axil. Waiting to remove the side buds will mean that they will be harder to remove as the bud stem will be thicker and woodier and there will be less of a benefit to increasing the size of the main flower. Today, side buds are still generally removed for wholesale and florist sales. However, many growers do not remove the side buds for local markets, bouquets and drying. The multi-flower stem has a longer overall vase life and provides more color.

Interestingly, peonies often have many ants on the flower buds. While annoying, they are not a problem as they are only there to harvest the tiny bits of sap on the buds. If there isn't much rain or the plants are growing under protection, the buds may need to be watered overhead to help wash off the sticky sap, which can impede opening of the flower buds.

Once plants are mature, all marketable flowers can be harvested as long as sufficient foliage remains on the plant to support next year's growth. For example, mature plants typically have a number of stems that do not flower and remain after harvest. In addition, cut the stem length needed. If the customers buy 45 cm stems, there is no need to pick longer stems and unnecessarily remove foliage. Generally, it takes 4–5 years for a plant to mature, although a few flowers can be harvested on plants in years 2 and 3. Do not remove foliage from plants until after it has senesced to ensure maximum photosynthate accumulation for the crown and roots.

Nutrition and irrigation

Supplemental irrigation is required in many climates to maximize yield and stem length from emergence to harvest. Drip irrigation is preferred to reduce foliar diseases and keep foliage clean. After harvest, plants can tolerate dryness, but irrigate as needed to keep the foliage healthy to maintain flower yields next season.

Before planting, producers should test the soil and amend accordingly. After planting, apply a low rate of dry granular fertilizer that is low in nitrogen. Be sure to not apply fertilizer on the crown itself. Fertilizer rates will vary with the production environment: heavier when grown in sandy soils, especially if in a rainy climate, and lighter if grown in a cool location with clay soil. If growing organically, apply a light layer of high-quality compost or other appropriate organic material around the plant.

Major pests

Established peonies are among the easiest crops to manage; however, *Botrytis* spp. can be a major problem. Botrytis causes dark spots on the foliage, rotting at the base of the stems and withering of the buds. After harvest, botrytis can spread rapidly when the humidity is high and free water is present. After harvest remove any buds or flowers that were infected by botrytis and did not open up.

While many insects, such as flea beetles, thrips, mites, mealybugs and scale, have been reported, relatively few cause significant problems. Ants can be found on peony buds, where they feed on sugar-rich exudates that form starting about 2 weeks before flowering. However, the ants do not cause problems. The exudates may attract other insects, such as bees, wasps and hornets, which can bother workers harvesting the flowers, and can make the buds particularly sticky, also making the buds challenging to harvest. The exudates are more of a problem in years without rain.

A number of other root and crown rots can cause problems including *Armillaria mellea*, *Phytophthora*, *Rhizoctonia*, *Rosellinia necatrix*, *Sclerotinia*, *Thielaviopsis* and *Verticillium*. Crown gall (*Agrobacterium tumefaciens*) has been noted. Several leaf spot diseases (*Cladosporium paeoniae*, *Cercospora paeoniae*, *Septoria paeoniae* and *Xanthomonas*) also occur (Dreistadt, 2001). Viruses, such as alfalfa mosaic, peony ringspot, tobacco rattle and tomato spotted wilt, can be a problem. Destroy any suspected plant because the infection agent will be carried on knife blades. Powdery mildew (*Erysiphe polygoni*) often occurs late in the summer, but is usually not a major problem. *Xanthomonas* can cause bacterial leaf spot.

With peonies being a long-term crop, it is not surprising that they are susceptible to a number of nematodes, but are generally local in occurrence. Root-knot nematodes (*Meloidogyne incognita*) are likely the most common, but *Pratyenchus* and *Aphelenchoides* can also be problems.

Postharvest management

Harvest stage, cold handling and storage temperatures are key to proper post-harvest management. Peony buds and flowers open very quickly, even at cold temperatures. Coupled with a vase life that ranges from only 4.4 days to 8.7 days (Gast, 1995, 2000), there is little room for error.

The opening of peony buds is separated into six stages (Eason *et al.*, 2002):

1. Tight bud with little true petal color showing.
2. Tight bud with true petal color showing.
3. Soft bud.
4. Very soft bud.
5. Almost open with petals not reflexed but still curving inward toward the center.
6. Fully open.

Peony producers need to be familiar with the harvest stages and determine the optimum stage of harvest for their cultivars. For example, in a study, authors determined that ‘Pink Hawaiian Coral’, ‘Red Charm’, ‘Edulis Superba’, ‘Red Magic’ and ‘Sarah Bernhardt’ should be harvested at stage 1; ‘Duchesse de

Nemours', 'Taff', 'Sorbet' and 'Monsieur Jules Elie' at stage 2; 'Kansas' at stage 3; and 'Karl Rosenfield' at stage 4 (Yu *et al*., 2011).

Peony stems are generally harvested early in the morning, but buds will continue to develop during the day, necessitating another harvest or two if the temperatures are warm. Larger operations are often harvesting stems all day long. Be aware that buds can continue to develop even at relatively low outdoor temperatures.

After harvest, stems should be immediately cooled to 0–1°C to prevent further development. The maximum time between harvest and cold storage is 2 h but should be much shorter if the temperature is warm. In the latter case, workers will be bringing stems to the cooler continuously.

Any surface moisture on the leaves, buds and stems should be allowed to dry to prevent botrytis development. Stems should be kept cold as they are being graded and bunched. If stems are to be stored, do not place the stems in water (hydrate) as that will encourage buds to open and encourage botrytis development. Stems should be stored in plastic-lined boxes. Long-term storage of more than 4 weeks is possible if the stems are kept close to 0°C and dry. At the end of storage, stems will be wilted and appear unusable, but generally rehydrate well. Longer storage of up to 12 weeks is possible, but vase life and flower size will be greatly reduced and flower deformities will increase. Experimentally, temperatures just below freezing may be useful in maintaining flower size and preventing deformities when storing peonies for up to 16 weeks.

When shipping, it is critical to maintain the cold chain and keep the duration as short as possible. Ice packs can be placed in the boxes to help prevent warming. After dry storage, stems should be recut and placed in a hydrating solution and then placed in a holding solution. Peony is not thought to be ethylene-sensitive, but STS has a beneficial effect.

REFERENCES

Byrne, T.G. and Halevy, A.H. (1986) Forcing herbaceous peonies. *Journal of the American Society for Horticultural Science* 111, 379–383.

Cheng, F., Zhong, Y., Long, F., Yu, X. and Kamenetsky, R. (2009) Chinese herbaceous peonies: cultivar selection for forcing culture and effects of chilling and gibberellin (GA3) on plant development. *Israel Journal of Plant Sciences* 57, 357–368.

Dole, J., Stamps, R., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers Press, Oberlin, Ohio.

Dreistadt, S.H. (2001) *Integrated Pest Management for Floriculture and Nurseries*. University of California Division of Agriculture and Natural Resources Publication 3402.

Eason, J., Pinkney, T., Heyes, J., Brash, D. and Bycroft, B. (2002) Effect of storage temperature and harvest bud maturity on bud opening and vase life of *Paeonia lactiflora* cultivars. *New Zealand Journal of Crop and Horticultural Science* 30, 61–67.

Evans, M.R., Anderson, N.O. and Wilkins, H.F. (1990) Temperature and GA3 effect on emergence and flowering of potted *Paeonia lactiflora*. *HortScience* 25, 923–924.

Gast, K.L.B. (1995) Production, postharvest, freeze-drying evaluation of fresh-cut peonies. Report of Progress 767, Agricultural Experiment Station, Kansas State University.

Gast, K.L.B. (2000) Production and postharvest evaluations of fresh-cut peonies. Report of Progress 866, Agricultural Experiment Station, Kansas State University.

Halevy, A.H., Weiss, D., Naor, V., Cohen, M., Levi, M. and Skuier, D. (1995) Introduction of herbaceous peony as commercial cut flower in Israel. *Dapei Meida* 5, 58–62 (in Hebrew).

Hanks, G. (2018) A review of production statistics for the cut flower and foliage sector. The National Cut Flower Centre, Agriculture and Horticulture Development Board (AHDB), Holbeach St. Johns, Lincolnshire, UK.

Kamenetsky, R. and Dole, J.M. (2012) Herbaceous peony (*Paeonia*): genetics, physiology and cut flower production. *Floriculture Ornamental Biotechnology* 6, 62–77.

Kamenetsky, R., Barzilay, A., Erez, A. and Halevy, A.H. (2003) Temperature requirements for floral development of herbaceous peony cv. 'Sarah Bernhardt'. *Scientia Horticulturae* 97, 309–320.

Loyola, C.E., Dole, J.M. and Dunning, R. (2019) North American specialty cut flower production and postharvest survey. *HortTechology* 29, 338–359.

United States Department of Agriculture (USDA) (2019) Floriculture crops 2018 summary. National Agricultural Statistics Survey, Washington, DC.

Yu, X., Guo, P., Lu, G. and Zhang, Q. (2011) Optimum harvesting time of herbaceous peony buds for cutting flowers. *Journal of Forestry Research* 22, 137–140.

RANUNCULUS

Scientific name: *Ranunculus asiaticus*
Common names: ranunculus, Persian buttercup
Ranunculus are tuberous-rooted, herbaceous perennials that are native to northern Africa, Southwest Asia and southern Europe. The native species has five petals and resembles *Anemone coronaria* (poppy anemone), but commercially cultivated ranunculus are double-flowered forms containing numerous petals. Compound leaves are made up of finely divided leaflets. Ranunculus lack heat tolerance, so they go dormant during summer months. Commercially, ranunculus are frequently treated as annuals and thus are replanted annually.

Market

This cool-season perennial produces lush ball-shaped flowers that are mainly sold during winter and spring. While not a high-volume species, ranunculus is regularly in the top 20 most commonly traded flowers at the Royal FloraHolland auctions in the Netherlands (Hanks, 2018). Ranunculus is among the top

20 flowers grown in the North American cut flower industry with nearly half of all growers producing this crop (Loyola *et al.*, 2019).

Cultivars and related species

Ranunculus colors range from white to yellow and orange to dark red and purple. The bicolors are especially striking with contrasting colors on the edges of each of the dozens of petals or in the center petals. Novelty types include those with leafy green petals in the center of the flowers (Fig. 2.21) or those with single flowers. Cultivars suitable for potted cultivars are available, but are shorter and should be avoided.

Production practices

Ranunculus can be propagated from seed or from their unusual tuberous roots that have the appearance of a tiny, brown octopus. Seed is generally used for potted ranunculus, while cut flower crops are typically grown from tuberous roots. Ranunculus are generally greenhouse- or tunnel-grown, but can be grown outdoors in limited areas where the temperatures stay above freezing, but stay cool long enough to produce a crop. Ranunculus can be grown in ground beds or in crates or containers, but the substrate in containers can warm faster than ground beds or crates, resulting in a shortened production period.

Dry, untreated corms can be planted, but rapid shoot emergence and floral initiation will occur by pretreating the corms before planting. One commercial

Fig. 2.21. Novelty ranunculus cultivars of various colors are available with leafy green centers. (Photo: J. Dole.)

recommendation calls for soaking the tuberous roots for 3–4 h in running water (Fred C. Gloeckner Co., 2017). Fungicides can be included in the soaking process for the last 30–40 min, during which the water is shut off. Other sources recommend soaking for 12–48 h after a 4–5-week cold treatment at 4–5°C (Elber, 1970; Ohkawa, 1986).

Once soaking is completed, remove the corms, place in moist but not wet peat moss and hold at 10–13°C for 10–13 days or until the roots or shoots reach ⅛ to ¼ inches long (Fred C. Gloeckner Co., 2017). Corms can be stored in plastic bags with perforations or in flats (be sure to keep peat moss moist). Presprouting can also be accomplished by placing dry tubers in flats of moist perlite or other media for 2–3 weeks at 16–18°C.

For increased efficiency of greenhouse space, tubers can be planted in 32–50-cell plug trays for 4–6 weeks prior to planting in the ground beds (Table 2.11) (Houck, 1994).

Ranunculus are best grown at night temperatures of 7–9°C and day temperatures of 14–18°C. Avoid day temperatures >21°C, which will result in yellow lower leaves and begin the dormancy process. Applying an organic mulch to ground beds can keep the soil cooler and extend the flowering period. Plants should be grown in full sun, which is especially important during the winter when days are naturally short (Fig. 2.22). Later in the spring, reduce the light intensity by shading the plants to moderate temperatures, which will allow plants to continue to produce flowers for a longer period of time.

Depending on the climate, tuberous roots can be planted from late July (cool climates) to early October (warm climates). Flowering will commence about 3 months later and should continue as long as proper temperatures are maintained.

Irrigation and nutrition

Ranunculus produce lush leaves and flowers that lack heat and drought tolerance, thus the soil or substrate needs to be kept moist, especially during hot weather. Allowing plants to dry out to the point of wilting will result in yellow lower leaves and, if wilting occurs frequently, plants will begin to go into dormancy. On the other hand, overwatering can result in root and crown rots.

Table 2.11. Tuberous roots are spaced as follows.

Planting method	Tuber size (cm)	Spacing within rows (cm)	Spacing between rows (cm)
Beds (greenhouse, tunnel, field)	3/5	10	20
	5/6	15	20
Double rows set 90 cm apart	3/5	20	35
	5/6	25	35

Fig. 2.22. Greenhouse ranunculus production in Italy. (Photo: J. Dole.)

The substrate should be well drained but also hold moisture well as this species has a fairly narrow range for optimum moisture. pH should be 5.8–7.5, with an electrical conductivity of 1.25–1.75 dS/m. Ranunculus are considered to have a moderate to heavy fertilizer requirement. Recommendations vary from 100 to 150 ppm N constant liquid fertilization to fertilizing twice a week with 300 ppm N and 280 ppm K from calcium nitrate and potassium nitrate (Armitage 1987; De Hertogh, 1996). As with many cool-season crops, ammonium and urea should be avoided or used only at low rates (Meynet, 1993).

Major pests

As with many cut flower crops, thrips, whitefly and aphids are common. Leaf miners and caterpillars can also cause problems. Impatiens necrotic spot virus is a serious threat and is spread by thrips.

During production, root and crown rot caused by *Pythium*, *Rhizoctonia*, *Schlerotinia rolfsii* or *Sclerotinia sclerotorium* can be a problem, especially if substrate is too moist and humidity is high. The latter conditions are also favorable to botrytis, which can blight foliage and flowers. Tubers are frequently soaked in a fungicide solution prior to planting and presprouting treatments. Other diseases include powdery mildew (*Ersiphe*), downy mildew (*Peronospora ficariae*), aster yellows, rust (*Puccinia* and *Uromyces*), smut (*Entyloma* and Urocystis), leaf spot (*Ramularia*), bacterial blight (*Xanthomonas campestris*) and bacterial leaf spot or stem rot (*Pseudomonas*) (Dreistadt, 2001; Li *et al.*, 2018).

Postharvest management

Harvest flowering stems when the buds are well colored and soft, but not yet opened. Flowers harvested for wholesale customers should be harvested slightly more immature – when the buds are more firm but starting to show color. Buds will continue to open and have a long vase life, but petals will be smaller than those harvested later.

Flowers for direct sale to consumers can be harvested later when the petals are just starting to open or when they have opened/closed once or twice, but the petals are delicate so handle with care. Since flowers close at night and open during the day, harvest in the morning to reduce petal damage. Buds will continue to open and have a long vase life, but petals will be smaller than those harvested later after the petals have expanded.

Flowers should last 7–10 days with the use of floral preservatives. Flowers can be stored for short durations at 1–2°C, but a slightly colder temperature, 0–1°C, is needed for longer storage. Stems do not store well dry; place stems in a holding preservative (contains a moderate rate of carbohydrate) for short-term storage and in water for long-term storage. Ethylene sensitivity is variable, but most often ranunculus cultivars are insensitive or have low sensitivity.

REFERENCES

Armitage, A. (1987) New crops: the present and the future. *Greenhouse Grower* 5, 50.
De Hertogh, A.A. (1996) *Ranunculus asiaticus*. In: *Holland Bulb Forcer's Guide*, 5th ed. International Flower Bulb Centre, Hillegom, the Netherlands, pp. C147–C151.
Dole, J., Stamps, R., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers Press, Oberlin, OH.
Dreistadt, S.H. (2001) Integrated pest management for floriculture and nurseries. University of California Division of Agriculture and Natural Resources Publication 3402.
Elber, Y. (1970) Cold storage treatment for earlier bloom of Ranunculus tubers. In: *Proceedings of the 18th International Horticultural Congress*, vol. I. Tel Aviv, Israel, p. 145.
Fred C. Gloeckner Co. (2017) Ranunculus. Available at: http://64.41.82.172/pdfs/Ranunculus-Brochure-2017.pdf (accessed 11 January 2020).
Hanks, G. (2018) A review of production statistics for the cut flower and foliage sector. The National Cut Flower Centre, Agriculture and Horticulture Development Board (AHDB), Holbeach St. Johns, Lincolnshire, UK.
Houck, S. (1994) Ranunculus. *Greenhouse Manager* 13, 45–49.
Li, W., Ten, L.N., Kim, S.H., Lee, S.Y. and Jung, H.Y. (2018) Occurrence of bacterial stem rot of *Ranunculus asiaticus* caused by *Pseudomonas marginalis* in Korea. *Research in Plant Disease* 24, 138–144.
Loyola, C.E., Dole, J.M. and Dunning, R. (2019) North American specialty cut flower production and postharvest survey. *HortTechology* 29, 338–359.
Meynet, J. (1993) Ranunculus. In: De Hertogh, A. and Le Nard, M. (eds) *The Physiology of Flower Bulbs*. Elsevier, Amsterdam, pp. 603–610.
Ohkawa, K. (1986) Grown and flowering of *Ranunculus asiaticus*. *Acta Horticulturae* 177, 165–172.

ROSE

Scientific name: *Rosa* × *hybrida*
Common name: rose
The genus *Rosa* includes >100 species originating from several continents. The modern rose is a woody perennial that has been hybridized from eight species, primarily from East Asia, Europe and the eastern Mediterranean (Applied Plant Research, 2001). A detailed discussion of the history of rose genetics can be found in Office of the Gene Technology Regulator (2009).

Roses are the top-selling cut flower worldwide, holding nearly 30% of the entire cut flower market. Production has been on the decline for past two decades in Europe, Israel, Japan and the USA as it has moved to Kenya, Ethiopia, Ecuador and Colombia, where the climate and labor situation are better. As an example, Dutch rose production decreased from 932 ha in 2000 to 280 ha in 2015 (Center for the Promotion of Imports, n.d.) but while production has been reduced, Dutch growers have been able to maintain demand in the local auctions for their product based on product freshness and through the production of exclusive cultivars, not available from imports.

Market

The breakdown of rose market by flower color roughly includes: 40% red, 20% yellow, 20% pink, 10% orange and 10% white. Stem length, bud/flower size and stem diameter are quality indicators that affect pricing. Roses benefit from being leading products in both weekly sales programs and in holiday markets, e.g. Valentine's Day, Mother's Day and International Women's Day.

Breeders maintain freshness in the product lines by continuing to expand the palette of colors, bicolors and tones available (Fig. 2.23), although cultivars are not quickly changed since the plants stay in production for many

Fig. 2.23. (**A**) New flower colors, such as this pink and green flower, keep roses exciting for customers to purchase, while painting and dyeing creates unique market opportunities. (**B**) Funky tie-dyed petals. (**C**) Elegant painting with classic colors. (**D**) St. Patrick's Day marketing. (Photos: J. Faust.)

years. For the truly exotic roses, paints and dyes provide unique looks that are biologically impossible to achieve.

As growers of the most visible and well-known cut flower, rose growers have been leaders in addressing the public demand for socially responsible and sustainable production. Certification programs guide growers in the use of sustainable practices that serve for the betterment of the environment while being socially responsible to workers and the surrounding community. The certification labels identify and promote the flowers grown on these farms.

Cultivars

Hybrid tea roses provide the iconic rose image. The three main flower classifications for hybrid teas are:

- *Standard*: >9 cm flower diameter. Axillary buds below the terminal flower are moved when they are pea-sized.
- *Sweetheart*: <9 cm flower diameter. A petite version of the standard form.
- *Spray*: Center bud is removed, and three or more small flowers develop per stem.

Garden roses differ from hybrid teas roses in that they typically possess numerous petals, and they are harvested with open flowers (Fig. 2.24). The petals are typically as wide as they are long, and the flowers are often fragrant. The stems are shorter and thicker than hybrid teas, and stem yield is lower.

Hundreds of cultivars are in the market. Since plantings may exist for 6 or more years, the choice of cultivar is a major commitment. Consequently, growers conduct in-house variety trials prior to introducing a new cultivar. The trials are used to identify disease resistance and productivity.

Production practices

Roses are vegetatively propagated by a couple of different methods. Bud grafting (budding) entails removing an axillary bud of the desired cultivar and inserting it into virus-free rootstock (Fig. 2.25). Three to four weeks later, the shoot above the union is severed. Six weeks later, the aerial part of rootstock is removed. A second method, termed stenting, involves taking a single-node cutting of the root stock and grafting a scion of the desired cultivar in one action (Fig. 2.26). Thus, graft formation and adventitious root formation occur simultaneously. Stenting takes 3 weeks and is more commonly performed in hydroponic systems since the transplants are smaller, while ground-bed plantings benefit from the larger bud-grafted transplants. Bud grafting and stenting avoid transfer of soil-borne organisms, such as nematodes and *Phytophthora*.

Fig. 2.24. Example of garden roses, which are harvested with a more opened flower than hybrid tea roses. (Photo: J. Faust.)

Rootstocks vary between geographic locations. Rootstock selection affects sprouting of axillary buds, e.g. vigorous rootstocks provide more stems and increased cut flower yield. Rootstocks can originate from seedlings or cuttings from stock plants, but cuttings create less variation.

Roses grown for international transport are primarily grown under protected cultivation. In temperate climates, roses are often grown in glass greenhouses with heating and cooling, while in subtropical locations, a single layer of polyethylene film covers an unheated greenhouse. Also, roses grown for domestic sales in subtropical locations may be grown outdoors. Indoor production can be done in ground beds or in hydroponic systems with soilless substrates (Fig. 2.27), e.g. rockwool is popular in Europe, while cocopeat or rice hulls are common nearer the equator. Some growers will use a mix of soil and soilless production, planting the hardier cultivars in the soil, while the more disease-susceptible cultivars are grown in substrates; however, hydroponics are becoming the main production method as growers reinvest in facility improvements. Garden roses may be grown outdoors without protection.

Planting density ranges from 5–10 plants/m^2. Higher density increases yield (stems/m^2) but reduces stem diameter and shoot weight (Fig. 2.28). Multiple wire supports (20 × 20 cm) are required to maintain straight stems. Cytokinin can be painted on selected dormant buds to stimulate shoot development.

Fig. 2.25. Bud grafting entails removing a bud from the desired cultivar (scion) and inserting it between the xylem and phloem tissue on the stem of the rootstock. (Photo: J. Faust.)

Fig. 2.26. Rose stenting has become popular as it accomplishes grafting and root stock propagation in one action (Photo: J. Dole.)

Fig. 2.27. Hydroponic roses grown with two troughs per bed. The troughs contain rice hulls as the substrate. (Photo: J. Faust.)

Shoots emerging from the rootstock, termed suckers, must always be removed as they will not produce the desired flowers of the scion cultivar.

Full production occurs within 6–8 months of planting, however rose plantings are made for several years and will continue as long as the plants are high-yielding and the cultivar remains popular. Two planting systems are used.

Traditional method

The plants are contained in beds. When stems are harvested, nodes are left in canopy to develop future stems. Over time, the plants get taller with each harvest. Eventually, the plants are cut back during a period of low demand. Workers may require stilts to access the top of the canopy for scouting and harvesting (Fig. 2.29).

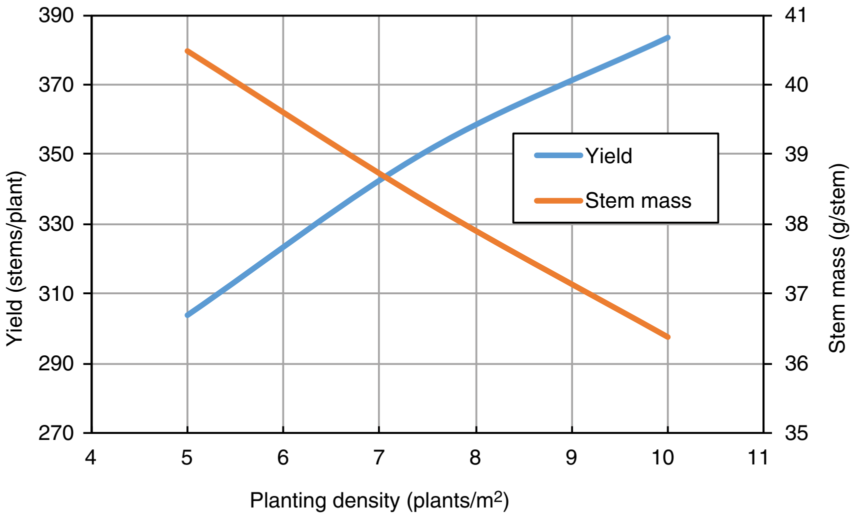

Fig. 2.28. Relationship between planting density, yield and stem mass. (From Applied Plant Research, 2001.)

Bending method

This technique was developed in the 1990s. The concept involves bending the main stem above the second node rather than pinching. New shoots emerge from the bottom two, five-leaflet nodes, and they are supplied with carbohydrates from the bent portion of the stem. The buds on the bent portion are inhibited from forming new shoots (Fig. 2.30). As stems develop, undesirable stems continue to be bent rather than removed by pruning. This technique essentially separates the perennial foliage and the shoots to be harvested. This allows biocontrol methods to be easier to implement since pest management primarily focuses on the perennial (bent) foliage where the population of biologicals can become well established. Pesticides can be targeted to the harvestable shoots where pests, like thrips, are more likely to be problematic. When the shoot is in flower, the entire stem is harvested, thus the crop does not gain height over time, and no annual cutback is required, so harvesting is not interrupted.

Ideal temperatures range from 14–18°C night temperature to 20–24°C day temperatures. Time from bud break to harvest decreases from 55 to 29 days as temperature increases from 15 to 22°C (van den Berg, 1987). Petal number increases and petals become shorter and wider with lower temperatures. Excessively low temperatures result in misshapen flowers, termed bullheads. High temperatures (>27°C) may result in reversion to five-petaled flowers.

Supplemental lighting is provided during winter months in temperate climates to improve stem quality and yield. A typical light intensity is 50 μmol/m^2/s. Low-light conditions promote the number of ‘blind’ shoots, i.e. lacking flowers.

Fig. 2.29. The traditional method of growing roses results in the crop gaining height over time since nodes must be left in the canopy below the harvested stems. Consequently, workers may require stilts to allow them to access the top of the canopy. (Photo: J. Faust.)

Carbon dioxide enrichment is also beneficial when supplemental light is being used.

High relative humidity during rose production creates two problems. First, botrytis infection increases when condensation regularly forms on plant tissues

Fig. 2.30. The bending method is used to separate the perennial foliage and the shoots to be harvested. The bent stems provide carbohydrates to the developing stems. This system allows for a separation of pest management techniques on the two sets of shoots, thus making biocontrol techniques easier to implement. (Photo: J. Faust.)

or when relative humidity exceeds 94%. This condition can occur nightly in locations with warm day temperatures and cool night temperatures. Second, high relative humidity conditions (>85%) result in malfunctioning stomata, i.e. stomata fail to properly regulate water loss. Consequently, when the stem is harvested and processed through the postharvest environment, the foliage will lose water faster than water can be taken up by the stem (Fanourakis *et al*., 2010). This results in bent neck symptom. As a guideline, every 4% increase in relative humidity leads to a loss of 1 day of vase life.

Bud nets may be placed over individual flower buds for different purposes (Fig. 2.31). Red-flowered cultivars display fewer blackened petals when nets are used. Nets can also increase final bud/flower size.

Roses are harvested daily, although during non-peak seasons the Saturday harvest will also include the flowers that will be ready to cut on Sunday. Harvests

Fig. 2.31. Nets are placed over rose buds during development to reduce blackened petals on red flowers. Nets also increase bud/flower size. (Photo: J. Faust.)

may be performed twice daily during warm periods and peak holidays. Flowers harvested too immature will be susceptible to bent neck or may fail to open in the postharvest environment. Mature flowers have a longer vase life. When harvesting, cuts are made closely above the bud and the attached leaf should be removed to improve bud break. Botrytis aggressively attacks the stem tissue above the bud and serves as a source of spores that spread to neighboring plants, so it is helpful to directly treat this portion of the stem to reduce botrytis infection.

Standard stem lengths range from 50 to 80 cm, although stems as long as 180 cm are harvested for special markets. Stem length is promoted by high light, high carbon dioxide, high humidity and no water stress. Yields of 2.5 million/ha/year have been reported (Wijnands, 2005).

Outer guard petals surround each rose flower bud (Fig. 2.32). These petals are left on the plant as an indicator of freshness, and they can later be removed by the florist or customer.

Irrigation and nutrition

In the 1990s rose production began to shift to hydroponic systems using substrates such as rockwool. In subtropical locations, cocofiber and rice hulls are used. Crops

Fig. 2.32. Outer guard petals surround each rose flower bud. These petals are left on the plant as an indicator of freshness, and they can later be removed by the florist or customer. (Photo: J. Faust.)

are irrigated with drip lines that operate multiple times daily. The optimized water and nutrients supplied in hydroponic systems produce increased yields and quality while reducing soil-related problems (pathogens and nematodes). Hydroponic systems delivering as low as 80 ppm N have been demonstrated to have no loss in yield (Cabrera *et al.*, 1996). Table 2.12 provides general guidelines for nutrient solutions for roses. Calcium nutrition is particularly important for botrytis management (see the rose 'Postharvest management' section that follows).

Major pests

Detailed descriptions of integrated pest management (IPM) practices in rose are provided by Joshel and Melnicoe (2004). The major pests are two-spotted spider mites and western flower thrips. Biocontrol methods have been successfully implemented in large-scale rose production systems, and pesticide application has decreased (see Chapter 7). This has allowed other secondary pest populations to increase, e.g. aphids, mealybugs and whiteflies.

Botrytis, downy mildew and powdery mildew are the main fungal pathogens. Roses continually drop leaves throughout the year, which creates a source of inoculum for fungi like *Botrytis* sp. Thus, removing greenhouse debris is a constant chore in rose production. *Agrobacterium tumefaciens* (crown

Table 2.12. Suggested nutrient ranges in fertigation solutions used for roses grown in hydroponic substrates. The low-range number refers to solutions in closed systems while the high-range number refers to solutions in open systems. Closed systems capture the effluent (leachate) from substrate and recirculate it. Open systems do not recirculate the effluent. (From Applied Plant Research, 2001.)

	Fertilizer concentration range	
	ppm	mM
NO3-N	60–154	4.3–11.0
NH4-N	11–21	0.8–1.5
N (total)	71–175	5.1–12.5
P	16–39	0.5–1.25
K	86–176	2.2–4.5
Ca	80–130	2.0–3.25
S	32–64	1.0–2.0
Mg	15–27	0.6–1.125
Fe	0.8–1.4	0.015–0.025
Mn	0.28	0.005
B	0.09–0.13	0.008–0.0012
Zn	0.20–0.23	0.003–0.0035
Cu	0.03–0.05	0.0005–0.00075
Mo	0.05	0.0005

gall) can be difficult to control on rose farms once it has appeared. A host of other diseases can occur including rust, various leaf and petal spots, cane blights and numerous viruses. Several nematodes present problems in soil production systems, e.g. root-knot nematode (*Meloidogyne*), root lesion nematode (*Pratylenchus*), *Xiphinema* and many others.

Weed management is also a significant issue on this long-term crop. Weeds not only compete with the roses for nutrients and water, but can also support insects that can move up into the roses.

Postharvest management

Postharvest temperatures should be maintained from 1 to 3°C and relative humidity at ~80%. Stems can be stored dry for a couple of weeks prior to shipping. Harvesting more mature flower buds improves vase life, while immature buds are more susceptible to bent neck, a phenomenon where the rate of water loss exceeds water uptake. The stem tissue immediately below the flowers that has not yet lignified is particularly susceptible to bending when lacking sufficient water. Water uptake is inhibited by bacteria growing in the stem, blocking water uptake, but excessively low-humidity postharvest environments can also cause this problem.

Botrytis is the most serious postharvest problem on roses. Infections that occur during production are expressed in the postharvest environment. The initial symptoms appear as small, beige-colored spots on the flower petals that expand as the mycelium (shoots and roots of the fungus) spreads through the tissue. Petals have only 5–10% of the calcium concentration compared with leaves, so they are particularly susceptible to botrytis infection (Fig. 2.33).

The petal concentration of calcium can be boosted with foliar sprays or by immersion dips of the harvested flowers into calcium solutions prior to packaging for transport. Dip applications of calcium improve the calcium concentration in all petal layers, while spray applications of calcium in the greenhouse only improve the calcium concentration of the outer array of petals, the calyx and receptacle, but not the inner layers of petals. Fungicide spray applications also tend to protect the exposed tissues; however, in the last days prior to harvesting the stem, the inner petals begin to be exposed and are unprotected from botrytis spores landing on their surface. As a consequence, it is common to see botrytis infection starting on the inner petals while the outer petals that have been treated with fungicides develop no infection (Fig. 2.34) (Muñoz *et al.*, 2019).

Botrytis blight symptoms can also occur at the base of the flower, i.e. on the receptacle. The flower will bend over at this point of infection. These symptoms differ from bent neck, which occurs on the stem tissue immediately below the flower.

Ethylene sensitivity varies with cultivar. The main symptoms are petal abscission (shatter), petal wilting or failure of flowers to open. Anti-ethylene

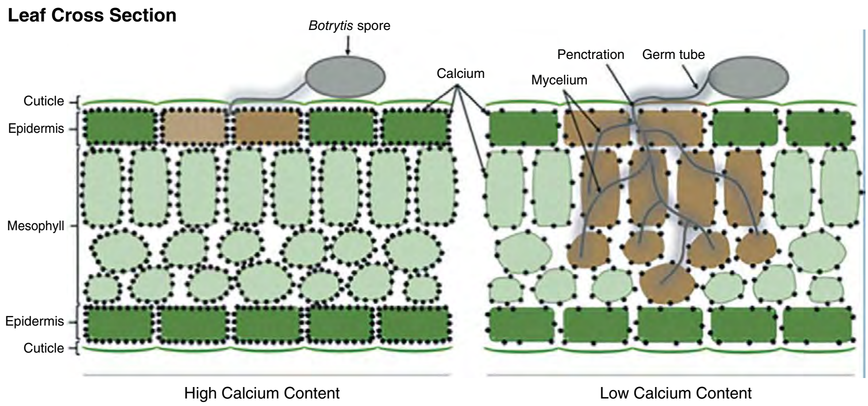

Fig. 2.33. Increased calcium concentration in plant tissues improves tissue resistance to botrytis infections. Botrytis feeds from plant cells and in the process, kills the cells. Calcium strengthens cellular structure, making it more difficult for the mycelium to penetrate. (Source: J. Faust and K. Bennett.)

Fig. 2.34. Botrytis blight infection often occurs on inner petals that have become exposed in the last several days prior to harvest and, unlike the outer petals, have not been treated and protected by fungicides. (Photo: J. Faust.)

compounds, such as STS applied in the pre-packaging bucket solution or 1-MCP sachets placed in shipping boxes, are beneficial for sensitive cultivars. However, since not all cultivars benefit, these compounds are not frequently used across the industry.

Sea transport of roses is expanding from South American and African growers. The primary challenges include bent neck and botrytis blight. A pre-packaging quick (1-s) dip into a solution of 100–150 ppm hypochlorite has been recommended for botrytis control prior to long-distance transport (Woltering *et al*., 2015). Bent neck can be addressed by keeping the relative humidity low during production and harvesting flowers at the proper stage of maturity.

Vase life of 7–14 days is to be expected, depending on harvest cold-chain management and the use of vase solutions. Wilted stems should be placed in warm water (40°C) for rapid hydration.

REFERENCES

Applied Plant Research (2001) *Handbook for Modern Greenhouse Rose Cultivation*. Glasshouse Horticulture Research Unit, Wageningen University, Naaldwijk, the Netherlands.

Cabrera, R.I., Evans, R.Y. and Paul, J.L. (1996) Nitrate and ammonium uptake by greenhouse roses. *Acta Horticulturae* 424, 53–57.

Center for the Promotion of Imports (n.d.) Exporting roses to the Netherlands. Ministry of Foreign Affairs. Available at: www.cbi.eu/market-information/cut-flowers-foliage/roses/europe (accessed 1 August 2020).

Fanourakis, D., Matkaris, N., Heuvelink, E. and Carvalho, S.M.P. (2010) Effect of relative air humidity on the stomatal functionality in fully developed leaves. *Acta Horticulturae* 870, 83–88.

Joshel, C. and Melnicoe, R. (2004) Crop timeline for California greenhouse grown cut roses. US Environmental Protection Agency, Office of Pesticide Programs.

Muñoz, M., Faust, J.E. and G. Schnabel (2019) Characterization of *Botrytis cinerea* from commercial cut flower roses. *Plant Disease* 103, 1577–1583.

Office of the Gene Technology Regulator (2009) The Biology of Hybrid Tea Rose (*Rosa* × *hybrida*). Australian Government, Department of Health and Ageing. Available at: http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/Content/5DCF28AD2F3779C4CA257D4E001819B9/$File/The%20Biology%20of%20Hybrid%20Tea%20Rose.pdf (accessed 25 August 2020).

van den Berg, G.A. (1987) Influence of Temperature on Bud Break, Shoot Growth, Flower Bud Atrophy and Winter Production of Glasshouse Roses. PhD dissertation, Wageningen University.

Wijnands, J. (2005) Sustainable international networks in the flower industry. *Scripta Horticulturae* 2, 1–92.

Woltering, E.J., Boerrigter, H.A.M., Mensink, M.G.J., Harkema, H., Macnish, A.J., Reid, M.S. and Jiang, C.Z. (2015) Validation of the effects of a single one second hypochlorite floral dip on *Botrytis cinerea* incidence following long-term shipment of cut roses. *Acta Horticulturae* 1064, 211–219.

STATICE

Scientific name: *Limonium* species and hybrids
Common names: statice (annual form), German statice, limonium, sea-lavender (perennial and hybrid forms)
Limonium produces a dense rosette of basal leaves from which flowering stems emerge. The inflorescence is a panicle or corymb with tiny, short-lived, individual flowers. The showiest portion of the inflorescence is actually the papery calyx, which retains its color indefinitely.

Market

With its strong, often wiry, leafless stems and tight papery flower clusters, statice is a natural cut flower. Most statice have two-colored florets with the outer sepals coming in a variety of colors and the true, white-petaled florets visible in the center of the florets. The various species are useful as a filler flower for small- to medium-sized arrangements and bouquets. Statice is also one of the staples of the dried flower industry as it dries easily while remaining durable. Statice is readily tinted, allowing the creation of novel colors.

Statice was among the top 10 flowers grown in a survey of South and Central America cut flower production and among the top 20 species grown in North America (Loyola *et al.*, 2019a, b).

Cultivars and related species

The many species grown for cut flower production can be separated into two groups. Annual statice (*Limonium sinuatum*), and perennial or hybrid statices (*Limonium bellidifolium*, *Limonium latifolium* (now known as *Limonium platyphyllum*), *Limonium perezii*, *Limonium tartaricum* (now known as *Goniolimon tataricum*)).

Annual statice is available in the broadest range of colors, including white, yellow, pink, rose, lavender and purple. Its relatively thick stems have leafy wings. Annual statice is actually a short-lived perennial or biennial, Zones 8–10, that is typically grown as an annual. Plants struggle in the summer heat of warm climates.

Perennial or hybrid statices are also grown commercially. Large-scale cut flower production mostly uses the hybrids. The color range of this group of statice species and hybrids is more restricted than that of annual statice and limited to white, pink, rose, lavender and purple. While cold hardiness of the various species ranges from Zones 3–10, most commercially important hybrids are not cold hardy. Note that some varieties have a mild, musky odor that may be unappealing.

Production practices

Annual statice

Depending on the location, annual statice is grown in ground beds inside greenhouses or tunnels or is grown outdoors (Fig. 2.35). Plants can be propagated from seed or tissue culture. Seed-propagated plants work well for small operations, while large-scale producers typically use plugs derived from tissue culture.

Plants are typically planted at densities of 6–12 plants/m^2. When planting, be sure that the plants are not too deep and the centers are not covered in soil. One layer of netting is commonly used to support the flowering stems.

Flowering is promoted by low temperatures of 11–13°C for 3–8 weeks during the seedling stage (Armitage and Laushman, 2003). Long days of 14 h or more also promotes earlier flowering and higher-quality stems. GA at 150–500 ppm can be applied when plants are 15–20 cm across to promote flowering, especially under warm conditions. A second application can be later applied to plants still not flowering. GA is not needed if plants have been appropriately precooled. Remove flowers stems that develop before the plant's size and rosettes have a diameter of 25–30 cm.

Crop time from planting ranges from approximately 10 weeks in the summer to 14–16 weeks in the winter with an additional 3–4 weeks for harvesting.

Fig. 2.35. Annual statice grown in ground beds inside a greenhouse. (Photo: J. Faust.)

If plants are greenhouse-grown, maintain temperatures at a minimum temperature of 10°C with 12–15°C night and 21°C day temperatures being optimal.

Perennial or hybrid statice

Perennial statice is typically greenhouse- or tunnel-grown, although it can be field-grown in locations with mild climates. Most plantings are started with plants from tissue culture. Plants are planted in January to May under protection and from May to August outdoors. Plants will begin flowering 3–4 months after planting.

Prepare soil well as the plants can be in production for up to 4 years, although they are often replaced sooner to maintain productivity. Plants are typically spaced 30 × 30 cm in two rows per bed and supported by one layer of netting. Closer spacing can be used to increase productivity but quality will be reduced. Greenhouse-grown plants should be maintained at an average daily temperature of 22–27°C with night temperatures of 12–16°C.

Irrigation and nutrition

Statice is tolerant of a range of soil and substrate types as long as it is well drained. Poorly drained situations tend to cause root and crown rots. If diseases develop, rotate plantings. Soil pH should be around 6.5.

Annual statice should be kept moist but not too wet, which can encourage root and crown rots. The first few weeks after planting are most critical, after which time irrigation can be reduced. While statice has fairly rigid stems that are not prone to wilting, be sure to keep the substrate moist enough for good stem elongation. Overhead irrigation is used until the young plants are well established, after which time drip irrigation is typically used. Flowers should be kept dry to avoid botrytis infection.

Seedlings or young tissue culture plants of annual statice should be irrigated with 50–100 ppm N and K when first planted and approximately 100 ppm N after established. Overfertilization will result in lush, vegetative plants with low flower production. Perennial statice generally requires less fertilizer than annual statice.

Major pests

When grown under protection, spider mites are particularly problematic. Thrips and aphids can also be a problem. Armyworms, cut worms, other caterpillars and beetles can be a problem in outdoor production.

Botrytis cinerea is one of the most common diseases, attacking both foliage and flowers. Foliar symptoms include yellowing, abscission and small white or brown spots. On flowers, small brown or white spots will occur, the latter being prevalent on light-colored flowers. When humidity levels are high, fuzzy gray mold will be evident. Botrytis is the most important postharvest disease and can rot entire boxes of product. Stems infected during production will produce the characteristic gray mold during storage and shipping, especially if shipping temperatures are warm or shipping duration is too long. Be sure to pack dry flowers, and don't overpack buckets to allow for air movement within the cut stems.

Anthracnose and crown rot, caused by *Colletotrichum gloeosporiodes*, can be serious, causing leaf and flower spots, foliar yellowing, crown rot, defoliation and total crop loss (Moorman, 2016). Crop rotation and fungicides can help control this disease.

Outdoors in the United States and Canada, aster yellows disease can be devastating (Dreistadt, 2001). The disease is spread by leaf hoppers that migrate north during the summer after overwintering in southern locations. In areas where the leaf hoppers overwinter, year-round transmission can occur. Disease spread can be slowed by controlling the vector (leaf hoppers), but that is hard to accomplish in field production; therefore, infected plants must be removed immediately to minimize the spread.

A number of other diseases can occur including bacterial blight (*Corynebacterium*), bacterial rot (*Pseudomonas*), bacterial soft rot (*Dickeya dadantii*, formerly known as *Erwinia chrysanthemi*), cercospora leaf blight (*Cercospora insulana*), downy mildew (*Peronospora statices*), powdery mildew (*Erysiphe polygoni*), rhizoctonia crown rot (*Rhizoctonia solani*), rust (*Uromyces*), southern blight (*Sclerotium rolfsii*), verticillium wilt (*Verticillium dahliae* and *Verticillium albo-atrum*) and viruses (broadbean wilt, carnation mottle, clover yellow vein, cucumber mosaic, statice Y, tobacco rattle, tomato bushy stunt or turnip mosaic virus) (HilverdaKooij, n.d.; Dreistadt, 2001; Moorman, 2016).

Postharvest management

Commercial statice cultivars have a rosette of basal leaves from which the flowering stems arise. This plant structure lends itself to easy harvest (Fig. 2.36), although separating the stems that are ready from those that are not yet ready can be challenging as the stems intertwine. Stems are harvested when at least 40% of the individual florets are open.

Stems have an initial vase life of 4–8 days, but the papery florets continue to look attractive even after the stems stop taking up water and start to senescence. In this semi-dried state, the flowers can last for up to 3 weeks.

Stems should be hydrated with water or a commercial hydration solution. Many cultivars are ethylene-sensitive and benefit from an STS or 1-MCP treatment. Ethylene damage may not be readily apparent on statice as the papery sepals still look attractive, but the inner petals will be damaged and overall vase

Fig. 2.36. Annual statice being processed in the greenhouse immediately after harvest. (Photo: J. Faust.)

life will be decreased. Stems should also be placed in a pre-packaging postharvest bucket solution containing 10% sucrose plus a germicide or treated with a commercial postharvest solution containing sugar (Doi and Reid, 1995). Carbohydrates in the floral solutions not only extend the vase life of individual florets but also allow more florets to open, thus extending the overall vase life of each stem.

Statice can be stored or shipped at 1–2°C. The foliage on annual statice readily turns yellow while the flowers still look attractive. Proper postharvest handling will help prevent foliage yellowing.

REFERENCES

Armitage, A.M. and Laushman, J.M. (2003) Limonium. In: *Specialty Cut Flowers*, 2nd edition. Timber Press, Portland, Oregon, pp. 387-–403.

Doi, M. and Reid, M.S. (1995) Sucrose improves the postharvest life of cut flowers of a hybrid *Limonium*. *HortScience* 30, 1058–1060.

Dole, J., Stamps, R., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers Press, Oberlin, Ohio.

Dreistadt, S.H. (2001) *Integrated Pest Management for Floriculture and Nurseries*. University of California Division of Agriculture and Natural Resources Publication 3402.

HilverdaKooij (n.d.) Cultural directives Limonium perennial varieties. Available at: www.haifa-group.com/sites/default/files/crop/Limonium%20perennial%20varieties.pdf (accessed 15 December 2019).

Loyola, C.E., Dole, J.M. and Dunning, R. (2019a) North American specialty cut flower production and postharvest survey. *HortTechnology* 29, 338–359.

Loyola, C.E., Dole, J.M. and Dunning, R. (2019b) South and Central America cut flower production and postharvest survey. *HortTechology* 29, 898–905.

Moorman, G.W. (2016) Statice diseases. PennState Extension. Available at: https://extension.psu.edu/statice-diseases (accessed 15 December 2019).

SUNFLOWER

Scientific name: *Helianthus annuus*
Common names: sunflower, girasol
Sunflowers are an annual species native to the North America and originally domesticated as a food crop (Smith, 2006). Like other Asteraceae family members, the inflorescence is a head or capitulum consisting of ray and disk florets. The large, heart-shaped, petiolate leaves are hairy and often removed during harvest.

Market

Sunflowers range from small to very large flowering heads depending on the production conditions. Stems with large heads are generally used for direct retail to consumers or very large flower arrangements. Stems with small heads are used in mixed bouquets. Sunflowers with intermediate-sized heads are the most versatile and are used in large mixed bouquets, arrangements and as single-species bunches.

Sunflower is one of the top 20 most commonly traded flowers at the Royal FloraHolland auctions in the Netherlands (Hanks, 2018). Sunflower was ranked 4th fourth in frequency of production in a survey of the North American cut flower industry with close to 75% of respondents growing this crop (Loyola *et al*., 2019).

Cultivars and related species

The wild sunflower is a widely branching plant that has been domesticated into a tall upright single-stem plant with one large flower with many large seeds.

Most modern cut flower cultivars have a similar form, but cultivars are available that readily produce side branches and are often grown as a pinched crop. Heavily branched hybrid cultivars have been recently introduced that produce harvestable flowers for one to several months. Cut flowers from these well-branched cultivars are suitable for bouquets and smaller arrangements.

Petal colors on ray florets include creamy white, pale green, yellow/gold, orange and bronzy red, and disk florets include brown, yellow and green. Bicolored petals are also available. Most cultivars have outward-facing heads; cultivars are available with heads that are more upright-facing, allowing them to be more easily used in arrangements. The petals of the disk florets can be short, intermediate or long, the latter are known as fully double flowers.

Novel forms include cultivars without petals but with large, multiple green or purplish sepals. Cultivars with narrow or twisted petals are also available. Breeders have also been introducing cultivars with enhanced resistance to downy mildew, designated by the letters DMR. Considering the continued interest in ornamental sunflowers, expect the ongoing introduction of new and unusual cultivars.

The most important and commonly grown cultivars are those with orange petals and brown disk florets as that color combination is thought to be the typical sunflower by customers (Fig. 2.37). Cultivars with bronzy colors generally sell better in the fall, while those with white to pale yellow petals and light-colored centers are grown year-round in small numbers. Most cultivars used for cut flower production do not produce pollen, since pollen is quite messy for retailers and customers.

Of the 60+ *Helianthus* species, a few others are cultivated and occasionally used as cut flowers. Swamp sunflower, *Helianthus angustifolius*, is a tall perennial with large clusters of flowers with yellow petals and small brown centers. Willowleaf sunflower, *Helianthus salicifolius*, produces large masses of yellow flowers with small dark centers. Maximillian's sunflower, *Helianthus maximilliani*, is a large perennial plant with long arching stems adorned with many 3-inch yellow flowers with gold centers. All of these species flower in late summer and early fall and can be used in bouquets and large arrangements.

Production practices

Crop time ranges from 7–12 weeks depending on temperature and the photoperiod sensitivity of the cultivar. Currently, most cultivars grown for cut flower production are single stems grown for one-time harvest. This necessitates planting every 1–3 weeks to provide a continuous harvest. Be aware that crop time will decrease with increasing temperatures during the warm season.

Cultivars vary from short-day to day-neutral to long-day response with short-day or day-neutral responses being most common. Generally, plants are most responsive to photoperiod during the first 3 weeks after germination (Wien, 2007). Short-day cultivars grown under short days will flower up to

Fig. 2.37. Freshly harvested cut sunflowers. (Photo: J. Dole.)

3 weeks earlier than those grown under long days. For short-day cultivars, long days can be used to increase height and head size of plants, while short days can be used to shorten crop time, reduce height and reduce head size. Similar but opposite responses will occur with long-day cultivars. Day-neutral cultivars

are best during the short days of winter when short-day cultivars tend to be too short and the heads too small. Alternatively, short-day cultivars can be grown under photoperiodic lighting that provides long-day conditions.

The size of the flower head and the thickness of the stem will vary with the planting conditions. Smaller heads and thinner stems can be encouraged by:

- close spacing
- pinching
- use of transplants as compared to direct seeding
- reduced water and/or fertilizer
- use of selected cultivars, especially those that are free-branching.

Plants are spaced 5–30 cm apart, depending on the cultivar and size of flower head desired (Fig. 2.38). Small heads will generally be produced with plant spacing of 5–10 cm within the row, intermediate-sized heads with 15–20 cm spacing and large heads with >25 cm spacing. Field production commonly uses 20–25 cm within-row spacing.

Most sunflower production uses single-stem/plant production, which produces long stems and intermediate- to large-sized flowers. However, young plants can be pinched to produce smaller flower heads and thinner stems and a harvest window delayed 1–2 weeks. Plants should be pinched as soon as possible, generally when they have three pairs of leaves (Wien, 2012, 2016). Pinching older plants will produce short, unmarketable stems. Pinching works best on cultivars that tend to naturally branch.

Sunflowers require high light during production and grow best at 18–24°C. Sunflowers are generally considered to be a warm-season crop but can tolerate freezing temperatures for short durations, if properly acclimated. Keep in mind, however, that plants grow very slowly at temperatures <10–13°C (Schuster, 1985).

Sunflower crops can be established by direct sowing or by transplants. If direct sowing, plant after temperatures are >10°C. For transplants, the seeds can be sown into 50- or 72-cell plug flats at 21–24°C. Sow seeds 3–4 weeks before transplanting. Avoid delaying transplanting as plants will be rootbound, thin-stemmed and short.

Irrigation and nutrition

Sunflowers generally require high levels of nutrition and water. During greenhouse or tunnel production, maintain a substrate pH of 5.8–6.5 and an electrical conductivity of 0.7–1.2 dS/m. Provide 100–175 ppm N. For field production, prepare soil ahead of time with 112 kg N/ha and apply one application of 112 kg N/ha midway through the crop cycle (Ahmad *et al.*, 2012). Irrigate sunflowers frequently, just prior to foliage wilting. Sunflower stems are strong and thick and not prone to wilting, which reduces the likelihood of

Fig. 2.38. Bed of young sunflower plants. Note tight spacing for intermediate-sized heads. Plants are also at the correct stage for pinching, if smaller heads are desired. (Photo: J. Dole.)

curved stems. However, insufficient irrigation will cause short stems and small flower heads.

Major pests

A number of diseases plague sunflowers (Markell *et al.*, 2008). Most common are the various leaf diseases, including downy mildew (*Plasmopara halstedii*), powdery mildew (*Erysiphe cichoracearum*), rust (*Puccinia helianthi*), fungal leaf spots/blights (*Alternaria helianthi*, *Alternaria* (many species) and *Septoria helianthi*), and bacterial leaf spots (*Pseudomonas syringae* pv. *helianthi*). Cultivars with resistance to downy mildew are available and should be used where the disease is common. While very common, leaf diseases may or may not prevent the flowers from being sold. Foliage disease damage tends to be most prevalent on the lower leaves, which are removed, leaving one to three upper leaves to frame the flower heads. Many growers remove all of the leaves, especially for those flowers destined for shipping in boxes.

Stem rots and wilts can affect large production areas, necessitating the rotation of sunflower plantings. Two *Sclerotinia* diseases can occur, cottony rot (*Sclerotinia sclerotiorum*), which is most prevalent during cool, wet weather, and southern blight (*Sclerotium rolfsii*), which is most common during hot weather. Both diseases produce bright white mycelial growth under proper conditions. Charcoal rot (*Macrophomina phaseolina*) infects stems at the soil line and moves upward through the stem. *Fusarium* spp. cause a distinctive pink, orange, red or purple discoloration of the internal stem pith. Phoma black stem (*Phoma macdonaldii*) produces black lesions on the stems. Verticillium wilt (*Verticillium dahlia*) is characterized by interveinal chlorosis and necrosis as well as wilting. Phomopsis stem canker (*Phomopsis helianthi* and *Phomopsis gulyae*) show symptoms on the leaves as well as the stems.

Head rots can be especially frustrating as they often occur as the flowers are to be harvested. Causal organisms include the fungi *Schlerotinia sclerotiorum*, *Botrytis cinerea* and *Rhizopus* (*Rhizopus stolonifera*, *Rhizopus oryzae* and *Rhizopus microsporus*), and bacteria, *Pectobactrium carotovorum* subsp. *carotovorum* and *Pectobactrium atrosepticum*. These diseases tend to be most common during wet weather, especially when cloudy. Damage from hail, insects or birds will increase the likelihood of infection.

Aster yellows can be an occasional problem as well as bacterial soft rot (*Dickeya* and *Pectobacterium*) and a couple of petal blights (*Itersonilia perpexans* and *Stemphylium* spp.). Several viruses are known to occur, including sunflower mosaic, sunflower chlorotic mottle, tobacco streak, tomato ringspot, tomato spotted wilt and tobacco ring spot virus.

Outdoors insect pests are also numerous, including caterpillars, beetles, weevils and midges, most of which attack the heads, but some can also defoliate sunflowers. Most unusual and frustrating is the head-clipper weevil, which lays eggs in the heads, and feeds on the stem below the head resulting in the head falling off. The fallen heads support the developing and overwintering larvae. Fortunately, this pest is not widespread. Grasshoppers and beetles can be prolific in some years and cause extensive damage, especially to the petals. Of course, nematodes, especially *Meloidogyne*, but also *Belonolaimus*, *Helicotylenchus*, *Paratrichodorus*, *Pratylenchus* and *Xiphinema*, can occur on this crop, especially since it is commonly grown outdoors.

In greenhouses or tunnels, aphids, whiteflies, thrips and spider mites can be problems and can damage the flowers. Some of the caterpillars that are common outdoors can find their way inside during periods of warm weather. These caterpillars can appear quickly and cause major damage in a short period of time, so frequent scouting is a critical practice.

Rounding out the extensive list of possible pests are birds and rodents, both of which are interested in the seeds; however, most sunflowers are harvested before seed formation. To reduce problems, clean out beds of remaining stems after harvest.

Postharvest management

Harvest flowers when one to two petals have started to lift off the center disk. Flowers harvested for wholesale are tighter than those harvested for direct sales to the final consumer. In the latter case, the petals may be fully expanded, but the center disk should still be immature with only a few disk florets open. Most leaves are removed when harvesting, leaving only two to three at the top to frame the head. Growers producing cut sunflowers for export usually remove all of the foliage to reduce weight. In addition, the foliage may turn yellow or brown while the heads still look good.

Sunflowers are a fairly durable cut flower. Stems should be harvested into acidified water, water with chlorine tablets or a commercial postharvest solution. Vase life should be 7–9 days with the use of a storage/shipping bucket solution. Pollenless cultivars are preferred as they tend to have a longer vase life. The consumer will have a longer vase life if a vase solution/flower food is used.

Flowers can be stored at 2–5°C for up to a week. If stems are going to be stored longer, harvest at a more open stage, as stored flowers tend to not open up well. Sunflowers are not sensitive to ethylene.

REFERENCES

Ahmad, I., Dole, J.M. and Nelson, P. (2012) Nitrogen application rate, leaf position and age affect leaf nutrient status of five specialty cut flowers. *Scientia Horticulturae* 142, 14–22.

Dole, J., Stamps, R., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers Press, Oberlin, Ohio.

Hanks, G. (2018) A review of production statistics for the cut flower and foliage sector. The National Cut Flower Centre, Agriculture and Horticulture Development Board (AHDB), Holbeach St. Johns, Lincolnshire, UK.

Loyola, C.E., Dole, J.M. and Dunning, R. (2019) North American specialty cut flower production and postharvest survey. *HortTechnology* 29, 338–359.

Markell, S., Haverson, R., Block, C., Gulya, T. and Mathew, F. (2018) Sunflower Disease Diagnostic Series. North Dakota State University, PP1727. Available at: www.ag.ndsu.edu/publications/crops/sunflower-disease-diagnostic-series (accessed 23 December 2020).

Schuster, W.H. (1985) *Helianthus annuus*. In: Halevy, A.H. (ed.) *Handbook of Flowering*, Vol. III. CRC Press, Boca Raton, Florida, pp. 98–121.

Smith, B.D. (2006) Eastern North America as an independent center of plant domestication. *PNAS* 103, 12223–12228.

Wien, C. (2007) Day-neutral sunflowers. *The Cut Flower Quarterly* 19, 48–49.

Wien, C. (2012) Can we make sunflowers more productive with the right pinching and spacing combinations? *The Cut Flower Quarterly* 24, 50–51.

Wien, C. (2016) Pinching sunflowers produces more stems – what about profits? *The Cut Flower Quarterly* 19, 14–15.

TULIP

Scientific name: *Tulipa* × *gesneriana*
Common name: tulip

Tulips are herbaceous perennials that develop from true bulbs. They are naturally distributed in temperate climates from southern Europe to Central Asia and have been cultivated for their showy flowers for many centuries. The single, terminal flower consists of six tepals and six stamens, while the style has three distinct lobes. The simple leaves develop from the main stem and are blue-green with a waxy coating. They diminish in size moving up the stem.

Market

One of the most popular flowers in the world, tulips have been the second most commonly traded flowers at the Royal FloraHolland auctions in the Netherlands (Hanks, 2018). Tulips are the second most important domestically produced cut flower in the USA (USDA, 2019) and were grown by 47% of respondents in a survey of the North American cut flower industry (Loyola *et al*., 2019).

Cultivars and related species

With a color range almost as diverse as that of gladiolus, tulips can be found in virtually any color from white to almost black, except for true blue, and in a broad array of multicolors. Thousands of cultivars are available and are categorized into 15 groups based on flowering time, flower form, height and parentage:

1. Single Early Group.
2. Double Early Group.
3. Triumph Group (Fig. 2.39).
4. Darwin Hybrid Group (Giant Darwin hybrid tulips).
5. Single Late Group.
6. Lily-flowered Group.
7. Fringed Group.
8. Viridiflora Group (Green tulips).
9. Rembrandt Group.
10. Parrot Group.
11. Double Late Group (Peony flowering tulips).
12. Kaufmanniana Group.
13. Fosteriana Group (Emperor tulips).
14. Greigii Group.
15. Miscellaneous (Species tulips).

Cut flower cultivars are generally from the Double, Triumph, Double Late (Peony-flowered), Darwin and Lily-flowered groups.

Tulipa × *gesneriana* is thought to be a complex garden hybrid developed centuries ago in Turkey from a number of species (Maarten *et al*., 2013). While many other beautiful *Tulipa* species are cultivated, few have the substance and vase life to be commercially viable.

Fig. 2.39. ‘Debutante’ tulip is a member of the Triumph group. (Photo: J. Dole.)

Cut tulips are typically available from late December through April from bulbs produced in the northern hemisphere, and from August through December for bulbs produced in the southern hemisphere.

Production practices

Most cut tulips are greenhouse-grown, but many local growers produce cut tulips outdoors or in tunnels. While tulips are perennials, the bulbs are generally used only once for most efficient use of the space. A few areas of the world have ideal climatic conditions, e.g. long, cool spring and summer, that allow tulips to regenerate bulbs and perennialize. Even then, however, the resulting plants often lose vigor relatively quickly and produce quality flowers only for a couple of years.

Bulbs are purchased from commercial suppliers either precooled at 5 or 9°C or uncooled. Precooled bulbs should be stored at the same temperature as which they were precooled or lower. If bulbs have not been precooled, store at 20°C until mid-October, after which time the temperature should be reduced to 17°C. Bulbs are quite sensitive to ethylene during storage; be sure to store them in an ethylene-free environment and provide air circulation to draw away any ethylene being produced by the bulbs themselves.

Bulbs are available in various sizes and those used for cut flower production are generally 10/11 cm, 11/12 cm or 12/+ cm. The specific size to use will depend on the cultivar, cost, time of year and desired cut stem quality. Generally, the larger the bulb, the bigger the flower. Larger bulbs may be needed late in the forcing season to overcome the small flowers and short stems that result from extended storage. Cut tulip can be produced outside of the normal forcing season (late December to April in the northern hemisphere) using bulbs from the southern hemisphere or 'ice tulips', i.e. frozen bulbs.

The cooling process for bulbs, whether it is applied before or after the bulbs are planted, should not commence until the bulbs have matured enough to perceive the cold treatment. Bulbs are mature enough when they reach Stage G. This can be determined by cutting open bulbs and examining the developing shoot. Applying cold temperatures prior to Stage G may result in aborted or poorly colored flowers. If bulbs are not at Stage G, they should be held at 20°C to allow them to continue to mature. Bulbs that are mature but not yet ready to plant should be held at 17°C.

After bulbs reach Stage G, they are typically subjected to precise cold-temperature treatments to ensure optimal flowering in the shortest time span. The amount and duration of the cold treatments varies with the time of year that the treatments begin, cultivar, and desired flowering time. Most cultivars should receive 15–16 weeks of cold. Generally, bulbs are placed at 9°C for optimum rooting after which time the temperature is lowered to 5°C, which is the optimum temperature for shoot elongation and for satisfying the cold requirement. After shoots have sufficiently elongated, the temperature is reduced to 0–2°C to greatly slow shoot and root development and to hold plants until they are brought out of the coolers and forced in flower at a warm temperature. Depending on the schedule and root/shoot development, the temperatures might be lowered immediately or in stages.

In some situations, part or all of the cold treatment, 5°C, is provided to dry bulbs, which is known as precooling. Precooling is used when:

1. The basal plate is not yet completely mature.
2. There is insufficient space in the cooler (less room is required for non-potted bulbs).
3. The added time is needed to allow any *Fusarium* present to become more evident and the infected bulbs can be removed.
4. Additional cold cannot be provided after planting, such as in hydroponic systems or in greenhouses, tunnels or the field where there is no or limited temperature control.

In the latter case, if additional cold temperatures can be provided to allow further development after planting, a higher precooling temperature of 9°C can be used.

With all of these considerations in mind, cut tulips can be produced using one of several systems (International Flower Bulb Centre, n.d.):

- Crates (trays) using bulbs precooled to 9 or 5°C or uncooled bulbs. If uncooled bulbs are used, the entire crate of substrate and bulbs is given the appropriate temperatures.
- Hydroponic trays using 5 or 9°C precooled bulbs (most common for large-scale cut tulip production).
- Ground beds in the greenhouse, tunnel or field using bulbs precooled to 9 or 5°C or uncooled bulbs.

Regardless of the system used, there is a limit to how long tulip bulbs can be stored or cold-treated before cut stem quality declines to an unmarketable state. In such cases, bulbs from the southern hemisphere or ice tulips can be used. Ice tulips are created by planting bulbs in crates, holding them for 2–4 weeks at 9°C to allow root development and then freezing the crates at −1.5 to 2.0°C to stop development. The crates are wrapped in plastic to prevent drying out. Flowers produced from ice tulips will generally be lower quality than those produced from southern hemisphere bulbs planted at the same time.

Bulbs can be produced in crates filled with a well-drained substrate, in a hydroponic system or directly in the ground (Table 2.13). Bulbs are planted with 5 cm of substrate above the tip of the bulb. For planting in crates, a peat–sand mix, pH 6–7, is usually used. The sand adds weight to the mix, which helps to prevent bulbs from pushing themselves out of the substrate from excessive root growth. Crates are filled with at least 5 cm of substrate, bulbs are

Table 2.13. Planting density, described as dense, normal or sparse, will vary with the cultivar, bulb size, time of year and foliage density. (From International Flower Bulb Centre, n.d.)

	Early forcing			Late forcing		
Bulb size (cm)	Dense	Normal	Sparse	Dense	Normal	Sparse
	Bulbs per tray (60 × 40 cm)					
12/-	85	100	110	75	85	100
11/12	100	115	130	90	100	115
10/11	–	–	–	100	115	130

planted, and then the crates are filled with additional substrate. An additional 2-cm layer of sand may be added to help prevent bulbs from growing out of the substrate owing to excessive root growth.

Greenhouse night temperatures should be 10–13°C during forcing for best quality. High temperatures, >20°C, may result in flower bud abortion and/or poor-quality stems.

Irrigation and nutrition

Tulips planted in substrates need to be kept continuously moist to ensure proper root development, which is especially critical for 5°C precooled bulbs. During forcing, proper moisture is also necessary for the plants to develop long stems and large flowers.

Tulips have minimal nutritional requirements during cold treatment and forcing, because the bulbs provide a reservoir of nutrients to the new growth. Calcium nitrate may be applied to help prevent tulip topple.

Major pests

Diseases are the major pests on commercial cut tulip production with *Fusarium oxysporum* f. sp. *tulipae* being the most problematic. *Fusarium* infects the bulbs causing dark brown spots, often covered in white, tan or pinkish mold growing on the outer tunic of the bulb. Bulbs may also be soft or very lightweight. Infected bulbs will generally not sprout, but those few that do will be stunted. To make matters worse, ethylene emanating from infected bulbs may damage non-infected bulbs. If more than 10% of the bulbs are infected with *Fusarium*, the entire lot may need to be discarded (De Hertogh, 1996). All infected bulbs must be discarded and planting crews must be properly trained to inspect bulbs. Generally, there is little a grower can do to control *Fusarium*, it is best to purchase disease-free bulbs.

Several other fungi cause problems for tulips. *Penicillium*, also known as blue mold, commonly appears on the surface of bulbs during cold-temperature treatments. While blue mold is generally only unsightly, it occasionally causes problems when it penetrates into the bulb tissue. *Botrytis tulipae* infects both leaves and the bulbs resulting in a disease known as ‘fire’. If the bulbs are infected, they may not produce shoots. If the shoots are infected, they will be stunted or deformed, usually curling to one side. If the leaves are infected, white to tan spots will be produced. Fungicides can be used to prevent botrytis development.

Pythium may infect and rot bulbs, preventing the shoots from emerging. *Pythium* can be separated from *Fusarium* infection by the soft wet rot. Finally, *Rhizoctonia tuliparum* causes gray bulb rot of tulip and *Thielaviopsis* can cause root rots. These fungal diseases are best prevented by using pathogen-free substrate.

Bacterial diseases reported include bacterial soft rot (*Dickeya* or *Pectobacterium*). Nematodes can be problems, especially *Ditylenchus dipsaci*, but also *Aphelenchoides*, *Paratrichodorus*, *Pratylenchus* and *Trichodorus*. Viruses, such as tulip breaking, tobacco necrosis, tobacco rattle, tobacco mosaic, cucumber mosaic virus, arabis mosaic, lily symptomless and tulip virus x, can occur and are best prevented by purchasing healthy bulbs (Moorman, 2016).

Considering all of the potential diseases, it is good news that aphids are the only common insect that is a problem with tulips. Fortunately, tulips forcing is generally so fast that aphids rarely have enough time to get established.

Postharvest management

For immediate use, tulips stems can be harvested when well colored but before they begin to open. For wholesale use, harvest when tight with color only at the tip (Fig. 2.40). Exact harvest stage will vary with the cultivar. Tulip flowers develop quickly, even in cool production temperatures, and often must be harvested multiple times per day.

For the longest storage and vase life, pull up the entire plant and keep the bulb attached (Dole *et al.*, 2017). Stems with bulbs can be stored dry and the bulbs can be removed when cut stems are needed. For the longest stems, cut the bulb away, leaving the extra inch or so of stem tissue within the bulb. If growing outdoors in a perennial production system, leave two leaves on the plant to nourish the bulb. Stems will be short, greatly limiting the marketing of the cut stems. Be aware the tulip do not readily perennialize except in areas with long, cool springs.

Tulip stems continue to elongate after harvest and will curve upward if stored horizontally or at an angle. For straight stems, store bunches upright and fill each bucket with enough flowers that they do not sit at an angle. Store cut stems at 0–2°C with 85% relative humidity. Tulip flowers can continue to develop even at cold temperatures. Thus, it is important to maintain

Fig. 2.40. Cut tulips ready for harvest. (Photo: J. Dole.)

cold temperatures and monitor development in the cooler. Stems should be kept cold as they are being processed, graded and bunched.

Most postharvest and vase solutions have little effect on tulip. However, products specifically developed for tulips will help keep foliage green and reduce stem bending. These products are used at the grower level, but may also be used at the wholesaler level. Experimentally, growth retardants have been incorporated into the bucket solution or applied as a spray to prevent stem elongation. With proper treatments, flowers should last 7–10 days.

REFERENCES

De Hertogh, A. (1996) *Holland Bulb Forcer's Guide*. The International Flower Bulb Centre, Hillegom, the Netherlands.

Dole, J., Stamps, R., Carlson, A., Ahmad, I., Greer, L. and Laushman, J. (2017) *Postharvest Handling of Cut Flowers and Greens*. Association of Specialty Cut Flower Growers Press, Oberlin, Ohio.

Hanks, G. (2018) A review of production statistics for the cut flower and foliage sector. The National Cut Flower Centre, Agriculture and Horticulture Development Board (AHDB), Holbeach St. Johns, Lincolnshire, UK.

International Flower Bulb Centre (n.d.) The Forcing of Tulips. Hillegom, Holland. Available at: https://bulbs.nl/wp-content/uploads/TULIPS-Forcing-Guide.pdf (accessed 3 July 2020).

Loyola, C.E., Dole, J.M. and Dunning, R. (2019) North American specialty cut flower production and postharvest survey. *HortTechnology* 29, 338–359.

Maarten J.M.C., Govaerts, R., David, J.C., Hall, T., Borland, K. *et al*. (2013) Tiptoe through the tulips – cultural history, molecular phylogenetics and classification of *Tulipa* (Liliaceae). *Botanical Journal of the Linnean Society* 172, 280–328.

Moorman, G.W. (2016) Tulip Diseases. Available at: https://extension.psu.edu/tulip-diseases (accessed 30 November 2019).

United States Department of Agriculture (USDA) (2019) Floriculture crops 2018 summary. National Agricultural Statistics Survey, Washington, DC.

3

CUT FOLIAGES

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INTRODUCTION

Cut foliage refers to leaves and stems harvested for the purpose of providing texture, color and depth to bouquets and floral arrangements. While traditionally known as greenery or fillers, cut foliage has expanded beyond use as merely a green background for flowers. Today's cut foliage species possess dramatically colored or textured foliage that acts as a partner to the flowers. In fact, foliage is more and more often the primary component of arrangements and bouquets, drawing together a range of colors and patterns – silver, chartreuse, bronzy-reds, burgundy, various variegations and every shade of green imaginable. Foliage stands alone as a cover for foam shapes such as religious symbols or offers visual interest when used to line the sides of long, clear vases to hide flower stems. Lastly, significant cultural or religious symbolism is attached to certain species, which are used for specific celebrations, such as chamaedorea palm leaves during the Christian Easter celebration.

Cut foliage is an important economic contributor to the floriculture industry with an international export value of US$1.4 billion, a 100% increase from 2001 to 2019. Most cut foliage species are grown in tropical and subtropical locations, while the leading exporting countries are located in temperate climates (i.e. the top five exporting countries are the Netherlands, Italy, Denmark, the USA and Canada). These statistics reflect the fact that the sales, shipping and delivery are managed in countries that are not growing significant quantities of the product, and the export values are often attributed to the location of the broker organization, not the grower. The leading cut foliage-producing countries include Costa Rica, Colombia, Ecuador, Guatemala and Italy.

Over 100 plant species are used for their cut foliage, yet growers often focus their production on one or a few species that are particularly well adapted to the local climate. The following generalizations hold true for the production and postharvest characteristics of the majority of cut foliage species:

 Cut Flowers and Foliages (eds J.E. Faust and J.M. Dole).

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- They are grown as perennial crops where a portion of the plant is harvested, while the remaining leaves sustain plant growth for future harvests.
- The plants are produced in ground beds or fields, not on bench systems or in hydroponic systems. Thus, the costs of production are generally lower than for cut flower production.
- The plants are not grown inside greenhouses and are, therefore, not provided temperature control.
- A range of light environments – from full sun to heavy shade – are provided according to requirements of the foliage species. Shade-requiring species are grown under shade cloth placed over a simple, greenhouse-like structure.
- Foliage plants are relatively easy-to-grow species that require less extensive integrated pest management programs compared with most cut flower species.
- The plants have resilient tissues that allow them to withstand damage during harvest, shipping and arrangement. Resiliency arises, in part, from the fact that many species used for cut foliage are relatively slow growing. Slow growth contributes not only to resilient tissues but also to a relatively long vase life compared with cut flowers.
- Foliage is rarely the limiting factor in the vase life of a mixed bouquet.

CATEGORIZING CUT FOLIAGE SPECIES

The range of species used for cut foliage is vast, so categorizing plants into meaningful groupings, e.g. minimum temperature tolerance, climatic preference, light environment and life cycle, can help us understand how species are interrelated through their physiological responses to the environment (temperature and light) and their life cycles. Exceptions exist, but in most cases these responses dictate where and how the plants are best grown in commercial operations.

Minimum temperature tolerance

The low temperature tolerance determines the best practices for cold-chain management for survival and/or ability to remain free of cold damage during storage and transport. Mixing species with different minimum temperature tolerances, therefore, results in a non-optimal environment for one or more of the species. Mixing is not recommended, because it either increases the risk for cold damage or decreases vase life owing to high respiration rates. Minimum temperature tolerance is broken down into two categories: cold tolerant and chilling sensitive.

Cold tolerant

Cold-tolerant species tolerate cold, non-freezing temperatures (>0°C). To minimize respiration rates and maximize vase life, these species are typically stored and shipped at 1–5°C.

Chilling sensitive

Chilling-sensitive species are damaged by cold, non-freezing temperatures (>0°C and <10–15°C). These species are typically stored at 12–15°C to avoid chilling injury while minimizing respiration rates. Risk of chilling injury increases with the magnitude and duration of exposure to chilling temperatures.

Climate

Climatic zones are indicative of the annual temperature and rainfall patterns that determine the most suitable locations for cut foliage production. For our purposes, three broad climates are differentiated: tropical, subtropical and temperate. Each climate is further subdivided into two additional categories. Tropical climates are designated as either lowland or highland tropical locations. Subtropical climates are either humid or dry. Temperate climates are designated either warm-season or cool-season. The natural climatic distribution of a plant species and its life cycle within those climates are factors in the determination of the most appropriate location for the commercial production of that species as a cut foliage crop.

Tropical

Tropical climates are characterized by moderate to high temperatures and non-freezing temperatures. Tropical locations occur from Lat. 0–23°N and °S. Rainfall patterns vary within the tropics, but rainy and dry seasons are typical. Freezing temperatures do not occur, and chilling temperatures are uncommon. The *lowland tropics* are hot, humid environments that rarely drop below 20°C. Species that perform well in lowland tropical locations have relatively high optimal temperatures for growth and productivity ranging from 25 to 35°C. Cut foliage species native to the lowland tropical forests are often understory species that are not exposed to high light conditions; thus, they require shaded environments for commercial production. *Highland tropics* occur at high altitude (>1500 m) locations within equatorial regions. The average high temperatures are 20–30°C, while the low temperatures are near 10°C. Highland tropics are also referred to as the tropical savannah and are the preferred locations for cut flower production of many species. They are also useful for cut foliage production of subtropical and temperate climate species, as the ambient temperatures are too cool for lowland, tropical species.

Subtropical

Subtropical climates are characterized by hot summers and mild winters with occasional freezing temperatures. Subtropical climates can be further subdivided into *humid subtropical* areas, where a rainy season occurs during the hot periods, and *dry subtropical* (or Mediterranean) climates, where rainfall occurs primarily during the cooler months, and the hot periods are dry. Subtropical climates typically occur from Lat. 23–35°N or °S, but they can also occur at high elevations within tropical locations.

Temperate

Temperate climates occur from Lat. 35–66°N and °S, and they experience four seasons with wide temperature variation from summer to winter. When considering plant growth, temperate-climate species can be divided into two categories – *warm season* and *cool season* – which refer to the optimal temperatures for growth and development. Cool-season plants are grown from fall through winter and/or from winter through spring and typically have a relatively low optimal average daily temperature ranging from 16 to 22°C. These species typically fail to tolerate the heat of summer (average daily temperature (ADT) >25°C). W*arm-season* species are grown from spring through summer and typically have an optimal average daily temperature range from 22 to 28°C. Plants grown in temperate climates tolerate day temperatures that exceed the optimal temperatures if the night temperatures are sufficiently cool to create an acceptable average daily temperature. For example, daily maximum temperatures may exceed 30°C, but cooler night temperatures (15–22°C) reduce the overall heat stress experienced by the crop.

Hardiness zone

The low and high temperature tolerance for the survival of a plant species is identified by its hardiness zone range. Table 3.1 provides definitions for the hardiness zones presented for individual species.

Light

Full sunlight indicates that plants are best grown outdoors in direct sunlight to achieve maximum growth, yield and quality (Fig. 3.1). Shade structures, tunnels, greenhouses or a natural plant canopy can be used to reduce the light intensity below ambient levels. The most common descriptor for the light environment provided to cut foliage is the percentage of shade or light reduction. Light shade can be translated as providing a 25–40% reduction in solar radiation. Moderate shade can be translated as providing a 40–60% reduction

Table 3.1. Hardiness zones used to describe the low and high temperature tolerance for the survival of plant species.

Hardiness zone	Temperature (°C)
2	–40 to –50
3	–30 to –40
4	–20 to –30
5	–10 to –20
6	0 to –10
7	0 to 10
8	10 to 20
9	20 to 30
10	30 to 40
11	40 to 50

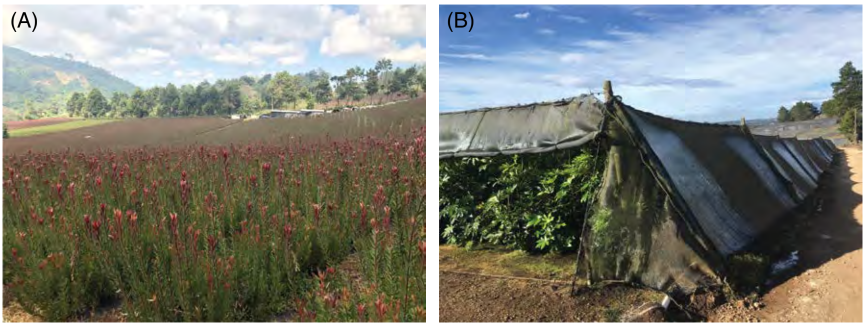

Fig. 3.1. (**A**) Outdoor leucadendron production; and (**B**) shade house production of fatsia (aralia) in Guatemala. (Photos: J. Faust.)

in solar radiation. Heavy shade can be translated as providing a 60–75% reduction in solar radiation. Percentage shade can be calculated by comparing the light intensity measured above the plant canopy to the light intensity measured outdoors in direct sunlight.

Daily light integral measurements provide a more precise measure of the light environment The daily light integral measured outdoors ranges from 20 to 60 mol/m^2/day on sunny days in most locations when plants are grown outside. *Heavy shade* environments provide a daily light integral of 5–10 mol/m^2/day, while *moderate shade* provides 10–15 mol/m^2/day and *light shade* typically provides 15–20 mol/m^2/day. Daily light integrals rarely exceed 20 mol/m^2/day when plants are grown inside a structure such as a greenhouse or shade house, because high light levels are associated with excessively high air temperatures. Unfortunately, these measurements require data-logging equipment and thus are not commonly made by cut foliage producers.

Life cycle

The main life cycle difference between species is whether the plant is an annual or a perennial. Annuals complete their life cycle in one season that ends when either the plants flower or the temperatures exceed the plant's tolerance for either heat or cold. Perennials complete their life cycle over many years, so they do not require frequent replanting. Leaves and stems can be harvested from the plants while sufficient tissue remains after the harvest to allow additional growth and productivity. For annuals, the entire plant is harvested and then the beds are replanted. Perennials can be harvested seasonally, or, in some cases, harvesting can be performed weekly for an indefinite period of time. Perennial species can be further divided into herbaceous perennials, woody plants and geophytes.

Annuals

In temperate climates, *warm-season annuals* are grown from spring through summer and then die from exposure to freezing temperatures, while *cool-season annuals* are grown during the fall, winter and/or spring and die from exposure to excessively hot temperatures.

Herbaceous perennials

Herbaceous perennials produce herbaceous, aboveground tissues. *Temperate herbaceous perennials* are native to temperate climates and typically have dormant, underground perenniating tissues during the winter months from which shoots emerge in the spring. Temperate herbaceous perennials can be deciduous or evergreen. *Tropical herbaceous perennials* grow year-round in subtropical or tropical locations and have evergreen foliage. Growth of these species may come in flushes associated with the wet and dry seasons.

Woody

Woody plants grown for cut foliage produce new shoots and leaves from aboveground woody tissues. *Temperate woody* cut foliage species can be deciduous or evergreen shrubs or trees and are typically trimmed aggressively to maintain a well-branched, relatively short plant that is convenient for harvesting the stems. *Tropical woody* cut foliage species are usually evergreen but may have seasonal flushes of new growth depending on rainfall patterns.

Geophytes

Geophytes survive by creating underground storage organs that assist the plant in avoiding dry or cold seasons. Bulbs, corms, tubers and storage roots are examples. After planting, the geophyte typically produces foliage that is harvested for a period of time until growth slows. Then, the crop is removed and new geophyte structures, e.g. bulbs, are planted.

HARVEST AND POSTHARVEST

When cut foliage is harvested, it is usually bundled and marketed in bunches (Fig. 3.2A). Ten stems per bunch is typical, but the numbers range from 5 to 20, depending on the dimensions of the foliage. Shrink-wrapping is done during the packaging of leatherleaf fern, although this can create postharvest problems if shipping/storage temperatures are too warm (Fig. 3.2B). Sometimes multiple species are combined and sold as boxes. Combination boxes allow growers the flexibility of harvesting and packing according to product availability. Cut foliage requires less specialized postharvest handling than cut flowers, e.g. unique flower food products are not used for different species. Wild-harvesting is still practiced on several important foliage species, although overharvesting and destruction of native populations is a growing concern. Foliage products are frequently sold directly to florists, designers and bouquet makers rather than to consumers, who tend to focus on the flowers. However, do-it-yourself websites offer direct marketing of a broad array of foliage for brides and event planners. Unfortunately, cut foliage does not command the same prices per stem in the market as cut flowers despite having similar labor costs to harvest and similar shipping and handling costs.

The postharvest handling and processing of cut foliage has several unique techniques that differ from cut flowers. Desiccation is a major factor limiting the vase life of many foliage species. To reduce water loss, anti-transpirants are applied in the postharvest environment by dipping stems into tanks of the solutions. Leaf shine is often sprayed on foliage to improve appearance and to hide spray residue that may be on the leaves, and leaf shine can also reduce water loss. Cut foliages are frequently packaged by wrapping the bunches in plastic films to maintain humidity and minimize water loss in storage and shipping environments. Finally, paint, dye and glitter are sometimes applied to resilient cut foliage species, thereby expanding the palette of colors naturally available and providing unlimited marketing possibilities (Fig. 3.3). Paints, dyes and glitters also can be used to hide imperfections.

Blemishes of any type are unacceptable for cut foliage, so foliar pathogens and pests are all concerns for growers. Since cut foliage crops are frequently grown outdoors or under shade curtains, the foliage gets wet when it rains, which contributes to pathogen spread. Large crates of harvested foliage may be dipped in fungicide baths prior to processing and packaging (Fig. 3.4). Common fungal and oomycete pathogens include: *Xanthomonas* leaf spot, *Fusarium* stem rot, *Phytophthora*, anthracnose, *Cercospora* and *Myrothecium*. *Erwinia carotovora* is the most common bacterial pathogen blight. Spider mites and caterpillars cause damage that renders foliage unusable. Details for pest and disease management systems designed for cut flower and foliage production are provided in Chapters 6 and 7.

Fig. 3.2. (**A**) Fatsia (aralia) being bundled into bunches during processing. (**B**) Leatherleaf fern being shrink-wrapped prior to international shipping. (Photos: J. Faust.)

The following section provides descriptions of species frequently grown for their foliage. Species are organized based on their native climate, e.g. tropical, subtropical or temperate, followed by less commonly available species, i.e. minor species.

Fig. 3.3. Painted foliage provides a means of expanding the market uses for cut foliage and can aid in covering up blemishes and imperfections. Examples of painted ruscus (**A**), liriope (**B**) and buxus (**C** and **D**). (Photos: J. Faust.)

TROPICAL CUT FOLIAGE SPECIES

Aglaonema	Chinese evergreen	Many cultivars derived from *Aglaonema commutatum*, *Aglaonema costatum*, *Aglaonema crispum* and *Aglaonema modestum*	Araceae

Aglaonema are evergreen, perennial herbaceous plants native to humid tropical and subtropical forests of Asia and the Pacific. The lanceolate/oblong leaf blades are up to 46 cm long × 8 cm wide and are held upright with 20 cm petioles. Numerous variegated patterns are available, including irregular silver, gray, lime, pink and red splotching.

Aglaonema production for cut foliage occurs in humid subtropical or tropical locations. Heavy shade is required during production (70–90% shade), especially when temperatures exceed 35°C. Symptoms of excess light are downward bent, chlorotic leaves that are attempting to avoid light interception. Field plantings require 1350–1550 kg N/ha/year (Henny *et al.*, 1991a). Hardy to Zone 10b.

Fig. 3.4. A crate of cut foliage being treated in a fungicide bath prior to processing and packaging. (Photo: J. Faust.)

Foliage is cut when recently but fully matured. Plants are chilling sensitive (<10–12°C), so leaves must be not be stored or shipped at cold temperatures (Stamps, 1999). Chilling symptoms are identified as gray splotches on mid to older leaves. Cut foliage has a vase life of 7–14 days and is best held in water alone since floral preservatives reduce vase life. Anti-transpirants can delay desiccation. Some cultivars are somewhat sensitive to ethylene, so methylcyclopropene (1-MCP) treatments can be beneficial. Plant tissues are considered to be poisonous and can irritate mucous membranes, and the latex sap can cause dermatological reactions.

Alpinia	Ginger lily	*Alpinia zerumbet* (shell ginger), *Alpinia sanderae* (variegated ginger, syn. *Alpinia vittata*), *Alpinia purpurata* (red ginger)	Zingiberaceae

Alpinias are evergreen perennial species native to humid, tropical locations in East Asia. The growth habit includes rhizomatous stems that form large clumps on cane-like stems that reach 2–3 m. The lanceolate-oblong leaves are 30–80 cm long × 10–20 cm wide and lack a petiole. Of the species listed above, *A. zerumbet* has the best vase life, and 'Variegata' is the most widely grown foliagetype. Alpinia foliage is noteworthy for its irregular spaced, white streaks that run parallel to the pinnate veins in the leaf blades (Leite *et al.*, 2015). Various ginger lilies are frequently cultivated as cut flowers.

The plants grow well in full sunlight, but light to moderate shade (30–50%) is recommended for cut foliage production (Stamps, 1999). Alpinia requires protection during freezes. Grow in moist, well-drained soils. Storage and shipping temperatures should be 12–15°C and pack moist to prevent desiccation (Kobayashi *et al.*, 2007). In China and Japan, the leaves are also used for wrapping traditional foods.

Anthurium	Laceleaf	*Anthurium andreanum*	Araceae

Anthuriums are piphytic herbaceous, tropical rainforest plants growing to 1 m tall. They are native to Colombia and Ecuador where they thrive on moist soils with high organic matter and humid, shady environments. The arrowhead-shaped leaves are 20–30 cm long. They are normally grown as a cut flower, but the thick, stiff, velvety foliage is also attractive and long-lived as cut foliage (Stamps, 1999). The hardiness range is Zone 10 to 11.

Anthurium clarinervium (native to southern Mexico) and *Anthurium crystallinum* (native from Panama to Peru) have prominent white veins on velvety, dark, green, heart-shaped leaves.

Production is done in shade houses with 75–80% shade (Henny *et al.*, 1991b). Recommended storage and shipping temperatures are 12–15°C, while high humidity should also be maintained to prevent desiccation. Vase life is 1–2 weeks, and anti-transpirants may lengthen vase life. Dipping leaves in cytokinins (200 ppm benzyladenine) can extend vase life, and leaf shine can improve appearance. The latex sap in the stem and leaf tissues can cause dermatological irritation and can be poisonous if consumed.

Calathea	Prayer plant	*Calathea* spp.	Maranthaceae

Calathea species are native to the understory of humid, tropical rainforests in the Americas, and the species used for cut foliage are primarily from Brazil. They possess strikingly unusual and colorful patterns of green, yellow, white, red, purple and black across the evergreen leaves that fold upward nightly. Leaf quality is best when temperatures are <32°C. The most commonly used calathea species for cut foliage are listed below.

Calathea makoyana (peacock calathea) has broad oval leaves reaching 40–50 cm in length. The upper leaf surfaces have dark-green blotches along the pinnate veins while the undersides are deep purple. The petioles are reddish. *Calathea lancifolia* (syn. *insignis*, rattlesnake plant) possesses erect, lanceolate leaves, 50 cm long with wavy, undulate margins and alternating blotches of light and dark green running up the leaf blade, creating a snake-like appearance. The lower leaf surface is maroon. *Calathea louisae* (emerald feather) grows up to 80 cm tall while the leaf blades are 25 × 10 cm. Stripes of light and dark green alternate along the pinnate veins.

Calathea foliage is best grown under heavy shade (80–90%) (Poole *et al.*, 1991a), and the hardiness ranges from Zones 11–12. Store and ship at 12–15°C and moist conditions. Anti-transparents may be necessary to reduce water loss, and leaf shine can improve leaf appearance. Calathea are more difficult to grow than many foliage species and are susceptible to spider mites in low relative humidity environments (Stamps, 1999).

Codiaeum	Croton	*Codiaeum variegatum*	Euphorbiaceae

Crotons grow into shrubs and small trees in their native tropical habitats of India, Malaysia and islands of the South Pacific. Tremendous variation occurs in the leaf shape and color. Leaves can be broad and elliptical to narrow, twisted and linear. Colors within individual leaves can be green, yellow, orange, red, black and white in all sorts of irregular splashed and spotted patterns. The thick, hard, glossy, individual leaves or entire stems displaying multiple leaves can be used for floral arrangements (Stamps, 1999).

Cut foliage production can be done in subtropical and tropical locations. Moderate shade (30–50%) is required to obtain the best leaf pigmentation (Stamps and Osborne, n.d.). Plants grow quite well in full sunlight, but leaf color will be faded and leaf size will be reduced. Leaf color is also enhanced by cooler weather. Plants are damaged by freezing temperatures. Field-grown plants require ~1000 kg N/ha/year. Plants are hardy in Zones 9b–11.

Fully mature croton foliage can be harvested and stored at 16°C for up to 2 weeks. Colder temperatures (2–4°C) are tolerated for shorter periods. Vase life can be 1–4 weeks. The use of floral preservatives is not recommended. Desiccation is the primary limiting factor for vase life, so anti-transpirants can be beneficial, and leaves should be packed wet. Leaf shine is frequently used. Petioles may form adventitious roots while in the vase of a floral arrangement. In these cases, vase life is exceptionally long; however, this is not a means of propagating the plant and no new shoots will arise from the leaf. Rooting can also occur at the base of harvested stems.

Cordyline	Ti plant	*Cordyline fruticosa* (syn. *Cordyline terminalis*, *Dracaena*)	Asparagaceae

A palm-like, woody plant growing to 4 m tall. Distributed throughout humid, tropical climates in the Pacific, where it is used extensively in religious ceremonies and rituals. It also has numerous uses including as a food, medicine and dye.

Glossy, lanceolate leaves are arranged in a fan-like pattern. Individual leaves range from 30–60 cm long and 5–10 cm wide. Many colors are available including green, red, dark maroon, blackish-green and red-edged tricolored (red, yellow, green), which places the plant among the most colorful foliage available.

Moderate to heavy shade (60–75%) is required for good pigment development. Plants are susceptible to freezing temperatures and fluoridated water. New plants are propagated from cane pieces as with dracaena and yucca. Outdoor fertilization requires ~1700 kg N/ha/year. Plants are hardy in Zones 10–12. Vase life can be up to 3 weeks following cold storage for 10 days at 5–10°C (Favero *et al.*, 2012). Avoid colder temperatures to prevent chilling injury. Maintain humidity in the postharvest environment to reduce desiccation. Leaf shine can enhance appearance. Leaves can be manually curled and rolled in arrangements.

Cyperus	Umbrella sedge, papyrus	*Cyperus alternifolius*, *Cyperus papyrus*	Cyperaceae

This genus represents a vast array of mostly aquatic plants native to subtropical and tropical climates in the Mediterranean and Africa. A couple of those species produce ornamental whorls of leaves that appear at the apex of the flowering stems creating a globular, umbrella or mop-like appearance. All sedges possess triangular stems.

Cyperus alternifolius (umbrella sedge, syn. *Cyperus involucratus*) produces tufts of 10–30 cm long leaves that emerge from the top of the stems and form a single layer that resembles the spokes of a wheel. *Cyperus papyrus* (papyrus sedge) is the plant originally used by the Egyptians to make paper. The long, naked stems are densely tufted and sphere-like with numerous leaves reaching outward radially 10–20 cm.

Sedges tolerate full sun if adequate water is provided (Stamps, 1999). Stems are harvested at lengths of 60+ cm and stored at 2–5°C. The vase life is 1–4 weeks. Dehydration is an issue, so stems should not be bent or crushed and must be stored in moist conditions. Sedge foliage is useful in contemporary floral designs.

Dracaena	Corn plant, dragontree, lucky bamboo	*Dracaena* spp.	Asparagaceae

Of the 40 or so species, several are grown commercially for their cut foliage and for their decorative stems. *Dracaena fragrans* (corn plant) (syn. *Dracaena* *deremensis*) is a multi-stemmed shrub or small tree native to tropical Africa with a similar appearance to *Cordyline*. It has glossy, lanceolate leaves up to 1.5 m long and 10 cm wide that droop as they mature. Numerous cultivars have assorted linear variegation patterns. 'Massangeana' is the most common and has a yellow to lime-green strip down the center of each leaf. *Dracaena marginata* (Madagascar dragontree, syn. *Dracaena reflexa*) has long (up to 40 cm), narrow sword-like leaves that come in white, pink and red variegation patterns. *Dracaena sanderiana* (lucky bamboo, ribbon plant) is a smaller species with 1–2 cm diameter stems that are trained into spirals and other shapes. The 15–25 cm long, narrow, variegated leaves can be left on the stems or removed, which creates a bamboo-like appearance. *Dracaena surculosa* (gold-dust dracaena) has irregular yellow-white splotches on small (2 × 6 cm) elliptical leaves.

Moderate to heavy shade (60–80%) provides distinct variegation patterns, while higher light levels will cause leaf damage or will decrease variegation. Production occurs in humid, tropical locations. Vase life is 2–4 weeks. Avoid exposure to cool temperatures (<12°C) and desiccation, but most species can be stored for up to a week at 2–4°C, except for *D. marginata*, which is more temperature sensitive.

Molineria	Whaleback palm leaf	*Molineria capitulata* (syn. *Curculigo capitulata*)	Hypoxidaceae

Native understory plant in humid, tropical forests in Southeast Asia and the Pacific. Resembles a young palm. Pleated, gracefully arching foliage up to 1 m long and 10 cm wide. Has a vase life of 7–10 days.

Monstera	Swiss-cheese plant, split-leaf	*Monstera deliciosa*	Araceae

Epiphytic, vining plants native to humid, tropical forests in southern Mexico and throughout Central America where they grow 20 m on trees using aerial roots for support. The large (up to 90 cm long × 75 cm wide), thick, glossy, green leaf blades are deeply lobed/incised with numerous holes (Stamps, 1999). The leaves grow larger as the stems get more woody. Hardy to Zones 10–11.

Store and ship at 2–3°C and in high humidity environments. Note that the fruits are edible, but the sap from the leaves can be poisonous and cause dermatological reactions.

Pandanus	Screw pine	*Pandanus* spp.	Pandanaceae

Pandanus describes a large collection of tropical species that have leaves that are used for many purposes across the Pacific, some of which have also found a place as cut foliage species. Screw pines are palm-like trees with tough, leathery, strap-like leaves that range in length up to 90 cm long × 10 cm wide. The leaf margins may be edged with serrated spines, so care must be exerted during handling. The leaves naturally twist and turn. Selections with dark-green, purple, and white and lime-green variegated leaves are available. The plants are grown in full sun. Cut leaves are stored at 12–15°C and have a vase life of 2–3 weeks.

Philodendron	Tree philodendron, selloum	*Philodendron bipinnatifidum* (syn. *Philodendron selloum*)	Araceae

Native to humid, tropical forests in South America, where it climbs up trees using aerial roots for support. Numerous cultivars are available providing a range of leaf shapes, variegation and colors, including coppery-bronze, orange and purplish-black. The durable leaves (40 cm long × 20 cm wide) can be entire or be deeply lobed (Stamps, 1999).

Store cut foliage at 12–15°C in a humid environment. Leaf shine can be beneficial. Vase life is up to 2 weeks. Ethylene can cause leaf yellowing in the postharvest environment. The sap from the leaves can be poisonous and cause skin irritation.

Phoenix	Phoenix palm, pygmy date palm	*Phoenix roebelenii*	Arecaceae

Phoenix palm has fronds that are 60–90 cm long consisting of a graceful arching midrib with numerous, pinnate, gray-green leaflets (15–25 cm) that softly droop at their tips creating a delicate appearance (Fig. 3.5). Spines are

Fig. 3.5. Vase of Phoenix palm with tips of leaflets snipped off. (Photo: J. Faust.)

present at the leaf base. Native to humid tropical areas of Southeast Asia from Yunnan province, China to Laos and Vietnam, where this evergreen is typically <3 m tall and spreads by underground rhizomes. Grown in full sunlight or light shade. Tolerates a light frost (−2°C). Store and ship at 2–5°C.

Sansevieria	Snake plant	*Dracaena trifasciata* (syn. *Sansevieria trifasciata*)	Agavaceae

An evergreen perennial native to tropical West and Central Africa. The long leaves (0.5–1 m long × 5–10 cm wide) are linear, stiffly erect, sword-like, succulent and provide an architectural statement in floral designs. Numerous cultivars are available for their unique variegation patterns that vary in color (white, cream, yellow) and patterns (longitudinal, cross-banded), while the leaves are various shades of green, gray-green and silver-green. Plants are grown in moderate to heavy shade (40–90%) (Henley *et al.*, 1991a).

The pointed leaf tips need protection from physical damage during packaging and shipping. Sansevieria is chilling sensitive, so it needs to be stored and shipped above 10°C. High nitrogen rates used during production can increase chilling sensitivity.

Schefflera	Umbrella tree	*Schefflera actinophylla*, *Schefflera arboricola*	Araliaceae

The plants grow in full sun, but foliage production typically takes place under light to moderate (30–50%) shade. It is hardy in Zones 10–12. Two main species are used for cut foliage. *Schefflera actinophylla* (umbrella tree) is a multi-stemmed, evergreen tree native to humid, tropical forests in northern Australia, New Guinea and Java, where it grows to 15 m tall. The palmately compound leaves have 7–16 elliptic-ovate leaflets that spread to 50 cm in diameter in a radial pattern. Umbrella tree has become an invasive species in some areas. *Schefflera arboricola* (dwarf umbrella tree) is a smaller form of the umbrella tree that is native to Taiwan, where it is an evergreen shrub reaching 9 m tall. The palmately compound leaves have seven to nine obovate-oblong leaflets that spread to 20 cm in a radial pattern. Stems containing multiple leaves are harvested as cut foliage. Cultivars with irregular white to cream variegation patterns are available. Dwarf umbrella tree is very sensitive to ethylene damage in the postharvest environment.

Damage occurs at freezing temperatures, so storage and shipping should occur at 2–5°C (Stamps, 1999). Vase life is up to 2 weeks. The fertilization program should supply 2000–2700 kg N/ha/year (Poole *et al.*, 1991b). The plant sap contains calcium oxalate and can cause skin irritation and possible poisoning.

SUBTROPICAL CUT FOLIAGE SPECIES

Acacia	Mimosa, wattle	*Acacia* spp.	Mimosaceae

Acacia include thornless species of woody shrubs and trees native to Australia that are used for cut foliage. Compound leaves with fine-textured, pinnately divided leaflets are characteristic of acacia; however, some Australian species have flattened, leaf-like petioles, termed phyllodes. Cut foliage is produced outdoors in full sunlight in Mediterranean locations in France and Italy from September through March and in Australia from September through March.

Several species have become popular as filler in mixed bouquets: *Acacia baileyana* (Cootamundra wattle) has blue-gray, fern-like, pinnately divided leaflets and will form a small tree up to 10 m tall in its natural environment of south-eastern Australia. The cultivar 'Purpurea' has purple leaves and is grafted to maintain this color. Plants can benefit from light shade. Cut stems of this species are unattractive when dried out, so the vase life is shorter than other acacias. Cootamundra wattle can become an invasive species in favorable climates. *Acacia cultriformis* (knife-leaf wattle) is a 2–4 m shrub with triangular phyllodes that are blue-green, thick and leathery. Also sold for its golden, globular flowers that appear in leaf axils and terminal. Knife-leaf wattle is native to eastern Australia, has a good vase life and is very drought and frost tolerant. *Acacia merinthophora* (zig-zag wattle) is a 3–4 m shrub with stems that change direction at each node resulting in a zig-zagged pattern. Dark-green phyllodes are needle-like (up to 30 cm long × 1 mm wide) and curved or arching. The cut stems can be used in dried arrangements. Zig-zag wattle is native to Western Australia, but tolerates humidity better than other acacias from this area. Plants are frost tender and are propagated by seed (Horlock and Faragher, 2000).

Leaves are harvested when mature. Minimize water stress while harvesting and never leave out of water for >1 h, since plants are prone to wilting. Storage is not recommended due to high potential for wilting. Postharvest environment should be 1–4°C and 90% relative humidity. Vase life is 7 days, but maintaining moisture is essential. Several other species offer future potential, including *Acacia aphylla* and *Acacia holosericea*, and several species are currently produced for their flowers including: *Acacia buxifolia*, *Acacia retinodes* and *Acacia dealbata.*

Afrocarpus	Weeping podo, African fern pine	*Afrocarpus gracilior* (syn. *Podocarpus gracilior*)	Podocarpaceae

An evergreen tree, 20–40 m tall, native to humid, subtropical regions of East Africa, with small, linear (10 × 0.6 cm) leaves that are sessile or have very short petioles. The leaves are spirally attached to arching, flexible stems that are harvested as cut foliage. The stems have a graceful appearance that provides greenery in bouquets and a finer texture than podocarpus. Plants are grown in full sunlight and heavily trimmed to maintain short, multi-stemmed shrubs from which vigorous young shoots will emerge. Store and ship at 2–5°C. Vase life is up to 3 weeks. Foliage and stems can be dyed and painted to provide additional interest to arrangements.

Agonis	Western Australian peppermint, willow myrtle	*Agonis flexuosa*	Myrtaceae

A small tree or large shrub growing up to 10 m. It is native to Western Australia. Feathery, reddish to burgundy leaves have a wispy, willow-like appearance. Stems are branching with side shoots that are naturally curved. The cut foliage resembles mature forms of eucalyptus and has a peppermint scent when crushed.

Asparagus	Asparagus fern, tree fern	*Asparagus* spp.	Asparagaceae

Perennial evergreen species possessing underground tubers and tiny, needle- or fern-like leaves that are actually flattened stems, called phylloclads or cladodes. The leaves create a delicate, fern-like appearance in floral designs and as filler/greenery in bouquets. Most of the ornamental asparaguses are native to southern and eastern Africa. Some species are climbing and several have spines. Small white flowers develop into red berries that may be poisonous. Several species have become invasive plants after originally being introduced as ornamentals. Asparagus prefers moist soils but are quite drought tolerant.

Asparagus setaceous (syn. *Asparagus plumosus*, asparagus fern) is the most common species used for cut foliage and the first cut foliage species grown in Florida in the late 1800s (Stamps, 1999). The plant has a twining, climbing growth habit and reaches 3 m tall. They are native to wet, tropical forests throughout the eastern region of Africa. Commercial production takes place under moderate shading in shade houses or under natural plant canopies. Tubers are produced by the root system. The light, wispy appearance allows it to be used for small floral designs, such as corsages and boutonnieres. The plants produce red fruits (berries) that are poisonous, and the plants can be invasive in favorable climates. It is hardy to Zones 9–12.

Asparagus densiflorus (foxtail fern) has dense clusters of phyllodes tucked close to the stem creating a long tubular or cone-like appearance. 'Myers' (Myers asparagus) is a commonly available cultivar. *Asparagus aethiopicus* (syn. *Asparagus sprengeri*, Sprenger asparagus) has a scrambling habit. Occasional spines will appear along the stems. It forms small red berries. Plants may spread and it has become invasive in Hawaii, Florida and New Zealand. *Asparagus virgatus* (tree fern, African broom fern, tiki fern) is an evergreen perennial native to southeastern Africa that has a lacey appearance on vertical, 1 m tall stems. It produces small, red berries. *Asparagus falcatus* (bamboo asparagus, sicklethorn) is a rhizomatous, climbing plant native to South Africa and Madagascar. It grows up to 7 m and thorns form on older woody stems. The shiny green leaves are narrow and grass-like (10 × 1 cm) and twist and turn to create an informal appearance.

Asparagus retrofractus (syn. *Asparagus macowanii*, Ming fern or zig-zag asparagus) grows to 2–3 m. The phylloclades appear in tufted clusters of 20–30 that resemble a pompom. The internodes are oriented in an alternating fashion creating a zig-zag appearance. *Asparagus asparagoides* (smilax asparagus, bridal creeper) is a climbing species that reaches 3 m in height. The leaves are broader (2 cm wide) than other asparagus species and resemble smilax. Multiple plants are trained up strings and wound together to form garlands. This species has become invasive in Australia and New Zealand.

Store and ship asparagus species in moist packaging at 2–3°C. Vase life ranges from 1–3 weeks across species. Benzyladenine treatments may delay senescence.

Arachniodes	East Indian holly fern, shield fern	*Arachniodes simplicior* 'Variegata' (syn. *Aspidium aristatum* var. *simplicius*, *Polystichum aristatum*)	Dryopteridaceae

This is a rhizomatous, evergreen fern with a showy, soft-yellow stripe down the midribs of each leaflet. It is native to warm temperate to subtropical regions in China and Japan, where it grows up to 0.5 m tall. The glossy, lime-green cut foliage resembles leatherleaf fern (*Rumohra*), and it is sometimes referred to as variegated leatherleaf fern (Stamps, 1999). The fronds produce fertile spores that are considered undesirable in floral arrangements. It is used as a woodland landscape in temperate climates where it is very slow growing, while cut foliage production is possible in warmer, subtropical locations. Shield fern requires moderate to heavy shade, and tolerates temperatures down to −10°C. It is hardy in Zones 7–10.

Aspidistra	Cast iron plant	*Aspidistra elatior*	Asparagaceae

Aspidistra is a slow-growing evergreen that is native to China, Japan and the Himalayas, where it grows in moist, subtropical forests. Leaves up to 1 m long (one-third petiole, two-thirds leaf blade) and 10–15 cm wide emerge from rhizomes. The leaves are simple with parallel venation that creates linear aspects in arrangements. Leaves can be twisted and rolled into different shapes. Green and variegated forms exist. Variegation is long and linear or random yellow/white spotted patterns, but these cultivars are highly variable and slower growing than green leaves. Reverted green leaves need to be removed from variegated crops. Spotted cultivars have smaller, narrower leaves.

Plants are very tolerant of heat and drought, although they are most productive under moist conditions. Plant survive freezing temperatures to −5°C, however, the foliage will be damaged. Sunlight causes permanent sunburn when grown under <30% shade, so 50–80% shade is recommended (Stamps, n.d.a). Higher shade results in longer vase life. Store and ship at 2–5°C. Aspidistra is extremely durable as cut foliage, lasting up to 3 months in vases.

Aucuba	Gold dust plant, spotted Japanese laurel	*Aucuba japonica*	Garryaceae

Aucuba is a well-branched shrub native to moist, subtropical forests in China, Korea and Japan, where plants can reach 3 m tall and wide. The oppositely arranged leaves are broadly elliptic to ovate (5–10 cm wide × 10–20 cm long) and the ornamental forms have gold variegation in randomly arranged spots or large blotches centered along the midrib. Plants are grown in moderate to heavy shade, especially in hot climates, and are hardy to Zones 7–9. Cut stems are typically 2 years old. Store and ship at 2–3°C. Vase life is 2+ weeks, and stems may root if placed in sufficient light.

Chamaedorea	Parlor palm, fish-tail palm, tepee palm	*Chamaedorea* spp.	Arecaceae

Chamaedorea are small palms (<6 m) with slender cane-like stems that grow in the understory of rainforests. The plants spread by underground rhizomes and are frost-sensitive. The leaves are called *xaté* (pronounced SHA-tay) in Latin America, where they are wild-collected. The wild-collectors are called *xateros*. Xaté harvesting is important to the economies of rural communities in Mexico and Guatemala (Voight, 2011). Overharvest of native populations is a concern, and plantations have been established under natural forest canopies to address the commercial demand. Four main species are harvested as xaté.

Chamaedorea elegans (parlor palm, emerald palm) is the most widely used chamaedorea. Fronds are pinnately divided into numerous leaflets. Palm fronds are wild-harvested in Mexico, Guatemala and Belize (Stamps, 1999). The foliage is frequently sold for Easter celebrations (Palm Sunday) and as funeral decoration in North America. The plants grow to 2–3 m in height. Parlor palm requires more shade (70–80%) than other species (40–70%) (Henley *et al.*, 1991b). *Chamaedorea oblongata* and *Chamaedorea tepejilote* are additional pinnate-leaved species harvested as xaté. *Chamaedorea tepejilote* (tepee palm, pacaya palm) is a 6 m tall, understory, tropical rainforest tree resembling bamboo and grown in Mexico, Central American and Colombia. Pinnate leaves up to 1.5 m long, and leaflets droop from the rachis. It tolerates temperatures to −2°C. The immature male inflorescence is a popular food, named pacaya, in Guatemala and El Salvador. *Chamaedorea ernesti augusti* (fish-tail palm) has large, distinctive bifid (deeply cleft into two parts) leaves and grows to 2 m.

Cocculus	Laurel-leaved snail tree	*Cocculus laurifolius*	Menispermaceae

Cocculus are shrubby evergreen trees native to China and Japan. Glossy, green leaves and arcuate venation taper to the pointy apex of the leaf blade. Arching stems work well as greenery in bouquets as well as cascading and pedestal designs.

The best growth and yield occur outdoors in full sun, but it can be grown in greenhouses or under shade structures where the leaf color is best (Cervelli *et al.*, 2001). Longer branches develop when grown in greenhouses compared with open air production. Shade reduces plant growth, but improves quality. Plants are hardy to Zones 8–11.

Stems are harvested when leaves are fully mature and 60–90 cm in length. High humidity during processing, storage and shipping is essential. Store at 2–3°C. Vase life is quite good at 1–3 weeks. Floral preservatives should not be used. All tissues may be poisonous.

Cycas	Sago palm, king sago	*Cycas revoluta*	Cycadaceae

Tough, thickened leaflets are displayed on a pinnately divided leaf that can be 1 m long × 30 cm wide. The glossy, green leaflets have sharp, piercing tips. This evergreen is native to Japan where it grows extremely slowly but can eventually reaches 6 m. Sago palm is not actually a palm, but certainly resembles one. Grows well in full sun to light shade and subtropical locations. Plants are hardy to Zones 8–10. Store and ship leaves at 5–10°C in moisture-retentive packaging. Vase life is 2–3 weeks. Gibberellic acid (50 ppm) has been shown to improve vase life of cycad leaves up to 101 days (Maliheh *et al.*, 2016).

Cyrtomium	Holly fern	*Cyrtomium falcatum*	Dryopteridaceae

East Asia native, which produces 50 cm fronds with thick, leathery pinnae that possess a wavy, toothed margin resembling holly (*Ilex*) leaves. This evergreen is easy to grow for cut foliage, but it is slow growing. Holly fern is damaged by freezing (<0°C) temperatures and is susceptible to fern anthracnose (Stamps, 1999). Plants are hardy to Zones 7–10. Cut stem production requires moderate shade and moist, well-drained soils with high organic matter content. Holly fern is a popular landscape plant in temperate climates, where it is deciduous and has escaped from cultivation on several continents.

Danaë	Italian ruscus	Danaë racemosa (syn. Ruscus racemosus)	Asparagaceae

Slow-growing, evergreen shrub with glossy, green foliage that is native to dry, subtropical climates from Iran to the Caucuses. Italian ruscus has slender, arching stems up to 50–60 cm long holding glossy, green, pointed, twisted leaves (5 cm) that provide a textured appearance resembling mature eucalyptus or nandina stems. Like *Ruscus*, the leaves are actually flattened stems called phylloclades. Bright orange-red berries are produced at the tips of the side branches forming along the stem. Cut foliage is produced in moderate to heavy shade. Stems can be stored at 2–3°C, and vase life can be up to 3 weeks. Danaë makes an excellent filler for bouquets and is frequently painted or dyed.

Davallia	Rabbit's foot fern	Davallia solida	Davalliaceae

A tropical, epiphytic fern with infertile fronds resembling leatherleaf fern. Papery scales give the creeping rhizomes a hairy appearance. It is native to Fiji Islands. The fronds are 30 × 15 cm on plants that can reach 1 m. 'Plumosa' has graceful, feathery foliage. Davallia requires moderate to heavy shade and is chilling sensitive, so fronds need to be stored at 12–15°C (Stamps, 1999).

Eucalyptus	Gum trees	Eucalyptus spp.	Myrtaceae

Eucalyptus cut foliage is harvested from several species of trees native to subtropical climates in Australia. Many species exist and offer considerable potential for providing variation in textures and subtle colors, which has launched their popularity for wedding arrangements in recent years. Eucalypts have juvenile and adult stages of development. The juvenile, or immature, stage often has stiff, glaucous leaves that enclasp the stem and create a blue, gray or silver appearance. Some species have round (*Eucalyptus cinerea*, *Eucalyptus glaucescens*, *Eucalyptus gunni*, *Eucalyptus polyanthemos*, *Eucalyptus pulverulenta*), oval (*Eucalyptus populnea*) or oblong (*Eucalyptus parvula*, syn. *Eucalyptus parvifolia*) leaves. The adult stage has glossy, fine-textured, willow-like leaves, e.g. *Eucalyptus mourei* has green, narrow leaves with red stems and red/pink tones in the young leaves. *Eucalyptus rubida* has red/pink tones in the young leaves and red stems, *Eucalyptus nicholii* has long thin gray-green leaves and *Eucalyptus coccifera* has glaucous lanceolate leaves with white petioles. Most eucalypt foliage is fragrant. Some species are also sold with flowers or 'seeded', i.e. possessing peppercorn- to acorn-sized seed capsules.

Heavy pruning is performed at the end of the harvest season to manage plant size and to stimulate juvenile lateral shoots that will become the next flush of cut foliage. Stems should be cut back to a height of 1.0–1.2 m to maximize yield (Wirthensohn *et al.*, 1996). Trees cut to lower heights (0.5 m) produce the longest stems. Eucalypts are not frost tolerant, so they are mostly grown in Zones 8–10. Some species grow fast and are handled as an annual crop in temperate climates.

A 2% sucrose holding solution can extend vase life. Storage can be wet or dry for up to 4 weeks at 5°C. A vase life of 1–3 weeks can be expected. Eucalypts can be dried and dyed to create different colors and will last indefinitely.

Fatsia	Japanese fatsia, aralia, figleaf palm	*Fatsia japonica*	Araliaceae

An evergreen, humid, subtropical shrub native to Japan, Korea and Taiwan. The plant grows to 3 m and produces palmately lobed leaves that are individually harvested as cut foliage. Each leaf has seven to nine lobes that expand to 20–30 cm in diameter and are held upon a 30–50 cm long petiole. Production occurs under moderate shade. Plants are frost tolerant down to −5°C and hardy to Zones 8–10. Store and ship at 2–5°C and in a moist environment. Treatment with leaf shine and anti-transpirant can be beneficial. Vase life is 1–2 weeks. × *Fatshedera lizei* (tree ivy) is an intergeneric hybrid resulting from a cross between fatsia and *Hedera helix* (English ivy) that is more cold hardy and has smaller leaves (Stamps, 1999).

Grevillea	White oak, silky oak, toothbrush plant	*Grevillea* spp.	Proteaceae

Grevillea includes over 200 species, many of which are grown for their ornamental flowers; however, several have proven to be useful as cut foliage.

Grevillea baileyana (white oak) is a tree native to subtropical and tropical rainforests in northeast Australia and Papua New Guinea, where it reaches up to 30 m in height. The juvenile leaves are pinnately dissected into many narrow, pointed lobes, while the mature leaves are entire. The upper side of the leaf is dark green, while the lower surface is gold to bronze to red. Plants prefer full sun to light shade and are hardy to Zone 9. The vase life is excellent and it can last up to 3 weeks (Srhoj, 2005). *Grevillea robusta* (silky oak, silver oak) has attractive, fine-textured, fern-like leaves that reach 30 cm in length. The undersides of the leaves are silvery or rust-colored. Other grevillea species are grafted onto *G. robusta* rootstock to improve disease resistance and reduce soil-borne problems. *Grevillea hookeriana* (red toothbrushes) is native to southwest Australia, with leaves that are divided into needle-like appendages.

Leucadendron	Conebush	*Leucadendron* × *hybrida*	Proteaceae

Erect, evergreen shrubs growing to 2–3 m in height in dry, subtropical locations in South Africa. Primarily sold for their colorful and durable foliage, they also produce woody, cone-like flowers that provide additional interest in floral displays. The leaves emerge in a spiral pattern around the stiff stem that can be cut at various lengths up 90 cm. Hybridization of multiple species has resulted in a tremendous array of foliage color, including dark reddish-purple, nearly black, chartreuse and silver, depending on the cultivar (Fig. 3.6). Foliage color also intensifies on the leaves (bracts) positioned immediately below the terminal cone. The bracts turn upward in a tulip-like shape. Species contributing to the modern hybrids include: *Leucadendron argenteum* (silver tree), *Leucadendron laureolum* (golden conebush), *Leucadendron meridianum* (silver conebush) and *L. salginum* (sunshine conebush). Leucadendron are dioecious (separate male and female plants), but the cones of both sexes are attractive.

Liriope	Lilygrass, lilyturf	*Liriope* spp.	Asparagaceae

Plants are grown in full sunlight, tolerate mild frosts to −3°C and are grown in Zones 9–11. Leaf and bract pigmentation improves with higher light levels. As with most plants in the Proteaceae family, low phosphorus levels in the soil are essential. Store and ship at 2–5°C. Vase life is up to 3 weeks. Pulsing solutions with 5% sucrose or glucose before storage and 2% sucrose or glucose in the vase solution reduces leaf blackening and desiccation (Philosoph-Hadas *et al.*, 2010).

Liriope is a grass-like plant with long, narrow leaves (1–1.5 cm × 40–80 cm) and native to humid, subtropical forests in China and Southeast Asia.

Fig. 3.6. Buckets of leucadendron stems ready for packing and shipping. (Photo: J. Faust.)

Commercially cultivated liriope likely originate from *Liriope gigantea* and/or *Liriope muscari* and can be confused with *Ophiopogon*. The evergreen leaves are bright green and glossy. Variegated leaf forms are available with linear, white lines running along the veins or margins. Rhizomes allow the plant to colonize planting beds. Leaves are harvested by pulling them from the crown rather than cutting, then the leaves are recut during processing and packaging. Package moist and cold (2–3°C). Liriope is frequently sold in larger bunches than most foliage, e.g. 25 leaves per bunch. Vase life is up to 3 weeks for green-leaf forms, while the variegated forms have about half that vase life.

Nageia	Nagi	*Nageia nagi* (syn. *Podocarpus nagi*)	Podocarpaceae

Nageia is a dioecious tree native to subtropical forests in China and Japan. Nagi has glossy dark-green, leathery leaves that resemble Italian ruscus (Stamps, 1999). The 15 × 5 cm leaves often twist to form a flattened, planar orientation along the stem. They also lack a midrib, which distinguishes it from other plants in the Podocarpaceae. Plants are tolerant of full sun and freezing to −4°C.

Olea	Olive	*Olea europaea*	Oleaceae

Olives are small trees native to the Mediterranean coasts of Europe and North Africa and are primarily cultivated for their fruits; however, the foliage is also valuable when cut for ornamental arrangements. The sage gray undersides of the leaves contrast with the green upper leaf surfaces to provide a two-tone appearance. The oblong (2 × 10 cm), simple leaves have margins that are entire and recurved with an acute apex. They appear opposite one another along the stem and are oriented in many different directions. Stems are curved, and side branches occur along the main stem. The net effect is a relaxed, 'natural' appearance, similar to eucalyptus.

Ophiopogon	Lilyturf, lilygrass, evergreen giant mondo grass	*Ophiopogon jaburan Vittatus* (syn. *Mondo jaburan*)	Asparagaceae

Ophiopogon is an evergreen, Asian native closely related to and difficult to distinguish from liriope. In general, ophiopogon has smaller (0.5–1 cm × 50 cm) leaves than liriope. Variegated leaf forms are available with linear white lines running along the midrib or margins. Rhizomes allow the plant to colonize planting beds. Leaves are harvested by pulling them from the crown rather than cutting, then the leaves are recut during processing and packaging. Package moist and cold (2–3°C).

Pittosporum	Japanese pittosporum, Japanese mock orange, pitt, pitto	*Pittosporum tobira*	Pittosporaceae

An evergreen shrub naturally distributed from the eastern Mediterranean to East Asia. The obovate leaves are alternately arranged along the woody stems that terminate in a cluster of leaves that appear to be in a whorl, resembling a green flower. Leaves come in green and variegated forms. The green-leaf form has shiny, bright-green leaves in contrast to the variegated form that has a duller, gray-green leaf surrounded with a clear, white margin. Pittosporum is best grown in moderate (50%) shade (Stamps, 1999) and is hardy to −8°C, but is most frequently grown as cut foliage in Zones 9–10. Vase life is 1–3 weeks. Anti-transpirants are beneficial and stems need to be packed in moist conditions to prevent desiccation. Store and ship at 2–3°C. Ethylene contributes to leaf abscission, so silver thiosulfate (STS) may be beneficial to prevent ethylene damage. Pittosporum is popular as a filler in bouquets.

Pittosporum tenuifolium (New Zealand pittosporum, mini pitt) is very similar to Japanese pittosporum except it produces a smaller leaf with a finer-textured appearance. Green and variegated forms are also available. Vase life is shorter for *P. tenuifolium* compared with *Pittosporum tobira.*

Restio	Cape rush	Various genera	Restionaceae

Restios are a group of perennial, clump-forming, grass- and sedge-like species native to South Africa that provide long-lasting cut foliage. The plants have green photosynthesizing stems, called culms, and spike-like inflorescences. The leaves appear as small sheaths at each joint along the culm. Restios are grown in full sunlight and are often wild-collected. Several related species are used as cut foliage.

Elegia tectorum (small cape rush, syn. *Chondropetalum tectorum*) is the best-known restio. Slender, dark-green culms reach up to 1 m, and each joint is wrapped in a deciduous, brown papery bract that reveals a mahogany band when it falls off, creating an appearance that resembles equisetum. The flowers are brown-black spikelets that are produced at the top of each culm. Hardy to −3 to −6°C. *Elegia capensis* grows in marshy locations in clumps up to 2 m tall and wide, resembling large, branched horsetails (*Equisetum*). *Chondropetalum elephantinum* (large cape rush) resembles *Elegia tectorum* but grows to 2 m in height and has thicker culms. *Ischyrolepis subverticillata* grows to 1.5 m with branched culms that resemble horsetails. *Restio*, *Rhodocoma* and *Thamnocortus* are genera that contain many additional species that vary in size and texture but otherwise have similar characteristics to other restios.

Rumohra	Leatherleaf fern	*Rumohra adiantiformis*	Dryopteridaceae

Leatherleaf is the single most popular international cut foliage plant owing to its low production costs, keeping quality, year-round availability and versatility in use as greenery for floral designs and bouquets. Its natural distribution occurs across subtropical and tropical regions of the southern hemisphere, including South America, Africa and the Pacific, but production is not limited to southern latitudes.

Fronds are triangular in shape with coarsely toothed pinnae. Leathery pinnae are produced on 30–60 cm long fronds. Sori (spore-bearing structures) are present on the undersides of the pinnae. Scales are prominent on the stipes (petioles). Numerous cultivars have been selected for commercial production, and the most popular cultivars are propagated by tissue culture. Plants are grown under moderate to heavy shade (Fig. 3.7). Heavier shade (70%) increases frond size (area) and yield (Cervelli *et al.*, 2003). Production locations typically are in subtropical regions with an annual precipitation ranging from 100–150 cm/year. While leatherleaf normally grows on moist, high organic matter soils, production can be done well on sandy soils if provided with proper irrigation and fertilization management. Nitrogen application rates are 100–400 kg N/ha/year (Stamps, n.d.b). The time from leaf emergence to maturity is ~23 days. Productivity ranges from 0.15 to 0.73 leaves harvested per plant per day (Strandberg, 2005). When grown in cooler temperatures (20°C), photosynthesis approaches a maximum rate at ~150 μmol/m^2/s, while at warmer temperatures (30°C) the maximum photosynthesis rate

Fig. 3.7. Shade house production of leatherleaf fern in Guatemala. (Photo: J. Faust.)

occurs near 300 μmol/m^2/s (Stamps *et al.*, 1994). Plants are typically grown in Zones 9–11.

Infertile fronds are primarily harvested, although the presence of sori (spore-producing structures on the underside of the frond) does not have detrimental effects on postharvest performance. Leatherleaf is sold in bunches containing up to 25 fronds. Vase life is up to 3 weeks but can be shorter if it is harvested during warm periods when night temperatures exceed 25°C. Fronds are stored at 1–6°C. High humidity is beneficial and anti-transpirants can help reduce water loss. Avoid floral preservatives.

Ruscus	Spineless butcher's broom, Israeli ruscus	*Ruscus hypophyllum* (syn. *Danaë racemosa*)	Asparagaceae

Ruscus is a spineless, evergreen shrub with a rhizomatous, spreading habit that grows to 1 m tall and is native to Western Europe through Iran. Note that *Ruscus aculeatus* (butcher's broom) has spines, which makes it less useful for the floral trade.

The elliptical leaves are more accurately described as phylloclades, cladodes or cladophylls that are actually flattened stem tissue. The phylloclades are 7 cm long × 4 cm wide, tapering to a point on both ends. The true leaves are minute, scale-like and do not photosynthesize. Israeli ruscus has a broader phylloclade than Italian ruscus (*Danaë racemosa*) (Fig. 3.8). Floral buds and red berries will develop in the middle of the phylloclades.

Fig. 3.8. Vase of Israeli ruscus stems. (Photo: J. Faust.)

Moderate to heavy shade (50–80%) produces the largest leaves, longest leaves and longest vase life (Stamps, 1997; Singh *et al.*, 2017). Yields have been reported as high as ~680,000 stems/ha/year (Stamps, n.d.c). Plants can be damaged by freezing temperatures. Cut stems are 50–60 cm long and store best at 2–5°C. The storage period can be several months long. Ruscus has excellent vase life of 1–4 weeks or possibly longer making it a popular greenery item for mixed bouquets. The cut stems can also be painted or dyed (Fig. 3.3).

Serenoa	Saw palmetto, fan palm	*Serenoa repens*	Arecaceae

A small, multi-trunked, evergreen palm growing to 3 m tall that is native to subtropical coastal areas in the southeastern USA, where it grows as an understory plant in pine forests. Twenty leaflets form a semi-circle on a palmately compound frond that reaches up to 1 m long. Leaf colors range from green to blue-green to silver-white. The sturdy petiole is edged with sharp spines that give this plant its common name.

Store and ship at 2–5°C with a moisture-retaining barrier. Avoid desiccation with the use of an anti-transpirant. Leaf shine is useful on green-leaved plants, but may mask the waxy, glaucous coating that gives the silver-blue leaves their appeal. Vase life is 1–2 weeks.

Washingtonia	Mexican fan palm	*Washingtonia robusta*	Arecaceae

Mexican fan palm grows up to 20 m tall and is native to northwestern Mexico and the southwestern USA. Fronds are bright green to olive green and grow up to 1 m long. The tips of the leaflets curve, and the petioles are edged with sharp teeth. Fronds, as well as partially unfolded fronds, called 'stalks', are sold for Palm Sunday and other Easter religious celebrations. Individual leaflets are stripped off immature leaves and sold as palm strips and used for weaving into various symbols and shapes. Ashes from the burnt leaves are used to celebrate Ash Wednesday. Plants are cold tolerant to −15°C and grow best in low relative humidity and full sunlight. *Washingtonia* can become invasive in favorable locations.

TEMPERATE CUT FOLIAGE SPECIES

Camellia	Camellia	*Camellia japonica*	Theaceae

In the home landscape, camellias are known for their large spectacular flowers in the fall and winter. However, the flowers last only 2–4 days after harvest, while the glossy evergreen foliage, 5–10 cm long, lasts for 2–4 weeks. Stems can be harvested as soon as the growth hardens in the midsummer and harvesting continues through early spring when growth commences again. Do not harvest more than one-third of the plant in any one season. After harvest, stems can be held dry at 2–4°C for up to 3 weeks.

The relatively slow-growing plants are hardy in Zones 7–9, but the foliage is prone to winter damage in Zones 7 and 8 during cold spells. Plants require an acid soil, pH 5–5.5, and grow best in partial shade, allowing them to be grown in areas that might be otherwise unused. The foliage is prone to discoloring if grown in the full sun.

Many other *Camellia* species are available and have potential. In particular, *Camellia sasanqua* has smaller, finer-textured leaves, 4–7 cm long.

Euonymus	Japanese euonymus	*Euonymus japonicus* *E. fortunei*	Celastraceae

Many cultivars in this genus show potential for cut production, but the two most common species are *Euonymus japonicas*, with long, upright stems and long, glossy leaves of 2.5–8 cm long, and *Euonymus fortune*, with small leaves, up to 2.5 cm, and procumbent stems. *Euonymus japonicus* grows 3–4.6 m tall and is cold hardy in Zones 7–9. A number of cultivars are available with green leaves or variegated with yellow or white. Dwarf cultivars should be avoided.

Euonymus fortunei grows only 30 cm tall as a ground cover but can reach 21 m in length as it spreads across the ground or climbs over structures. Other forms of this species form low mounding or even upright shrubs. Many variegated cultivars are available for this species as well.

Harvest foliage when mature, hydrate in clean water and pack quickly. Anti-transpirants may be applied to improve appearance and extend vase life. Hold at 2–5°C in moisture-retentive boxes or in water. Vase life is 2–3 weeks.

Galax	Galax	*Galax urceolata*	Diapensiaceae

Galax is native to the Appalachian mountains of the southeastern USA, where it grows on the forest floor. The green, kidney-shaped leaves can develop an attractive purplish color in the winter. Leaves are up to 15 cm wide on a petiole that can be up to 35 cm long. The largest leaves are the most desired and they are wild-harvested from tetraploid populations that occur only in part of its range. Illegal poaching is a serious problem with this species as most of the populations are found on restricted public lands. Legal harvest from National Forest lands is only allowed with proper permits from July to April.

The individual leaves should be carefully cut or pulled to prevent damage to the main plant. After harvest the leaves are stored in moisture-retentive boxes and stored or shipped at 2–5°C. After unpacking leaves, recut petioles and place in water. Leaves have a vase life of many weeks.

Hedera	English ivy	*Hedera helix*	Araliaceae

English ivy has a centuries-long history of cultivation and use in floral arrangements. The vines of glossy green palmate leaves are versatile, lending themselves to being wrapped around centerpieces and topiaries. Hundreds of cultivars are available, some with variegated and unusual leaves, and with leaf sizes that range from 1.5–15 cm wide.

English ivy has both a juvenile, vining form and a shrub-like adult form. Only the juvenile form is commercially important. Plants are hardy in Zones 4–9 and most cultivars do best in partial shade. Note that English ivy has become invasive in many areas and its production may be restricted. Many other *Hedera* species are cultivated, some of which might have commercial potential as well.

Stems can be harvested any time of the year and should be submerged in water for 2–4 h after harvest to hydrate and prevent wilting. Interestingly, if a particular shape is needed, place stems in the desired shape before submerging and they will retain this shape after hydration. After hydration, stems can be stored in plastic bags at 2–5°C. Vase life is typically around 1 week, but stems are prone to rooting, especially when held in water, which can extend the vase life for weeks.

Magnolia	Southern magnolia	*Magnolia grandiflora*	Magnoliaceae

While the southern magnolia is best known as a landscape tree with lush fragrant flowers, it is quite useful as a cut foliage. The large leaves, 13–25 cm long, are thick and glossy with a rusty brown underside. Southern magnolia trees are native to the southeastern USA in Zones 7–10, but widely planted elsewhere. Many cultivars are available that range in vigor, under-leaf coloring and leaf size. Cultivars with smaller leaves may be particularly useful. Plants grow fairly slowly but handle pruning and harvesting well.

Foliage can be harvested any time after the leaves mature, usually beginning in late August. It is more popular for the Christmas holidays. Stems 60–90 cm are cut and can be used for floral arrangements, but more commonly for garlands and wreaths. After harvest, hydrate in water, cool and pack in moisture-retentive boxes. Store and ship stems at 2–3°C. The leaves typically last 5–10 days when used fresh, but can be used out of water where they can last for weeks, slowly drying out.

Nandina	Nandina, heavenly bamboo	*Nandina domestica*	Berberidaceae

Both the fruit and the foliage of nandina can be used commercially, although the foliage is most common. This evergreen shrub is hardy in Zones 6–10 and a number of cultivars are available that range in height (up to 2.4 m), vigor, fruit color, and leaf size, shape and color. Avoid dwarf cultivars intended for the landscape. While tolerant of partial shade, the best fall color develops in full sun. Space plants 1 m apart and cut back to the ground every 1–2 years to produce fresh foliage and long stems. Plants can be invasive in the right locations, so handle accordingly.

Mature leaves, which are 30–90 cm long, can be harvested starting in late summer and continuing through Christmas. Immature foliage will not last as long. The fine-textured foliage develops reddish, purple and bronze tones in the fall, which makes the foliage popular for fall arrangements. After harvest, place into clean water for hydration, then pack into moisture-retentive boxes. After storage recut and place in a holding solution. Stems can be stored and shipped at 1–2°C in moisture-retentive boxes. Vase life is 5–10 days.

Ocimum	Basil	*Ocimum* spp.	Lamiaceae

Several long-stemmed culinary herbs are commonly used as aromatic foliage in mixed bouquets, including basil (*Ocimum* spp.), dill (*Anethum graveolens*), mint (*Mentha* spp.), oregano (*Origanum* spp.), rosemary (*Salvia rosmarinus*) and sage (*Salvia officinalis*). Of these, basil is one of the most diverse, available in a variety of foliage shapes, colors and fragrances. Several species are commonly grown as cut foliage. Cinnamon basil (*Ocimum basilicum*), lemon basil (*Ocimum* × *citriodorum*) and 'African Blue' (*Ocimum kilimandscharicum* × *basilicum* 'Dark Opal') are among the most popular owing to their long stems and small, attractive leaves. The culinary Italian basil and red basil (both *O. basilicum*) are sometimes used as well, but the stems are not very long. Many other species exist that might be useful as a cut foliage. The terminal spikes of small flowers can be attractive, especially with 'African Blue' and 'Cardinal', but are not the main attraction. Leaves range from 0.5–11 cm long, although cultivars popular for cut use are generally in the middle of the range.

Basils are annual or tender perennials typically treated as warm-season annuals. Most varieties are seed propagated, producing harvestable stems in as little as 4 months. However, 'African Blue' is cutting propagated. Plants can be grown in the field, tunnel or greenhouse. Stem length is typically longer under cover.

Harvest stems when long enough to be useful. Basil is prone to wilting, so it is best harvested in the early morning or late evening. Cut stems should be placed in a commercial hydration solution for at least 4 h, then place in a commercial holding solution as basil is quite responsive to floral preservatives (Table 3.2). Basil is susceptible to chilling injury if held at 3–5°C; therefore, stems must be stored at 10°C. Basil is also sensitive to ethylene; thus, be sure the environment is ethylene free. An anti-ethylene agent can be used to prevent ethylene damage.

Table 3.2. Vase life of two basil cultivars treated with either water or a commercial hydration solution for 4 h after harvest before being placed in water or a commercial holding solution for 44 h. After treatment, stems were placed in water until terminated. (From Clark *et al.*, 2010; Dole *et al.*, 2013.)

Cultivar	Water		Commercial solution	
	Water	Commercial solution	Water	Commercial solution
	Vase life (days)			
Aromato	12.9	22.5	14.7	23.6
Cardinal	4.7	10.6	8.9	14.0

Phormium	New Zealand flax, flax lily	*Phormium tenax*	Asphodelaceae

Phormium plants are grown from their long, thin leaves attractively colored with various combinations of maroon, bronze, rosy-pink, red, white, yellow and green. Leaves are up to 7 cm wide and 1.8 m long. As the common name indicates, phormium is native to New Zealand. Many cultivars are available ranging from compact plants only 45 cm tall to large 2.7 m plants. The most commercially viable plants are likely in the middle of that range. Harvest well-colored, mature leaves.

Plants are reliably hardy in Zones 9–11, but with protection can overwinter in Zones 7 and 8. In the colder zones, plants will die back to the ground. Plants grow best in full sun. In prime locations, plants will produce tall flower stalks, but this is not common.

Physocarpus	Ninebark	*Physocarpus opulifolius*	Rosaceae

Ninebark is native to central and eastern North American and is cold hardy in Zones 2–7. Cultivated forms of this shrub have yellow, bronze or burgundy foliage that lasts up to 3 weeks. Cultivars vary in height from 1.5–3 m tall and leaves from 3–8 cm long. Ninebark has small clusters of white flowers that lead to interesting clusters of seedpods. The flowers tend to shatter quickly, but stems of foliage and seedpods are commonly sold as well. Harvest foliage after it matures in midsummer. Cut stems should be treated with a holding solution to maximize vase life (Greer and Dole, 2017).

During the winter, cut remaining stems back to the ground, which encourages new, strong branches to grow from the base of the plant that develop into long, easily harvestable stems. Without winter pruning, the plants become large with a tangle of twiggy stems that are not commercially useful.

Polystichum	Western sword fern	*Polystichum munitum*	Dryopteridaceae

Sword fern is evergreen and native to the temperate climate of western North America where it is wild-harvested. The plants grows up to 2 m tall and in clumps. Individual fronds are 40–60 cm long and single pinnate with the pinnae alternating up the rachis, creating a sword-like appearance.

It grows in moist, humus soils and moderate shade. Infertile fronds are harvested as cut foliage to avoid spores or fertile fronds can be collected before the spore-producing structures (sori) have begun to turn brown. Storage and shipping is best at 2–4°C and in moisture-retaining materials. Avoid desiccation and recut petioles (stipes) and place in water, not floral preservative. The vase life is 10–14 days. The plants grow in Zones 7–9.

Christmas fern (*Polystichum acrostichoides*) is an evergreen fern native to the temperate climate forests of eastern North America. Fronds are 30–80 cm long and 5–10 cm wide. It is similar in appearance to western sword fern but the plant is smaller (1 m tall), and the cut foliage is not typically exported outside of the region.

Salal	Lemonleaf, salal	*Gaultheria shallon*	Ericaceae

Salal is popular for its lustrous evergreen foliage in an attractive alternating zig-zag pattern up the stem. The leaves are 5–10 cm long and 2–8 cm wide. Salal is wild-harvested from its native coastal range from northern California to southern British Columbia and Alaska. Plants can grow up to 3 m tall in good locations with moist, acid soil, but are generally shorter. The best foliage comes from plants growing in partial shade. Salal can be cultivated in similar conditions and is hardy in Zones 8–10. In the spring, plants should be cut back hard to encourage new growth. Salal is an invasive species in the UK and would likely be problematic in other similar climates.

Cut stems can last 10–20 days and can be stored for up to 10 days at 2–5°C. Salal produces pink flowers and edible blue berries, but is generally harvested only for its foliage.

Senecio	Dusty miller	*Jacobeae maritima* (syn. *Senecio cineraria*)	Asteraceae

Dusty miller is known for its soft leaves densely covered in grayish or silvery hairs. This tender perennial is typically grown as a warm-season annual in temperate climates but may overwinter in Zone 8 or warmer. If plants overwinter, they will produce bright yellow flowers, which are attractive but of limited value as a cut flower. Flowers can be removed to encourage leaf production.

A number of cultivars are available that vary in the shape of the leaf and height. Vegetative plants are not very tall, topping out at 38–45 cm, limiting their use to weddings, personal flowers, small bouquets and small arrangements. Plants can be grown in the field, tunnel or greenhouse.

Plants grow fast from seed and are relatively easy to grow. Foliage can be harvested in 4 months or so. Harvest individual leaves or stems when they are well colored. To avoid wilting, harvest in the morning into water or hydration solution. Leaves will last 7–10 days.

Vaccinium	Huckleberry, huck	*Vaccinium ovatum*	Ericaceae

This evergreen shrub, 1.2–2.4 m tall, is native to the coastal western USA and Canada in Zones 7–9. It bears glossy leathery green foliage, 2–3 cm long, on attractive reddish brown stems. The young foliage has a reddish color, which can also develop during the winter, leading to another common name, red huck. Note that red huckleberry is also the common name of a related deciduous species, *Vaccinium parvifolium*, that is harvested for its green branches with red buds in the spring. Huckleberry also produces flowers and fruit, but they are not used commercially. Stems 30–75 cm long are wild-harvested from plants that grow 1–3 m tall. No more than 40% of a plant should be harvested each season. Plants can be cultivated in full sun with an organic soil with a pH of 4–5.5.

Stems are harvested from late summer through early spring when the new growth has a reddish color. Special postharvest treatments are not needed. Stems can be held at 2–5°C for up to 2 weeks. Stems have a vase life of 14–20 days.

Xerophyllum	Common beargrass	*Xerophyllum tenax*	Melanthiaceae

Beargrass is a perennial native to coastal northern California, Oregon and Washington, as well as to inland mountains of northern Idaho, western Montana and limited adjacent areas in Wyoming and Canada. While not a grass, it gets its common name from its long, thin, grass-like leaves. The 2–10-mm-wide leaves are up to 90 cm long and have a long history of being used by Native Americans in basket weaving and the creation of personal ornaments.

Beargrass is predominantly wild-harvested as it can be abundant in the right locations and is relatively difficult to cultivate (Hummel *et al.*, 2012). The leaves can be harvested year-round, with most harvesting occurring in spring and summer. There are increasing concerns about the viability of wild-harvesting bear grass, owing to its popularity. The longest leaves are pulled from the center of the plants and combined into 0.22–0.45 kg bunches. The leaf edges are sharp, so harvesting must be done with care.

Beargrass is stored at 2–4°C in moisture-retentive boxes to prevent water loss or in water if already processed for use. After receipt, recut the leaves and place them in a hydrating solution. Beargrass can last up to 3 weeks in the vase, but typically has a 7–14-day vase life.

MINOR CUT FOLIAGE SPECIES

Species are continually being experimented with and added to the list of useful cut foliages (Fig. 3.9). Typically, these plants are produced and used regionally until they prove to have widespread market appeal. The scientific and common name, production information, estimated vase life and optimum harvest stage are listed for 72 minor species (Table 3.3). Warm-season annuals refer to those that require warm temperatures and do not tolerate frost or freezing temperatures. Cool-season annuals are those that are planted in the fall, winter or early spring, depending on the locations, and grow best with cool temperatures. Most cool-season annuals tolerate some frost.

Zones indicated refer to cold-hardiness zones. Note that for some cut flowers, multiple species are grown and the cold-hardiness zones and vase life might vary greatly within the range reported in the table. Even within a species, cold-hardiness zones can vary greatly with the cultivar, production location and production method, so treat zones listed accordingly. Also, note that while many plants can be grown in cooler climates (zones), cost-effective production typically takes place in warmer zones.

In some cases the large range in the vase life is because of the use of floral preservatives; the lower number is typically the vase life when only water is used and the higher number is when floral preservatives are used.

See Chapter 4 for a few additional species that are primarily used as cut flowers but can also be marketed for their foliage.

Fig 3.9. Thlaspi foliage with seed pods displayed with white hydrangea blooms. (Photo: J. Faust.)

Table 3.3. Minor cut foliages. (From Dole *et al*., 2017 and other sources, e.g. Premium Greens Australia, 2020.)

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Abies spp.	Fir	F	W	3–6	21–35	Branches with mature foliage
Artemisia ludoviciana	Artemisia	F	P	4–10	10	Well-colored shoots just as the lower stem is becoming slightly woody and before the flowers form
Baloskion pallens *Baloskion tetraphyllum*	Didgery sticks Dingo fern	F	TP	9–11	14–28	Leaves fully mature
Bambusa spp.	Bamboo	F	W	9a+	28+	Hardened foliage with good color
Buxus microphylla *Buxus sempervirens*	Boxwood	F	W	5–9	7–14	Branches with fully mature leaves
Callitris columellaris	Bribie pine	F	W	9–11	14–28	Branches with fully mature leaves
Caustis blakei *Caustis flexuosa*	Koala fern Emu feather	F	TP	9–10	5–7	Outermost or uppermost branches have grown and extended to at least 4 cm to create a feathery appearance
Chamaecyparis spp.	Cedar	F	W	6–8	14–28+	Branches with fully mature leaves
Cupressus spp.	Cypress	F	W	6–10	14–21	Branches with mature foliage
Elaeagnus pungens, *Elaeagnus* × *ebbingei*	Elaeagnus	F	W	6–9	14–21	Branches with fully mature leaves
Equisetum hyemale	Horsetail, snake grass, scouring rush	F	P	4–9	7–21	Mature fertile or infertile stems
Gleichenia dicarpa	Star fern	F	TP	9–11	14–28	Fronds fully mature
Hibiscus acetosella	African rose mallow	TF	TP	8–11	7	Stems with well-colored foliage in early morning
Ilex spp.	Holly	F	W	3–9	7–21	Branches with fully mature leaves
Juniperus spp.	Juniper, red cedar	F	W	2–9	14–21	Branches with fully mature foliage

Lepironia articulata	Puzzle stix	F	TP	10–12	14–28	Leaves fully mature
Ligustrum lucidum, Ligustrum japonicum	Ligustrum, privet	F	W	8–10	7–21	Branches with fully mature foliage
Myrica cerifera, Myrica gale, Myrica pennsylvanica	Waxmyrtle, bayberry	F	W	3–11	42+	Branches with mature foliage
Myrtus communis	Common myrtle	F	W	8–10	7–14	Branches with fully mature foliage
Nephrolepsis exaltata	Sword fern	GT	P	8b+	5–10	Recently mature fronds
Oreopanax capitatus	Picon	F	W	10–11	30+	Leaves fully mature
Photinia × fraseri, Photinia glabra	Photinia	F	W	7–9	7–10	Branches with newly mature red leaves
Pinus spp.	Pine	F	W	2–9	14+	Branches with fully mature needles
Platycladus orientalis	Oriental or Chinese arborvitae	F	W	6–9	7–21	Branches with mature foliage
Podocarpus macrophyllus, Podocarpus drouynianus	Podocarpus, podo, emu grass	F	W	7–10	10–21	Branches with fully mature foliage
Quercus spp.	Oak	F	W	4–10	5–14	Branches with fully mature, well-colored leaves
Persoonia virgate	Sapphire bush	F	W	9–11	14–28	Branches with fully mature foliage
Persoonia longifolia	Barker bush					
Rhapis excelsa	Lady palm	F	W	10–12	7–10	Leaves fully mature
Rhamnus alaternus	Buckthorn	F	W	7–10	7–14	Branches with fully mature leaves
Rosemarinus officinalis	Rosemary	F	W	8–11	7–14	Branches with well-colored foliage
Schoenus melanostachys	Flexi grass	F	TP	9–11	14–28	Leaves fully mature

Continued

Table 3.3. Continued.

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Stachys byzantine	Lamb's ear	GTF	P	4–7	7–10	Well-colored leaves
Stenocarpus angustifolius	Forest lace	F	W	10–11	14–28	Branches with fully mature foliage
Thlaspi arvense	Pennycress	F	A	–	7–10	Mature, green seed heads
Thuja plicata, Thuja occidentalis	Arborvitae	F	W	3–9	7–21	Branches with mature foliage
Tillandsia usneoides	Spanish moss	F	TP	8–11	Weeks	Any time
Weigela florida	Weigela	F	W	5–8	5–10	Branches with mature foliage
Xanthorrhoea johnsonii, Xanthorrhoea latifolia, Xanthorrhoea glauca	Steel grass	F	W	8–11	14–28	Leaves fully mature
Zamia pumila	Coontie	TF	P	8–11	10–14	Fully mature leaves

F = field, G = greenhouse, T = tunnel, A = annual, P = perennial, TP = tender perennial, W = woody.

REFERENCES

Cervelli, C., Fadelli, P.G. and Tallone, A. (2001) Growth of *Oreopanaz capitatus* and *Cocculus laurifolius* in different protected environments. *Acta Horticulturae* 559, 91–96.

Cervelli, C., Castello, S. and Fadelli, P.G. (2003) Leaf distinctive features and production of leatherleaf fern grown in greenhouse under different shading levels. *Acta Horticulturae* 634, 521–526.

Clark, E.M.R., Dole, J.M., Carlson, A.S., Moody, E.P., McCall, I.F., Fanelli, F.L. and Fonteno W.C. (2010) Vase life of new cut flower cultivars. *HortTechnology* 20, 1016–1025.

Dole, J.M., Carlson, A.S. Crawford, B.D. and McCall, I.F. (2013) Vase life of new cut flowers. *Acta Horticulturae* 1000, 63–70.

Favero, B.T., Carmell, Q.A.C. and Dias, G. (2012) Vase life of new tropical cut foliage: *Cordyline terminalis*. *Acta Horticulturae* 945, 351–356.

Greer, L. and Dole, J.M. (2017) *Woody Cut Stems*. Association of Specialty Cut Flower Growers Press, Oberlin, Ohio.

Henley, R.W., Chase, A.R. and Osborne, L.S. (1991a) Sansevieria Production Guide. CFREC-Apopka Foliage Plant Note RH-91-30. Available at: https://mrec.ifas.ufl.edu/foliage/folnotes/sansevie.htm (accessed 26 August 2020).

Henley, R.W., Chase, A.R. and Osborne, L.S. (1991b) Chamaedorea Palm Production Guide. CVREC – Apopka Foliage Research Note RH-91-10. Available at: https://mrec.ifas.ufl.edu/Foliage/folnotes/chamaed.htm (accessed 26 August 2020).

Henny, R.J., Chase, A.R. and Osborne, L.S. (1991a) Aglaonema Production Guide. CVREC-Apopka Foliage Research Note RH-91-2. Available at: https://mrec.ifas.ufl.edu/foliage/folnotes/aglaonem.htm (accessed 26 August 2020).

Henny, R.J., Chase, A.R. and Osborne, L.S. (1991b) Anthurium Production Guide. CVREC-Apopka Foliage Research Note RH-91-3. Available at: https://mrec.ifas.ufl.edu/Foliage/folnotes/anthuriu.htm (accessed 26 August 2020).

Horlock, R. and Faragher, J. (2000) Acacia Cut Flower and Foliage Production Manual. Rural Industries Research and Development Corporation. Available at: https://knowledge.flowersmagazine.com.au/acacia-cut-flower-foliage-production-manual/ (accessed 26 August 2020).

Hummel, S., Foltz-Jordan, S. and Polasky, S. (2012) Natural and Cultural History of Beargrass (Xerophyllum tenax). USDA General Technical Report PNW-GTR-864. Available at: https://www.fs.fed.us/pnw/pubs/pnw_gtr864.pdf (accessed 26 August 2020).

Kobayashi, K.D., McEwen, J. and Kaufman, A.J. (2007) Ornamental Ginger, Red and Pink. Cooperative Extension Service, University of Hawaii at Manoa. OF-37. Available at: https://www.ctahr.hawaii.edu/oc/freepubs/pdf/OF-37.pdf (accessed 26 August 2020).

Leite, K.P., Filho, J.C.C.A., Silva, S.S.L., de Araujo, P.G.P., Ferreira, I.V.S., Bastose, S.M.S.L. and Loges, V. (2015) Selection of Alpinias as cut foliage. *Acta Horticulturae* 1087, 261–265. Available at: https://www.ishs.org/ishs-article/1087_33 (accessed 26 August 2020).

Maliheh, A., Hossein, Z., Azim, G. and Mahnaz, A. (2016) Gibberellic acid (GA3) and benzyl adenine (BA) effects on the vase life of cycad's cut foliage. *Journal of Ornamental Plants* 6, 1–10.

Philosoph-Hadas, S., Perzelan, Y., Rosenberg, I., Droby, S. and Meir, S. (2010). Leucadendron 'Safari Sunset': postharvest treatments to improve quality of cut foliage during prolonged sea shipment. *Acta Horticulturae* 869, 207–218.

Poole, R.T., Chase, A.R. and Osborne, L.S. (1991a) Calathea Production Guide. CFREC-Apopka Foliage Plant Research Note RH-91-9. Available at: https://mrec.ifas.ufl.edu/foliage/folnotes/calathea.htm (accessed 26 August 2020).

Poole, R.T., Chase, A.R. and Osborne, L.S. (1991b) Schefflera Production Guide. CRFEC-Apopka Foliage Plant Research Note 91-31. Available at: https://mrec.ifas.ufl.edu/Foliage/folnotes/scheffle.htm (accessed 26 August 2020).

Premium Greens Australia (2020) Foliage. Available at: https://premiumgreensaustralia.com/portfolio/foliage/ (accessed 26 August 2020).

Singh, R., Singh, P. and Kaur, J. (2017) Manipulation of shade and plant density for enhanced production of cut-foliage in *Ruscus hypophyllum* L. *Journal of Horticultural Science* 12, 78–81.

Srhoj, J. (2005) North Queensland Native Foliage for the Flower Industry. Rural Industries Research and Development Corporation. Available at: https://knowledge.flowersmagazine.com.au/north-queensland-native-foliage-for-the-flower-industry/ (accessed 26 August 2020).

Stamps, R.H. (1997) Effects of shade level on growth and vase life of milky way aspidistra, variegated mondo grass and Israeli/Holland ruscus. University of Florida Cooperative Extension Service. *Cut Foliage Grower* 12, 1–6. Available at: https://pdfs.semanticscholar.org/decd/cb1645ad6387aa4821ab67ff4a0c03876df0.pdf (accessed 26 August 2020).

Stamps, R.H. (1999) Foliage Plants for use as Florists' 'Greens'. CFREC Cut Foliage Research Note RH-99-A. Available at: https://mrec.ifas.ufl.edu/cutfol/cutpubs/CFRN_99A_foliage_as_cuts.pdf (accessed 26 August 2020).

Stamps, R.H. (n.d.a) Aspidistra Production and Use. UF-AFAS Extension. Available at: https://ufdcimages.uflib.ufl.edu/UF/00/08/93/74/00001/EP14700.pdf (accessed 26 August 2020).

Stamps, R.H. (n.d.b) Irrigation and Nutrient Management Practices for Commercial Leatherleaf Fern Production in Florida. University of Florida, IFAS Extension BUL 300. Available at: https://edis.ifas.ufl.edu/ep027 (accessed 26 August 2020).

Stamps, R.H. (n.d.c) Florida/Holland/Israeli Ruscus Production and Use. University of Florida, IFAS Extension. Circular 1268. Available at: https://ufdcimages.uflib.ufl.edu/UF/00/08/93/76/00001/EP10400.pdf (accessed 26 August 2020).

Stamps, R.H., Nell, T.A. and Barrett, J.E. (1994) Production temperatures influence growth and physiology of leatherleaf fern. *HortScience* 29, 67–70.

Stamps, R.H. and Osborne, L.S. (n.d.) Croton Production and Use. UF-IFAS Extension. Available at: https://edis.ifas.ufl.edu/ep106 (accessed 26 August 2020).

Strandberg, J.O. (2005) Seasonal variations in production and development of leather leaf fern leaves. *Annals of Applied Biology* 143, 125–264. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1744-7348.2003.tb00290.x (accessed 26 August 2020).

Voight, C.N. (2011) Xate Palm (*Chamaedorea* sp.) Enrichment in Western Belize: the Ecological Effects of Management in Relation to Understory Plant Species Richness, Diversity, and Composition. MA Thesis, University of Florida.

Wirthensohn, M.G., Sedgley, M. and Ehmer, R. (1996) Production and postharvest treatment of cut stems of *Eucalyptus* L. Her. Foliage. *HortScience* 31, 1007–1009.

4

Specialty Cuts

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INTRODUCTION

Cut flower growers are a creative but practical group of individuals. They view almost any plant as a potential cut material either for use in a short-term event or as a long-term addition to their crop mix. The result is a large number of species that can be grown commercially for their flowers, seedpods, fruit, foliage and decorative stems. A tour of the Royal FloraHolland Flower Auction in Aalsmeer, the Netherlands, the Sydney Flower Market in Australia or the New England Flower Market in the USA reveals the amazing diversity of plant materials sold as cuts around the world.

The bulk of the cut flower industry depends on a few major species (see Chapter 2), most of which are grown under protection. However, gladiolus (*Gladiolus* hybrids) and peonies (*Paeonia* hybrids) are typically field grown and gypsophila (*Gypsophila paniculata*), Dutch iris (*Iris* × *hybrida*) and sunflower (*Helianthus annuus*) are grown in both types of environments. This chapter will provide a brief overview of the multitude of other species that are used as commercial cuts and their general production methods.

The terminology around specialty cut flowers varies with the country. In the USA, any flowers other than the major imported species, such as alstroemeria, carnation, chrysanthemum and rose, are known as specialty cut flowers and comprise the bulk of domestic production. In many areas of the world specialty cut flowers are also known as 'minor' or 'summer' cuts since many are produced outdoors during the summer. However, the latter term is problematic in that many specialty cuts, especially woody cuts, are harvested in the fall, winter and early spring, and others are grown under protection during the same time period.

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PRODUCTION ENVIRONMENT

Greenhouses

Large-scale cut flower production generally relies on greenhouses, which allows the environment and plant growth to be controlled (Fig. 4.1 and Fig. 4.2). Regulating the environment means that crops can be timed, growth patterns can be managed to increase stem length, pests can be more easily controlled, and crops can be protected from wind and rain. While greenhouse production can be done in raised soil beds, most production uses very well-drained substrates, such as coir, rice hulls or rock wool, or hydroponics. Since greenhouses require a relatively high initial capital investment and have ongoing maintenance costs, the crops grown inside need to be high value, productive (produce a large number of stems/m^2), and have a relatively short crop time or continuously produce stems. All water and fertilizer applications are controlled with irrigation systems and fertilizer injectors.

Tunnels and shade houses

Tunnels, either with or without sides, and without heating or cooling systems, provide some of the benefits of greenhouse production but with much reduced cost (Fig. 4.2). The climate can be controlled to a certain extent, but much less

Fig. 4.1. Beds of cut *Callistephus* in greenhouse. (Photo: J. Dole.)

than in greenhouses. Many species grow better in tunnels than in the field owing to protection from rain, wind and excessive light. The temperature can be modestly controlled in tunnels with sides allowing the season to be extended in the fall and allowing earlier production in the spring.

Shade houses can be used to grow high-value cuts that might be damaged from high light or protected from damaging winds. Hydrangea (*Hydrangea macrophylla*) are commonly grown in shade houses to produce higher-quality flowers and to reduce water loss as the plants are sensitive to drying out.

Tunnel and shade house production is typically directly in the soil or in raised beds (Fig. 4.3). In some cases, drainage lines will need to be provided. Crops are generally fertigated using a constant liquid injector.

Field

The widest range of species are grown in the field owing to the lower production costs, allowing many perennials and woody trees, shrubs and vines to be

Fig. 4.2. Tunnel-grown *Celosia* 'Chief Scarlet' can be sold fresh or dried. (Photo: J. Dole.)

economically produced (Fig. 4.4). Smaller operations often rely on field production. However, many businesses include one or more tunnels to grow those species that produce higher-quality cuts under protection and to extend the season. A fully climate-controlled greenhouse is often added to allow for propagation and year-round production of selected species.

In the field, production can be planted in rows spaced far enough apart for a tractor or rototiller to pass between the rows as with many vegetable operations. However, the row system is limited to specific crops because of the difficulty of supporting the crops and of the high potential for soil and other debris to be splashed on the foliage and flowers. Consequently, most field cut production occurs in beds.

Field soils usually need to be amended with fertilizer, either organic or inorganic, and organic matter prior to planting. Periodic soil tests will guide producers on which fertilizers to use and how much should be applied. In addition, the soil pH may need to be raised with lime or lowered with sulfur. Most crop species grow well with a soil pH between 6.2 and 6.8. Inadequate nutrition will reduce yields and quality. However, excessive fertilization wastes fertilizer, may pollute the ground or surface water and can produce weak, soft growth on some species.

Supplemental fertilizers, either organic or inorganic, may be needed later in the production season, especially in the warm climates where the growing season can be 6 months to 1 year. Supplemental fertilizers can be applied dry or through fertigation. Fertigation is less labor intensive once the fertilizer injector is incorporated into the irrigation system.

Most soils benefit from the regular addition of organic matter, which can increase aeration and drainage of heavy clay soils and increase the nutrient and water retention of sandy soils. A variety of different sources of organic matter can be added including compost, cover crops, manures, straw, hay, silage and wood chips. Manures may need to be composted or aged prior to application or applied several weeks prior to planting. Straw, hay and wood chips may also need to be composted prior to use because they can temporarily deplete the soil of nitrogen as they decompose. If applied directly, additional nitrogen may be needed. Also, all organic matter must be free of weed seeds. The introduction of weed species to the farm will only increase the cost of weed control.

Organic matter can be applied in the fall after the fields are cleared, in the spring prior to planting or as a mulch during production to also reduce weeds and water loss. Applying organic mulch during production can be labor intensive. The amount to apply will vary with the operation, with those in warmer climates needing more to maintain proper soil organic matter than those in colder climates where decomposition takes place more slowly. Think of adding organic matter as feeding the soil, the proper amount will maintain healthy soils and healthy crops.

Cover crops provide a relatively easy method to introduce large amounts of organic matter to soil. Cover crops can be planted in the fall after the annuals have been removed or in the spring after the winter annuals/biennials have been harvested. Cover crops can and should be planted on any areas that will remain un-

Fig. 4.3. Production of *Hydrangea macrophylla* in shade house. (Photo: J. Dole.)

Fig. 4.4. Outdoor field of *Solidaster* in Kenya. Note lights for photoperiod control. (Photo: J. Dole.)

planted for 4 or more weeks. The alternative is to allow the area to grow up in weeds, which will make weed control more difficult when the area is later planted. Aisles can also be planted to a low cover crop to reduce weeds. A number of legume cover crops, such as alfalfa (*Medicago sativa*), cowpeas (*Vigna unguiculata*), crimson clover (*Trifolium incarnatum*), hairy vetch (*Vicia villosa*) and Austrian winter peas (*Lathyrus hirsutus*) fix nitrogen, which is added to the soil when the cover crop is incorporated into the soil. The use of cover crops will also help break the long-term weed reproductive cycle and help retain nutrients in the short term.

SITE SELECTION

For all production environments, the best sites are in full sun, relatively flat and have sufficient high-quality water for irrigation and postharvest. Flat sites are the easiest to manage in terms of providing irrigation or managing hydroponic systems. Also, harvested flowers are heavy enough without the added effort of carrying them up or down hills.

Field operations should also select a site with well-drained soil that is accessible at all times, even during wet weather, to allow flowers to be harvested. The site should be open enough to allow good air movement to reduce disease problems, but protected from excessive winds, which can cause lodging and misshapen stems.

PRODUCTION AND SUPPORT SYSTEMS

Regardless of the production environment and system, production beds should be no wider than 75–120 cm, which is wide enough to allow one to several rows of plants for efficient use of space but narrow enough to allow easy harvest and proper pest control. Ground beds, in particular, should not be too wide as the workers harvesting the flowers will not only have to lean down but will have to reach into the middle of the beds without falling into the plants. Ground beds are often raised 5–20 cm high to encourage drainage and allow quick drying after rainfall or irrigation (Fig. 4.5). Beds can be mulched before planting with plastic or landscape fabric or after planting with organic materials to reduce weeds and water loss. Plastic mulch can also be used to increase soil temperature.

The aisles should be wide enough to allow people and equipment to move without damaging the plants, which tend to grow and lean out into the aisles. If there is sufficient space, main aisles should be wide enough to allow a small vehicle or carts to enter, which would decrease the effort associated with carrying harvested flowers.

Most cut flower species require support during production, which can be provided by means of a plastic or wire mesh stretched between posts, spaced in pairs every 20–30 ft (6–9 m). Harvesting flowers through mesh can be tiresome, however, and some species such as statice, ranunculus, anemones, etc. do not need support.

Fig. 4.5. Raised ground bed with drip irrigation and netting support. Note that posts lean outward forcing netting to be tighter as it is raised. (Photo: J. Dole.)

PLANT ESTABLISHMENT

Greenhouses and high tunnels need to produce as many cut flowers as possible to be profitable. Hence, the plant establishment period should be short and cost effective. For geophytic species, bulbs, corms, tubers or tuberous roots can be planted. For most species, growers use transplants such as plugs, large liners or cell packs to establish their plantings. Transplants can be purchased ready to plant from suppliers or can be grown on site. Purchased transplants reduce the hassle of propagating your own plants, which can be especially important with some difficult-to-propagate species, such as lisianthus (*Eustoma*). However, a limited number of species, cultivars and colors may be available and delivery is not always when the plants are needed. Transplants can be grown or purchased in a variety of plug or liner sizes. Small plug sizes are generally less expensive but may need to be irrigated frequently after planting until they are established. However, the young plants in small plugs sometimes exhibit less delay after transplanting. Small plugs will easily outgrow the flat if not planted promptly and can be difficult to irrigate properly during propagation. Although labor intensive, small plugs can be transplanted to larger cell packs if planting is delayed. Larger plugs or liners are usually more expensive but establish more easily and can be held in the greenhouse longer before they need to be planted.

New field plantings can be established by a variety of methods, in addition to the plugs, liners and storage organs described above. Direct seeding can be used with species that germinate and grow rapidly. Plants with large seeds, such as sunflowers (*Helianthus*) and zinnias (*Zinnia*), do well when direct sown. Some species, such as larkspur (*Consolida*) and ammi (*Ammi*), do not transplant well and are best direct sown. However, heavy rain can wash out the seeds or compact the surface of the soil, making it difficult for small seedlings to break through. The seeds can also be eaten by birds or rodents and generally grow more slowly than the neighboring weeds so proper weed control is critical to getting a good stand established.

Perennial plantings can be established by means of transplants, divisions or rooted cuttings. Dormant divisions can be planted soon after arrival from the supplier or held in a cooler or cool location until they can be planted. Non-dormant divisions and rooted cuttings should be planted as soon as possible. Some species, such as peony (*Paeonia*), produce the greatest number of long stems when left undisturbed for many years, while other species, such as yarrow (*Achillea*) and phlox (*Phlox*), produce the best stems when divided every 2–4 years. Dig, divide and replant a portion of the crop every year to make sure that the beds are always producing a high-quality crop.

With field production the cold hardiness of bulbs, corms, tubers or tuberous roots needs to be considered. Some species are not cold hardy and the bulbs must be dug each fall and stored in a cool location over the winter until replanted in the spring, such as dahlia (*Dahlia*) or gladiolus in cold climates. Other geophytic species, such as pineapple lily (*Eucomis*), can remain in the ground in the proper climates and be handled as for other perennials.

Although not usually cost effective, potted perennials, shrubs, vines and trees can be purchased. A few large-sized plants can be purchased to test the species and, if successful, larger numbers of plugs, divisions or rooted cuttings can then be purchased or propagated.

PLANT SPACING

Optimum plant spacing varies greatly with the operation. Greenhouses are high-cost spaced and require optimum production to be profitable. Tunnels and fields are lower cost, but optimum spacing is still important to ensure profitable production, reduced weeding and longer stems in some cases. Plants that become large are usually planted in two rows per bed, occasionally with plants staggered, while smaller, single-harvest annuals such as plume celosia

(*Celosia*) may be spaced only 10–15 cm apart with up 10 rows across a 120-cm bed. Generally, close spacing increases yield and profit per square meter of bed space but decreases yield per plant and air circulation. Thus, if initial plant costs are high, a wide spacing may maximize the number of harvestable stems per plant. In addition, wide spacing increases air circulation and may prevent or reduce diseases.

For some species close spacing can increase stem length, which may be particularly important with species that tend to be too short. However, close spacing does not increase stem length for all species. If the species forms a solid canopy of leaves, such as with zinnias, it is likely to respond to close spacing by growing taller. Plants such as grasses, which have an open canopy that allows light to penetrate to the crown, usually do not grow tall when spaced closer together.

Annuals are generally spaced anywhere from 10 × 10 to 45 × 45 cm apart. Perennial spacing ranges from 30 × 30 to 60 × 60 cm, and woody shrubs and trees are spaced 0.8 × 1.8 m or more apart. Most trees, shrubs and vines are heavily harvested to manage plant size, i.e. to keep the plants small enough to be efficiently handled.

IRRIGATION

In cut flower production, stem length and straightness are often critical. Plants that are allowed to wilt will produce shorter stems and the stems may form bends from leaning during wilting and then straightening up after rehydration. In the field, rain is not regular enough in most locations to eliminate the need for irrigation. Cut flowers are too high in value to leave to the vagaries of nature.

Newly planted transplants or seeds are usually hand or overhead irrigated to ensure that young plants with their small root systems receive adequate water. However, hand irrigation is rarely suitable for long-term production as it is time consuming and results in high labor costs. Overhead sprinkler irrigation is cost effective but is generally limited to when the plants are young. Overhead irrigation later in the season may splash soil on the foliage and flowers, cause lodging and increase disease problems.

Drip irrigation using tapes or emitters and microtubes is the preferred irrigation method for cut flower production under protection and in the field (Fig. 4.5). Drip irrigation and microtubes apply water efficiently to the roots with little evaporation and do not splash soil or debris on the foliage and flowers. Drip tapes or emitters can be laid after planting; one to three tapes per bed are used depending on the width of the bed, the water requirements of the crop and, in the case of field production, the soil type. With field row production, one drip tape can be used per row or double row (two rows closely spaced together).

WEED CONTROL

Weeds will become a major problem in any operation if not controlled. Weeds are most easily excluded and managed in greenhouses, less so in tunnels with open sides. In field operations, weeds are often the most time-consuming and labor-intensive practice besides harvest. Weeds can reduce flower quality and quantity, increase the harvesting time and cost, make insect and disease control more difficult, and increase irrigation requirements and produce seeds, which will make the problem worse later.

The first step in efficient weed control is preparing a clean bed or planting area. Hydroponic systems are relatively easy to clean and maintain. Soil or solid substrates can be more problematic. Steam pasteurization at 70–80°C or chemical sterilants can be used where available. In the field it is important to prepare the beds as close to planting as possible. The shorter the amount of time between field preparation and foliar canopy closure, the less of a problem weeds will be. When plant foliage completely shades the soil, fewer weed seeds will germinate and those that do will grow slowly. If using manual weeding or cultivation, it is important to make the last cultivation as close to planting as possible. If the field is prepared too early in advance of planting, the weeds will begin germinating and growing quickly. If the crop is planted immediately after preparing the soil, then the plants will begin to grow and develop a canopy, reducing the number of times cultivation or hand weeding is required. The first cultivation will generally be about 10 days after transplanting or germination of direct-sown crops. Often there is not enough time to prepare a field and plant immediately. One solution to this problem is to use the stale bed method: prepare a large area when convenient, allow weeds to sprout and kill them immediately before planting. In this case, flame weeding, herbicides and light cultivation can be used. Do not cultivate too deeply because that might bring up new weed seeds that can germinate.

Various mulches are used to prevent weeds or make them easier to control. Plastic sheeting is commonly used in many areas. The preferred type of plastic is white on the upper surface and black below to exclude light. Some growers use all black plastic in the cool season to warm the soil. Plastic mulches are difficult to reuse and disposal can be problematic. Machines are available that will form beds and lay plastic in one operation.

A high-quality landscape fabric can be used for many years, especially with perennials and woody crops. The fabric will last longer if covered with a thin layer of organic mulch to keep the light from breaking down the plastic. However, the organic matter will decay, allowing weeds to grow. Luckily, the weeds on top of the fabric are easy to remove by hand. Holes for the plants can be made with shears, specially made electric branding irons or propane torches. With both plastic and landscape fabric mulches, some hand weeding will be needed to pull weeds that grow in the holes along with the cut flowers.

After planting a variety of control methods can be used. Mechanical cultivation can range from a walk-behind rototiller to a tractor-mounted cultivator. Mechanical cultivation can be used to cultivate the aisles between beds or rows of crops. The aisles must be wide enough to allow the equipment to pass without damaging the foliage or the crops' roots. Within-row mechanical cultivation must be done before the crop is too tall to allow the tractor to pass over the crop.

Flame weeding is very effective and relatively inexpensive when properly used, but must be conducted carefully. With flame weeding a handheld or tractor-mounted propane burner emits a flame that is passed over the weeds. The weeds die from being seared with the high temperatures, not by being burned. Very young weed seedlings and broad-leaved weeds are easiest to kill with flame weeding. Flame weeding can be especially useful with direct seeding because the weed seedlings generally emerge first and the area can be flame-weeded prior to emergence of the cut flower seedlings.

An entire chapter could be written on chemical weed control. Herbicides are available in two types: (i) pre-emergent herbicides kill weed seedlings as they germinate through the soil; and (ii) postemergent herbicides are sprayed on the weeds and kill either the portion of the weed in direct contact with the herbicide or are systemically taken up and moved through the plant, killing the entire weed. Systemic postemergent herbicides are especially useful for controlling perennial weeds and those with underground rhizomes or storage organs. As with all chemicals, herbicides should be applied carefully so as not to poison the person applying the chemical or injure the cut flowers. Organic herbicides are available. Most work best as postemergent applications to young weeds.

The last and least favorite weed control method is hand or manual weeding. Even in the most mechanized operation, small amounts of manual weeding by hand or by hoe will be needed at the end of rows or around the base of plants growing in plastic or landscape fabric. A variety of hoes are available that can effectively cut and remove weeds without disturbing the roots of the cut flowers. While effective, hand weeding is time consuming and expensive in terms of labor costs.

SPECIALTY CUT SPECIES

Table 4.1 presents general information for over 180 plant species that are used for cut flowers, stems and fruits. See Chapter 3 for cut foliages. Following is a description of the categories used in the table.

Production environment

F = Field
T = Tunnel
G = Greenhouse.

Plant type

WSA = Warm-season annual refers to plants that require warm temperatures and do not tolerate frost or freezing temperatures.

CSA = Cool-season annuals grow best with cool temperatures and are typically planted in the fall, winter or early spring, depending on the locations. Most cool-season annuals tolerate some frost.
B = Biennials generally require all or part of two growing seasons to complete their life cycle.
P = Temperate herbaceous perennials generally live more than two growing seasons and are cold hardy. Plants usually require cold weather or long/short days for dormancy breaking and/or flowering.
BP = Bulbous perennial (geophytes) produce various types of storage organs, such as corms, tubers, bulbs and storage roots, that are used to propagate the plants and establish production beds.
CSP = Cool-season perennials generally live more than two growing seasons; optimum growth occurs during cool weather and plants may go dormant during the warm, summer season.
TP = Tropical perennials generally live more than two growing seasons but plants are not cold hardy and, thus, are grown either under protection or in tropical climates.
W = Temperate woody plants are cold hardy and are typically grown in Zones 8 or colder.
TW = Tropical woody plants are those that are not cold hardy and are typically grown in Zone 9 or warmer. Some fast-growing tropical woody plants, such as some eucalyptus species, can be grown in colder climates seasonally or under protection.

Hardiness zone

Hardiness zones are based on the average annual minimum temperatures. Maps have been created for the United States by the United States Department of Agriculture (USDA) (https://planthardiness.ars.usda.gov/PHZMWeb/). Similar maps can be found online for many areas of the world. Note that for some cut flowers, multiple species are grown and the cold-hardiness zones might vary greatly within the range reported in the table.

Vase life

Vase life might vary greatly within the range reported in the table because multiple species are included. Also, in some cases the large range in the vase life is because of the use of floral preservatives; the lower number is typically the vase life when only water is used and the higher number is when floral preservatives are used.

Harvest stage

The optimum harvest stage is the developmental stage that provides the longest fresh vase life, optimum quality after drying or allows for harvest, shipping and handling without damage.

Table 4.1. Specialty species cut for flowers, fruits or stems.

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Acacia spp.	Acacia	F	W/TW	8–11	5–7	Flowers: at least ¼ open Foliage: mature
Achillea cvrs.	Yarrow	F	P	2–9	5–12	Flowers fully open and pollen visible
Aconitum napellus	Monkshood	F	P	2–6	7–10	Up to ½ of lower flowers open
Agapanthus praecox	Lily-of-the-Nile	F	P	7–11	12–14	¼ of flowers open
Agastache cvrs.	Agastache	F	P	5–10	6–10	⅔ flowers open
Ageratum houstonianum	Ageratum	F	WSA	–	7–10	½ of flowers fully developed
Agrostemma githago	Corncockle	F	CSA	5–10	8–10	One to two flowers open
Alchemilla mollis	Lady's mantle	F	P	4–9	10	¼ of florets open
Allium spp. & cvrs.	Allium	F, T, G	P	3–11	14	≤¼ florets open
Alpinia purpurata	Ginger	F, T	TP	10–11	7–14	⅔ bracts open
Amaranthus caudatus	Love-lies-bleeding	F	WSA	–	7–10	Fresh: ½ to ¾ of florets open Dry: lower florets produce seed and inflorescence is firm
Amaranthus cruentus	Amaranthus	F	WSA	–	5–14	Fresh: ½ to ¾ of florets open Dry: lower florets produce seed and inflorescence is firm
Ammi cvrs.	Queen Anne's lace	F	CSA	8–10	7–12	½ to ¾ of flowers in umbel open
Ammobium alatum	Winged everlasting	F	WSA	–	28+	Buds are well colored but before yellow centers are visible
Anemone coronaria	Anemone	F, T, G	CSP	4–7	5–7	Wholesale: buds are fully colored Local: ⅓ to ½ of petals have started to open but before fully open

Continued

Table 4.1. Continued.

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Anethum graveolens	Dill	F, T	WSA	–	10	½ to ¾ of flowers in umbel are open
Anigozanthus cvrs.	Kangaroo paw	F	P	9–11	10–21	Three to four florets open and tip of spike firm
Anthurium cvrs.	Anthurium	G	TP	–	14–28	Flowers: ½ to ¾ flowers on spadix open and spathe unfolded Foliage: leaves are mature
Antirrhinum majus (Fig. 4.6)	Snapdragon	F, T, G	CSA	7–10	7–15	Wholesale: ⅓ flowers open Local: ⅓ to ½ flowers open
Aquilegia cvrs.	Columbine	F	P	3–8	5–7	½ flowers open
Asclepias cvrs.	Butterfly weed	F, T	P	4–12	9–14	½ to ⅔ flowers open
Aster cvrs.	Perennial aster	F, T, G	P	3–8	7–10	Three to four florets to ¼ of florets open
Astilbe cvrs.	Astilbe	F, G	P	3–7	5–10	½ to ¾ florets open
Astrantia major	Astrantia	F, T	CSP	5–9	5–7	Uppermost flowers open
Banksia spp.	Banksia	F	W	9–11	10–14	Heads fully formed and no florets have opened
Baptisia spp. & cvrs.	Baptisia	F	P	3–10	7–10 14 28+	Flowers: ⅓ open Foliage: mature Pods: mature and green or black
Bouvardia cvrs.	Bouvardia	G	TP	–	7–14	One to three flowers open
Brassica oleracea (Fig. 4.7)	Ornamental cabbage/kale	F, T, G	CSA	7–10	5–10	Any time stems are long enough and center leaves are well colored
Buddleia davidii	Butterfly bush	F	W	5–10	5–7	¼ to ¾ of buds open but lower florets not yet brown
Bupleurum rotundifolium	Bupleurum	F	P	6–9	7	⅓ of flowers fully open

Brunia spp.	Brunia	F	TW	9–11	10–15	Fully developed and well-colored inflorescences but florets not yet open
Calendula officinalis	Pot marigold	F, T	CSA	9–11	5–7	Flowers are just starting to open
Callicarpa spp.	Beautyberry	F	W	6–10	5–14	Most of the fruit clusters have ripened but before the oldest fruits start to senesce
Callistephus chinensis	Aster annual	F, T, G	WSA	–	7–14	Standards: outer ray florets open Sprays: at least three flowers open
Camellia japonica	Camellia	F	W	7–10	2–4 5–7	Flowers: fully open Foliage: fully mature
Campanula cvrs. (Fig. 4.8)	Campanula	F, T, G	P	3–8	7–14	One to two florets well colored and open
Capsicum cvrs.	Pepper	F	WSA	–	7–10	¾ of fruit is at the desired color
Carthamus tinctorius	Safflower	F	WSA	–	4–10	Most flowers heads well colored
Caryopteris × clandonensis	Blue mist	F	W	5–9	11–14	One or more lower whorls of flowers are open
Cattleya cvrs.	Cattleya	G	TP	–	7	3–4 days after flowers open
Celastris scandens	Bittersweet	F	W	3–8	28+	Stems when fruit are well colored
Celosia argentea	Celosia	F, T	WSA	–	10–14	Crested types when inflorescence is fully colored but prior to significant seed formation Plume or wheat types when more than half the flowers are open
Centaurea americana	American basket flower	F	WSA	–	7–10	Individual flowers ½ to ¾ open or when at least one flower fully open and other flowers showing color
Centaurea cyanus	Bachelor's button	F	CSA	8–10	7–10	At least one flower fully open and other flowers showing color

Continued

Table 4.1. Continued.

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Centaurea macrocephala	Basketflower	F	P	4–9	7–10	Flower are ½ to ¾ open
Centranthus ruber	Red valerian	F	P	5–7	7–10	First florets in terminal cluster are open
Cercis canadensis & *Cercis chinensis*	Redbud	F	W	4–9	6–7	At least ½ of buds open
Chaenomeles cvrs.	Flowering quince	F	W	4–8	6–10	Either tight bud with no color showing or just as the flowers are starting to open
Chamelaucium cvrs. (Fig. 4.9)	Waxflower	F	W	9–11	7–12	Wholesale: ¼ to ½ of florets open Local: ¾ of florets open
Chelone spp.	Turtlehead	F	P	6–9	5–7	Two to three lower flowers open
Cirsium japonicum	Plume thistle	F	P	3–7	7	Flowers fully open
Clarkia cvrs.	Godetia	F, T, G	CSA	9–10	7–18	Three to six or up to ½ flowers open
Clematis cvrs.	Clematis	F	W	3–10	3–10	Flowers: sepals beginning to open or ¼ flowers open on sprays Foliage: mature and seed heads before mature
Consolida ambigua	Larkspur	F, T, G	CSA	5b–10	6–9	One to five florets open
Convallaria majalis	Lily-of-the-valley	F, T, G	P	2–7	5–10	Three to four bells open and the rest are white
Coreopsis spp.	Tickseed	F	P	6–10	7–10	Fully open flowers
Cornus florida	Dogwood flowers	F	W	5–9	7–10	Bracts beginning to open but pollen not yet visible
Cornus spp. (Fig. 4.10)	Dogwood stems	F	W	2–7	28+	Stems well colored after foliage has fallen and before new growth

Corylus spp.	Filbert	F	W	4–9	7–14	Stems after leaves drop and before pollen shows on catkins
Cosmos bipinnatus	Cosmos	F, T	WSA	–	5–9	Petals on apical flower opening but not yet flat
Cotinus spp.	Smoketree	F	W	5–8	7–12	Flowers: inflorescence is well colored Foliage: after stems have hardened off
Craspedia globosa	Billy buttons	F	WSA	–	14–39	Flowers fully colored
Crocosmia × crocosmiiflora	Crocosmia	F	P	5–9	10–14	One to two flowers open
Curcuma alismatifolia (Fig. 4.11)	Siam tulip	T, G	BP	9–11	14–21	Small flowers are visible among the bracts
Cyclamen hybrida	Cyclamen	G	P	–	14–21	Flowers fully open
Cymbidium cvrs. (Fig. 4.12)	Cymbidium orchid	G	P	–	14–21	Terminal flower on spike is open
Cytisus cvrs.	Broom	F	W	5–9	6	⅓ of flowers open
Dahlia cvrs. (Fig. 4.13)	Dahlia	F, T, G	BP	7–10	4–5	Outer couple of rows of petals open
Delphinium cvrs.	Delphinium	F, T, G	P	3–7	6–12	Wholesale: one to two florets open Local: ½ to ⅔ of florets open
Deutzia cvrs.	Deutzia	F	W	5–7	4–7	Buds swollen or just beginning to open
Dianthus barbatus	Sweet William	F, T, G	CSA, B	4–10	9–14	At least three or up to ⅕ of florets open
Digitalis purpurea	Foxglove	F	WSA, B	4–8	8–9	Two to three lower or up to ⅓ florets open
Echinacea cvrs.	Coneflower	F	P	3–8	5–16	Petals fully expanded and first ring of disk florets open
Echinops bannaticus & Echinops ritro	Globe thistle	F	P	3–8	7–10	½ to ¾ of the inflorescence colored

Continued

Table 4.1. Continued.

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Eremurus cvrs.	Foxtail lily	F	P	4–7	5–10	Wholesale: lowermost flowers show color Local: lower three to five rows of florets open
Eryngium cvrs.	Sea holly	F	P	3–7	10–12	Entire inflorescence well colored
Eucharis amazonica	Amazon lily	G	TP	–	7–10	Flowers just opened
Eucomis cvrs.	Pineapple lily	F, T	P	6–10	14–28	½ or more flowers open
Eupatorium spp. (syn. several new genera)	Eupatorium, Joe-pye-weed	F	P	4–10	7–10	A few florets open
Euphorbia fulgens	Scarlet plume	G	TP	–	7–10	¼ of flowers open
Euphorbia marginata	Snow-on-the-mountain	F	WSA	–	7–10	Bracts fully colored but flowers not yet open
Euphorbia pulcherrima	Poinsettia	G	TW	–	14–28	One to two cyathia showing pollen
Eustoma grandiflorum (Fig. 4.14)	Lisianthus	F, T, G	P	8–10	10–14	One or two flowers in color
Forsythia × *intermedia*	Forsythia	F	W	4–8	6–10	For immediate use: buds show color For forcing: stems with tight buds
Gardenia jasminoides	Gardenia	F	W	7–11	2–7	Petals start unfolding
Gentiana spp.	Gentian	F, T, G	P	4–7	14–21	One to two flowers open or ¾ buds well colored

Gloriosa superba	Gloriosa	G, T	TP	9–11	7–14	Individual flowers: newly open Stems: two flowers are fully open and there are several buds
Gomphocarpus physocarpus	Swan plant, hairy balls, balloon plant	F	TP	7–10	7–10	Fruit fully developed
Gomphrena cvrs.	Gomphrena	F	WSA	–	12–21	Flower heads large and rounded but not yet elongated
Hamamelis cvrs.	Witch hazel	F	W	4–8	5–9	Flowers in bud or when buds are just starting to open
Heliconia spp. (Fig. 4.15)	Heliconia	F	TP	9–12	5–7	⅔ bracts open
Helleborus cvrs.	Hellebore	F, T, G	P	4–9	10–17	Flowers fully colored with stamens visible and up to formation of seed pods
Heptacodium miconioides	Seven-son flower	F	W	5–8	7–12	Sepals are fully colored
Heuchera cvrs.	Heuchera	F	P	3–10	7–10	At least half of the flowers fully open
Hibiscus sabdariffa	Roselle	F	TP	8–11	7+	Pods when enough are well colored
Hippeastrum cvrs.	Amaryllis	F, T, G	BP	8–10	3–10	Buds are colored
Hyacinthus orientalis	Hyacinth	F, T, G	BP	5–8	3–9	Local: lowermost one to two florets are open Wholesale: lowermost florets start to show color
Hydrangea arborescens	Smooth hydrangea	F	W	4–9	7–10	Sepals fully colored and papery
Hydrangea macrophylla	Bigleaf hydrangea	F	W	6–9	6–12	Fully open from point of well-colored sepals to those with papery sepals

Continued

Table 4.1. Continued.

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Hydrangea paniculata	Peegee hydrangea	F	W	4–8	6–14	Three stages: immature with some green showing, fully mature with all white sepals, mature with papery sepals
Hydrangea quercifolia	Oakleaf hydrangea	F	W	5–9	2–9	Half the flowers on the panicle are open
Hylotelephium cvrs.	Sedum	F	P	3–9	21–28	From green through fully open flowers
Hypericum cvrs.	Hypericum	F	P	6–8	6–12	Stems with recently colored fruit
Ilex spp. (Fig. 4.16)	Holly	F	W	3–9	7–21	Foliage: fully mature Fruit: well colored but not yet discoloring
Iris chinensis (syn. *Belamcanda*)	Blackberry lily	F	P	8–10	5 21+	Flowers: one or two just opening Fruit: black and covering begins to shed
Iris × *hollandica*	Dutch iris	F, T, G	BP	8–10	3–6	Flower has emerged from sheath, petal color showing
Kerria japonica	Kerria	F	W	5–9	6–10	One to two flowers open
Kniphofia uvaria	Red hot poker	F	P	5–10	7–10	Several florets open and almost all florets showing color
Lamprocapnos spp. (syn. *Dicentra*)	Bleeding heart	F, T, G	P	2–9	8–17	At least one flower fully colored and open
Lathyrus odoratus	Sweet pea	F, T, G	CSA	8–10	3–10	First flower open
Lavetera trimestris	Rose mallow	F	WSA	–	7	Petals beginning to uncurl
Leucadendron cvrs.	Leucadendron	F	W	9b–11	7–21	Bracts are well colored and leaves mature
Leucanthemum × *superbum*	Shasta daisy	F	P	5–9	7–10	Single flowers: one or two rows of disk florets showing pollen Double flowers: outer petals fully open

Leucospermum cvrs.	Leucospermum, pincushion	F	W	9–11	10–18	½ styles open
Leycesteria formosa	Himalayan honeysuckle	F	W	7–9	7–12	Inflorescences as soon as foliage hardens off
Liatris cvrs. (Fig. 4.17)	Liatris	F	P	3–9	10–12	Three to four florets open with use of a preservative, otherwise ½ open florets
Linaria maroccana	Linaria	F, T	WSA	–	3–18	Two to four florets open
Lobelia cvrs.	Lobelia	F	P, WSA	4–8	8–11	One to three flowers open
Lunaria annuua	Moneyplant	F	B	5–9	7–10	Green pods for fresh use: fully developed green pods
						Brown pods: dry and papery covers can be removed
Lupinus spp.	Lupine	F, T, G	CSA, P	3–7	7–11	One to four florets open
Lysimachia clethroides	Gooseneck loosestrife	F	P	3–9	5–12	⅓ to ½ florets open
Malus, *Crataegus* cvrs.	Apple, hawthorn	F	W	4–7	3–4	Flowering stems: colored flower buds
					7–10	Fruiting stems: well-colored fruit
Matthiola incana (Fig. 4.18)	Stock	F, T, G	CSA, B	7–10	7–10	6 to 10 florets open
Moluccella laevis	Bells of Ireland	F, T	CSA	9–10	8–10	Inflorescence long enough but before oldest calyces discolor
× *Mokara* cvrs.	Mokara orchid	G	P	9–11	14–21	⅔ flowers open
Monarda cvrs.	Bee balm	F	P	4–10	8–10	⅓ or one ring of florets open
Musa spp.	Banana	F	TP	7–11	7–10	Bracts well colored, immature fruit may or may not be present
Nandina domestica	Nandina	F	W	6–10	5–10	Foliage: mature
					7–21	Fruit: well colored

Continued

Table 4.1. Continued.

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Narcissus cvrs.	Daffodil	F, T, G	BP	3–9	3–6	Singles: gooseneck stage when flower shows color and at 90–120° angle. Doubles: flower just starting to open
Nerine bowdenii	Nerine	F, T, G	BP	7–10	6–14	Buds well colored and oldest bud just starting to open
Nigella spp.	Love-in-a-mist	F	CSA	7–11	6–10	Flowers: fully colored petals Pods: mature and well colored
Ocimum cvrs.	Basil	F	WSA	–	5–14	Stems long enough
Oncidium cvrs.	Dancing ladies orchid	G	TP	–	7–14	Flowers in the bud stage
Origanum spp.	Oregano	F	P	5–10	7–10	Flowers when purple and ⅓ open
Ornithagalum spp.	Ornithagalum	F	BP	7–10	7–28	First flower open and buds well colored
Oxypetalum caerulea	Tweedia	F, T, G	P	8–10	6–10	⅓ florets open
Ozothamnus diosmifolius	Rice flower	F	TW	9–11	10–14	Florets are mature yet unopened and the inflorescence is fully expanded and does not readily wilt after harvest
Papaver nudicaule	Iceland poppy	F, T, G	P	2–7	5–8	Calyx cracked and showing petal color (10% may not open) or when first open (cup stage)
Paphiopedilum cvrs.	Lady slipper orchid	G	TP	–	10–20	3 to 4 days after flower opening
Penstemon spp.	Penstemon	F	P	3–9	4–10	Approx. three florets open
Phalaenopsis cvrs.	Moth orchid	G	TP	–	7–14	3 to 4 days after flower opening
Philadelphus spp.	Mockorange	F	W	4–9	5–10	Bud stage or as the flowers start to open
Phlox paniculata	Phlox	F, T, G	P	3–8	7–9	Buds well colored but not yet open

Physalis alkekengi	Chinese lantern	F	P	3–9	12–20	Pods fully colored
Physocarpus opulifolius	Ninebark	F	W	2–7	10–22	Foliage hardened off
Physostegia virginiana	Obedient plant	F	P	3–9	6–12	Spikes elongated and two to four flowers open
Pieris cvrs.	Pieris	F	W	5–8	7–14	Buds: any time in fall or winter Flowers: just as they are opening
Platycodon grandiflorus	Balloon flower	F	P	3–8	8–10	Two to three open flowers
Polianthes tuberosa	Tuberose	F	P	7–10	7–14	Wholesale: two to three florets open Local: up to ½ of florets open
Protea spp. & cvrs.	Protea	F	W	9–10	7–14	Bracts separated but not reflexed from flower head
Prunus cvrs.	Plums and relatives	F	W	3–9	6–12	Very tight bud with little or no color
Rosa spp. & cvrs.	Rose hips	F	W	5–10	14–21	Fruit: green, just showing color, or well colored but before shriveling Flowers: see Chapter 2
Rudbeckia cvrs.	Black-eyed susan	F	WSA, P	3–9	8–24	Petals are fully open and first ring of disk florets open
Salix cvrs.	Pussy willow	F	W	4–8	7–10	Flowering stems: after bud scales fall off and before catkins begin to elongate
					14–21	Decorative stems: leaves have fallen
Salvia spp.	Salvia, sage	F	P	4–9	7–10	White flower petals visible on lower three to four flowers
Saponaria officinalis	Bouncing bet	F	P	3–9	5–7	First flower open

Continued

Table 4.1. Continued.

Scientific name	Common name	Production environment	Plant type	Hardiness zone	Vase life (days)	Harvest stage
Scabiosa atropurpurea	Pincushion flower	F	WSA	–	6–9	Half to fully open flowers
Scabiosa caucasia	Scabiosa	F	P	3–7	6–10	Outer petals fully developed
Silene armeria	Catchfly	F	P	5–8	5–7	¼ to ⅓ florets open
Solidago & × *Solidaster* cvrs.	Goldenrod	F, T, G	P	2–9	10–	¼ to ½ florets open
Spirea cvrs.	Spirea	F	W	3–8	3–7	From tight, colored bud to up to ⅓ florets open
Stachys byzantine	Stachys	F	P	4–7	7–10	Mature foliage
Stephanotis floribunda	Stephanotis	G	TW	10–11	3–5	Fully open flowers
Strelitzia reginae	Bird-of-paradise	F	TP	10–12	7–14	Orange tepals first appear, but before they emerge from the bract
Symphoricarpos spp.	Snowberry	F	W	3–7	6–10	Most fruit are well colored but before the oldest ones turn brown
Syringa cvrs.	Lilac	F, G	W	3–7	5–10	First florets open to ½ florets open
Tagetes erecta	Marigold	F, T	WSA	–	6–14	Wholesale: ½ of petals have opened Local: fully open flowers
Telopea cvrs.	Waratah	F	W	8–11	7–14	0 to 5% florets open
Thalictrum spp.	Meadow-rue	F	P	3–8	4–11	Most florets open
Trachelium caeruleum	Trachelium	F, T, G	WSA	–	7–11	½ to ¾ florets open
Trachymene coerulea	Blue lace flower	F	WSA	–	10	⅓ florets open
Triteleia laxa	Brodiaea	F, T	P	6–9	10–14	1 to 2 days before first flower opens

Trollius spp.	Globeflower	F	P	2–9	5–7	Half open flowers
Ulmus alata	Elm	F	W	6–9	28+	Newly matured branchlets with wings
Verbena bonariensis	Verbena	F	P	6–9	7–10	Most florets open
Veronica longiflora	Speedwell	F, T, G	P	4–8	7	⅓ to ½ flowers open
Veronicastrum virginicum	Culver's root	F	P	3–8	7–10	First florets open
Viburnum spp.	Viburnum	F	W	3–9	2–3	Fragrant types: ½ florets open
					5–10	Snowball types: ½ florets open
					7–10	Fruit: well colored
Viola × *wittrockiana*	Pansy	F, T, G	CSA	7–10	3–4	Flowers almost open
Viola odorata	Violet	F, T, G	P	6–10	7	Flowers almost open
Vitex spp.	Vitex	F	W	6–9	3–5	Flower clusters open
Weigela florida	Weigela	F	W	5–8	3–4	Flowers: open
					5–10	Foliage: mature
Xerochrysum bracteatum (syn. *Helichrysum*)	Strawflower	F	WSA	–	7–10	Bracts unfolding and center just visible
Zantedeschia cvrs. (Fig. 4.19)	Calla	F, T, G	P	7–10	6–8	Flowers: just before the edge of the spathe begins to turn downward
						Foliage: mature
Zinnia violacea (Fig. 4.20)	Zinnia	F	WSA	–	7–14	Outer petals fully open and one row of florets open

Fig. 4.6. Greenhouse production of *Antirrhinum*, one of the most popular specialty cut flowers. (Photo: J. Dole.)

Fig. 4.7. Production of cut *Brassica*. (Photo: J. Dole.)

Fig. 4.8. Close up of *Campanula medium* 'Champion Pink'. Campanula responds well to commercial holding solutions and has a long vase life. (Photo: J. Dole.)

Fig. 4.9. Field of commercial *Chamelaucium* in Australia, where it is a native wildflower. (Photo: J. Dole.)

Fig. 4.10. Field of *Cornus alba* stems ready for harvest. (Photo: J. Dole.)

Fig. 4.11. *Curcuma alismatifolia* is a long-lasting member of the ginger family and comes in white and shades of lavender in addition to the pink shown here. (Photo: J. Faust.)

Fig. 4.12. *Cymbidium* is one of the most popular orchids used for cut flower production. (Photo: J. Faust.)

Fig. 4.13. *Dahlia* is one of the most popular specialty cut flowers available in an astounding array of colors, shapes and sizes. (Photo: J. Dole.)

Fig. 4.14. The long-lasting flowers of *Eustoma* are susceptible to thrips damage. Note the use of *Capsicum* plants as trap crops for thrips control. (Photo: J. Dole.)

Fig. 4.15. Lobster claw *Heliconia* is one of the largest and most spectacular cut flowers. (Photo: J. Dole.)

Fig. 4.16. Field of *Ilex verticillata* grown under bird netting to prevent loss of the berries. (Photo: J. Dole.)

Fig. 4.17. While *Liatris* is typically greenhouse grown, it can be grown in tunnels or fields as shown here. (Photo: J. Dole.)

Fig. 4.18. *Matthiola* is one of the most fragrant of the specialty cut flowers. (Photo: J. Dole.)

Fig. 4.19. *Zantedeschia* comes in a wide array of colors and is grown in greenhouses, tunnels or fields. (Photo: J. Dole.)

Fig. 4.20. *Zinnia* is one of the most popular field-grown specialty cut flowers in the USA owing to its wide color range and ease of cultivation. (Photo: J. Dole.)

5

IRRIGATION AND FERTILIZATION

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INTRODUCTION

In contrast to most agronomic and horticultural crops, greenhouse-grown crops, and in particular cut flowers, are recognized for their intensive use of fertilizer and water inputs. This notoriety is readily apparent from estimates of annual nitrogen (N) fertilizer and irrigation water applications for some ornamental crops and commodities (Table 5.1). Note that these are not crop requirements, but rather they are estimates of application rates that are based on data from research and demonstrative studies, and as such they might even underestimate actual application rates used in commercial operations. Studies have shown that these application rates are often in excess of the actual crop requirements (Cabrera *et al.*, 1993; Aydinsakir *et al.*, 2011; Velázquez *et al.*, 2012). Even lower use efficiencies of water and fertilizers have been reported in container-grown crops managed with open fertigation systems (i.e. without capture and recycling of drainage/leachates and runoff). For example, an experimental greenhouse rose crop, with plants growing in 20-l pots filled with a peat:bark:sand substrate was fertigated with various treatments (Cabrera *et al.*, 1993). A representative treatment provided annual application rates equivalent to about 1840 kg/ha of N and 11,215 m^3/ha of water. The mass balance for this treatment indicated that the crop effectively used only 1125 kg/ha of N and 8320 m^3/ha of water, with losses of 39% and 26% of the applied N and water, respectively. Needless to say, the projected economic and environmental costs of such fertilizer and water use efficiencies are significant.

Like in many other sectors of agriculture, cut flower crops are facing significant challenges related to the availability and use of irrigation water, as well as the environmental impacts of their intensive irrigation and fertilization practices. Climate change is resulting in severe and prolonged droughts and fierce competition for water resources among agricultural, urban and industrial sectors, which is severely affecting the sustainability of cut flower growing operations. These issues are prevalent across all eco-geographic regions from sites where precipitation is relatively abundant to arid regions where cut flowers are grown. The aesthetic, non-edible nature of these crops

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Table 5.1. Estimates of annual application rates of nitrogen fertilizer and irrigation water in selected ornamental crops and commodities.

Crop	Nitrogen fertilization (kg/ha/year)	Irrigation rate (m^3/ha/year)
Greenhouse roses[a]	2100–4900	24,000–38,000
Greenhouse flowering potted plants[b]	Up to 3150	–
Container nursery stock[c]	1000–2800	15,000–21,000
Foliage plants[d]	1000–2900	15,000–25,000
Lawns (warm and cool season grasses)[e]	50–290	3600–7600
Field nursery stock[f]	50–170	–

[a]White, 1987; White and Holcomb, 1987; Cabrera *et al*., 1993, 1995; Cabrera, 1997a, b.
[b]Nelson, 1991; Reed, 1996.
[c]Fare *et al*., 1992; Beeson and Brooks, 2008; Warsaw *et al*., 2009; Cabrera *et al*., 2013.
[d]Henley and Poole, 1981; Joiner *et al*., 1981, 1983; Reed, 1996.
[e]Heckman and Murphy, 2003; Hermitte and Mace, 2012; Cabrera *et al*., 2013.
[f]Davidson *et al*., 2000.

is a compounding factor as this may severely limit access to large volumes and sources of high-quality irrigation waters and they may receive a higher degree of scrutiny regarding their environmental impacts compared with food and fiber crops (Cabrera *et al*., 2018). All this means the cut flower industry needs to embrace proactively efficient and sustainable best management practices for irrigation and fertilization. The objective of this chapter is to address some of the foundational concepts, and science-based management practices, on the irrigation and fertilization of major flower crops growing in soil and soilless systems. To this end, some key principles of plant physiology related to water relations and mineral nutrition will serve as the foundation of the themes and practices covered here.

CROP WATER RELATIONS AND IRRIGATION MANAGEMENT

Water is essential to the biology and productivity of plants and crops and constitutes 70–95% of the herbaceous (non-woody) biomass of plants. Water is the major transporter of metabolites through cells and tissues, and along with solutes, provides the positive pressure, or turgor, against cell walls, which is the main driver of growth through cell expansion. Reductions in the availability of water to plants and crops lead to loss of turgor – wilting – which almost immediately reduces or impairs a plant's expansive growth and physiological functions like photosynthesis and nutrient uptake.

While water constitutes the largest fraction in non-woody plant tissues, only a small fraction – as low as 1% – of the water absorbed by a plant through its entire life is retained in this biomass, and the rest is 'lost' through transpiration. This observation is appreciated from the calculation of water use efficiency (WUE), broadly defined as the unit of plant biomass produced per unit of water applied or used. The *effective* WUE is defined as the ratio of biomass (dry weight (DW) or fresh weight (FW) in grams of harvested tissue) per volume of water applied in liters (Raviv and Blom, 2001). Greenhouse roses grown in an open (flow-through, non-recycling) soilless growing system averaged an *effective* WUE of 0.7–1.8 g DW/l (Cabrera *et al*. 1993; Cabrera, 1997a, b; Raviv and Blom, 2001), while roses grown in recirculating hydroponic systems yielded 2.3–2.8 g DW/l (Cabrera, 1997a; Raviv and Blom, 2001).

The apparently inefficient use of water by plants is a consequence of the need to capture carbon dioxide and its assimilation through photosynthesis, while facilitating the essential transport of ions and other molecules from the soil and effectively cooling leaves during transpiration. The maximum efficient use of water by crops to provide maximal crop yield occurs when water is freely available to them (not restricted) through the growing season, and transpiration is allowed to continue at its maximum potential rate (Hanan, 1998; Lambers *et al*., 2008). Consequently, any factors that restrict water supply or its uptake by plants will reduce its transpiration thus proportionally reduce its biomass output (Fig. 5.1). On this basis, reduced water availability can significantly diminish or

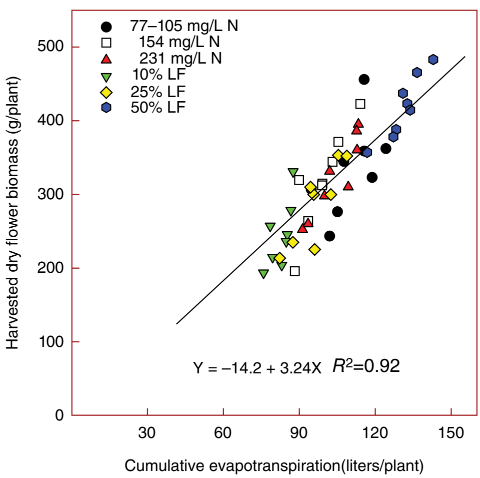

Fig. 5.1. Relationship between evapotranspiration and biomass of harvested flowers of rose plants fertigated over 1 year with nutrient solutions varying in nitrogen concentration at a fixed leaching fraction (25% LF) and a fixed nitrogen concentration (154 ppm N) at varying leaching fractions (10%, 25%, 50% LF). (From Cabrera *et al*., 1993; Cabrera, 1997b.)

prohibit the sustainability of flower production; however, capture and rational reuse of drainage effluents in soilless production systems can increase crop WUE and allow for sustainable commercial production (Raviv *et al.*, 1998, 2019).

Water relations in soil substrates and plants

The movement of water through the soil/substrate–plant–atmosphere continuum (SPAC) is commonly described by the concept of water potential (Ψ), defined as the potential energy of water in each of these components expressed as energy per unit volume, in comparison to the potential of pure water at the same temperature and atmospheric pressure. The water potential of pure water is set at 0, and therefore most water potential values will be negative. At a given temperature and pressure, the total water potential (Ψ^{Total}) of each component or compartment in the SPAC is composed of the algebraic sum of various factors as described in the following simplified equation:

$$\Psi^{Total} = \Psi_{\mathbf{m}} + \Psi_{\mathbf{o}} + \Psi_{\mathbf{p}} + \Psi_{\mathbf{g}} \qquad \text{(Eq. 5.1)}$$

Where Ψ^{Total} = overall water potential of each SPAC component (soil/substrate, plant, air), $\Psi_{\mathbf{m}}$ = matric potential, $\Psi_{\mathbf{o}}$= osmotic potential, $\Psi_{\mathbf{p}}$= pressure potential, $\Psi_{\mathbf{g}}$= gravitational potential.

In general, water in the SPAC will move down a gradient from a zone with a higher (less negative) water potential, e.g. the soil/substrate, to one with a lower (more negative) water potential, e.g. the air (Table 5.2).

Water potential components in soil/substrate

The water potential of soil or substrate, Ψ^{soil}, is largely defined by matric potential (Ψ_m) + osmotic potential ($\Psi_{\mathbf{o}}$). The matric potential combines capillary (cohesive) forces and adsorptive forces (adhesion of water to solid soil or substrate surfaces), namely the strength with which soil or substrate particles bind water. High flower productivity of roses in sandy-loam soil has been reported when the matric potential is maintained within −5 to −20 kPa and significantly reduced as the matric potential approaches −50 kPa (Plaut *et al.*, 1973; White and Holcomb, 1987; Oki *et al.*, 2001; Arévalo-Hernández, 2011). In the case of carnations, growing in clay-loam soil, optimum marketable flower yield and quality was achieved with a matric potential of −45 kPa. In contrast, frequent irrigations used to maintain a matric potential of −15 kPa reduced marketable flower yields, and a stressful matric potential of −75 kPa reduced both flower yield and quality (Hanan and Jasper, 1969; Taylor *et al.*, 2004).

The desirable range of matric potential for coarse-textured container soilless substrates is −1 to −10 kPa, which is much higher (or less negative) than

Table 5.2. Representation of total water potential (kPa) along the components of the soil–plant–atmosphere continuum (SPAC) in an idealized greenhouse rose crop. Water in the SPAC will move down a gradient from a zone with a higher (less negative) water potential, e.g. the soil/substrate, to one with a lower (more negative) water potential, e.g. the air.

Soil–plant–atmosphere continuum	Total water potential (kPa)
Air (inside greenhouse)[a]	
30°C, 50% relative humidity	–100,000
30°C, 70% relative humidity	–50,000
Leaf	
Air spaces inside stomata[b]	–3000 to –7000
Cells[c]	–700 to –1000
Stem	
Xylem[d]	–400 to –750
Root	
Cells[e]	–400 to –650
Soil (sandy-loam)[f]	–120 to –150
Soilless substrate	–70 to –90

[a]Hanan, 1998; Lambers *et al.*, 2008.
[b]Hanan, 1998; Lambers *et al.*, 2008.
[c]Raviv and Blom, 2001; Liu *et al.*, 2006.
[d]Kim *et al.*, 2004; Liu *et al.*, 2006; Arévalo-Hernández, 2011.
[e]Augé and Stodola, 1990.
[f]Plaut *et al.*, 1973; Raviv and Wallach, 2007; Lieth and Oki, 2019; Arévalo-Hernández, 2011.

in soils (Raviv and Wallach, 2007; Nikolaou *et al.*, 2019). As water tensions become higher (more negative) than −10 kPa, herbaceous flower crops like chrysanthemums (Kiehl *et al.*, 1992) start experiencing wilting in a typical peat-based substrate. The productivity of intensively managed greenhouse roses having high foliage to root ratios is maximized in coarse-textured substrates, like volcanic rock, when high matric potentials (−1 to −5 kPa) are maintained (Raviv and Wallach, 2007).

Matric potential can be measured in soils with a relatively simple and inexpensive tensiometer (Castilla Prados and Montalvo López, 2005; Lieth and Oki, 2019). Because of the direct relation of soil matric potential to plant water availability, tensiometers require no site-specific calibration and are well suited for direct use in irrigation management. Historically, tensiometers could reliably read soil water tensions from −10 kPa to −80 kPa, while their usefulness in coarsely textured soilless media was limited (Bianchi *et al.*, 2017; Nikolaou *et al.*, 2019). However, new tensiometers fitted with low-tension (or 'high-flow') ceramic tips can respond to the dynamic matric potential changes observed in coarse substrates in small containers and shallow, heavily amended raised greenhouse beds measuring in the 0 to –30 kPa range (Oki *et al.*, 2001; Bianchi *et al.*, 2017).

Osmotic potential describes the forces between dissolved particles (mainly ions) and water molecules, and is a measure of the solute concentration of a (soil) solution. The osmotic potential of pure water is 0, and if a solution has any solutes at all, its osmotic potential is negative. The higher the solute concentration, i.e. total dissolved solids (TDS), salts or ions, the lower (more negative) the value of the osmotic potential. The soil solution refers to the water held in the pore spaces of soils or substrates. It contains dissolved ions emanating from their solid phases and from applied fertilizer salts. The osmotic potential of the soil solution can significantly contribute to the total soil water potential and affect water uptake.

The total content of dissolved ions or salts in a solution is quickly, inexpensively and reliably determined by measuring its electrical conductivity (EC), i.e. its ability to conduct electricity. The units for EC are dS/m, S/cm or mmhos/cm, which are all equivalent. For soil solutions and fertilizer solutions, there is a close relationship between their osmotic potential (Ψ_o) and EC, as described by the empirical relationship:

$$\Psi_o \approx -36 \cdot EC \qquad \text{(Eq. 5.2)}$$

With Ψ_o and EC provided in units of kPa and dS/m, respectively.

For a typical fertigation solution with an EC of 1.8 dS/m or a soil solution extract with an EC of 3.0 dS/m, the average osmotic potential is −62 kPa or −104 kPa, respectively. These values denote the salinity threshold for many ornamental and flower crops (Niu and Cabrera, 2010; Cabrera *et al.*, 2017). The osmotic potential of typical fertigation solutions and soil solutions in contact with the roots of intensively fertilized flower crops will contribute more to the total soil water potential in the rootzone than the matric potential, and largely dictates its effective water availability and potential uptake by the plants.

Water potential components within the plant

The total water potential of plant tissues, such as stems and leaves, is largely dependent on two components: osmotic potential (Ψ_o) and pressure potential (Ψ_p). Osmotic potential is a measure of the solute concentration of a solution; such as the cytoplasm of plant cells, which has fairly high concentrations of solutes (mineral ions, sugars and amino acids), and the xylem fluid, which has relatively low solute concentrations (mostly mineral ions). As the osmotic potential of a plant cell, tissue or organ decreases (becomes more negative), it causes a decrease in the total water potential of that compartment, which acts to ‘draw’ water into it via the process of osmosis. The presence of semipermeable membranes in living plant cells permits easy movement of water molecules via osmosis, while ion and solute movement are highly restricted. The osmotic potential values of root cells of well-watered and drought-stressed rose plants range from –0.9 to −1.6 MPa (Augé and Stodola, 1990).

Cell walls play a major role in the physical pressure exerted on water within cells, which is referred to as hydrostatic pressure or pressure potential (Ψ_p), and which can be positive or negative. Positive pressure potential values are found inside living cells (which raises their total water potential) and are responsible for the turgor pressure that drives expansive growth and ensures that a plant's leaves and shoots maintain their shape. Pressure potential values in root and leaf cells of rose plants are typically in the range of 0.6–0.8 MPa (Augé and Stodola, 1990), but can reach as high as 1.5 MPa in well-watered plants (Augé *et al.*, 1990). In contrast, the water in the dead xylem vessels of an actively transpiring plant are typically under suction tension or a negative pressure potential (Augé, 2001; Lambers *et al.*, 2008), and this component largely dictates the water potential of the stems, as water in the xylem has very low solute concentrations, yielding almost negligible osmotic potential values.

Leaves are the last plant tissue in the SPAC (Table 5.2), and they drive water movement through the plant by having the lowest water potential within the plant. Opening of the stomata exposes the leaf tissue to the significantly lower (more negative) water potential of the surrounding air, which can range from −50 to −100 MPa on warm, sunny days. This drives transpiration. The growth of developing cells and tissues is highly responsive to changes in their water potential. Even the most transient or moderate water stresses along the SPAC that lead to reductions in water potential, and more specifically to reductions in turgor pressure, will quickly slow or stop the expansive growth of developing shoots and leaves (Hsiao, 1973). As cut flower crops are intensively harvested, the continuous growth of new shoots and leaves requires the maintenance of high (less negative) leaf water potential. For greenhouse roses, the maintenance of leaf water potential from −0.4 to −1.0 MPa has been considered suitable to sustain desirable-to-maximum flower yields and stem lengths, and wilting has been observed when the leaf water potential exceeds −1.2 MPa (Raviv and Blom, 2001; Kim *et al.*, 2004).

Irrigation water quality

While many plants respond satisfactorily to irrigation waters of relatively wide-ranging chemical composition, the aesthetic requirements of cut flower crops make them more sensitive to some chemical constituents, more so if water is applied by methods that wet the foliage and flowers. Furthermore, water quality can determine which crops can be grown, how their biomass and stem yield will be affected, and how irrigation and fertilization practices must be managed to produce quality floral products (Cabrera, 2011; Cabrera *et al.*, 2017). Thorough evaluation of water analyses must precede decisions to grow any crops, since these analyses define the chemical footprint of each water source used. A summary of guidelines for the interpretation of the chemical quality of irrigation water sources intended for flower and ornamental species is shown in Table 5.3.

Table 5.3. Guidelines for interpretation of the chemical quality of irrigation sources used in the production of cut flowers. (From Bailey, 1996; Petersen, 1996; Sonneveld and Voogt, 2009; Cabrera, 2011; Cabrera *et al.*, 2017.)

	Potential hazard	
Type of problem	None to negligible	Moderate to high
Salinity		
EC (dS/m or mmhos/cm)	<0.5	0.75–3.0
Permeability		
Sodium adsorption ratio (unitless)	<3.0	6.0–9.0
Ion toxicity due to root and/or foliar absorption		
Boron (ppm)	0.3–0.5	0.5–2.0
Chloride (ppm)	<110	140–360
Fluoride (ppm)	<1.0	>1.0
Sodium (ppm)	<70	70–210
Unsightly foliar deposits and plugging of drippers		
Bicarbonate (ppm)	<120	180–360
Iron (ppm)	<1.0	>1.0
Manganese (ppm)	<1.0	>1.0
Soil/substrate pH maintenance		
Alkalinity (ppm $CaCO_3$)	60–120	180–360
pH	5.0–8.0	>8.0

Salinity

The chemical property of irrigation water that is most impactful to the productivity and aesthetic quality of flower crops is salinity, which is expressed either as EC or TDS (for EC ≤ 5, the EC of 1 dS/m ≈ 640 ppm TDS). Salinity can quickly and significantly decrease the osmotic potential of the soil solution. This is further exacerbated when fertilizer is added to the irrigation water (fertigation), thus reducing water absorption rate by roots. In addition to osmotic effects, relatively high concentration of some ions in water, like sodium (Na), chloride (Cl) and boron (B), can be toxic to plants (Table 5.3).

While selection of salt-tolerant species and cultivars, and suitable irrigation and leaching practices could be employed to deal with moderately saline and brackish irrigation waters (Cassaniti *et al.*, 2013), a relatively passive and continuous use of these waters in flower crops will likely result in progressively severe problems. To address this issue, the use of desalination and water purification systems has been adopted in high-value crops in regions plagued by significant water salinity issues, such as foliage crops in South Texas (Reed, 1996) and flower crops in Israel (Yermiyahu *et al.*, 2007). While desalination and water purification can be economically feasible for these crops, it is accompanied by high energy requirements (3.0–3.5 kWh/m^3 sea water) and a large carbon footprint (0.4–6.7 kg CO_2eq/m^3 sea water) (Tal, 2018). Additionally, some toxic ions, such as Na, Cl and B, readily pass through reverse-osmosis (RO) membranes (Yermiyahu *et al.*, 2007), and without further treatment will reach toxic concentrations for most flower crops (Table 5.3).

pH and alkalinity

The pH of irrigation water and the buffering capacity of its alkalinity are also major components of water quality, and are dominant factors affecting the pH of the soil solution and the availability of nutrients to the crop. High pH-alkalinity levels in irrigation water can be successfully managed with inline acid-injection systems (Bailey, 1996). Key to this management practice is the use of continuous, inline pH monitoring of water and fertigation solutions. Close monitoring and adjustment of pH is imperative when employing desalinized water sources, as their reduced EC and low buffering capacity, e.g. low alkalinity, increase the risks of corrosion in metal irrigation distribution pipes and widely fluctuating rootzone pH in soilless-grown (substrate and hydroponic) crops (Yermiyahu *et al.*, 2007).

Blending of poor-quality irrigation water with desalinized water provides an economical strategy that provides the chemical quality and stability required to sustain the production of quality flower and foliage crops (Reed, 1996). However, the disposal of wastewater (concentrated brine) generated from desalinized/purification treatments represents another set of economic, legal and environmental challenges.

Irrigation management

Maximum yield in crops is achieved when water is freely available throughout the growing season and transpiration is maintained at its maximum potential rate (Fig. 5.1). A steady water supply presumes the maintenance of a high (less negative) soil water potential, a water potential gradient along the SPAC to sustain water uptake and the turgor pressure needed for maximum elongation of developing tissues, e.g. flower shoots. Therefore, the task is to provide a timely supply of water to maintain the pool of available water in the rootzone to satisfy its demand. Additionally, irrigation dilutes the EC levels that significantly lower the osmotic potential of the soil solution and leaches ions whose uptake and accumulation in the plant might lead to toxicities.

Regardless of the irrigation systems used or available to a crop, continuous decisions need to be made concerning the volume and frequency of water application. Qualitative approaches are commonly employed to address these questions, including a grower's subjective criteria ('look and feel') of a plant and soil/substrate water status, and the use of clock/timers to run irrigation on fixed time intervals. However, more quantitative approaches are needed to address environmental concerns, such as the efficient use of dwindling high-quality water sources and water pollution issues.

The basic input for determining how much water to apply requires the actual or estimated crop evapotranspiration (ET) rate (Fereres *et al.*, 2003). *Actual* ET can be measured with a weighing lysimeter, or a leaching lysimeter, where the water used by one or a few plants located within a crop is measured. ET can also be estimated from climatic models using data from a weather station, e.g. Penman–Monteith model (Steduto *et al.*, 2012). It is preferred to have climate data from inside the greenhouse, albeit it could be derived from data from a nearby outside weather station (Jaafar and Ahmad, 2019). *Estimated* ET is calculated using weather data and empirical coefficients determined for each crop at different stages of crop development (Fereres *et al.*, 2003). If climate data are not available, ET can be estimated from pans filled with water (pan evaporation) (Castilla Prados and Montalvo López, 2005). Alternatively, ET can be estimated with the use of atmometers, which measure the amount of water evaporated from a wet porous ceramic surface covered with a fabric and mounted on top of a cylindrical water reservoir (Hanan, 1998). The operation of an atmometer is as simple as reading a rain gauge. In this case, the depletion of the distilled water in the reservoir is viewed from a plastic sight tube mounted on its sidewall. By covering the ceramic surface with a fabric, the atmometer can simulate water loss from a reference crop at full canopy cover.

Monitoring of soil/substrate moisture is the most popular quantitative irrigation scheduling technique used in ornamental crops (Incrocci *et al.*, 2014). Tensiometers provide a relatively simple mechanical means of monitoring plant available moisture content in the rootzone. There are electronic soil moisture sensors that provide a volumetric measure of soil/substrate moisture content based on various electrical properties, e.g. resistance, capacitance and time-domain reflectometry. These sensors are gaining acceptance and use in large commercial container-grown crops (Lieth and Oki, 2019). Volumetric water content of a substrate must be calibrated to the local situation, e.g. the specific substrate and container dimensions.

Air–water balance in soils and substrates

The expansive growth of young developing tissues – like flower shoots – is extremely sensitive to even the lowest water stress (Hsiao, 1973), thus maintenance of high soil water potential values is desirable in flower crops, e.g. preferably higher (less negative) than −0.05 MPa for substrates and −0.1 MPa for soils (Table 5.2). The maintenance of such high soil water potentials requires rootzone moisture contents near the field and container capacity in soils

Table 5.4. Air-filled porosity requirements for selected flower and foliage species. (From Bunt, 1988.)

Air porosity (%)			
Very high (>20%)	High (20–10%)	Intermediate (10–5%)	Low (5–2%)
Orchids (*epiphytic*)	Snapdragons (*Antirrhinum*)	Chrysanthemum	Carnation
	Foliage plants	Gladiolus	Ivy (*Hedera*)
	Orchids (*terrestrial*)	Hydrangea	Rose
		Lily (*Lilium*)	Strelitzia

and substrates, respectively. However, at these points the porosity of the soil/substrate occupied by air is at its lowest, thus the risk of oxygen deficiency is heightened depending on the requirements of the crop roots (Table 5.4). Air porosity can be improved by modifying particle size distribution in the substrate or by using containers with a taller profile.

The potential for oxygen deficiency increases significantly in long-term crops being grown in mostly organic substrates that degrade over time. For example, over a 100-week production cycle in commercial carnation crops growing in rice hulls, total and air-filled porosities were reduced on average by 13% and 40%, respectively, while the water-holding capacity increased by 30% over the same period (Quintero *et al.*, 2013). These changes in physical properties were attributed to changes in particle size distribution and their spatial redistribution within the substrate profile. Longer-term crops, such as roses, would have an even more dynamic change in physical properties over time.

Water footprint

The efficiency of water utilization in crop production has been described historically by the concept of water use efficiency, WUE, the unit of biomass or harvested product produced per unit of water applied or used. Issues with availability of, competition for and pollution of fresh water resources has recently introduced the concept of water footprint (WF). This ‘sustainability’ concept attempts to provide a comprehensive indicator of direct and indirect volumes, consumed and polluted by source, used to produce a product, measured over its entire supply chain and specified geographically and temporally (Hoekstra *et al.*, 2009). The overall value of water footprint includes three components:

- ‘Blue’ water footprint (WF_{blue}) = consumption of surface and ground water resources along the supply chain of a product. Consumption refers to loss of water from the available ground-surface water body in a catchment area via evaporation, returns to another catchment area or the sea and its incorporation into a product.

- 'Green' water footprint (WF_{green}) = consumption of rainwater stored in the soil.
- 'Gray' water footprint (WF_{gray}) = refers to pollution, and is defined as the volume of freshwater that would be required to bring the load of pollutants to existing water quality standards.

The WF for a specific product is expressed in terms of water volume per unit of product (liter/unit) or unit of mass (usually m^3/ton or l/kg). An estimated 86% of the WF of humankind is within the agricultural sector (Hoekstra *et al.*, 2009), and the heavy use of agrochemical products significantly contributes to its gray water (pollution) footprint.

The WF of a single rose flower stem (20–35 g FW) produced in the Lake Naivasha Basin in Kenya was estimated to be 7–13 l/stem (Mekonnen *et al.*, 2012), distributed as 22% green, 45% blue and 34% gray (Table 5.5). A similar range of total WF (6–20 l/stem) was calculated for stems harvested from an experimental rose crop subjected to various N and irrigation treatments in California (Fig. 5.1), but with significant differences in the contribution of its components, which averaged to 0% green, 42% blue and 58% gray (Table 5.5).

Table 5.5. Water footprint (WF) of cut rose flower stems from commercial growing operations near Lake Naivasha, Kenya, and calculated from an experimental rose crop in a greenhouse in California, USA. (From Cabrera *et al.*, 1993; Mekonnen *et al.*, 2012.)

	Flower productivity		Water footprint (l/stem)			
Location/treatments	Stems/m^2	Stem fresh weight (g)	Green[a]	Blue[b]	Gray[c]	Total
Kenya	134	20	1.6	3.3	2.5	7.3
	107	25	2.0	4.1	3.1	9.2
	77	35	2.8	5.8	4.3	12.8
California, USA						
77–105 ppm N – 25% LF	406	27	0	4.5	2.2	6.7
154 ppm N – 25% LF	408	26	0	4.0	6.4	10.4
231 ppm N – 25% LF	451	24	0	3.8	11.0	14.8
154 ppm N – 10% LF	341	24	0	3.3	3.0	6.4
154 ppm N – 25% LF	395	24	0	4.0	6.1	10.1
154 ppm N – 50% LF	494	28	0	6.4	14.0	20.4

[a]Green WF refers to the consumption of rainwater stored in the soil (soil moisture).
[b]Blue WF is the volume of surface (including evaporation losses) and groundwater consumed or applied to grow the crop.
[c]Gray WF is the volume of freshwater that would be required to assimilate, i.e. dilute, the load of agricultural pollutants based on existing water quality standards.

The large WF_{gray} for a California-grown stem is linked to significantly higher N fertilizer applications, which effectively demand a higher volume of water to dilute their pollution contribution to local bodies of water.

On a comparative FW basis, the average WF of rose flower crops in Kenya and California of 0.42 l/g falls between the world averages for vegetables and fruit crops at 0.3 and 1.0 l/g, respectively. Interestingly, these WF values are much lower than those estimated for cereal and oil crops at 1.6 l/g and 2.4 l/g, respectively (Mekonnen and Hoekstra, 2011). Conversely, the share of the WF_{gray} for a heavily fertilized cut flower rose crop accounts for a much larger fraction (33–74%) of the total WF (Table 5.5), compared with the average 12% WF_{gray} reported for irrigated crops across the world.

Increases in the efficient utilization of water resources are paramount for the sustainability of irrigated agriculture in the 21st century, since water is at the forefront of today's economic, social and environmental issues. Consumers of imported products in developed countries – those with the highest per capita consumption of cut flowers – are increasing their demand for products documented to have been grown with sustainable, environmentally sound methods that yield reduced carbon, water and agrochemical footprints (Donohoe, 2008; Rikken, 2010). Along with the tenets of eco-label certifications already in place, there are proposals to use WF indexes in water-sustainability agreements between key players along the cut flower supply chain (Mekonnen *et al.*, 2012). The expectation is that this 'WF premium' will raise awareness among consumers, and encourage flower-growing operations to use water resources in a sustainable manner.

MINERAL NUTRITION AND FERTILIZATION MANAGEMENT

Most cultivated plants, including cut flowers, require 14 essential mineral elements to successfully complete their life cycle. While these elements are categorized as macronutrients (N, P, K, Ca, Mg, S) and micronutrients (Cl, Fe, Mn, B, Zn, Cu, Mo, Ni), denoting their relative concentration in plant tissues, their irreplaceable functions in the physiology of a plant require due consideration to their supply and monitoring when managing the crop fertilization to ensure maximum yields and quality.

Nutrient availability to crops growing in soils, substrates and hydroponic nutrient solutions is typically defined by the nutrients supplied by fertilizers; however, actual nutrient availability is dependent on the movement of nutrients from the *rootzone* to the *rhizosphere* (Fig. 5.2). The rootzone is defined as the bulk soil or substrate volume where roots grow, while the rhizosphere is the

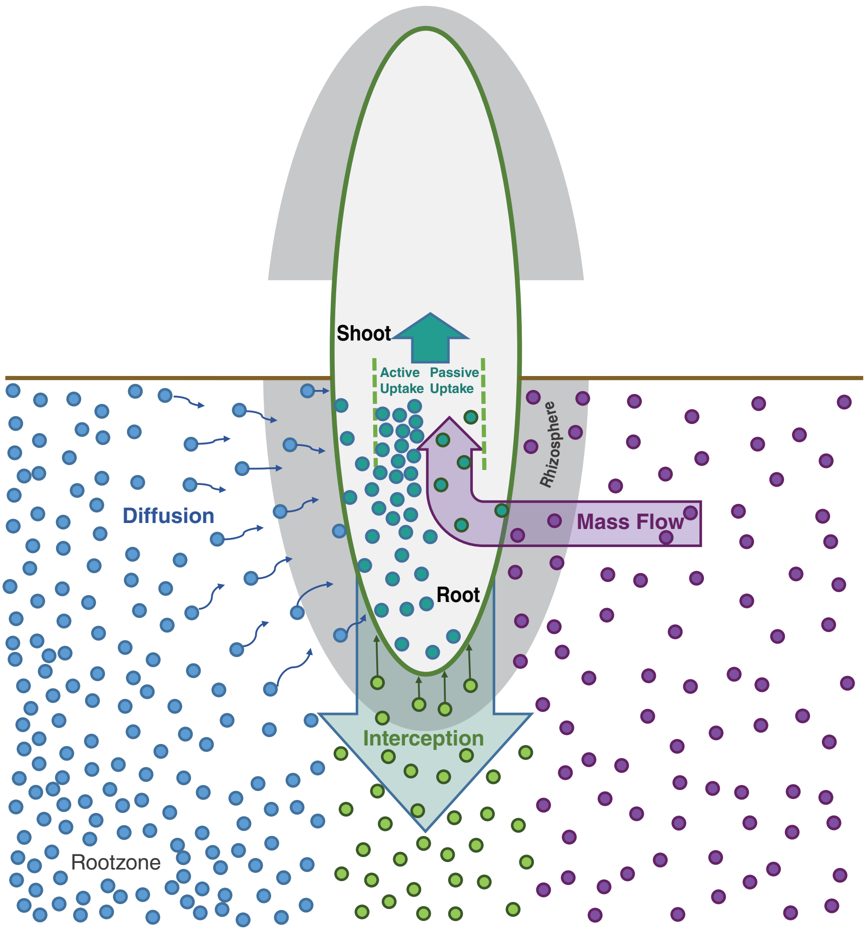

Fig. 5.2. Three rootzone nutrient mobility components (diffusion, interception and mass flow) allow for nutrient (ion) uptake in the rhizosphere. Active uptake is a selective process that requires the expenditure of energy by the plant, and allows for accumulation of ions in the plant at a greater concentration than in the surrounding rhizosphere. The removal of nutrients by the plant from the rhizosphere creates a gradient in the concentration of nutrients across the rhizosphere that drives the diffusion of nutrients from the rootzone to the rhizosphere. Passive uptake is a non-selective process in which the nutrient moves into the root with the mass flow of water from the rhizosphere. Passive uptake is driven by water movement resulting from transpiration in the leaves, thus environmental conditions affecting transpiration will also impact passive nutrient uptake. (Illustration by J. Faust and R.I. Cabrera.)

space or region immediately adjacent to the root surfaces, i.e. the plant–root interface.

Nutrient delivery

Nutrient mobility and spatial availability to root surfaces are governed by root interception, diffusion and mass flow processes (Fig. 5.2) (Barber, 1995; Marschner, 1995). *Interception* is the process by which nutrients come into contact with roots and are absorbed as the roots penetrate and grow through a soil/substrate. *Diffusion* refers to the transport of nutrients from the bulk soil solution in the rootzone to the rhizosphere along a concentration gradient that has been created by a depletion of nutrients in the rhizosphere by active plant uptake. *Mass flow* is defined as the transport of the bulk soil solution along the water potential (Ψ) gradient created by transpiration from the leaves. The type of production system, the frequency of fertilization and the fertilizer concentration determine the potential contribution of these three rootzone nutrient mobility components to meet actual crop nutrient demand. For example, mass flow dominates nutrient movement to the rhizosphere in hydroponic systems, as there are no physical or chemical limitations imposed by the substrate. Mass flow of nutrients is also highly significant in frequently fertigated soils/substrates; however, diffusion increases in importance during periods when transpiration rates are low, e.g. overcast, cold and humid days.

Factors affecting nutrient uptake

Once nutrients are delivered to the root surfaces (Fig. 5.2), nutrient uptake is modulated by several external (environmental and in the soil) and internal factors to the plant.

External factors in the environment influencing water availability and uptake (mass flow):

- Solar radiation, temperature, precipitation/irrigation, relative humidity, atmospheric pressure (elevation), wind.

External factors in the rootzone and rhizosphere that affect nutrient uptake:

- Nutrient concentrations (diffusion).
- Water supply rate to the root surfaces (mass flow).
- pH, ion exchange capacities, nutrient balance, O_2, temperature.
- Microorganisms (fungi, bacteria) in soil, substrate and soil solutions.

Internal factors affecting nutrient uptake:

- Plant tissue nutrient status.
- Available energy from carbohydrate reserves.

- Nutrient demand driven by the stage of plant growth and/or development.

Since greenhouse production creates a steady environment, a broad over-arching principle for greenhouse flower crops is that plant growth and development ultimately drives the overall nutrient demand and uptake.

Nutrient uptake capacity and behavior

Plant roots have a defined biological capacity to absorb ions from the external soil solution. The nutrient uptake capacity of a plant's root system (per unit of volume or mass) provides a short-term appraisal of the uptake behavior over a narrow range of ion concentrations presented uninterruptedly (in stirred hydroponics) to the roots (Mattson and Lieth, 2008; Griffiths and York, 2020). These lab experiments can help to describe long-term crop nutrient uptake and its dependence on physiological and environmental conditions.

The root's nutrient uptake capacity differs for ions that are actively and passively absorbed. Active uptake of the ions NO_3^-, NH_4^+, K^+, $H_2PO_4^-$ and SO_4^{2-} requires energy (carbohydrate) consumption and thus their uptake increases rapidly as the nutrient concentration increases until a saturation level is reached (maximum uptake rates). Above that level, additional nutrient concentration provides little additional nutrient uptake (Fig. 5.3A, green line). The N uptake capacity in hydroponic roses, provided as nitrate (NO_3^-) (Fig. 5.3B) and ammonium (NH_4^+) (Fig. 5.3C), follows this behavior over a very narrow concentration range, and the curve model estimates that the uptake capacity will be nearly saturated (reach ≥90% of the maximum) at concentrations of only 7 ppm (for both ions). Again, these observations are only possible in hydroponics under conditions of an unimpeded and continuous supply of ions to the root surfaces. The actual uptake capacity of plants growing under normal production conditions will be modulated by the variable contributions of ion diffusion and mass flow processes, affected by fertilizer supplies and the multiple rootzone, plant and environmental factors mentioned above. It should be stated that the energy requirement of active nutrient uptake allows the plant to exert a great degree of control of how much and when these ions are absorbed.

The uptake behavior of boron (B) is linear in response to B supply, because B uptake is strictly passive, i.e. no metabolic energy is required or expended to take up the ion (B is absorbed as uncharged boric acid) (Fig. 5.3A, blue line). Conversely, the ions Mg^{2+}, Ca^{2+}, Na^+ and Cl^- follow an uptake pattern that is intermediate between the active and passive uptake curves (Fig. 5.3A, black line). This pattern occurs because these nutrients are taken up actively at low concentrations and passively at higher concentrations. Passively absorbed ions pose a challenge as their uptake is closely linked to water uptake, and thus their accumulation in tissues is directly dependent on the rate of

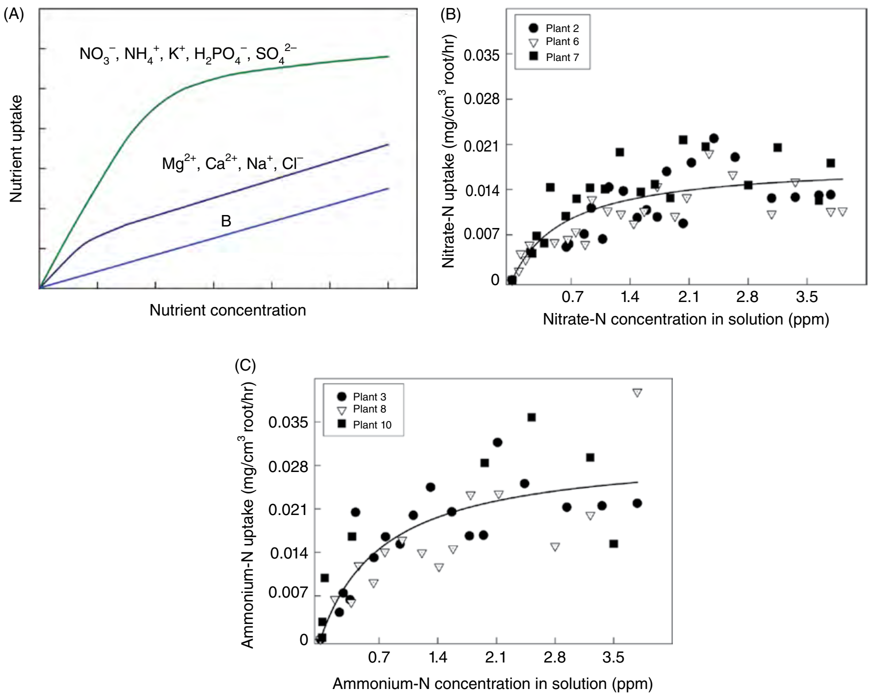

Fig. 5.3. Generalized nutrient uptake responses to nutrient concentrations (**A**) supplied continuously and unimpeded to plant roots (adapted from Marschner, 1995), and uptake capacity of nitrate-N (**B**) and ammonium-N (**C**) in laboratory experiments with hydroponically grown cut flower roses. The nutrient concentrations shown are not indicative of concentrations provided in commercial hydroponic systems. (Unpublished data from R.I. Cabrera.)

transpiration. Therefore, from a crop management perspective, careful monitoring and modulation of the supplied concentrations of Ca, B, Na and Cl is particularly required, in concert with canopy transpiration demand, to minimize deficiencies in Ca and B, or to minimize the accumulation of toxic levels of Na and Cl in tissues.

Under an adequate and steady supply of nutrients, e.g. continuous mass flow with a nutrient solution, and optimal rootzone and environmental conditions, the net uptake rate of many mineral nutrients depends on the actual plant's growth rate (Marschner, 1995). Interactions and feedback mechanisms between growth processes and the plant's internal concentrations of nutrients and carbohydrates (energy) are happening through various time scales and developmental stages of a crop. For example, hydroponically grown roses have distinctive hourly nutrient and water uptake rates over the course of one day (Fig. 5.4A). Interestingly, as

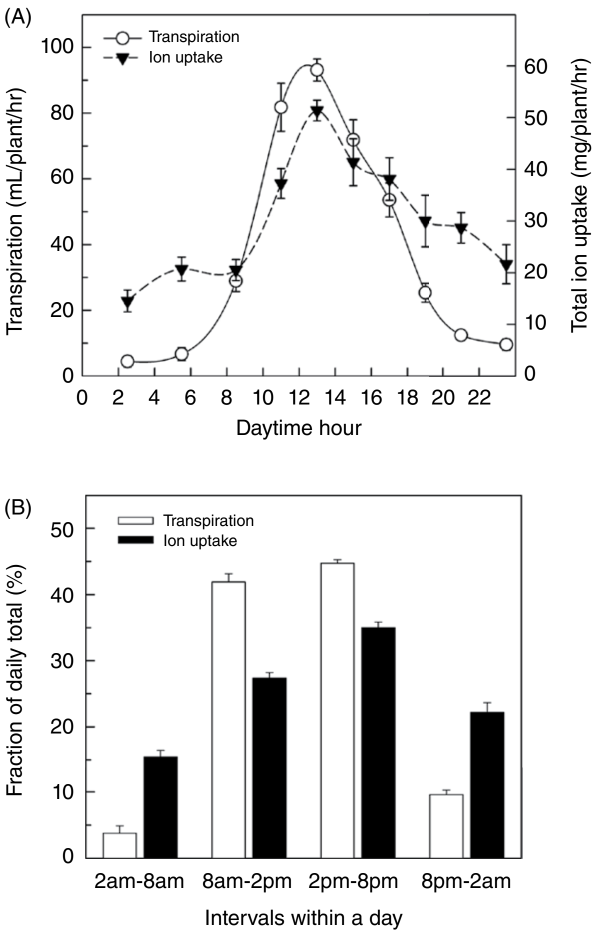

Fig. 5.4. Hourly transpiration and total ion uptake rates (**A**), and their relative distribution (**B**) over discrete intervals within 24-h periods in rose plants growing in recirculating hydroponic units. (From Solís-Pérez and Cabrera, 2012.)

much as 25% and 43% of the overall water and nutrient uptake, respectively, were observed during the dark (night) periods (Fig. 5.4B). Shade-intolerant woody plants with fast shoot elongation rates, like greenhouse roses, are hypothesized to have significant nocturnal transpiration that helps to maintain a higher and faster carbohydrate export during the dark (night) periods, along with sustained high mass flow and nutrient uptake (Marks and Lechowicz, 2007).

Plant responses to nutrient supplies

There is a classical response curve of a crop's productivity to increasing nutrient supply. For instance, annual biomass and flower yields in roses increase to a maximum with increases in applied nitrogen (N) concentration up to 90 ppm N, then they remain at a plateau up to 150 ppm N, but drop as the applied N concentrations increase further to 220 ppm (Fig. 5.5A). This response highlights two facts: (i) plants can have a fairly broad range of nutrient concentrations at which they can grow acceptably well; and (ii) as nutrient concentrations increase beyond a certain range, an undesirable osmotic effect will eventually reduce growth and yield. It is also noteworthy to observe that roses regulate the net uptake and accumulation of nitrogen in leaf tissues, with the tissue having near-constant concentrations (~3.3% N) with nitrogen supplies of 90–220 ppm N (Fig. 5.5B) (Cabrera, 2000). As already discussed,

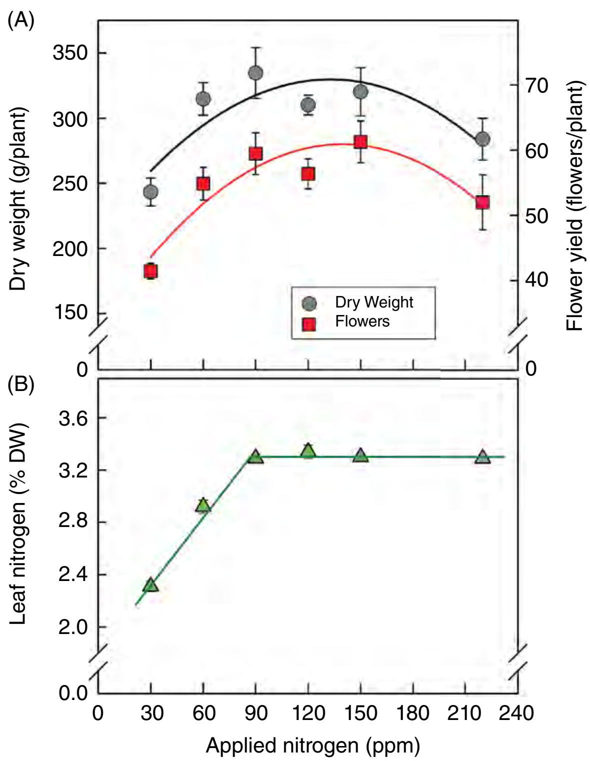

Fig. 5.5. Cumulative annual dry biomass and flower yield (**A**), and average leaf nitrogen (**B**) of a substrate-grown rose crop in response to concentration of nitrogen applied. (From Cabrera, 2000.)

for actively absorbed nutrients, like nitrogen, the plants exert a great degree of control over how much of it is taken up and accumulated in its tissues.

The osmotic effects of (over)fertilization need to be continuously considered for each production system (soil, substrate, hydroponics). The objective at hand is to provide only those nutrient supplies or concentrations that approach near-maximal flower yields and stop there. The diffusion and mass flow limitations of widely spaced fertigation events in soil and in some soilless substrates would require the supply of higher nutrient concentrations. Roses growing in a peat-based substrate were observed to have maximum biomass and flower yields with N concentrations of 90 ppm (Fig. 5.5A), but lower concentrations should produce maximal yields in more frequently fertigated substrates and in hydroponics. As proof of this, Cabrera *et al.* (1995) successfully grew a year-round experimental cut flower rose crop in a recirculating hydroponic system with a dilute nutrient solution (¼-strength Hoagland Solution with an EC of 0.5 dS/m) containing 42 ppm NO_3–N. In a follow-up study with a nutrient solution containing only 28 ppm N (supplied as either NO_3–N, NH_4–N or NH_4NO_3), the flower and dry biomass yields from this hydroponic rose crop surpassed (by as much as 53%) roses growing in a peat-based substrate and fertigated with 77–231 ppm N (Cabrera *et al.*, 1993, 1996). The superior biomass and flower yields in the hydroponic rose culture were attributed to the high (less negative) water potential in the continuously provided dilute solution. The fertigation solutions applied to the substrate-grown roses had EC values of 1.1–1.9 dS/cm and dry-down periods in between irrigations (every 3–5 days). These conditions resulted in transient water stress and nutrient stress owing to reduced mass flow and reduced diffusion of nutrients to the rhizosphere, both of which negatively impacted crop growth and yield.

Nutrient solution management

The nutrient diffusion limitations imposed by infrequent fertigations in substrates/soils are typically managed in practice by supplying more concentrated nutrient solutions (Paradiso *et al.*, 2003), which can lead to stressful osmotic potentials that negatively impact plant water relations and expansive growth. Thus, the cut flower yield of roses (Cabrera *et al.*, 1995, 1996), carnations (Metwally *et al.*, 2016) and gerberas (Maloupa *et al.*, 1996; Zheng *et al.*, 2004) are significantly higher supplying less concentrated nutrient solutions in hydroponic and intensive substrate production systems compared with soils.

A review of the literature on nutrient solutions used to fertigate crops growing in soils, substrates and in hydroponic cultures reveals numerous fertilizer recipes. A comparison of the historically most widely used and cited nutrient solutions in floriculture and horticulture research is provided in Table 5.6. Notably, these recipes all share a relatively similar range of concentrations and ratios between nutrients for major cations and anions, which

Table 5.6. Nutrient concentration ranges for historical nutrient solutions used to fertigate crops in soils, substrates and for hydroponic cultures, and examples of recipes used in some flower crops.

	Nutrient solution recipes				
Nutrient	Historical ranges[a]	Rose[b]	Rose[c]	Carnation[d]	Gerbera[e]
	Nutrient concentration in ppm (mM)				
Cation					
Mg^{2+}	36–49 (1.5–2)	28 (1.2)	24 (1.0)	24 (1.0)	28 (1.2)
K^{+}	156–313 (4–8)	176 (4.5)	117 (3.0)	235 (6.0)	246 (6.3)
Ca^{2+}	160–180 (4–4.5)	130 (3.3)	80 (2.0)	60 (1.5)	140 (3.5)
NH_4^+–N	0–14 (0–1)	21 (1.5)	14 (1.0)	35 (2.5)	17 (1.2)
Anion					
NO_3^-–N	168–196 (12–14)	154 (11)	105 (7.5)	146 (10.4)	174 (12.4)
$H_2PO_4^-$–P	31–62 (1–2)	39 (1.3)	16 (0.5)	34 (1.1)	43 (1.4)
SO_4^{2-}–S	48–112 (1.5–3.5)	40 (1.3)	32 (1.0)	32 (1.0)	48 (1.5)
Total N	168–210 (12–15)	175 (12.5)	119 (8.5)	181 (12.9)	190 (13.6)
	Electrical conductivity (dS/m)				
	1.6–2.0	1.5	1.0	1.4	1.7
	Nitrogen form (%)				
NH_4^+–N	0–7	12	12	19	9
NO_3^-–N	93–100	88	88	81	91

[a]Major ion concentrations found in Hoagland, Long Ashton, NFT (nutrient film technique) and Steiner nutrient solutions. The average micronutrient concentration ranges for these solutions are (in ppm): 2–4 Fe, 0.5–0.6 Mn, 0.3–0.5 B, 0.05-–0.11 Zn, 0.02–0.06 Cu, 0.01–0.04 Mo.
[b]de Hoog (2001).
[c]Cabrera (2000, modified half-strength Hoagland).
[d]Hartman and Holley (1968).
[e]Savvas and Gizas (2002).

have been used to grow a wide range of crops successfully under differing conditions. The concentration ranges and EC values of these historical solutions are useful in soil-grown crops that are fertigated infrequently; however, these values are relatively high for cut flower crops growing in limited substrate volumes and in hydroponics.

The examples of specific nutrient solution recipes used for roses, carnations and gerberas (Table 5.6) show a trend for lower ion concentrations and EC values compared with the historical ranges, which effectively reduces the osmotic potential in the rootzone. The overall osmotic effect of a nutrient solution, even in moderate, transient or short-lived occurrences, can significantly impact expansive growth, including the elongation of cut flower stems. For example, cut flower roses grown in coconut coir were fertigated with a nutrient solution that maintained substrate EC at 1.0 dS/m, and were exposed to a brief 2-h period with the same solution supplemented with sodium chloride (NaCl) to raise the substrate EC to 2.8, 4.7 and 7.6 dS/m. The flower stem elongation rates were measured continuously (every 6 s) over this short experimental period, averaging 1.0 mm/h in the control plants with the substrate EC of 1.0 dS/m. The brief 2-h osmotic stress with these substrate ECs of 2.8, 4.7 and 7.6 dS/m reduced the stem elongation rate by 13%, 28% and 79%, respectively (Oki and Lieth, 2004). These results support the longstanding recommendation to limit the EC in the rootzone of cut flower crops to <3.0 dS/m (Sonneveld *et al.*, 1999; Cabrera and Perdomo, 2003; Cabrera *et al.*, 2009).

Over the past 20 years, progressive cut flower growers have reduced their nutrient solutions from 150–250 ppm N to 80–120 ppm N. These decisions reduce production costs and waste, and thus contribute to the economic and environmental sustainability of the industry.

Nitrogen forms in nutrient solutions and pH management

While all essential mineral nutrients have important roles in the growth, yield and completion of the life cycle of plants, N often has the greatest observable effects. Nitrogen, supplied as either ammonium (NH_4^+) or nitrate (NO_3^-) constitutes up to 80% of the total cations and anions taken up by plants (Marschner, 1995). Therefore, the actual form of N provided to a crop has major effects on the uptake of other cations and anions, the rhizosphere pH, the plant's internal pH regulation, and its overall growth and yield responses.

The uptake of one molecule of NO_3^- by the roots produces an equivalent OH^- molecule released into the rhizosphere thus contributing to a rise in its pH, whereas the uptake and assimilation of one molecule of NH_4^+ releases an equivalent H^+ contributing to lowering its pH (Fig. 5.6). Plant preferences

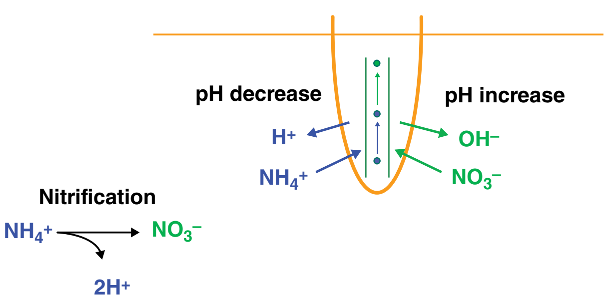

Fig. 5.6. The form of nitrogen supplied to a crop can have a significant effect on the pH of the soil solution and rhizosphere, affecting the uptake of other ions and overall plant growth responses. (Illustration by R.I. Cabrera.)

for either N form are documented for many crop species, and in general those species that have evolved in calcareous soil environments, e.g. *Limonium* and *Gypsophila*, have a preference for NO_3^-, whereas those evolving from acidic soil environments, e.g. azaleas and camellias, prefer NH_4^+. However, the largest growth and yield in most cultivated plants are obtained when they are supplied with a combined supply of both sources. Ammonium to nitrate ratios of 1:5 to 1:3 have been reported to produce the highest yields in several flower crops, including roses, gerberas and carnations (Hanan, 1998; Savvas *et al.*, 2003; Bar-Yosef *et al.*, 2009; Sonneveld and Voogt, 2009). Conversely, cut flower species that produce better yields with larger NH_4^+ fractions include proteas (Hawkins and Cramer, 2011) and anthuriums (Dufour and Guerin, 2005).

When plants are supplied with mixed NH_4^+ and NO_3^-, they show a preferential uptake of NH_4^+, leading to an accumulation of protons (H^+) in the rhizosphere. A high concentration of H^+ is the definition for low pH. Thus, NH_4^+ uptake is directly associated with a reduction in rootzone pH. For example, without a closely controlled pH, rose plants growing in 27-l recirculating hydroponic units dropped their solution pH from 6 to 4 in ~6 h (Cabrera *et al.*, 1996). A large supply of NH_4^+ and the preferential uptake of NH_4^+ can lead significant growth reductions as the plants cannot store it (in contrast to NO_3^-). Thus, the plant has to metabolize most or all of the NH_4^+ by using carbohydrates that could have been used to support further growth.

Nitrification is a process by which soil/substrate microorganisms, such as nitrifying bacteria, utilize NH_4^+ for their metabolism, and release two H^+ for every absorbed NH_4^+ (Fig. 5.6), thus potentially contributing to large pH reductions over short periods of time (hours to days). In addition to its common occurrence in soils, nitrification has been confirmed in peat- and pine bark-based substrates (Taylor *et al.*, 2013) and in aeroponic and hydroponic nutrient solutions (Padgett and Leonard, 1993).

Overall, from a practical perspective, a judicious use of the NH_4^+ concentration and its fraction of the total N supplied in a nutrient solution can be used effectively to maintain/manage soil solution pH in both soil and soilless production systems, and sustain the highest growth rates and yields. Conservative fractions of 5–15% of the N being delivered in the NH_4^+ form are recommended as a suitable baseline for cut flower production (Table 5.6). Lower NH_4^+ fractions should be considered during winter seasons for flower crops growing in far northern or southern latitudes, where low-light conditions, i.e. low DLI, reduce the pool of assimilated carbohydrates available to support growth processes and the assimilation of NH_4^+ taken up by the roots.

Recirculating and recycling nutrient solutions

Water scarcity, competition for good-quality water sources for irrigation, and environmental concerns and pressures are challenging the current *modus operandi* and the sustainability of floriculture production around the world. In addition to adopting best management practices in free drainage (open) growing systems, there is mounting pressure to capture all water and nutrients applied in recirculating production systems (Voogt and Bar-Yosef, 2019). Recirculation refers to 'closed' fertigation systems where the bulk of the re-used solution volume moves dynamically (usually several times a day) through the crop's rootzone, going through holding tanks and rigorous filtration and water-treatment processes. Conversely, water-recycling systems refer here to the capture of drainage and runoff effluents into open/outdoor retention ponds that also receive rainwater and storm water collected from the greenhouses. This mixed pond water (effectively a diluted solution) is treated (filtration, disinfection), blended with primary water sources and then injected with fertilizer before being delivered to the crop.

The capital investment costs for the equipment and technology required for constructing and maintaining recycling and recirculation systems are relatively high compared with the current costs of water and fertilizer, thus the economic incentive for growers to modernize can be lacking (Raviv *et al.*, 2019; Voogt and Bar-Yosef, 2019). Thus, the actual incentives for change might come in the form of government regulations or requirements for eco-label certifications imposed by or within the flower marketing chains.

On the technical aspects of recycling and recirculation there are some main factors that limit the potential and extent of their adoption, including how to deal with ion composition and balance, i.e. osmotic and specific ion effects, of the primary water sources and the effluent, and management of plant pathogens. Outdoor/open pond-based recycling systems in regions with adequate to high precipitation are likely to have less difficulty dealing with the monitoring and adjustment of the chemistry of the recycled solutions compared with those in drier environments, since frequent precipitation contributes to dilution of the captured effluents in open reservoirs (Majsztrik *et al.*, 2017). This being said, the chemical quality of the primary irrigation water sources (Table 5.2) will dictate whether recirculation and recycling will be technically and logistically manageable in a location. A rapid or dynamic accumulation of total and/or specific undesirable (toxic) ions requires higher dilution rates and/or frequent solution discharges. For closed recirculation systems, continuous monitoring of primary water sources and the operational nutrient solution are mandatory, along with iterative computation of mass balances (inputs and outputs of salts and nutrients), which also require knowledge of a crop's evapotranspiration and ion uptake rates at different development stages (Voogt and Bar-Yosef, 2019).

Irrigation water sources with a low EC (<0.5 dS/m) are essential for recirculating systems, whereas those up to ~1 dS/m can be manageable in recycling systems. This guideline is based on the notion that the addition of nutrients will raise the EC of the applied fertigation solution up to 2.0–2.5 dS/m. Once subjected to water and nutrient uptake by plants, the rhizosphere's EC and osmotic potential may be in a range (≥ 3 dS/m and ≥ 108 kPa, respectively) that can quickly and significantly reduce the elongation of flower shoots in highly sensitive (alstroemeria, Sooneveld, 1988) and moderately sensitive (gerberas, Ganege Don *et al.*, 2010; roses, Cabrera *et al.*, 2009) crops. The actual threshold EC of the nutrient solution in recirculated or recycled solutions will be crop- and even cultivar-specific, and will be modulated by irrigation management (frequency and volumes applied and leached), growth stage, climate and season of the year (Voogt and Bar-Yosef, 2019). In crops fertigated with a moderate to high frequency and with standardized leaching fractions, it is common to attain steady-state soil solution conditions where the crop can produce satisfactory yields despite relatively high EC values and high concentrations of specific ions like Na and Cl that would be otherwise considered excessively high under less-frequent or lower-volume fertigation practices (Raviv *et al.*, 1998; Cabrera and Perdomo, 2003). In other words, sustained near-mass flow conditions arising from frequent irrigation can allow the use of higher EC fertigation solutions by maintaining low or non-stressful osmotic potentials in the rhizosphere, and minimizing the concentration of ions like Na, Cl and B.

The potential for nutrient imbalances is an important consideration when reusing drained effluents, more so in closed recirculating systems with long-term crops (Savvas and Gizas, 2002). The prevention of nutrient imbalances in these systems understandably requires monitoring of specific ions, and their replenishment in ratios that are similar to their mean absorption ratio (Sonneveld and Voogt, 2009), or lessening of the uptake of the undesirable ions. For example, in one study with roses, nutrient solutions were salinized with 276 ppm Na^+ (12 mM) and counterbalanced by different ratios of the anions Cl^-, NO_3^- and SO_4^{2-} (Solís-Pérez and Cabrera, 2007). Plants fertigated with nutrient solutions containing higher fractions of the counter-anions SO_4^{2-} and Cl^- performed better in terms of growth than those dominated by NO_3^-.

Monitoring plant and growing medium nutrient status

Soil and tissue analyses have been traditionally used to gauge the potential availability of nutrients and plant nutrient status, respectively, and to guide adjustments to fertilization programs so as to ensure sustained flower yields and quality. For soil-grown crops, where soil fertility conditions are usually well buffered, sporadic soil and leaf tissue analyses are collected to determine if nutrient concentrations fall within ‘normal’ ranges, and then to make adjustments in the fertilization programs for the next growing season. When observing the development of incipient nutrient disorders, symptomatic and normal leaf samples are collected and analyzed to determine if ‘emergency’ corrective nutrient applications are needed, or if foliar applications are warranted.

Compared with soils, modern soilless production systems do not allow room for errors (Raviv *et al.*, 2019), as their very small root volumes undergo large and dynamic (temporal and spatial) changes in water and nutrient availability, requiring timely and intensive fertigation practices and management.

Therefore, a frequent, and even continuous, monitoring of the root zone chemistry has become the new diagnostic practice in soilless production systems (Cabrera and Solís-Pérez, 2017). Over the past 3+ decades, monitoring the pH and nutrient status of soilless substrates has evolved from the sporadic to targeted use of destructively collected samples for saturated media extracts or dilution extractions (e.g. 1:2 or 1:5 substrate to water ratios), to non-destructive pour-through and soil solution extraction procedures (Bunt, 1988; Sonneveld and Voogt, 2009; Franco-Hermida *et al.*, 2017). Nowadays, a more expeditious approach for intensively fertigated substrate-grown crops is to monitor the volume and chemistry of the applied and drained/leached solutions. At a minimum, routine and frequent (daily, hourly or even every few minutes) measurements of rootzone pH and EC, along with substrate moisture content or tension, are needed for crops growing in small volumes of substrate or in hydroponic cultures, and require the use of reliable instruments and their frequent calibration. Furthermore, the collected data need to be promptly logged and processed for swift and timely manual adjustments or be programmed for automated (software-driven) actions by fertigation-control equipment.

The common method used to assess the nutrient status of a crop is the critical foliar nutrient range, through which a leaf nutrient concentration value is compared with a 'normal' or reference level. The determination of 'normal' leaf nutrient concentrations has been done empirically, based largely on subjective visual ratings of what constitutes a desirable foliage greenness (Carlson and Bergman, 1966; White, 1987) and with relatively less consideration of flower yield production parameters (Cabrera, 2000; Cabrera and Solís-Pérez, 2017). Therefore, a major inconvenience of this method is the difficulty in determining which elements are effectively the most limiting and when, after adjusting their application, they will produce a significant yield response (Franco-Hermida *et al.*, 2013).

A nitrogen nutrition study in greenhouse roses revealed that leaf N concentration correlates linearly and significantly with chlorophyll content and leaf color attributes (Cabrera, 2000) (Fig. 5.7A). The color or chroma of a surface is measured with a chroma meter and reported in a tridimensional scale (L*a*b scale), where each attribute can have positive or negative values, which combined give a quantitative definition of color, instead of a subjective scale like light green to dark green in the case of leaves. While the 'greenest' foliage was observed in rose flower shoots having a 'normal' leaf N concentration of 3.0–3.6%, the flower DW yields within this concentration range varied erratically by 60% and could not be correlated (Fig. 5.7B). Conversely, dry flower yields were well correlated with lower leaf N concentrations and were maximal within the 2.5–2.9% range, where leaves could subjectively be considered light green in color. This study highlights important observations such as a tight plant control on tissue N accumulation, i.e. no luxury consumption beyond 3.6%, a correlated yield response within a defined leaf N status and the like-

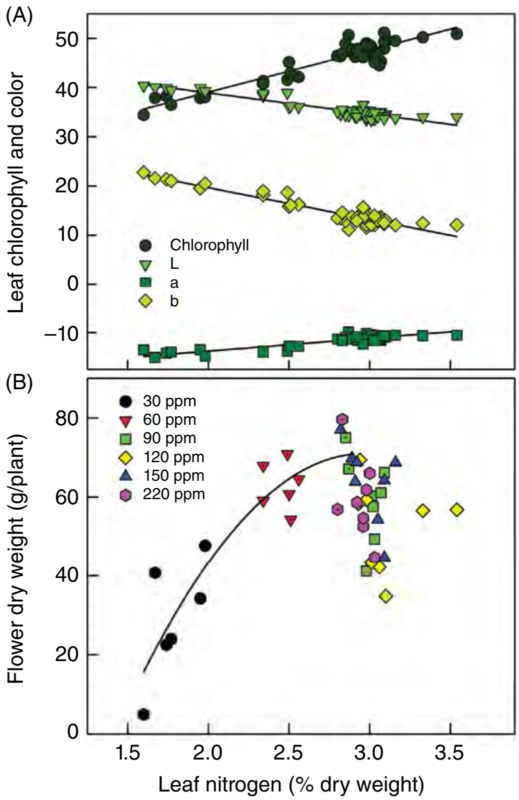

Fig. 5.7. Relationships between leaf nitrogen status, leaf chlorophyll and color (L*a*b scale) attributes (**A**), and flower dry weights (**B**). (From Cabrera, 2000.)

lihood that nutrient imbalances occurring beyond this range are responsible for a broad spread in yields regardless of differences in perceived plant health (greenness).

Integrative nutrient diagnosis techniques

Nutrient imbalances affecting crop productivity can be present even when the individual tissue nutrient concentrations are within the conventional sufficiency ranges and no visual deficiency symptoms are present. A solution to this challenge of missing or misinterpreting 'hidden' tissue nutrient imbalances is the application of integrative nutrient diagnosis techniques like the Diagnosis and Recommendation Integrated System (DRIS) and Compositional Nutrient Diagnosis (CND). These methods compare the results of leaf analysis with norms based on nutrient ratios, not on individual nutrient values, generated from an 'ideal' high-yielding plant population (Fageria, 2001). The results are presented as individual elemental indices that quantify in hierarchical order the effect of each nutrient on the crop's mean nutrient balance index (NBI) (Fig. 5.8). The elemental index values, presented on a continuous scale, can be positive or negative, specifying a likely nutrient excess or deficiency. A sizable database of leaf nutrient analyses with their respective yield data is needed to generate the DRIS and CND nutrient diagnostic norms and their theoretical validation for a crop. Thereafter, these norms need to be experimentally validated to confirm their practical application.

Recently, DRIS and CND norms were generated and validated for greenhouse roses (Franco-Hermida *et al.*, 2013, 2017, 2020), and deemed suitable for both soil and soilless growing systems, and across a range of cultivars, rootstocks and plant ages. The experimental validation of these norms was done in a plot of 15 soil beds (1 × 30 m), each with 206 rose (2-year-old) plants (6.9 plants/m^2), within a commercial rose greenhouse. Soil and leaf tissues were initially sampled and diagnosed with DRIS procedures, and used to establish 'corrective' adjustments to the nutrient solution, namely reductions to iron (Fe, from 4.0 to 1.3 ppm) and slight increases in manganese (Mn, from 1.0 to 1.2 ppm), zinc (Zn, from 1.0 to 1.15 ppm) and copper (Cu, from

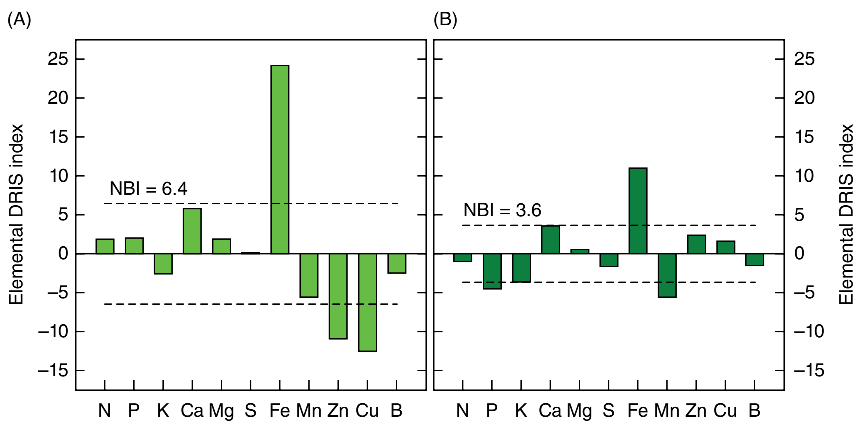

Fig. 5.8. Integrated nutrient diagnosis techniques, like the Foliar Diagnosis and Recommendation Integrated System (DRIS), can be used to diagnose and improve the balance of individual elements within a crop, and enhance its quality and yield. The individual and mean nutrient balance index (NBI) was determined for 'Freedom' rose plants receiving a standard (**A**) and a modified (**B**) fertigation formulation over a single 11-week flowering cycle. The fertigation formulation changes, based on DRIS diagnosis from the preceding flowering cycle, included a reduction to iron (Fe, from 4.0 to 1.3 ppm) and slight increases in manganese (Mn, from 1.0 to 1.2 ppm), zinc (Zn, from 1.0 to 1.15 ppm) and copper (Cu, from 1.0 to 1.3 ppm). (From Franco-Hermida *et al.*, 2020.)

1.0 to 1.3 ppm). After one 11-week flowering cycle, the flower yields were recorded along with full leaf tissue analyses and subjected again to DRIS analysis. Compared with the plants fertigated with the control nutrient solution (Fig. 5.8A), plants receiving the modified nutrient solution (Fig. 5.8B) were able to adjust the elemental index values of Fe, Zn and Cu, bringing them closer to or within the limits of the NBI, which was also reduced compared with that in the control plants (NBI 3.6 vs. 6.4).

According to DRIS theory, changes in fertilization programs that bring the individual and mean nutrient balance indexes closer to zero offer the greatest probability of yield responses. In this regard, the rose plants receiving the adjusted nutrient solution (Fig. 5.8B) produced 10.8% more flowers, had 10% longer stems and had 32% more flowers in the longest stem grade category (>70 cm), and less in the non-exportable grade (<40 cm). While the harvested flower number was not statistically different from the plants receiving the control nutrient solution, the other variables were. Nevertheless, considering that these results are from only one 11-week flowering cycle, the projection is that the statistical and economic significance of the flower yields integrated over longer production periods will improve. Overall, these results strengthen the predictive capacity of integrative nutrient diagnosis techniques (DRIS, CND) that allows for the introduction of sensible and gradual changes to nutrient supply, and lead into positive yield responses and enhanced fertilizer use efficiency in comparison with traditional nutrient diagnostic methodology.

REFERENCES

Arévalo-Hernández, J.J. (2011) Evaluación del efecto de la aplicación de diferentes láminas de riego en el cultivo de rosa (*Rosa* sp. cv. 'Freedom'), bajo invernadero en la Sabana de Bogotá. MSc Thesis, Universidad Nacional de Colombia.

Augé, R.M. (2001) Water relations, drought and vesicular-arbuscular mycorrhizal symbiosis. *Mycorrhiza* 11, 3–42.

Augé, R.M. and Stodola, J.W. (1990) Apparent increase in symplastic water contributes to greater turgor in mycorrhizal roots of droughted *Rosa* plants. *New Phytologist* 115, 285–295.

Augé, R.M., Stodola, J.W. and Pennell, B.D. (1990) Osmotic and turgor adjustment in *Rosa* foliage drought-stressed under varying irradiance. *Journal of the American Society for Horticultural Science* 115, 661–667.

Aydinsakir, K., Tuzel, I.H. and Buyuktas, D. (2011) The effects of different irrigation levels on flowering and flower quality of carnation (*Dianthus caryophllus* L.) under drip irrigation. *African Journal of Biotechnology* 10, 14826–14835.

Bailey, D.A. (1996) Alkalinity, pH and acidification. In: Reed, R.W. (ed.) *Water, Media and Nutrition for Greenhouse Crops*. Ball Publishing, Batavia, Illinois, pp. 69–91.

Barber, S.A. (1995) *Soil Nutrient Bioavailability: A Mechanistic Approach, 2nd Edn*. Wiley, New York.

Bar-Yosef, B., Mattson, N.S. and Lieth, H.J. (2009) Effects of NH4:NO3:urea ratio on cut roses yield, leaf nutrient content and root proton efflux in closed hydroponic system. *Scientia Horticulturae* 122, 610–619.

Beeson Jr., R.C. and Brooks, J. (2008) Evaluation of a model based on reference crop evapotranspiration (ETo) for precision irrigation using overhead sprinklers during nursery production of *Ligustrum japonica*. *Acta Horticulturae* 792, 85–90.

Bianchi, A., Masseroni, D., Thalheimer, M., Medici, L.O. and Facchi, A. (2017) Field irrigation management through soil water potential measurements: a review. *Italian Journal of Agrometeorology* 2, 25–38.

Bunt, A.C. (1988) *Media and Mixes for Container-grown Plants*. Unwin Hyman Ltd., London.

Cabrera, R.I., (1997a) Water use by roses. *Roses Incorporated Bulletin* August, 38–42.

Cabrera, R.I. (1997b) Eficiencia en el uso del agua en rosas desarrolladas bajo distintos regímenes de fertilización nitrogenada y riego. *Revista Chapingo - Serie Horticultura* 3, 5–12.

Cabrera, R.I. (2000) Evaluating yield and quality of roses with respect to nitrogen fertilization and leaf tissue nitrogen status. *Acta Horticulturae* 511, 133–141.

Cabrera, R.I. (2011) Importancia de la calidad química del agua en el fertirriego en cultivos ornamentales. In: Flórez Roncancio, V.J. (ed.) *Avances sobre Fisiología de la Producción de Flores de Corte en Colombia*. Editorial Universidad Nacional de Colombia, Bogotá, pp. 17–26

Cabrera, R.I. and Perdomo, P. (2003) Reassessing the salinity tolerance of greenhouse roses under soilless production conditions. *HortScience* 38, 533–536.

Cabrera, R.I. and Solis-Perez, A.R. (2017) Mineral nutrition and fertilization management. In: *Reference Module in Life Sciences*. Elsevier, Amsterdam, pp. 1–10. DOI: 10.1016/B978-0-12-809633-8.05087-1

Cabrera, R.I., Evans, R.Y. and Paul, J.L. (1993) Leaching losses of nitrogen from container-grown roses. *Scientia Horticulturae* 53, 333–345.

Cabrera, R.I., Evans, R.Y. and Paul, J.L. (1995) Cyclic nitrogen uptake by greenhouse roses. *Scientia Horticulturae* 63, 57–66.

Cabrera, R.I., Evans, R.Y. and Paul, J.L. (1996) Nitrate and ammonium uptake by greenhouse roses. *Acta Horticulturae* 424, 53–57.

Cabrera, R.I., Solís-Pérez, A.R. and Sloan, J.J. (2009) Greenhouse rose yield and ion accumulation responses to salt stress as modulated by rootstock selection. *HortScience* 44, 2000–2008.

Cabrera, R.I., Wagner, K.L. and Wherley, B. (2013) An evaluation of urban landscape water use in Texas. *Texas Water Journal* 4, 14–27.

Cabrera, R.I., Solís-Pérez, A.R. and Cuervo-Bejarano, W.J. (2017) Tolerancia y manejo de salinidad, pH y alcalinidad en el cultivo de flores. In: Flórez, V.J. (ed.) *Consideraciones sobre producción, manejo y poscosecha de flores de corte con énfasis en rosa y clavel*. Editorial Universidad Nacional de Colombia, Bogotá, pp. 63–73.

Cabrera, R.I., Altland, J. and Niu, G. (2018) Assessing the potential of nontraditional water sources for landscape irrigation. *HortTechnology* 28, 436–444.

Carlson, W.H. and Bergman, E.L. (1966) Tissue analysis of greenhouse roses (*Rosa hybrida*) and correlation with flower yield. *Proceedings of the Journal of the American Society for Horticultural Science* 88, 671–677.

Cassaniti, C., Romano, D., Hop, M.E.C.M. and Flowers, T.J. (2013) Growing floricultural crops with brackish water. *Environmental and Experimental Botany* 92, 165–175.

Castilla Prados, N. and Montalvo López, T. (2005) Programación del riego. In: Cadahía López, C. (ed.) *Fertirrigación: Cultivos Hortícolas, Frutales y Ornamentales*. Ediciones Multi-Prensa, Madrid, Spain, pp. 277–298.

Davidson H., Mecklenburg, R. and Peterson, C. (2000) *Nursery Management: Administration and Culture*, 4th Edition. Prentice Hall, Upper Saddle River, New Jersey.

de Hoog, J. (2001) *Handbook for Modern Greenhouse Rose Cultivation*. Applied Plant Research (PPO), Aalsmeer, the Netherlands.

Donohoe, M. (2008) Flowers, diamonds, and gold: the destructive public health, human rights, and environmental consequences of symbols of love. *Human Rights Quarterly* 30, 164–182.

Dufour, L. and Guerin, V. (2005) Nutrient solution effects on the development and yield of *Anthurium andreanum* Lind. in tropical soilless conditions. *Scientia Horticulturae* 105, 269–282.

Fageria, V. (2001) Nutrient interactions in crops plants. *Journal of Plant Nutrition* 24, 1269–1290.

Fare, D.C., Gilliam, C.H. and Keever, G.J. (1992) Monitoring irrigation at container nurseries. *HortTechnology* 2, 75–78.

Fereres, E., Goldhamer, D.A. and Parsons, L.R. (2003) Irrigation water management of horticultural crops. *HortScience* 38, 1036–1042.

Franco-Hermida, J.J., Henao-Toro, M.C., Guzmán, M. and Cabrera, R.I. (2013) Determining nutrient diagnostic norms for greenhouse roses. *HortScience* 48, 1403–1410.

Franco-Hermida, J.J., Quintero-Castellanos, M.F., Cabrera, R.I. and Guzmán, M. (2017) Determination of diagnostic standards on saturated soil extracts for cut roses grown in greenhouses. *PLoS ONE* 12, e0178500.

Franco-Hermida, J.J., Quintero-Castellanos, M.F., Guzmán, A., Guzmán, M. and Cabrera, R.I. (2020) Validating integrative nutrient diagnostic norms for greenhouse cut-roses. *Scientia Horticulturae* 264, 109094.

Ganege Don, K.K., Xia, Y-P., Zhu, Z., Le, C. and Wijeratne, A.W. (2010) Some deleterious effects of long-term salt stress on growth, nutrition, and physiology of gerbera (*Gerbera jamesonii* L.) and potential indicators of its salt tolerance. *Journal of Plant Nutrition* 33, 2010–2027.

Griffiths, M. and York, L.M. (2020) Targeting root ion uptake kinetics to increase plant productivity and nutrient use efficiency. *Plant Physiology* 182, 1854–1868.

Hanan, J.J. (1998) *Greenhouses: Advanced Technology for Protected Horticulture*. CRC Press, Boca Raton, Florida.

Hanan, J.J. and Jasper, F.D. (1969) Consumptive water use in response of carnations to three irrigation regimes. *Journal of the American Society for Horticultural Science* 94, 70–73.

Hartman, L.D. and Holley, W.D. (1968) Carnation nutrition. *Colorado Flower Growers' Association Bulletin* 221, 1–8.

Hawkins, H.-J. and Cramer, M.D. (2011) *The Protea Grower's Manual: Sustainable Nutrition and Irrigation*. Protea Producers of South Africa, Cape Town, South Africa.

Heckman, J. and Murphy J.A. (2003) Fertilizing the Home Lawn. Fact Sheet FS633, Rutgers Cooperative Extension. New Brunswick, New Jersey. Available at: https://njaes.rutgers.edu/FS633/ (accessed 16 October 2020).

Henley, R.W. and Poole, R.T. (1981) Water and foliage plants. In: Joiner, J.N. (ed.) *Foliage Plant Production*. Prentice Hall, Englewood Cliffs, New Jersey, pp. 203–228.

Hermitte, S.M. and Mace, R.E. (2012) The Grass is Always Greener… Outdoor Residential Water Use in Texas. Technical Note 12-01. Texas Water Development Board. Austin, Texas

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2009) *Water Footprint Manual: State of the Art 2009*. Water Footprint Network, Enschede, the Netherlands.

Hsiao, T.C. (1973) Plant responses to water stress. *Annual Review of Plant Physiology* 24, 519–570.

Incrocci, L., Marzialetti, P., Incrocci, L.G., Di Vita, A., Balendonck, J., Bibbiani, C., Spagnol, S. and Pardossi, A. (2014) Substrate water status and evapotranspiration irrigation scheduling in heterogenous container nursery crops. *Agricultural Water Management* 131, 30–40.

Jaafar, H.H. and Ahmad, F. (2019) Determining reference evapotranspiration in greenhouses from external climate. *Journal of Irrigation and Drainage Engineering* 145, 04019018.

Joiner, J.N., Conover, C.A. and Poole, R.T. (1981) Nutrition and fertilization. In: Joiner, J.N. (ed.) *Foliage Plant Production*. Prentice Hall, Englewood Cliffs, New Jersey, pp. 229–268.

Joiner, J.N., Poole, R.T. and Conover, C.A. (1983) Nutrition and fertilization of ornamental greenhouse crops. *Horticultural Reviews* 5, 317–403.

Kiehl, P.A., Lieth, J.H. and Burger, D.W. (1992) Growth response of chrysanthemum to various container medium moisture levels. *Journal of the American Society for Horticultural Science* 114, 224–229.

Kim, S-H., Shackel, K. and Lieth, J.H. (2004) Bending alters water balance and reduces photosynthesis of rose shoots. *Journal of the American Society for Horticultural Science* 129, 896–901.

Lambers, H., Chapin III, F.S. and Pons, T.L. (2008) *Plant Physiological Ecology*. Springer-Verlag, New York.

Lieth, J.H. and Oki, L.R. (2019) Irrigation in soilless production. In: Raviv, M., Lieth, J.H. and Bar-Tal, A. (eds) *Soilless Culture: Theory and Practice, 2nd Edn*. Academic Press – Elsevier, San Diego, California, pp. 381–423.

Liu, F., Cohen, Y., Fuchs, M., Plaut, Z. and Grava, A. (2006) Effects of vapor pressure deficit on leaf area and water transport in flower stems of soilless culture rose. *Agricultural Water Management* 81, 216–224.

Majsztrik, J.C., Fernandez, R.T., Fisher, P.R., Hitchcock, D.R., Lea-Cox, J., Owen, J.S., Oki, L.R. and White, S.A. (2017) Water use and treatment in container-grown specialty crop production: a review. *Water Air Soil Pollution* 228, 151, 27 p.

Maloupa, E., Fakhri, M.N., Chartzoulakis, K. and Gerasopoulos, D. (1996) Effects of substrate and irrigation frequency on growth, gas exchange and yield of gerbera cv. Fame. *Advances in Horticultural Science* 10, 195–198.

Marks, C.O. and Lechowicz, M.J. (2007) The ecological and functional correlates of nocturnal transpiration. *Tree Physiology* 27, 577–584.

Marschner, H. (1995) *Mineral Nutrition of Higher Plants, 2nd Edn.* Academic Press, San Diego, California.

Mattson, N. and Lieth, J.H. (2008) 'Kardinal' rose exhibits growth plasticity and enhanced nutrient absorption kinetics following nitrate, phosphate, and potassium deprivation. *Journal of the American Society for Horticultural Science* 133, 341–350.

Mekonnen, M.M. and Hoekstra, A.Y. (2011) The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences* 15, 1577–1600.

Mekonnen, M.M., Hoekstra, A.Y. and Becht, R. (2012) Mitigating the water footprint of export cut flowers from the Lake Naivasha Basin, Kenya. *Water Resources Management* 26, 3725–3742.

Metwally, N.E., El-Behairy, U.A., Abou-Hadid, A.F. and El-Gendy, S.A. (2016) Carnation production using different soilless culture systems under protected cultivation in Egypt. *Proceedings of 12th International Dryland Development Conference*. Alexandria, Egypt, pp. 304–308.

Nelson, P.V. (1991) *Greenhouse Operation and Management, 4th Ed.* Prentice Hall. Englewood Cliffs, New Jersey.

Nikolaou, G., Neocleous, D., Katsoulas, N. and Kittas, C. (2019) Irrigation of greenhouse crops – review. *Horticulturae* 5, 7.

Niu, G. and Cabrera, R.I. (2010) Growth and physiological responses of landscape plants to saline water irrigation – a review. *HortScience* 45, 1605–1609.

Oki, L.R. and Lieth, J.H. (2004) Effect of changes in substrate salinity on the elongation of *Rosa hybrida* L. 'Kardinal' stems. *Scientia Horticulturae* 101, 103–119.

Oki, L.R., Lieth, J.H. and Tjosvold, S. (2001) Irrigation of *Rosa hybrida* 'Kardinal' based on soil moisture tension increases productivity and flower quality. *Acta Horticulturae* 547, 213–219.

Padgett, P.E. and Leonard, R.T. (1993) Contamination of ammonium-based nutrient solutions by nitrifying organisms and the conversion of ammonium to nitrate. *Plant Physiology* 101, 141–146.

Paradiso, R., De Pascale, S., Aprea, F. and Barbieri, G. (2003) Effect of electrical conductivity levels of nutrient solution on growth, gas exchange and yield of two gerbera cultivars in soilless system. *Acta Horticulturae* 609, 165–171.

Petersen, F.H. (1996) Water testing and interpretation. In: Reed, D.W. (ed.) *Water, Media and Nutrition for Greenhouse Crops*. Ball Publishing, Batavia, Illinois, pp. 31–49.

Plaut, Z., Zieslin, N. and Arnon, I. (1973) The influence of moisture regime on greenhouse rose production in various growth media. *Scientia Horticulturae* 1, 239–250.

Quintero, M.F., Ortega, D., Valenzuela, J.L. and Guzmán, M. (2013) Variation of hydro-physical properties of burnt rice husk used for carnation crops: Improvement of fertigation criteria. *Scientia Horticulturae* 154, 82–87.

Raviv, M. and Blom, T. (2001) The effect of water availability and quality on photosynthesis and productivity of soilless-grown cut roses. *Scientia Horticulturae* 88, 257–276.

Raviv, M. and Wallach, R. (2007) Water availability to rose roots grown in soilless media, as a determinant factor of productivity. *Acta Horticulturae* 751, 23–32.

Raviv, M., Krasnovsky, A., Medina, S. and Reuveni, R. (1998) Assessment of various control strategies for recirculation of greenhouse effluents under semi-arid conditions. *Journal of Horticultural Science & Biotechnology* 73, 485–491.

Raviv, M., Lieth,J. H. and Bar-Tal, A. (2019) Growing plants in soilless culture: operational conclusions. In: Raviv, M., Lieth, J.H. and Bar-Tal, A, (eds) *Soilless Culture: Theory and Practice, 2nd Edn*. Academic Press – Elsevier, San Diego, California, pp. 637–669.

Reed, D.W. (1996) Closed production systems for containerized crops. In: Reed, D.W. (ed.). *Water, Media and Nutrition for Greenhouse Crops*. Ball Publishing, Batavia, Illinois, pp. 221–245.

Rikken, M. (2010) *The European Market for Fair and Sustainable Flowers and Plants*. Trade for Development Centre, Belgian Development Agency (BTC), Brussels.

Savvas, D. and Gizas, G. (2002) Response of hydroponically grown gerbera to nutrient solution recycling and different nutrient cation ratios. *Scientia Horticulturae* 96, 267–280.

Savvas, D., Karagianni, V., Kotsiras, A., Demopoulos, V., Karkamisi, I. and Pakou, P. (2003) Interactions between ammonium and pH of the nutrient solution supplied to gerbera (*Gerbera jamesonii*) grown in pumice. *Plant and Soil* 254, 393–402.
Solís-Pérez, A.R. and Cabrera, R.I. (2007) Evaluating counter-ion effects on greenhouse roses subjected to moderately-high salinity. *Acta Horticulturae* 751, 375–380.
Solís-Pérez, A.R. and Cabrera, R.I. (2012) Characterizing hourly, daily and seasonal ion and water uptake in hydroponically-grown roses. *Acta Horticulturae* 947, 347–354.
Sonneveld, C. (1988) The salt tolerance of Alstroemeria (Alstroemeria, X). *Acta Horticulturae* 228, 317–326
Sonneveld, C. and Voogt, W. (2009) *Plant Nutrition of Greenhouse Crops*. Springer, Dordrecht, the Netherlands.
Sonneveld, C., Baas, R., Nijssen, H.M.C. and de Hoog, J. (1999) Salt tolerance of flower crops grown in soilless culture. *Journal of Plant Nutrition* 22, 1033–1048.
Steduto, P., Hsiao, T.C., Fereres, E. and Raes, D. (2012) *Crop Yield Response to Water*. FAO Irrigation and Drainage Paper 66. Food and Agriculture Organization (FAO) of the United Nations, Rome.
Tal, A. (2018) Addressing desalination's carbon footprint: the Israeli experience. *Water* 10, 197.
Taylor, L.L. Niemiera, A.X., Wright, R.D., Evanylo, G.K. and Thomason, W.E. (2013) Nitrification in pine tree substrate is influenced by storage time and amendments. *Hortscience* 48, 115–122.
Taylor, R.D., Grout, B.W.W. and Hill, J. (2004) Use of a tensiometer-based control system to reduce irrigation of cut flower *Dianthus caryophyllus* 'Santorini' whilst maintaining flower yield and quality. *Acta Horticulturae* 664, 647–652.
Velázquez, R., Martínez, M., Bartolomé, T., Coleto, J.M., Rodrigo, S., Honorio, F., Poblaciones, M.J. and García, A. (2012) Effects of different irrigation and crop year on *Gerbera jamesonni* production in substrate. *Acta Horticulturae* 937, 519–524.
Voogt, W. and Bar-Yosef, B. (2019) Water and nutrient management and crops response to nutrient solution recycling in soilless growing systems in greenhouses. In: Raviv, M., Lieth, J.H. and Bar-Tal, A. (eds) *Soilless Culture: Theory and Practice*, 2nd Edition. Academic Press - Elsevier, San Diego, California, pp. 425–507.
Warsaw, A.L, Fernandez, R.T., Cregg, B.M. and Andresen, J.A. (2009) Water conservation, growth and water use efficiency of container-grown woody ornamentals irrigated based on daily water use. *HortScience* 44, 1308–1318.
White, J.W. (1987) Fertilization. In: Langhans, R.W. (ed.) *Roses: A Manual of Greenhouse Rose Production*. Roses Incorporated, Haslett, Michigan, pp. 87–135.
White, J.W. and Holcomb, E.J. (1987) Water requirements and irrigation practices. In: Langhans, R.W. (ed.) *Roses: A Manual of Greenhouse Rose Production*. Roses Incorporated, Haslett, Michigan, pp. 71–86.
Yermiyahu, U., Tal, A., Ben-Gal, A., Bar-Tal, A., Tarchitzky, J. and Lahav, O. (2007) Rethinking desalinated water quality and agriculture. *Science* 313, 920–921.
Zheng, Y., Graham, T., Richard, S. and Dixon, M. (2004) Potted gerbera production in a subirrigation system using low-concentration nutrient solutions. *HortScience* 39, 1283–1286.

6

Diseases and Disease Management

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INTRODUCTION

Cut flowers represent a diverse collection of species grown worldwide in different climates, production systems (e.g. outdoors and in greenhouses) and crop systems (e.g. in soils and in soilless hydroponic systems). However, plant–microbe interactions, sometimes resulting in disease development, are one of the unifying factors of these diverse scenarios. Cut flower diseases and their management create a complex, dynamic situation as pathogens adapt to different management strategies, which in turn are adjusted to alleviate heightened disease pressure. As with most horticultural crops, consumers expect to purchase blemish-free products while also expecting the products to have minimal chemical residues. In recent years, the cut flower industry has embraced more sustainable production practices and reduced chemical application; however, the difficulty of successfully addressing the disease management challenge with sustainable practices should not be underestimated. To meet this challenge, it is critical for growers to understand the biology of the disease-causing organisms and to be aware of the most recent research pertaining to the pathogen and its management.

This chapter describes the general principles of disease management that apply to all pathogens, followed by a detailed description of the major pathogens. These pathogens fall into four broad categories: fungi/oomycetes, bacteria/phytoplasma, viruses and nematodes. Pathogens in each category share attributes but can also be highly variable in their infection strategies, host range, favorable environmental conditions for disease development, survival, reproduction and dissemination strategies. The most important diseases of cut flowers, their causal microorganisms, symptoms and signs, epidemiology and management practices are addressed and organized by the primary tissues affected.

GENERAL PRINCIPLES OF DISEASE MANAGEMENT

In nature, plants and microorganisms interact in complex webs and only a small portion of those interactions result in disease. For disease to occur, three

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components need to exist concurrently: (i) a virulent pathogen, (ii) a susceptible host and (iii) a favorable environment. Together these components form the 'disease triangle' (Fig. 6.1). Disruption of, or adjustments applied to, these components will alter disease presence or severity. Management practices focus on disrupting, modifying or avoiding one or more of the three components. For example, selection of a resistant cultivar eliminates the susceptible host, quarantine protocols restrict the exposure of the pathogen to the host plant and altering the relative humidity can make the environment unsuitable for a pathogen to thrive.

Five fundamental principles for disease management are:

1. Exclusion.
- Avoid the entry and establishment of pathogens by using only pathogen-tested, clean propagation material.
- Restrict the entry of plants (or their parts) by quarantines or inspections at the points of entry; treat seeds and propagation material before planting.
- Identify production locations with low disease pressure.

2. Eradication.
- Remove infected plants and debris to reduce the inoculum in the crop once it has been established, but before it has extensively spread.

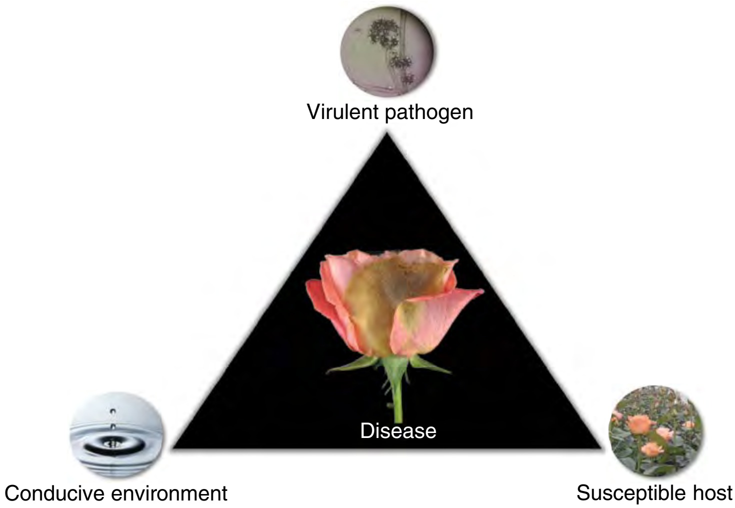

Fig. 6.1. The disease triangle. The presence of the virulent pathogen is presented as spores of *Botrytis cinerea*, the conducive environment includes rain and a high-humidity environment and the susceptible host is represented by the flowers of a susceptible rose cultivar. The interaction of these three elements results in development of the gray mold disease on the flower petals.

- Remove weeds that can serve as alternative hosts; disinfest tools, containers, soil equipment and surfaces that come in contact with the plant material; use traps and chemical strategies against vectors.
- Reduce the amount of inoculum by using antagonistic organisms and natural enemies.
- Apply eradication treatments such as UV radiation or soil fumigants and solarization (Fig. 6.2).

3. Protection.

- Create a chemical barrier to protect the susceptible hosts or their parts, e.g. by applying fungicides that can kill the pathogen or have inhibitory action over its germination, development, growth or reproduction.
- Introduce biological control agents to the soil or plant canopy.
- Treat or prevent wounds that can serve as pathogen entry points (Fig. 6.3).
- Create a physical barrier by covering the soil or substrate with plastic mulches or woven fabrics to allow aseptic practices and to protect the plants from soil-borne pathogens that can be transported to the plants via splashed water (Fig. 6.4).

4. Resistance.

- Choose genetically resistant or tolerant cultivars.
- Apply compounds that confer systemic-acquired resistance to induce a durable, preventative defense response against pathogens.

Fig. 6.2. Solarization of ground beds prior to planting a new cut flower crop. (Photo: J. Faust.)

Fig. 6.3. Wounds created after pruning and harvesting the plants can be protected by using disinfectants and hormonal treatments. (**A**) A dye may be added to facilitate the identification of the treated stems. (**B**) Untreated wounds are a recurrent entry point for pathogens such as *Botrytis cinerea*. (Photos: J. Faust.)

5. Therapy.
    - Employ strategies to remediate plants and eliminate persistent infections.
    - Use of antibiotics for bacteria control.
    - Use heat treatment to inactivate virus development.

FUNGAL AND OOMYCETE DISEASES AFFECTING FOLIAR AND FLORAL TISSUES

Botrytis blight, gray mold

Pathogen description

Botrytis cinerea is a ubiquitous, filamentous fungus that causes botrytis blight, gray mold, leaf spots, bulb rot, petal spots or canker cane symptoms in over 1400 plant species including ornamental crops and cut flowers (Fillinger and Walker, 2016). Other important *Botrytis* species for the cut flower industry include *Botrytis hyacinti*, *Botrytis eliptica* and *Botrytis tulipae*, which cause 'fire' disease symptoms including necrotic blotches on the leaves in lily, gladiolus and tulip, and *Botrytis gladiolorum*, *Botrytis paeoniae* and *Botrytis ranunculi*, which cause blight in gladiolus, peonies and ranunculus, respectively (Staats *et al.*, 2005). Infection by these *Botrytis* species can occur individually or in

Fig. 6.4. Weed barrier below a hydroponic gerbera crop reduces weeds, dust and splashing water. (Photo: J. Faust.)

association with *B. cinerea*. Symptoms of the infection can be developed in production or postharvest environments; however, the symptoms observed in postharvest are often the result of a latent infection acquired during the production stage.

Important hosts

Alstroemeria, carnation, chrysanthemum, dendrobium, gerbera, gladiolus, gypsophila, freesia, lily, peony, rose, ranunculus, statice and tulip.

Symptoms and signs

Botrytis infection symptoms depend on the infected tissue and host. Infection development in flower buds and petals is often expressed as necrotic, discolored, rounded or semi-rounded (Fig. 6.5A), sometimes water-soaked lesions, and soft spots that progress into larger necrotized areas (Fig. 6.5B). High humidity is conducive for *Botrytis* sporulation, resulting in symptomatic areas where gray masses of conidiophores and conidia encompass the tissue and are often accompanied by white to grayish mycelia (Fig. 6.5C). Symptoms of infection in the stems include necrosis, tan spots, cankers, wilted stems and slightly sunken grayish oval areas that may lead to the collapse of the stem

Fig. 6.5. Gray mold symptoms in roses resulting from *Botrytis cinerea* infections. (**A**) Early symptoms appear as semi-rounded discolored and necrotic lesions. (**B**) Typical symptoms developed during flower shipments. (**C**) Sporulation on symptomatic flower. (Photos: M. Muñoz.)

(Williamson *et al.*, 2007). Young, tender stems are more prone to develop infection, and infection in the stems often occurs because of wounded tissue. Flower heads from the Asteraceae family (aster, chrysanthemum, gerbera, sunflower) often express botrytis blight symptoms on the receptacle located at the back surface of the inflorescence. Symptoms include tan to dark-brown, sunken spots that can enlarge rapidly depending on the humidity.

In gladiolus corms, soft, sound, slightly sunken green to brown spots can be observed on the surface. As the disease progresses, the core and stems may develop necrotic rot symptoms. Sclerotia can be observed arising from infected corms. In tulips and lilies, symptoms of *Botrytis* spp. infection appear as necrotic yellow to brown lesions on the bulbs, often observed right under the outer scales of the bulbs. Black sclerotia (resistant structures) might appear in the outer scales. On the leaves early symptoms appear as small, elongated, yellow lesions that, as disease progresses, enlarge and become gray to brown blotches. Often several lesions start coalescing while they enlarge and form large areas of necrotic tissue, i.e. fire symptoms. Decayed and necrotic infected tissue might develop black sclerotia on the leaf surface.

Disease cycle

Airborne conidia produced under high relative humidity (>94%) on necrotic tissue are the main inoculum source (Williamson *et al.*, 1995); however, resistance structures called sclerotia can also contribute as inoculum and survive for long periods under unfavorable conditions in the soil, bulbs or plant debris. Once environmental conditions are suitable for the pathogen development, sclerotia will produce mycelium, conidiophores (conidia-bearing structures) and conidia.

The disease cycle starts when conidia are released into the air by a hygroscopic movement generated as a result of rapid changes in temperature and humidity (Jarvis, 1962). Conidia are also dispersed by air, water and human activity. When the conidium lands on plant tissue, a germination tube will develop if the environment is suitable, i.e. optimal temperatures range from 15–25°C and relative humidity >94% (Williamson *et al.*, 2007). The fungus degrades the plant tissue by excreting an arsenal of enzymes and toxins to acquire plant nutrients and facilitate tissue invasion, resulting in visible necrotic or discolored lesions on the tissue. Lesions grow as the infection progresses and infected cells collapse. Multiple lesions may coalesce to form larger necrotized areas. Finally, if the environmental conditions are suitable, conidia will be produced again. However, the infection process can have a latent or quiescent phase, meaning that after the germ tube emerges and penetration occurs, *Botrytis* will cease growth if the environmental or the host conditions, e.g. maturity, senescence and nutrient availability, are not appropriate. Under this scenario the infection can remain invisible until the adequate environment is present.

Management practices

The target of disease management programs for cut flowers is the harvested flower; however, to reduce botrytis blight in the postharvest environment, inoculum pressure must be reduced in the production environment. Conventional disease management relies on preventative applications of fungicides or in the best cases fungicide applications in the greenhouses are based on current disease pressure identified by scouting plants in the greenhouses (Fig. 6.6) and by placing harvested flowers in humid chambers (Fig. 6.7).

Fungicide efficacy can be evaluated based on sensitivity tests and fungicide resistance testing *in vitro* (Fillinger and Walker, 2016) and *in vivo*. Some of the major single-site fungicide groups include benzimidazoles, thiophanates, phenyl-carbamates, carboxamides, benzamide, phenylpyrroles, anilinopyrimidines, hydroxyanilides, imidazoles and pyridines; while multi-site fungicides are typically from the chlonitriles, e.g. chlorothalonil and phthalimides that include captan, sulfamides and dithiocarbamates (Leroux, 2007; Fillinger and Walker, 2016).

Development of fungicide resistance to several of the commonly used fungicides makes the sole use of fungicide applications unsustainable

Fig. 6.6. IPM team member records and reports daily scouting data, e.g. incidence of botrytis symptoms found on different cultivars in various greenhouse ranges on the farm. (Photo: J. Faust.)

(Muñoz *et al.*, 2019). Thus, an integrated approach considering different tools for disease management is key for future botrytis management programs. For example, *Trichoderma* spp. have shown potential as biocontrol agents for gray mold management in several ornamental crops (Gullino and Garibaldi, 2007). Other microorganisms that have been described as biocontrol agents for gray mold management include bacteria (*Bacillus* spp., Ongena *et al.*, 2009; *Pseudomonas* spp., *Streptomyces* spp., Lichatowich, 2007), yeasts (*Aureobasidium* spp., Schilder, 2013; *Candida* spp.) and fungi (*Gliocladium* spp., *Chlonostachys* spp., *Ulocladium* spp., Nicot *et al.*, 2016).

Timely sanitation practices reduce the *Botrytis* inoculum present in the greenhouse. Removal of plant debris in the crops and around the crops can prevent fungal sporulation from infected plant parts. Scouting strategies that allow the identification and removal of suspicious infected plants are key to avoid further progression of the disease in infected plants and secondary infections in the crop. The use of weather stations to monitor leaf

Fig. 6.7. Placing flowers or flower petals in humid chambers promotes symptom development and sporulation, allowing for accurate identification and reporting of disease incidence. Examples of various humid chambers are shown (**A**–**E**). (Photos: M. Muñoz and J. Faust.)

wetness, relative humidity and temperature can be useful to evaluate the environmental conditions and better time fungicide applications based on the existent and continuous environmental risk (Mackenzie and Peres, 2012).

Mineral nutrition and irrigation influence disease progression and the ability of the pathogen to start infections. Drip irrigation is preferred to overhead irrigation (Aissat *et al.*, 2008) since the foliage stays drier. Calcium and nitrogen concentration also influence gray mold development. For instance, increasing calcium concentration in plants reduces gray mold severity. Calcium has been related with inhibition of *Botrytis* production of cell wall-degrading enzymes that are required for the disease development and progression, thus reducing susceptibility to the disease (Chardonnet *et al.*, 2000; Yeriyahu, 2006). High nitrogen concentrations in the tissue have been linked to an increased susceptibility to *Botrytis* infection owing to increased plant growth. However, careful management of nitrogen concentration is required, since nitrogen deficiency reduces stem yield (Elad, 2016).

Powdery mildew

Pathogen description

Powdery mildews are obligate biotrophic pathogens, i.e. they cannot reproduce without a living host, and in most cases are host-specific. They live epiphytically on the plant surface and are most commonly present on the adaxial surface of the leaves or on the abaxial portion of other organs including buds, flowers and stems. The two main genera responsible for the development of powdery mildew symptoms in commercial cut flowers are *Podosphaera* (previously *Sphaerotheca*) and *Erysiphe* (Braun and Takamatsu, 2000).

Symptoms and signs

Signs of the infections appear as a mass of whitish powder developing over the plant surface. The powdery masses observed are mycelium and conidia (asexual spores) of the fungi developing in the host (Fig. 6.8). Signs are often observed in leaves, peduncles, thorns, stems and flowers. As biotrophic parasites, powdery mildew fungi do not immediately kill their host; instead they occupy space in the epidermis to access plant nutrients, thereby reducing the photosynthetic rate, increasing transpiration and respiration, and reducing plant growth and development, which leads to decreased crop yield (Takamatsu *et al.*, 2010).

Important hosts

Alstroemeria, chrysanthemum, gerbera, gypsophila, peony, ranunculus, rose, statice and sunflower.

Disease cycle

Under greenhouse conditions, the fungus reproduces asexually via airborne conidia that are dispersed from the inoculum sources by airflow. Once conidia

Fig. 6.8. Powdery mildew signs on gerbera flower (**A**) and leaves (**B**). (Photos: M. Muñoz.)

land on new host tissue, the spores will germinate if optimal temperature and relative humidity are present for 2–4 h (Domínguez-Serrano *et al.*, 2016). Optimal conditions for disease development include moderately warm day temperatures (21°C) and cool night temperatures (15°C); however, the pathogen performs well at temperatures up to 29°C (Jarvis, 1992). Relative humidity near 97–99% promotes conidia formation; however, free water on the host surface reduces conidia germination. Lower relative humidity (70–75%) is more conducive for conidia germination and appressorium, haustorium and mycelium formation. Nevertheless, specific humidity requirements vary depending on the pathogen species and host.

Following spore germination, a germ tube penetrates the host cuticle, followed by the formation of the haustorium (a specialized feeding organ developed from a modified hypha that has penetrated through the cell wall). The haustorium forms an invagination with the plasma membrane and increases the contact surface area. This allows for maximum nutrient absorption from the plant cell without infringement of the plasma membrane. Finally, mycelia develop and new conidia form on the plant surface. An infection cycle is completed in 3–7 days.

Management practices

The use of systemic fungicides and sulfur-based products has been the main strategy for powdery mildew management; however, increasing reports of the development of fungicide resistance in powdery mildew fungi are causing concerns about the sustainability of this strategy (Bélanger and Labbé, 2002; Hollomon and Wheeler, 2002). Mycoparasites have been described as effective to decrease powdery mildew, e.g. the *Ampelomyces quisqualis* complex (Kiss *et al.*, 2004; Park *et al.*, 2010). *Bacillus subtilis* and *Bacillus amyloliquefaciens* have been shown to be effective biocontrol agents for powdery mildew fungi (Gwynn, 2014). Other microorganisms known for their antagonist action against powdery mildew fungi include *Verticillium lecanii* (Kiss, 2003), *Gliocladium catenumatum* (Elmhirst *et al.*, 2011) and *Tilletopsis* spp. (Verhaar *et al.*, 1999). Applications of potassium silicate (Dallagnol *et al.*, 2012) and calcium chloride (Michel *et al.*, 2019) are also beneficial for powdery mildew management in greenhouses. Pruning and removal of infected plant tissue, as well as removal of fallen leaves and plant debris from the ground, reduce the sources of inoculum. The use of greenhouse ventilation and horizontal airflow fans can reduce the relative humidity in the plant canopy especially at night, thus helping to avoid long periods of a suitable environment for disease development (Horst and Cloyd, 2007).

Rust

Pathogen description

Rust fungi are airborne pathogens known for some of the most devastating global crop diseases. *Phragmidium*, *Uromyces* and *Puccinia* are most economically important genera for cut flower production. Similar to powdery mildew fungi, rust fungi are obligate parasites with a high host specificity. Rust spores travel by air currents, water particles, animals, humans, equipment and infected plants. The spores enter the plant via the stomata in leaves and establish between the plant cells. Infection symptoms and signs can be observed in all the aerial portions of the host plant; however, leaves and stems are most commonly affected. Rusts can produce up to five types of spores during different chronological periods that differ from each other morphologically and cytologically. Rust life cycles are unique in that they may rely on two unrelated plant hosts commonly belonging to different families to produce the different types of spores. Therefore, an infective spore type for one host is only produced in the alternative host, while the other spore types will be produced at the newly infected plant host. These five spore types are: spermatia, aeciospores, urediniospores, teliospores and basidiospores; however, not all rust fungi produce all five forms (Toome-Heller, 2016). Rust fungi do not generally cause the immediate death of plant tissue. As the infection advances, the fungus acquires plant nutrients and carbohydrates, alters plant growth and development, and in severe cases leads to wilt and defoliation.

Symptoms and signs

Symptoms include chlorotic to brown spots on the upper side of the leaves, abnormal stem growth, sepal distortion and gall formation. Orange to brown spore masses (aeciospores) appear on the underside of the leaves and on the stems. In severe cases, pustules with spore masses form on the upper side of the leaves.

Phragmidium includes a number of species that infect plants in the Rosaceae family. The most prominent species in commercially cultivated roses are *Phragmidium tuberculatum*, *Phragmidium mucronatum*, *Phragmidium americanum* and *Phragmidium fusiforme*, *Phragmidium speciosum* (Horst and Cloyd, 2007). Symptoms and signs vary depending on the environmental conditions and the time of the year. For example, in temperate climates basidiospores might be present together with powdery orange pustules containing aeciospores when plants are grown in greenhouses early in the spring. These pustules are initially limited to the underside of the leaves, but as disease progresses, they become visible on both leaf surfaces. Then, as the summer arrives, the pustules multiply and enlarge, red to orange pustules containing uredinospores appear in the underside of the leaves and chlorotic spots are shown parallel in the upper side of the leaves. As cooler temperatures start arriving early in the fall, black pustules with teliospores are formed. Teliospores allow rust fungi to overwinter in climates without severe winters. Continuous moisture for 2–4 h is required for establishing an infection. Optimal temperatures for infection occur from 18 to 21°C. Uredinospore viability is limited to 1 week when temperatures are above 27°C, (Horst and Cloyd, 2007).

The genus *Uromyces* includes important pathogens for statice (*Uromyces savulescui*, *Uromyces limonii*) (Vakalounakis and Malathrakis, 1987), carnation (*Uromyces dianthi*) (Jones, 1972), gladiolus and freesia (*Uromyces transversalis*, *Uromyces gladioli*) (Rodríguez-Alvarado *et al.*, 2006). Two spore types are often observed in the crops, uredinospores (yellow, orange to reddish masses of spores erupting from leaf, stems and sepal epidermis and over flower spikes, Vakalounakis and Malathrakis, 1987) and teliospores (yellow to dark-brown spore masses that develop through the epidermis of the stems) (Khouader *et al.*, 2011). *Uromyces savulescui*, *U. limonii* (Fig. 6.9), *U. dianthi* and *U. gladioli* are regulated in different countries around the world.

The genus *Puccinia* contains species that affect cut flower crops, including gladiolus and lily (*Puccinia gladioly*) (d'Oliveira, 1949), gypsophilia (*Puccinia arenarie*) (Henderson, 2004), sunflower (*Puccinia helianthi*) (Sendall *et al.*, 2006) and chrysanthemum (*Puccinia horiana*) (Water, 1981). *Puccinia horiana* is the causal agent of white rust of chrysanthemum (also described as CWR or Japanese rust), a quarantine pest for the Mediterranean Plant Protection Organization (EPPO), North American Plant Protection Organization (NAPPO), USDA APHIS and the Comunidad Andina (CAN). The most common symptoms of puccinia infection in different hosts occur on the leaves; however, bracts and stems can become affected.

Chrysanthemum white rust symptoms appear first on the upper surface of the leaves as green to yellow spots. As disease progresses the center of the sports turns brown, lesions enlarge and coalesce resulting in large necrotic areas. Signs of the pathogen are first observed on the underside of the leaves

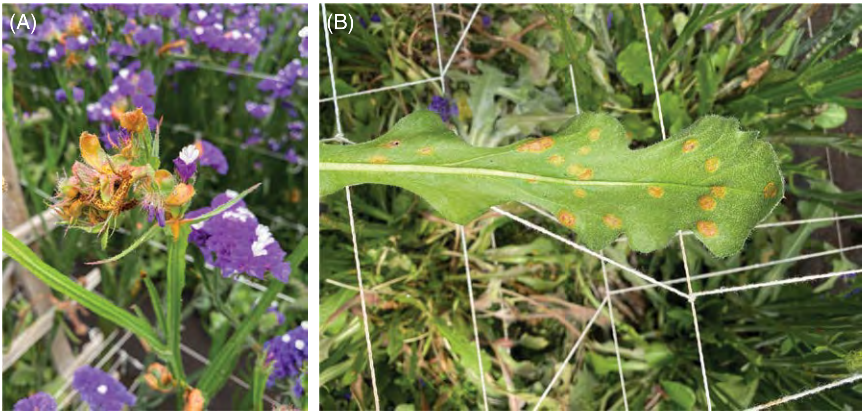

Fig. 6.9. *Uromyces limonii* pustules on statice flowers (**A**) and leaves (**B**). (Photos: M. Muñoz.)

as raised, waxy, pinkish pustules containing teliospores; under high disease pressure pustules can also be observed in the upper side of the leaves. As the infection continues the lesions in the upper surface become sunken, and the pustules become more prominent and they turn a whitish color, which indicates the production of the basidiospores, the disseminating structure for the pathogen. In flowers, chrysanthemum white rust symptoms appear as necrotic flecking that develop pustules in advanced stages of the disease (O'Keefe and Davis, 2015).

Management practices

Removal of infected leaves and stems and removal of old canes in the crop canopy is a good strategy for rust management. Additionally, reducing condensation and free water in greenhouses helps to impede the development of rust fungi.

Different fungicides have been used for rust management including single-site fungicides like strobilurins, demethylation inhibitors, methyl benzimidazole carbamates and multi-site fungicides like captan, mancozeb and chlorothalonil (Palmer and Vea, 2018). However, reduced sensitivity to triazoles and strobilurins has been described (Cook, 2001). Fungicide resistance management strategies are paramount.

Silicon is a mineral element that has been associated with reduction of severity of rust (Datnoff and Rodrigues, 2015).

The use of *Bacillus subtilis* and *Bacillus amyloliquefaciens* reduced the incidence of white rust and can increase plant height and flower yield (Dheepa *et al.*, 2016). *Cladosporium* species have been shown as antagonist for *P. horiana* teliospores (Torres *et al.*, 2017). *Verticillium lacanii* reduces rust incidence in carnation and spore production by *Uromyces dianthi* (Spencer, 1980). Removal of the secondary host (if known) can interrupt the disease cycle and decrease the amount of inoculum, thereby decreasing disease pressure.

Downy mildew

Pathogen description

Downy mildews in cut flowers are caused by different species of the oomycetes *Peronospora* spp., *Plasmopara* spp. and *Bremia* spp. These genera comprise species of obligate, host-specific, biotrophic parasites that require living host tissue to complete their life cycle.

Important hosts

Some of the most important causal agents for downy mildew and their cut flower hosts include: *Plasmopara halstedii* (syn. *Plasmopara helianthi* and *Peronospora halstedii*) infects sunflower, gerbera daisy and other species in the Asteraceae family (EPPO, 2008). *Peronospora sparsa* infects roses and other species of the Rosaceae family (Xu and Pettitt, 2017). *Peronospora statices* infects statice (Shirai *et al.*, 2016). *Peronospora dianthicola* infects carnation (Shirai *et al.*, 2016). *Peronospora gypsophilae* infects gypsophila (Ben-Ze'ev *et al.*, 2006). *Peronospora chlorae* infects lisianthus (Tepedelen Ağaner and Uysal, 2018). *Bremia lactucae* causes downy mildew on gerbera (Wolcan, 2010).

Symptoms and signs

Symptoms depend on the developmental stage of the host plant, the environmental conditions, cultivar, and disease severity. Symptoms are mostly present in the leaves; however, other plant tissues such as stems, flowers and roots can be infected and express disease symptoms and signs. Common symptoms include damping off in seedlings (associated with root infection), dwarfing, chlorotic to purplish mottling near the main leaf veins (Fig. 6.10). Advanced infections show interveinal leaf necrosis, leaf distortion and thickened leaves. Characteristic signs of the disease are observed on the lower surface of leaves as white to gray sporulation (sporangiophores and sporangia) that are developed under periods of high relative humidity and cool or moderately warm temperatures.

Disease cycle

The primary source of inoculum is airborne sporangia produced in infected plants from the same or neighboring crops, disseminated by wind or water splashing (Blancard, 2012b). Once sporangia land on host tissue, biflagellated zoospores are released, a cyst is produced and a germ tube is generated to penetrate the plant via stomata, wounds or directly through the cell wall. Then the pathogen colonizes the tissue and forms a haustorium (specialized structure that allows interaction with the plant cell without

Fig. 6.10. Purple mottling symptoms in the top side of a rose leaf caused by downy mildew. (Photo: H. Álvarez.)

entering the cell) to release effectors (molecules that modulate the interaction between the fungi and the plant and are related to plant immunity) and take up plant nutrients. As the disease progresses, sporulation will occur though natural openings if the environmental conditions are adequate for pathogen development. Conducive environmental conditions are high relative humidity (>90%) with or without free water on the surface and temperatures ranging from 2–26°C, while the optimal temperatures are 18–22°C (Bardin and Gullino, 2020). Survival structures for downy mildews include oospores (thick-walled survival structures) and mycelium in plant debris, twigs and stems of perennial plants. Under proper environmental conditions (high-humidity periods) oospores will germinate and grow sporangium (zoospore-bearing structures) and then release zoospores. Both sporangia and zoospores are moved via wind or water.

Management practices

Fungicide applications are the main strategy for downy mildew management. Commonly used systemic fungicides include mandipropamid, metalaxyl, azoxystrobin, potassium phosphite and fluopicolide; however, fungicide resistance development is a major concern for most of these products. Integrated management practices, including the selection of resistant cultivars, proper fungicide rotations, and the use of copper-based and broad-spectrum preventative fungicides in combination with systemic fungicides, are critical for sustainable management. Additionally, removal of decayed material and weeds, scouting and removal of infection sources, and use of disease-forecasting systems to identify high infection periods to better time fungicide applications are recommended disease management techniques (Bardin and Gullino, 2020).

Itersonilia petal blight

Pathogen description

Itersonilia perpexans has been characterized as a saprophytic and necrotrophic fungal pathogen that affects species in the Asteraceae family, including chrysanthemums, gerberas, china asters and sunflower (McGovern *et al.*, 2006). This pathogen has two different morphologies: yeast and hyphal phases. It produces airborne balistospores that may produce survival structures called chlamydospores during advanced stages of the disease. In suitable environmental conditions, chlamydospores germinate and produce balistrospores to start a new disease cycle.

Symptoms and signs

Initial symptoms of itersonilia blight infection vary between different hosts and cultivar. They include bleached pinpoint lesions on ray floret petals of china aster that enlarge as disease progresses and result in bleached streaks and eventually in necrosis of the entire flower (McGovern and Seijo, 1999), while symptoms in chrysanthemum and sunflower begin as necrotic brown to reddish small discolorations in the outermost array of ray florets or petals that enlarge, coalesce and might result in the necrosis of the entire blossom (Horst and Nelson, 1997; Seijo *et al.*, 2000) (Fig. 6.11). In sunflower *I. perpexans* infection has also been associated with lesions in hypocotyl and cotyledons of seedlings (Seijo *et al.*, 2000). Itersonilia blight is more severe in outer, mature florets than in immature, inner florets. Flowers often have latent infections, and symptoms appear in the postharvest environment. Symptoms are very similar to stemphylium and cladosporium ray speck and can also be confused with early symptoms of botrytis infection. Misdiagnosis of these organisms is common.

Fig. 6.11. Itersonilia petal blight symptoms in sunflower petals. (Photo: H. Álvarez.)

Disease cycle

Balistrospores are disseminated by air movement into host tissue. Periods of 8–12 h of continuous high relative humidity are required for spore germination and infection to occur. The pathogen favors high humidity and rainfall and initial lesions appear within 12 h if the relative humidity is over 70% while disease incidence often develops at relatively cool temperatures (10–15°C). Initial lesions will not enlarge if relative humidity is <70% (Horst and Nelson, 1997). Chlamydospores contribute to the survival of the pathogen under adverse conditions. The pathogen can also survive as a saprophyte in weeds and plant debris.

Important hosts

China aster, chrysanthemum, gerbera and sunflower.

Management practices

Removal of any symptomatic flowers is critical. Weeds in the Asteraceae family can be infected by *I. perpexans*, so weed control can decrease inoculum sources (McGovern *et al.*, 2006). Myclobutanil, potassium bicarbonate and propiconazole have been shown to effectively reduce itersonilia petal blight (McGovern *et al.*, 2006).

Stemphylium leaf and flower spot, ray speck

Pathogen description

Stemphylium spp. is an important fungal pathogen for several crops around the world, including ornamentals and cut flowers. For cut flowers, symptoms can be manifested in flowers (ray speck) and leaves (leaf spot).

Symptoms and signs

Typical symptoms of *Stemphylium* infection on flowers start as small (0.1 mm), round, red to purple-brownish lesions (Nishi *et al.*, 2009) that eventually enlarge over the petal tissue (Brahamanage *et al.*, 2019). Additionally, irregular-shaped, small, white to yellow spots appear as initial symptoms on the leaves. As the infection progresses, the center of the leaf spots will become necrotic causing stemphylium leaf blight, and more yellow spots will appear on the leaf tissue (Brahamanage, 2018). Stemphylium ray speck produces symptoms very similar to *Itersonilia*, *Botrytis*, *Helminthosporium* and *Alternaria*. Identification of *Stemphylium* requires microscope observation of the spores.

Disease cycle

Stemphylium spp. require free water on the flowers for at least 10 h and 16–30°C temperatures for a successful infection (Horst and Nelson, 1997). Fungal spores can survive in plant debris in the form of pseudothecia (a double-walled structure that encloses spores), and mycelium from which spores are released. When infection occurs, symptoms will appear in the florets as pinpoint necrotic lesions. Then, conidia (asexual spores) will form over the affected area and disperse through wind and human activity (Brahamanage, 2018).

Important hosts
Alstroemeria, carnation, china aster, chrysanthemum, dendrobium, gerbera, gladiolus and sunflowers.

Management practices
Removal of plant debris, non-harvested flowers and symptomatic plants to prevent possible sources of inoculum. Reduce leaf wetness duration by avoidance of overhead irrigation practices and increasing air circulation in the greenhouses (Horst and Nelson, 1997). The use of chlorothalonil has been proven effective as a preventative strategy for some *Stemphylium* species (Wick, 2018).

Alternaria leaf spot, flower spot, speck and blight

Pathogen description
Alternaria species are ubiquitous soil inhabitants that live as saprophytes in plant debris or soil, or as endophytes of plants. However, some opportunistic and necrotrophic *Alternaria* species can cause a significant economic impact on cut flowers (Darras, 2018). Pathogenic *Alternaria* species can cause stem canker, leaf blight, spot blight, ray speck and flower spot symptoms, especially under warm and humid conditions (Liu *et al.*, 2020). *Alternaria alternata* is the most common and causes disease in gerbera (Bhat *et al.*, 2013), chrysanthemum (Liu *et al.*, 2020), rose (Muñoz *et al.*, 2019), geranium, sunflower (Thomma, 2003), dendrobium (Uchida and Aragaki, 1991) and gypsophila crops. Other *Alternaria* species that cause a significant economic impact in cut flowers include: *Alternaria gysophilae*, *Alternaria juxtiseptata* and *Alternaria subelliptica*, which cause leaf spots in gypsophilla (Wolcan *et al.*, 2018b); *Alternaria helianthi*, *Alternaria zinnia*, *Alternaria helianthicola*, *A. Alternaria protenta* and *Alternaria helianthinficiens*, which cause leaf blight in sunflowers (Wu and Wu, 2003; Markell *et al.*, 2015); *Alternaria dianthi*, which causes leaf blight in carnation (Wolcan *et al.*, 2018a) and *Alternaria dianthicola*, which is responsible for flower blight in carnation (Duan *et al.*, 2015).

Symptoms and signs
Infection symptoms are expressed as gray to dark-brown leaf and petal spots with a purple to dark-brown halo. Signs of the pathogen include blackish spore masses that develop under high-humidity conditions and might develop as concentric rings (Darras, 2018). In immature carnation buds, water-soaked lesions form, while initial symptoms in sepals and leaves are pale yellow to

brown spots with darker brown to purple borders (Wolcan *et al.*, 2018a). In rose petals, necrotic circular lesions evolve into dark brown-black spots. Signs of the pathogen might appear over lesions as olive-green to black dusty-looking sporulation (Muñoz *et al.*, 2019). In chrysanthemum leaves and petals, symptoms of infection often develop through the edges as semi-rounded, dark-brown to black lesions that enlarge and necrotize whole leaves and petals. Initial symptoms in ray florets start as small (1–3 mm) semi-rounded red to brownish lesions (Trolinger *et al.*, 2018) that are known as 'ray speck' and can be misinterpreted as symptoms of *Botrytis*, *Stemphylium* or *Helminthosporium* infection (Horst and Nelson, 1997).

In sunflower leaves dark, angular and small spots are characteristic early symptoms. As the disease progresses, the spots enlarge and cause large necrotic areas and defoliation that is often more severe in lower leaves. Small, dark-brown streaks might appear along the stems.

Disease cycle

Alternaria species thrive under warm climates; however, they can adapt to a wide range of temperatures. *Alternaria* spp. conidia germinate after 45 min of exposure to temperatures between 28 and 30°C and high relative humidity. After germination, tissue penetration and infection are also favored by warmer temperatures and high humidity. For example, at 10°C this process requires 12 h; however, at 22°C the penetration and infection process takes only 3 h. The pathogen can remain latent if environmental conditions are not suitable. Periods of wetness longer than 6 h are required for symptom development (Darras, 2018). Free water or high relative humidity promotes sporulation over lesions. Conidia and mycelium can survive and overwinter in plant debris and seeds. Spores are disseminated by wind and splashing water (Darras, 2018).

Management practices

Ventilation in the greenhouses is an important strategy to improve air circulation and reduce humidity. Avoiding overhead irrigation reduces long periods of leaf wetness, thereby decreasing disease development (Darras, 2018). Removal of plant debris, soil disinfestation and use of healthy planting material reduce the possible inoculum sources (Bardin and Gullino, 2020). Systemic fungicides have shown a higher efficacy for disease management compared with non-systemic fungicides (Wolcan *et al.*, 2018a). Preventative treatments with difenoconazole result in a large reduction in disease incidence (Dahmen, 1992). Sunflower seeds treated with 100 ppm of difenoconazole, prochloraz, pyrifenox or triadimenol showed a significant reduction in diseased seedlings (Wu and Wu, 2003). Fungicide resistance management strategies should be implemented since fungicide resistance development has been documented for *Alternaria* spp. to several single-site fungicides and mancozeb (Malandrakis *et al.*, 2015).

Rose black spot

Pathogen description

Black spot is a common disease for roses worldwide caused by *Diplocarpon rosae.* Black spot incidence and severity are often higher in regions with warm (20–25°C) and wet climates with a high annual precipitation record. *Diplocarpon rosae* can produce two spore types that cause infection – asexual conidia and sexual ascospores – and two development stages including a biotrophic phase where the pathogen obtains its nutrients from the host without killing the plant cells, and a necrotrophic phase with the development of invasive intracellular hyphae that leads into development of reproductive structures (Gachomo *et al.*, 2006).

Symptoms and signs

Symptoms of the disease are observed in leaves and stems. Characteristic symptoms in the leaves include rounded to semi-rounded brown to black spots of about 1 cm in diameter often with fringed borders. In severe infections, the leaf spots enlarge and coalesce, forming large black areas on the leaves. Infected tissue produces ethylene, leading to chlorosis surrounding the black spots. Leaves frequently fall off, resulting in defoliated stems. Stem infections are more common in immature wood (first-year) and symptoms appear as raised purple to red blotches. Asexual fruiting bodies (acervuli) erupt though the host epidermis and bear conidia that might be observed over pale brown spots after several days of infection.

Important host

Rose.

Disease cycle

Diplocarpon rosae can survive in debris in the ground or inside the plant canopy (Horst and Cloyd, 2007) and harbor mycelium, ascospores or conidia. Both sexual and asexual spores cause primary infections in young leaves which occur via direct penetration (Gachomo *et al.*, 2006).

Spores are disseminated via wind and water splashing into the young leaves. As tissue colonization and invasion progresses, some black spot symptoms will start to show up (Horst and Cloyd, 2007). Eleven to 30 days later, asexual fruiting bodies will develop over lesions and produce conidia that are dispersed to new emerging leaves and start new infections (Pscheidt and Rodriguez, 2018). A cup-like sexual fruiting body (apothecia) bears ascospores that form months later on older infected tissue if environmental conditions are favorable.

Management practices

Removal of old leaves and canes from the plants, as well as removal of plant debris from the ground reduces inoculum pressure. Copper sulfate dust applications can protect the new leaves as they emerge. The use of strobilurins applied as protectants, and de-methylation inhibitors applied after symptom development are effective to decrease black spot severity (Gachomo, 2004). Avoid leaf wetness periods of 7–12 h. Avoid overhead and excessive irrigation (Horst and Cloyd, 2007).

FUNGAL AND OOMYCETE DISEASES CAUSING ROOT, CROWN, CORM, BASAL AND STEM ROTS

Presence of rotting plant tissue can become a major problem for cut flower production especially during the propagation phase. Different soil-borne and water-borne pathogens are responsible for these symptoms in different cut flower crops including the oomycetes *Pythium* spp. and *Phytophthora* spp. and fungi including *Fusarium* spp., *Rhizoctonia* spp. and *Thielaviopsis* spp. Disease symptoms can occur as a result of individual pathogen infection or interaction of different pathogens (Bardin and Gullino, 2020). Multi-site fungicides, including chlorothalonil, etridiazole and pentachloronitrobenzene, are recognized for their action against these pathogens, and some site-specific fungicides can be effective depending on the pathogen causing the rots. An integrated management approach is recommended to reduce development of resistance. Sanitation of propagation tools, avoidance of over- or underirrigation and removal of plant debris are important management strategies for these diseases. Some specificities associated with certain pathogens are described below:

Fusarium bulb, corm, stem rot and wilt

Pathogen description

The genus *Fusarium* comprises soil-borne fungal species that affect many cut flowers crops around the world. Fusarium infections can affect cut flowers at all production stages, from propagation to postharvest, causing wilts and crown, stem and root rots. Infections are more severe in warm environments. *Fusarium oxysporum* is the main species causing wilts in ornamental plants (Gullino *et al.*, 2015); however, different special forms '*formae speciales*' (f. sp.) of this pathogen and other *Fusarium* species are responsible for infection in different crops. Different races within the *formae speciales* of *F. oxysporum* have cultivar-specificity (Troisi *et al.*, 2013), and new *formae speciales* are frequently reported for different crops, making fusarium wilts and rots a continuous threat for cut flower production (Gullino, 2012). *Fusarium oxysporum* f. sp. *dianthi* and *Fusarium redelens* f. sp. *dianthi* cause wilt in carnation crops even after performing soil disinfestation and using clean stock plants (Gullino and Garibaldi, 2007), while *F. oxysporum* f. sp. *chrysanthemi* and *F. oxysporum* f. sp. *tracheiphilum* are related to vascular wilts in chrysanthemum and gerbera (Gullino and Garibaldi, 2007).

Important hosts

Aster, carnation, chrysanthemum, dendrobium, freesia, gerbera, gladiolus, gypsophila, lily, lisianthus and tulip.

Symptoms and signs

Symptoms of fusarium infection include vascular necrosis or discoloration, basal, crown, root, stem and bulb rots, stunting, chlorosis, leaf yellowing and vascular wilts. Fusarium wilts can be localized at specific portions of the plant or generalized throughout the entire plant, e.g. wilting of half a leaf, entire leaf, branch or wilting of the whole plant (Bardin and Gullino, 2020).

Disease cycle

Fusarium accesses the host plants via contaminated soil, plant material, trays and pots. The fungus produces resistance structures called chlamydospores that can survive for years in the soil or plant debris and tolerate adverse biotic and abiotic conditions. High humidity favors the infection. Characteristic macro- and microconidia can be produced on infected tissue and dispersed to new neighboring host by water splashing, air currents or by human manipulation of infected plants.

Management practices

Fusarium infections can remain symptomless as latent infections, thus it is important to keep the propagation material, growing substrate and tools as clean as possible to avoid spreading the disease (Gullino *et al.*, 2015). Seeds can be contaminated externally or internally with *Fusarium*, so treatment of seeds with fungicides can be effective as a preventative strategy (Bardin and Gullino, 2020). Aseptic practices, environmental conditions and cultural practices play an important role for disease management, e.g. avoidance of unnecessary wounds in the plants and disinfesting the pruning tools have been proven effective to reduce disease spread. Fungicides, including benomyl and fludioxonil, decrease fusarium incidence in different greenhouse crops (Reid *et al.*, 2002). Substrate also has an effect in disease management, e.g. 100% peat substrates have significantly less disease compared with 100% pine bark substrates (Wang and Jeffers, 2002). In chrysanthemums, some strains of *Trichoderma viride* have shown an antagonistic activity against fusarium wilts (Gullino and Garibaldi, 2007).

Pythium root rot

Pathogen description

Pythium is a common soil- and water-borne pathogen for cut flower production that belongs to the oomycetes, along with phytophthora and downy mildew species. Root rots, basal rots, stem rots and damping off are some of the typical symptoms in seedlings and young plants that can be caused by *Pythium* spp. (Blancard, 2012a). Pythium as well as Phytophthora diseases commonly arise when irrigation practices are mismanaged, since these pathogens are a natural inhabitant of soils and surface waters worldwide. Excessive irrigation may lead to root hypoxia (underoxygenated) or anoxic (no oxygen) conditions (Vartapetian *et al.*, 2014) resulting in physiological stress responses in the plant. Stress may increase vulnerability to other pathogens, and excess water facilitates the movement of swimming zoospores. On the other hand, prolonged periods of drought may weaken plant roots making the plant more vulnerable to *Pythium* (Blancard, 2012b).

Important hosts

Aster, chrysanthemum, gerbera, gypsophila and lisianthus.

Symptoms and signs

Initial symptoms include water-soaked lesions in basal stem, brown rots, root rots, seed decay and plant stunting. As disease progresses lesions expand, and plants collapse or there is damping off in seedlings. In stem lesions disease can cause blackened leaf petioles and axillary shoots contiguous to the initially infected stem. Foliar infections result in water-soaked necrotic lesions that might occur without additional symptoms in the basal stems or roots. Typical *Pythium* spp. signs can be observed under high humidity caused by condensation in the morning as white mycelium and often sporangia and/or oospores (sexual survival spores) develop over affected tissue (Horst and Nelson, 1997).

Disease cycle

Inoculum sources include contaminated soils, propagation material, trays and pots, equipment, shoes, infested water and irrigation equipment. *Pythium* spp. can remain viable in the soil for up to 12 years (Hoppe, 1966). Survival structures include thick-walled chlamydospores, oospores, encysted zoospores and sporangia. Sporangia can survive in air-dried soil for up to 11 months without losing the ability to germinate (Stanghellini, 1971). Saprophytic mycelium can also persist in plant debris. High moisture in the soil is conducive to disease development. *Pythium* spp. can adapt to a wide range of temperatures and according to those the symptoms are expressed differently, e.g. under warm temperatures (27–32°C) typical root rot and basal rot symptoms appear as described above; however, under lower temperatures (10–16°C) no evident water-soaked stem and basal rots are observed (Horst and Nelson, 1997), infected plants appear stunted and with foliar symptoms similar to nutrient deficiencies, and the root system is reduced (Le *et al.*, 2014).

Infection begins with germinated spores (biflagellated zoospores, sporangia) or active mycelia penetrating the recognized host, then the pathogen's enzymatic arsenal degrades the plant cell tissues to facilitate the growth of the pathogen inside the plant, resulting in macerated tissue that results in seedling death when the infection occurs in seeds and young plants (Blancard, 2012a). As infection progresses sporulation from the host tissue will occur as new sporangium and oospores (when sexual reproduction is possible). Water splashing or recirculating irrigation solutions facilitates movement of spores to new plants where the infection process will begin again (Bardin and Gullino, 2020).

Management practices

Best management practices focus on water treatment and proper irrigation strategies. Pre-plant management strategies include avoiding excess of nitrate availability (Dordas, 2008). Integrated management strategies combining treatment of seeds, corms and bulbs with mixtures of site-specific fungicides and broad-spectrum fungicides together along with solarization practices can minimize the incidence of pythium root rot (Mathur *et al.*, 2012). Solarization for 40–55 days before planting has been shown to decrease plant death caused by *Pythium* spp. and *Rhizoctonia* spp. and increase yield and crop life in gypsophila crops (Gamliel *et al.*, 1993). Khalil (2011) demonstrated a beneficial effect of increased electrical conductivity of the nutrient solution to increase the performance of *Trichoderma harzianum* against *Pythium ultimum.*

Phytophthora root and stem rot

Pathogen description

Phytophthora spp. are oomycetes that cause severe diseases in a wide range of plants affecting all plant parts. Several *Phytophthora* species are associated with diseases in cut flower crops including *Phytophthora cactorum*, *Phytophthora chrysanthemi* (Götz *et al.*, 2017), *Phytophthora nicotiniae* (Mullen *et al.*, 2001), *Phytophthora tentaculata* (Chitambar, 2016) in chrysanthemums; *Phytophthora cryptogea* in carnation, chrysanthemums (Ann *et al.*, 1990) and gerbera daisies (Kimishima and Goto, 1992); and *Phytophthora palmivora* and *Phytophthora drechsleri* in gerbera (Blair *et al.*, 2008).

Important hosts

Asters, carnation, chrysanthemums and gerbera.

Symptoms and signs

Root rots, stem rots and damping off are some of the typical symptoms in seedlings and young plants that can be caused by *Phytophthora* spp. (Blancard, 2012a). In more mature plants, leaf chlorosis, darkened veins, dieback, leaf and blossom blights, stem cankers, wilts, and root and crown discoloration are often caused by *Phytophthora* spp. Crown and root infections can lead to the wilting of the plants in 7–10 days after infection begins (Brisco-McCann and Hausbeck, 2018). Latent infections can go undetected for long periods of time until high humid conditions promote symptoms development. Phytophthora signs appear under high relative humidity conditions as white *mycelium* and sporangia and/or oospores (sexual survival spores) growing over lesions.

Disease cycle

The disease cycle is similar to the *Pythium* disease cycle described above. Mycelia are present in infected plant debris, oospores (sexual, not always produced) and chlamydospores (asexual, only produced by some *Phytophthora* species) are produced to overwinter and tolerate unfavorable conditions. Mycelia and oospores germinate when environmental conditions are adequate, and new sporangia will germinate directly to initiate new infections or will release motile biflagellate zoospores to start new infections. For zoospores to be released and find new hosts, free water is required.

Management practices

The life cycles and epidemiology of *Pythium* and *Phytophthora* are very similar, especially when infection occurs in seedlings. Thus, management strategies for both pathogens include proper irrigation, especially by avoiding exposure of the aerial plant parts to water for extended periods of time. Management strategies may include treatment of seeds, corms and bulbs with mixtures of site-specific fungicides and broad-spectrum fungicides and avoidance of excessive nitrate availability (Dordas, 2008)

Fungicides, such as azoxystrobin, mandipropamin, fluopicolide, dimethomorph, fenamidone, etridiazole, matalaxyl and mefenoxam, are effective to manage phytophthora wilts during the transplant stage (Hausbeck and Glaspie, 2008; Benson and Parker, 2011; Gould, 2012). In gerbera crops with water recirculation, reductions in the irrigation frequency together with an increased electrical conductivity of the nutrient solution reduce phytophthora crown rot (Thinggaard and Andersen, 1995). Increasing copper up to 0.28 ppm in the nutrient solutions of gerbera plants showed a significant reduction in disease severity after inoculating the plant with *Phytophthora cryptogea* and allowing the nutrient solution to recirculate (Toppe and Thinggaard, 1998).

Rhizoctonia root and stem rot

Pathogen description

Rhizoctonia spp. are soil-borne fungi that produce profuse mycelial growth and sclerotia (resistance and survival structures) but lack sporulation under high humidity and poor drainage conditions. Most *Rhizoctonia* species are pathogenic; however, some species form mycorrhizal associations to benefit plants through suppression of pathogenic species (Andersen and Rasmussen, 1996).

Plants are especially susceptible to rhizoctonia infection during vegetative propagation. *Rhizoctonia solani* is the species most frequently affecting cut flowers. *Rhizoctonia solani* is a necrotroph with significant phenotypic and genotypic diversity that has led to the differentiation of 14 different genetically isolated groups (anastomosis groups) that are not able to reproduce with each other and might have implications in host specificity, aggressiveness, epidemiology and molecular mechanisms of pathogenicity (Ajayi-Oyetunde and Bradley, 2018). Other *Rhizoctonia* species can cause disease in cut flowers, e.g. *Rhizoctonia tuliparum* is responsible for gray bulb rot symptoms in tulips, hyacinth, iris and lily (Schneider *et al.*, 1997).

Important hosts

Carnation, gerbera, gypsophila, lily, lisianthus, iris, statice and tulip.

Symptoms and signs

Rhizoctonia infection can cause damping off symptoms, wet rotting of bark, root rot, stem rot, hypocotyl rot, blights, bulb, neck and stem rot, stunting root rot, and yellow to gray discolorations and flaccid looking foliage. A typical symptom of *Rhizoctonia* infection occurs when pulling plants out from the soil: the roots detach from the plant and remain in the soil, while the base of the stem shows a soft and discolored rot.

Disease cycle

The fungus can survive for long periods in the soil or plant debris as mycelium or sclerotia. Mycelia enter the plant via wounds. Infection is favored by humid and warm environmental conditions.

Management practices

The presence of different *Trichoderma* species is associated with a decrease in the population of *R. solani* (Gullino and Garibaldi, 2018). Soil sterilization for 30 min at 60°C reduces severity of damping off symptoms caused by rhizoctonia (Rosskopf *et al.*, 2018). Keeping low humidity after pruning and during harvest reduces the risk of infection. Removal of weeds and plant debris from greenhouses is an important strategy to reduce inoculum. Azoxystrobin, captan, fludioxonil, iprodione, pentachloronitrobenzene (PCNB) and pyraclostrobin applications are recommended for disease management (Gould, 2012) with better results obtained using soil drenches (Wolcan *et al.*, 2018a).

Thielaviopsis root rot, black mold

Pathogen description

Thielaviopsis basicola is the most common *Thielaviopsis* species causing root rot symptoms in cut flowers, while *Thielaviopsi thielavioides* (formerly *Chalaropsis thielavioides*) causes black molds in roses (Horst and Cloyd, 2007). The fungus is broadly distributed in cool and wet climates. Seedlings and recently grafted plant material are the most susceptible growth stage. Disease outbreaks are more severe when soil pH is above 5.6 (Harrison and Shew, 2001).

Important hosts

Lisianthus, peony, rose, snapdragon and tulip.

Symptoms and signs

Disease symptoms are often more severe in cool (17–23°C), wet soils with a pH above 5.5. *Thielaviopsis* spp. infection symptoms include brown to black discoloration of roots that might be accompanied by chlamydospores (resistance spores). Infected plants display leaf chlorosis, stunting and wilting, damping off of seedlings, and discoloration and lack of feeder roots.

In roses black mold occurs in recently grafted material including stock and scion where disease causes failure in the graft union and leads to scion death. Signs of the pathogen include white to grayish mycelium that darkens with time and becomes covered by masses of black spores (Horst and Cloyd, 2007).

Disease cycle

The fungus gains access to the plant cells through wounds. *Thielaviopsis* spp. produce sclerotia, microsclerotia and chlamydospores. Fungal macroconidia and chlamydospores present in plant debris, soil and dust where the propagation material is handled are the primary sources of inoculum.

Management practices

Management strategies include lowering the soil pH below 5–5.5 when possible, in addition to crop rotation (McGovern, 2018). Use of clean propagation material and sanitation of propagation houses and tools help to reduce the inoculum. Shore flies have been associated with aerial transmission of *T. basicola* (Stanghellini *et al.*, 1999). Management practices targeting these insects can reduce the incidence of the disease.

BACTERIAL AND PHYTOPLASMA DISEASES AFFECTING FOLIAR AND FLORAL TISSUES

Pseudomonas bacterial wilt, bacterial leaf spot

Pathogen description

Pseudomonas spp. are soil-borne and can survive in the soil and on infected hosts. One of the most important species is *Pseudomonas cichorii*, a bacterium capable of causing disease in a wide range of hosts, including important cut flowers such as chrysanthemum, gerbera, sunflower and china asters (Hikichi *et al.*, 2013). *Pseudomonas syringae* (undetermined pathovar) causes cane blight in roses (Mohan and Bijman, 2010), and *P. syringae* pv. *morsprunorum* causes bacterial leaf blast and leaf spots (Pscheidt and Rodriguez, 2018). In sunflower, *P. syringae* pv. *tagetis* and *P. syringae* pv. *helianthi* (Markell *et al.*, 2015) cause apical chlorosis and bacterial leaf spot, respectively. Symptoms of *P. syringae* infection are more common during cool and wet seasons; however, bacteria leaf spot disease symptoms are likely to appear in other environmental conditions and seasons, with the first symptoms often observed in the lower leaves. Other *Pseudomonas* species relevant to cut flower crops include *Pseudomonas viridiflava* in china aster and chrysanthemum (Horita and McGovern, 2018), *Pseudomonas corrugate* in chrysanthemum (Fiori, 1992) and *Pseudomonas anthirrhini* causing seedling blight in snapdragon (Wegulo and Chase, 2018).

Important hosts

China aster, chrysanthemum, gerbera, rose and sunflower.

Symptoms and signs

Symptoms vary depending on the *Pseudomonas* species, host and environmental conditions. For example, *Pseudomonas cichorii* infection in chrysanthemums and gerbera daisies causes symptoms in leaves, buds and stems that initially appear as small to large, elliptical water-soaked spots that eventually enlarge, coalesce and become brown to black necrotic angular to irregular-shaped areas (Trolinger *et al.*, 2018). Main veins may turn brown and leaf spots might show concentric ring formation. Under high-humidity conditions symptoms may develop toward the leaf margins, and spots develop a soft appearance. Under low-humidity conditions, the spots are brittle, and the center can fall out resulting in shot-hole symptoms. In flower buds, symptoms appear as dark necrotic areas that might spread up to 2.5 cm down (Horst and Nelson, 1997). *Pseudomonas cichorii* can cause internal stem necrosis (Jones *et al.*, 1983). Cane blight in roses caused by *P. syringae* is characterized by reddish to brown areas at the base of the vegetative buds, or at leaf scars or at wounds that evolve into large necrotic dark purple to black areas that extend along the cane (Mohan and Bijman, 2010). Bacterial leaf spot symptoms caused by *P. syringae* pv. *morsprunorum* are characterized by spots on leaves, flowers, stems and calyx that have a sunken appearance and dark-brown coloration (Pscheidt and Rodriguez, 2018).

Disease cycle

Moisture is a determining factor for infection and disease development (Horst and Nelson, 1997), and optimal temperatures occur from 20 to 28°C. The bacterium infects the plant via natural or artificial wounds (Dicklow, 2015). Infected plant propagules and water splashing contribute to the bacterium spread. The agromyzid *Liriomyza trifolii* can transmit *P. cichorii* between chrysanthemum plants (Broadbent and Matteoni, 1990).

Management practices

Use pathogen-tested (and negative) propagation material. Avoid overhead irrigation. Sanitation practices, such as removing infected plants, disinfesting tools between plants, and cleaning clothing and workers' hands, are essential.

Xanthomonas bacterial leaf spot

Pathogen description

Bacteria in the genus *Xanthomonas* cause serious foliar diseases in several cut flower crops (Anaïs *et al.*, 2000). *Xanthomonas campestris* causes disease in hydrangea (Uddin *et al.*, 1996).

Important hosts

Hydrangea and peony.

Symptoms and signs

Initial leaf symptoms are small water-soaked spots that can rapidly turn into pale brown to reddish/purple, necrotic, semicircular to angular spots with chlorotic halos. Lesions can grow and coalesce resulting in leaf blights. Necrotic symptoms are also observed in stems and flowers. Systemic infection can lead to chlorosis and wilting of infected plants.

Disease cycle

Latent infections can occur, resulting in the spread of the bacteria by manipulation and propagation of infected plants. Bacteria enter the plant via wounds and natural openings in the leaf (stomata and hydathodes) and often first disease symptoms appear in the lower leaves. *Xanthomonas* spp. infect neighboring plants by water splashing, insects, human manipulation, and infested equipment and tools. Warm, humid and rainy weather favors the development of the disease.

Management practices

The use of disease-free propagation material is key to avoid the entrance of the pathogen to newly established crops. Avoidance of overhead irrigation, removal and elimination of infected tissue, and sanitation practices for tools between plants help to decrease the spread of the disease. The use of mancozeb, *Bacillus subtillis* and copper-based products can reduce disease severity (Norman and Ali, 2012). Captan as a seed treatment and in foliar sprays reduces the spread and incidence of the disease (Strider, 1980).

Rodococcus, fasciation, leafy gall

Pathogen description

Rodococcus fascians (formerly: *Corynebacterium fascians*, *Bacterium fascians*, *Pseudobacterium fascians*) produces the symptoms of leafy galls that serve as cores of meristem amplification (Goethals *et al.*, 2001). The proliferation of shoots results from disturbances in the phytohormonal balance and involves modulation of cytokinins, gibberellic acid and abscisic acid (Simón-Mateo *et al.*, 2006; Stes *et al.*, 2013).

Important hosts

Carnation, chrysanthemum, gypsophila, gladiolus, lily and tulip.

Symptoms and signs

Aerial portions of the plants appear bushy and stunted. Witches' broom formation and fasciation are characterized by abnormal flower and leaf proliferation including numerous, small leaves, inflorescences and rosettes. Gall formation occurs on leaves and at wounds on stems. Galls often appear as pale green or yellow-green. Galls are only formed at the site where the initial bacteria inoculation occurred (Goethals *et al.*, 2001).

Disease cycle

Disease development is favored by moderate temperatures and high humidity. *Rodococcus fascians* has an epiphytic behavior. Occasionally the bacterium enters the leaf via epidermal cells, which often results in the death of invaded cells. Contaminated propagation material seems to be the primary source of infection, while water splashing and contaminated tools contribute to the spread of the bacterium. The latent period between infection and symptom development is up to 6 months (Putnam and Miller, 2007). Aphids are capable of transmitting the pathogen; however, this has not been proven in field or greenhouse conditions. *Rodococcus fascians* can cause infection without preexisting wounds; however, symptoms are more severe when the pathogen gains access to the host via wounds (Simón-Mateo *et al.*, 2006).

Management practices

There are no known treatments for controlling *R. fascians*; thus, acquiring pathogen-free material for propagation is essential. Good sanitation practices are necessary, including disinfesting tools and surfaces with quaternary ammonium-based disinfestants (Wolcan *et al.*, 2018a), removal of infected plants and the reduction of insect populations, especially aphids.

Aster yellows

Pathogen description

Phytoplasmas are bacteria that lack a cell wall and are typically restricted to phloem vessels in the host plant. Phloem obstruction leads to generalized yellowing symptoms (Blancard, 2012a). Phytoplasmas do not immediately kill their hosts; however, plant vigor is reduced. *Candidatus Phytoplasma asteris* is the causal agent of aster yellows (Harrison and Helmick, 2008). The phytoplasma is transmitted to cut flower crops via vegetative propagation, grafting and by leafhoppers that acquire, retain and transmit the phytoplasma while feeding on the phloem.

Important hosts

Chrysanthemum, carnation, gypsophila, hydrangea, lily, statice and sunflower.

Symptoms and signs

Symptoms include yellowing, stunting, shortening of internodes, witches' broom formation, virescence (development of leaf-like structures instead of flowers), flower sterility, alteration of tissue pigments (purpling, red coloration, yellowing, bronzing), leaf deformation and reduced yield (Satta *et al.*, 2019).

Management practices

The use of plants derived from certified, pathogen-tested stocks ensures starting with a clean crop. Chemical treatments are not effective against phytoplasmas. Vector exclusion and management techniques are essential management strategies, together with the removal and elimination of any symptomatic plants. Several weed species are hosts to aster yellows, so removal of weeds contributes to reduction in the disease reservoirs.

BACTERIAL DISEASES AFFECTING ROOT, CROWN AND STEM TISSUES

Crown gall

Pathogen description

The causal agent for crown gall is *Agrobacterium tumefaciens* (syn. *Agrobacterium radiobacter, Rhizobium radiobacter*), a soil-borne bacterium that transfers segments of its DNA into the host genome, resulting in the proliferation of transformed cells forming tumors, or galls, on the host tissue.

Important hosts

Aster, carnation, chrysanthemum, gypsophila, peony and rose.

Symptoms and signs
Gall formation on roots, crown or basal part of stems (Fig. 6.12), stunted growth, reduced growth and flowering.

Disease cycle
Agrobacterium spp. are natural soil inhabitants that persist in the soil in the absence of plants for at least 2 years. The surface of roots can be a reservoir of this pathogen (Kado, 2002). The bacterium is spread by infested tools or soil, or by infected propagation material (Horst and Nelson, 1997). Wounds in the plant caused by mechanical injury, insect damage or emergence of lateral roots are the entry point for the pathogen. Once the bacterium recognizes the plant cues, part of the bacterium DNA is transferred to the host plant chromosomes where the transformation process will start (Tzotzos *et al.*, 2009). Uncontrolled production of the plant hormones auxin and cytokinin in transformed cells results in the formation of tumors (Gohlke and Deeken, 2014) that become visible one to several weeks after infection (Kado, 2002). The transformation of the host cells will start in <3 h during high relative humidity and warm temperature conditions (Wolcan *et al.*, 2018a). As galls grow in the plant, portions of them might fall in the soil from which splashing water can disperse the bacterium to neighboring plants.

Fig. 6.12. Crown gall caused by *Agrobacterium tumefaciens* developing in a rose stem. (Photo: J. Faust.)

Management practices
Obtain plant propagation material from clean, pathogen-tested sources. Soil solarization using clear plastic with anti-condensation coating and steam treatments reduce inoculum in the soil. Avoid wounding plants when possible. Sterilizing tools from plant to plant reduces the risk of disseminating the pathogen. The use of the antagonistic bacterium *Agrobacterium radiobacter* strain K84 as a preventative treatment during propagation, grafting, pruning or harvesting may also be helpful (Horst and Cloyd, 2007).

Erwinia, bacterial soft rot

Pathogen description
The genera *Dickeya* and *Pectobacterium* were formerly grouped together as part of the genus *Erwinia*; however, biochemical and genomic analysis led to the separation of these two genera (Samson *et al.*, 2005). The soft rot symptoms are a consequence of the plant cell wall-degrading enzymes produced by these bacteria (Perombelon and Burnett, 1991).

Important hosts
Alstroemeria, carnation, china aster, chrysanthemum, lily, sunflower and tulip.

Symptoms and signs
Symptoms include collapse and grayish discoloration of infected stems, foliar blight, plant wilting, stunting and death. In bulbs, discolored, water-soaked lesions appear in bulb scales. Eventually leaves show blight symptoms and neck rot. Internal symptoms include red to brown necrosis inside the vascular system of the stems and roots. Exudates from infected tissue produce a characteristically foul odor. Stock plants can be systemically infected while asymptomatic, which leads to the dissemination of the disease when plants are propagated (Trolinger *et al.*, 2018).

Disease cycle
The bacterium spreads though infected propagation material, plant debris, infested soil, water, tools, insects feeding in infected plants, airborne particles and workers' clothing. The bacterium enters the plant via natural openings and wounds. As infection progresses the bacteria can reach different plant tissues through the vascular system or the cortex. Disease development slows when temperatures are <27°C and <80% relative humidity (Horst and Nelson, 1997).

Management practices
Use plant propagation material derived from pathogen-tested sources. Remove and destroy any affected plants (Horst and Nelson, 1997). Sanitize all tools

after contact with each plant. Avoid overhead irrigation practices especially during propagation. Avoid excessive ammonium fertilization application.

VIRUS AND VIROID DISEASES

Pathogen description

Viruses are composed of nucleic acids (DNA or RNA) and a protein capsid. They rely on the host cell machinery and metabolism to replicate. Viroids are distinct from viruses in that they lack the protein capsid and are instead composed of just a circular molecule of RNA. The success of viruses and viroids is due in part to fast replication and mutation rates that allow them to rapidly adapt to new hosts, environments and vectors. Viruses and viroids are significantly smaller than any fungi and bacteria and lack some of the properties of these other pathogens. Thus, they cannot be detected and identified using the same methods as other pathogens. Purification, amplification and electrophoresis, comparison of physical properties, electron microscopy and serological testing are examples of the main strategies used to identify viruses.

Symptoms

Most plant viruses cause stunting, dwarfing and reduced yield. Symptoms include ring spot, oak-leaf or streaking patterns, mosaics and mottling (discoloration patterns that appear in different color intensities, and are intermingled with normal coloration of the tissue), necrosis, stunting, dwarfing, vein clearing, vein necrosis, vein banding, leaf curling, yellowing, tumors and color breaking. These symptoms can be confused with phytotoxicity, nutritional deficiencies, insect and mite feeding, symptoms of other pathogens and different stress types. Sometimes infected plants remain symptomless; these are considered latent infections.

Virus dissemination strategies

All viruses can be transmitted via vegetative propagation including budding, grafting and by cuttings, tubers, rhizomes, bulbs or corm propagation. Virus-infected budding or grafting material may result in an unsuccessful union with the rootstock. Additional transmission strategies include through sap, pollen, seed and dodder (a parasitic weed). Vector transmission can occur via insects, fungi and nematodes. The most common insect pests that play a role as vectors in floriculture crops include thrips, especially western flower thrips (*Frankliniella occidentalis*), green peach aphid (*Myzus persicae*) and sweetpotato whitefly (*Bemisia tabaci*). Nematode vectors include *Xiphinema* spp., *Longidorus* spp. and *Paralongidorus* spp. Vector transmission tends to be very specific; thus, a specific virus is associated with a specific vector. For example, thrips are the vectors for impatiens necrotic spot virus (INSV) and tomato spotted wilt virus (TSWV) both from the *Tospovirus* genus, and aphids transmit bidens mottle virus (BiMoV) and carnation vein mottle virus (CVMoV), both from the *Potyvirus* genus. Identification of viruses and their transmission mechanisms is key for implementing disease management strategies, e.g. recognizing specific virus–vector associations leads to disease management strategies that focus on the elimination of the vector. Table 6.1 includes important viruses and viroids for the cut flower industry, their typical symptoms and mechanisms of transmission.

General management strategies for virus and viroid diseases

Viruses cannot be removed from existing crop plants, so management strategies focus on prevention. Viruses can be removed via thermal or chemical treatment associated with tissue culture propagation; thus, new crops should be started from virus-tested (negative) sources. Vector exclusion and sanitation protocols must be rigorous for sensitive plant species. Virus testing and screening can be performed by specialized laboratories or can be done in-house with commercially available testing kits.

NEMATODE DISEASES

Description and importance

Nematodes are small, multicellular, soft-bodied, worm-like animals in appearance and comprise one of the most ancient, abundant and diverse types of animals on earth. Several insect-parasitic (entomopathogenic) nematodes are beneficial organisms and can be applied as effective biocontrol strategies for the management of thrips, fungus gnats and other insect pests. However, plant parasitic nematodes can cause serious economic burdens for cut flower production. Plant parasitic nematodes are distinguished from other nematodes by the presence of a hollow stylet or spear. Plant parasitic nematodes are distributed worldwide and several of them have a broad host range. The life cycle of most plant parasitic nematodes is very similar, and it includes eggs, four juvenile stages and adults where the nematodes differentiate into females and males.

Root-knot nematodes (*Meloidogyne* spp.), cyst nematodes (*Heterodera* spp. and *Globodera* spp.) and lesion nematodes (*Pratylenchus* spp.) are the three most economically important and damaging genera worldwide. Other important nematodes for cut flower crops include stem and bulb nematodes (*Ditylenchus* spp.), foliar nematodes (*Aphalenchoides* spp.), reniform nematodes (*Rotylenchus* spp.), pin nematodes (*Paratylenchus* sp.) and lesion nematodes (*Pratylenchus* sp.).

Nematodes have direct and indirect effects on plants. For example, damage of roots and other plant tissues will result directly from nematode feeding. Indirect effects are difficult to quantify but can add to significant losses. Examples of indirect effects include yield reduction, poor root health and

Table 6.1. Important viruses and viroids on cut flower species (hosts), symptomology and mechanism of transmission.

Host	Genus	Virus	Typical disease symptoms	Transmission
Alstroemeria	*Tospovirus*	Tomato spotted wilt virus (TSWV)	Chlorosis, mottling, stunting, necrosis and wilting	Thrips (*Frankliniella* spp., *Thrips* spp.)
	Carlavirus	Lily symptomless virus (LSV)	Symptomless	Aphids (*Macrosiphum euphorbiae*, *Myzuz persicae*, *Aphis gossypii*)
	Unknown	Iris yellow spot virus (IYSV)	Systemic necrosis. Necrotic ringspots and spots	Thrips (*Frankliniella fusca*, *Thrips tabaci*)
Carnation	*Caulimovirus*	Carnation etched ring virus (CERV)	Necrotic flecks and rings on leaves	Aphids (*Myzus persicae*, *Saponaria vaccaria*, *Silene armeria*)
	Tombusvirus	Carnation Italian ringspot virus (CIRV)	Chlorosis and spots on leaves, overall stunting	Mechanical
	Carlavirus	Carnation latent virus (CLV)	Symptomless	Vegetative propagation, sap
	Carmovirus	Carnation mottle virus (CarMV)	Mottle in leaves	Sap
	Closterovirus	Carnation necrotic fleck virus (CNFV)	Gray to white necrotic flecks and spots and purpling of leaves	Aphids (*Myzus persicae*)
	Dianhovirus	Carnation ringspot virus (CRV)	Leaf ringspots, mottle, leaf and flower distortion	Nematodes (*Longidorus elongatus*, *Longidorus macrosoma*, *Xiphinema diversicaudatum*)
	Potyvirus	Carnation vein mottle virus (CVMoV)	Mottling in leaves	Aphids (*Myzus persicae*)
	Closterovirus	Carnation yellow fleck virus (CYFV)	Yellow mottling, streaking and necrosis on leaves	Aphids (*Myzus persicae*)

	Cucumovirus	Cucumber mosaic virus (CMV)	Mosaic, mottling and overall stunting	Aphids (*Myzus persicae*), sap
	Tospovirus	Impatiens necrotic spot virus (INSV)	Necrotic spots on leaves	Thrips (*Frankliniella occidentalis*)
	Tospovirus	Tomato spotted wilt virus (TSWV)	Overall stunting, necrosis and spots on leaves	Thrips (*Frankliniella* spp., *Thrips* spp.)
China aster	*Cucumovirus*	Cucumber mosaic virus (CMV)	Mosaic, mottling and overall stunting	Aphids (*Myzus persicae*)
	Tospovirus	Chrysanthemum stem necrosis virus (CSNV)	Necrotic spots and mosaic in leaves	Thrips (*Frankliniella occidentalis, F. schltzeu*)
	Tospovirus	Groundnut ringspot virus (GRSV)	Necrotic spots and mosaic in leaves	Thrips (*Frankliniella* spp.)
	Tospovirus	Tomato chlorotic spot virus (TCSV)	Symptomless	Thrips (*Frankliniella* spp.)
	Tospovirus	Tomato spotted wilt virus (TSWV)	Overall stunting, necrosis and spots on leaves	Thrips (*Frankliniella occidentalis*)
	Tobravirus	Tobacco rattle virus (TRV)	Yellow, concentric ring spots on the leaves	Nematodes (*Paratrichodorus* spp., *Trichodorus* spp.)
	Potyvirus	Bidens mottle virus (BiMoV)	Mottling and leaf distortion	Aphids (*Myzus persica*), sap
Chrysanthemum	*Pospiviroid*	Chrysanthemum stunt viroid (CSVd)	Overall reduction in plant growth, leaf spots and flower bleaching	Mechanical, seed, pollen
	Pelamoviroid	Chrysanthemum chlorotic mottle viroid (CChMVd)	Mottling, stunting, delayed flowering, general chlorosis	Sap

Continued

Table 6.1. Continued.

Host	Genus	Virus	Typical disease symptoms	Transmission
	Carlavirus	Chrysanthemum virus B (CVB)	Symptomless	Mechanical, aphids (*Myzus persicae*, *Macrosiphum euphorbiae*, *Acrythosiphon solani*, *Coloradoa refomaculata*, *Macrosiphoniella sanborni*)
	Cucumovirus	Tomato aspermy virus (TAV)	Flower size reduction, color breaking and distortion. Overall stunting, mosaic and ringspots	Aphids (*Myzus persicae*, 80+ species)
	Cucumovirus	Cucumber mosaic virus (CMV)	Mosaic, mottling, mild to severe chlorosis and necrosis, overall stunting	Aphids (*Myzus persicae*)
	Tospovirus	Chrysanthemum stem necrosis virus (CSNV)	Severe necrotic streaks on stems, leaf distortion, leaf chlorotic and necrotic spots	Thrips (*Frankliniella occidentalis*, *Frankliniella schltzeu*)
	Tospovirus	Impatiens necrotic spot virus (INSV)	Mottling and necrotic spots on leaves	Thrips (*Frankliniella* spp.)
	Tospovirus	Tomato spotted wilt virus (TSWV)	Wilting, apical bud death, necrosis of axilar leaf buds, chlorotic leaf spots	Thrips (*Frankliniella* spp., *Thrips* spp.)
	Tospovirus	Iris yellow spot virus (IYSV)	Symptomless	Thrips (*Frankliniella fusca*, *Thrips tabaci*)
	Nepovirus	Tomato ringspot virus (ToRSV)	Ringspots and mottling on leaves	Mechanical, nematodes (*Xiphinema* spp.)
Dendrobium	*Carmovirus*	Carnation mottle virus (CarMV)	Mottle	Sap

Closterovirus	Dendrobium vein necrosis virus (DVNV)		Aphids (*Myzus persicae*)
Cucumovirus	Cucumber mosaic virus (CMV)		Aphids
Nepovirus	Tomato ringspot virus (ToRSV)		Nematodes (*Xiphinema* spp.)
Potyvirus	Bean yellow mosaic virus (BYMV)		Aphids
Potyvirus	Ceratubium mosaic virus (CerMV)		Aphids
Potyvirus	Clover yellow vein virus (ClYVV)		Aphids
Potyvirus	Colombian datura virus (CDV)		Aphids
Potyvirus	Dasheen mosaic virus (DsMV)		Aphids
Potyvirus	Dendrobium mosaic virus (DeMV)		Aphids
Potyvirus	Vanilla necrosis virus (VanNV)		Aphids
Potyvirus	Watermelon mosaic virus (WMV)	Mosaic and chlorotic spots on leaves	Aphids (*Myzus persicae*)
Rhabdovirus	Dendrobium ringspot virus (DRV)		
Tobravirus	Tobacco rattle virus (TRV)		
Tombusvirus	Cymbidium ringspot virus (CymRSV)	Chlorotic streaks in young shoots	Mechanical

Continued

Table 6.1. Continued.

Host	Genus	Virus	Typical disease symptoms	Transmission
	Tombusvirus	Lisianthus necrosis virus (LNV)		Mechanical
	Tospovirus	Tomato spotted wilt virus (TSWV)		Thrips
	Tobamovirus	Odontoglossum ringspot virus (ORSV)	Sunken necrotic or chlorotic lesions in leaves and flowers. Flower distortion and color breaking	Mechanical
	Tospovirus	Impatiens necrotic spot virus (INSV)	Chlorotic or necrotic spots with concentric rings. Leaf yellowing and distortion	Mechanical, thrips (*Frankliniella occidentalis*)
	Tospovirus	Capsicum chlorosis virus (CaV)	Chlorotic or necrotic spots with concentric rings. Leaf yellowing and distortion	Mechanical, thrips (*Frankliniella occidentalis*)
Freesia	*Cucumovirus*	Cucumber mosaic virus (CMV)		Aphids (*Myzus persicae*, *Aphis gossypi*)
	Potyvirus	Bean yellow mosaic virus (BYMV)		Aphids (*Myzus persicae*)
	Tobravirus	Tobacco rattle virus (TRV)		
Gerbera	*Cucumovirus*	Cucumber mosaic virus (CMV)	Floret and flower deformation and color breaking, severe mosaic patterns on leaves	Aphids (*Myzus persicae*, *Aphis gossypi*)
	Tospovirus	Tomato spotted wilt virus (TSWV)	Chlorotic leaf patterns, necrosis, and leaf distortion. On flowers distortion and discoloration	Thrips (*Frankliniella* spp., *Thrips* spp.)

	Nepovirus	Tomato ringspot virus (ToRSV)	Chlorotic or necrotic spots, mottling	Mechanical, nematodes (*Xyphinema* spp.)
	Nepovirus	Tobacco ring spot virus (TRSV)	Chlorotic or necrotic spots, mottling	Mechanical, nematodes (*Xyphinema* spp.)
	Tospovirus	Impatiens necrotic spot virus (INSV)	Light green mottling and ring spots	Thrips (*Frankliniella occidentalis*, *Frankliniella fusca*, *Frankliniella intonsa*)
Gladiolus	*Cucumovirus*	Cucumber mosaic virus (CMV)	Floret and flower deformation and color breaking, severe mosaic patterns on leaves	Aphids (*Myzus persicae, Aphis gossypi*)
	Potyvirus	Bean yellow mosaic virus (BYMV)	Mosaic and curling of leaves. Overall stunting. Color breaking in flowers	Aphids (*Myzus persicae*)
	Nepovirus	Tomato ringspot virus (ToRSV)		
	Tospovirus	Tomato spotted wilt virus (TSWV)		
	Tobravirus	Tobacco rattle virus (TRV)		
Gypsophila	*Nepovirus*	Tomato ringspot virus (ToRSV)	Chlorotic and necrotic spots and ringspots on leaves, vein necrosis, leaf crinkling, reduction in plant overall quality and yield	Mechanical, nematodes (*Xiphinema* spp.)
	Cucumovirus	Cucumber mosaic virus (CMV)	Mosaics on leaves	Aphids (*Myzus persicae*, *Aphis gossypi*)

Continued

Table 6.1. Continued.

Host	Genus	Virus	Typical disease symptoms	Transmission
Lily	*Potyvirus*	Lily mottle virus (LMoV)	Vein clearing, mottling, mosaic and yellow streaking on leaves. Smaller and curl leaves. Color breaking in flowers	Aphids
	Carlavirus	Lily symptomless virus (LSV)	Symptomless to leaf yellowing, mild pale vein clearing and mottling	Aphids (*Macrosiphum euphorbiae*, *Myzus persicae*, *Aphisgossipii*)
	Potexvirus	Lily virus X (LVX)	Symptomless to leaf yellowing, mild pale vein clearing and mottling	Mechanical
	Potexvirus	Plantago asiatica mosaic virus (PlAMV)	Rusty necrotic spots on the underside of leaves. Upper side might show grayish spots	
	Nepovirus	Strawberry latent ringspot virus (SLRSV)	Symptomless to asymmetric flower opening	Nematodes (*Xiphinema* spp., *Longidorus* spp., *Paralongidorus* spp.)
	Tobravirus	Tobacco rattle virus (TRV)	Chlorotic and necrotic spots, veinal chlorosis and curling of leaves	Nematodes (*Trichodorus* spp, *Paratrichodorus* spp.)
	Potexvirus	Tulip breaking virus (TBV)	Leaf mottling	Aphids

	Potexvirus	Tulip virus X (TVX)	Sunken chlorotic spots between veins in the leaves. Stripes on the outer portion of flowers	Mechanical
	Nepovirus	Arabis mosaic virus (ArMV)	Necrotic stripes and mosaic on leaves. Cream-colored scales often with necrotic ringspots on bulbs	Nematodes (*Xyphinema diversicaudatum*, *Xyphinema coxi*), seed
	Cucumovirus	Cucumber mosaic virus (CMV)	Light green mosaic, leaf necrotic spots, flower malformation	Aphids (*Myzuz persicae*), mechanic transmission
	Necrovirus	Tobacco necrosis virus (TNV)	Necrotic spots	Mechanical
Peony	*Tobravirus*	Tobacco rattle virus (TRV)	Mosaic, mottling, blotching, banding, concentric ringspots alternating yellow and green	Nematodes (*Trichodorus* spp. and *Paratrichodorus* spp.)
	Not Identified	*Lemoine disease	Overall reduction in plant growth, lack of flowering, irregular swelling areas on roots	Sap
Ranunculus	*Tospovirus*	Impatiens necrotic spot virus (INSV)	Mottling and ring spots	Thrips (*Frankliniella* spp.)

Continued

Table 6.1. Continued.

Host	Genus	Virus	Typical disease symptoms	Transmission
Rose	*Ilarvirus*	Prunus necrotic ringspot virus (PNRSV)	Rose mosaic virus complex: ringspots, mottling, mosaic, zig-zag patterns and vein banding on leaves, sometimes together with leaf drop. Flower size reduction, distortion and less flower production	Pollen
	Ilarvirus	Apple mosaic virus (ApMV)		Pollen
	Nepovirus	Arabis mosaic virus (ArMV)		Nematodes (*Xiphinema* spp., *Longidorus* spp., *Paralongidorus* spp.)
	Nepovirus	Strawberry latent ringspot virus (SLRSV)		Nematodes (*Xiphinema* spp., *Longidorus* spp., *Paralongidorus* spp.)
	Emaravirus	Rose rosette virus (RRV)	Fasciation, leaf elongation, foliage discoloration, higher susceptibility to abiotic stresses, witches' broom, distorted flowers, premature death	Mites (*Phyllocoptes fructiphilus*)
	Luteovirus	Rose spring dwarf associated virus (RSDaV)	Vein clearing, shorter and curved leaves	Vegetative propagation
	Potyvirus	Rose yellow mosaic virus (RoYMV)	Yellow mosaic and leaf ringspots, premature leaf senescence, necrotic canes	Aphids (*Myzus persicae*)
	Not identified	*Rose leaf curl	Leaves epinasty, necrosis of shoot tips, smaller leaves, yellow vein flecking	Unknown

Statice	*Cucumovirus*	Cucumber mosaic virus (CMV)	Mosaics on leaves	Aphids (*Myzus persicae*, *Aphis gossypi*)
	Tobravirus	Tobacco rattle virus (TRV)	Chlorotic and reddish spots on leaves	Nematodes (*Trichodorus* spp., *Paratrichodorus* spp.)
	Tombusvirus	Tomato bushy stunt virus (TBSV)	Stunting, reduced yield, smaller flower stalks	Mechanical
	Fabavirus	Broadbean wilt virus (BBWV)	Leaves wilting and deformation	Aphids
	Potyvirus	Statice Y virus (SYV)	Narrow and deformed leaves, mosaic pattern	Mechanical
	Carmovirus	Carnation mottle virus (CarMV)	Necrotic spots on leaves	Sap
	Potyvirus	Clover yellow vein virus (ClYVV)	Unspecified	Aphids, mechanical
	Potyvirus	Turnip mosaic virus (TuMV)	Stunting, mosaic, premature death	Aphids, sap
Sunflower	*Potyvirus*	Sunflower mosaic virus (SuMV)	Mosaic on leaves of young plants	Seed, aphids (*Myzus persicae, Capitphorus elaegni*)
	Potyvirus	Sunflower chlorotic mottle virus (SuCoMoV)	Chlorotic ring spots and mosaic on leaves	Aphids (*Myzus persicae*)
	Ilarvirus	Tobacco streak virus (TSV)	Chlorosis and spots on leaves, overall stunting	Thrips (*Thrips tabaci*), pollen
	Nepovirus	Tomato ringspot virus (ToRSV)	Chlorotic or necrotic spots, mottling	Mechanical, nematodes (*Xyphinema* spp.)
	Tospovirus	Tomato spotted wilt virus (TSWV)	Chlorotic oak-leaf patterns, necrosis, leaf distortion, flower distortion and discoloration	Thrips (*Frankliniella* spp. *Thrips* spp.)

Continued

Table 6.1. Continued.

Host	Genus	Virus	Typical disease symptoms	Transmission
	Nepovirus	Tobacco ring spot virus (TRSV)	Chlorotic or necrotic spots, mottling	Mechanical, nematodes (*Xyphinema* spp.)
Tulip	*Nepovirus*	Arabis mosaic virus (ArMV)	Overall reduced plant growth, twisted plants, gray to brown spots on lower leaf bases	Mechanical, seed, nematodes (*Xiphinema* spp.)
	Cucumovirus	Cucumber mosaic virus (CMV)	Color breaking in flowers, dwarfing plants, brown and sunken spots in bulbs	Mechanical, aphids
	Tobravirus	Tobacco rattle virus (TRV)	Leaf mottling	Mechanical, nematodes (*Trichodorus* spp., *Paratrichodorus* spp.), seed
	Potyvirus	Tulip breaking virus (TBV)	Leaf chlorosis, color breaking in flowers	Mechanical, aphids (*Myzus persicae, Aphis gossypii*)
	Carlavirus	Lily symptomless virus (LSV)	Leaf mottling, color breaking in flowers	Mechanical, aphid (*Myzuz persicae*)
	Necrovirus	Tobacco necrosis virus (TNV)	Necrotic streaks in leaves and stems	Mechanical, fungus (*Olpidium brassicae*)
	Potexvirus	Tulip virus X (TVX)	Streaks in leaves and flowers	Mechanical

anchorage, slow decline of the plants, higher susceptibility to other pathogens, premature leaf drop, damping off, wilting, chlorosis and virus transmission. Most of these symptoms are difficult to differentiate from biotic and abiotic problems; therefore, analysis by a nematology lab is often necessary to identify nematode infection.

Plant parasitic nematodes can be classified according to their habitat (ectoparasites, endoparasites and semi-ectoparasites or ecto/endo parasites) and lifestyle (migratory and sedentary). Ectoparasites feed from the outside of the tissue, while endoparasites completely enter into the host tissue to feed. Ecto/endo parasites feed with half of their body inside the host tissue and half outside. Migratory parasites feed on the host tissue without becoming attached. On the other hand, sedentary parasites become attached to the tissue and establish a permanent feeding site (Reddy, 2014). Table 6.2 shows the most important plant parasitic nematodes for cut flower crops, their lifestyle and typical habitat.

General management practices

Preventative practices include use of healthy nematode-free propagation material and sanitation of tools and machinery. Hot water treatments can eliminate foliar nematodes. Splashing water should be avoided as nematodes can spread in this manner. Nematicides for chemical management are strictly regulated owing to high toxicity and environmental concerns. Most of the nematicide applications can only be performed by certified applicators. Soil fumigation with 1,3-dichloropropene and chloropicrin have a significant effect in reducing nematode population densities in the soil (Melero-Vara and Lopez-Herrera, 2012). *Myrothecium verrucaria* is considered an effective soil treatment against plant parasitic nematodes. Active metabolites released by *M. verrucaria* have the potential to reduce gall formation and number of root-knot nematodes in the soil (Nguyen *et al.*, 2018). Steam treatments and solarization can also be effective. Some nematodes have a restricted host spectrum; however, others like *Meloidogyne incognita* have a broad host spectrum making weeds a potential reservoir of nematodes.

Root-knot nematodes – *Meloidogyne* spp.

Root-knot nematodes are common in cut flower crops. For example, in carnation crops losses in flower yield by *Meloidogyne incognita* can reach up to 27%, while mortality in susceptible cultivars might range between 40 and 60% (Reddy, 2014). Root-knot nematode infection increases susceptibility to other soil pathogens like *Fusarium*, *Phytophthora* and *Rhizoctonia* as a result of compromised root health (Horst and Nelson, 1997).

Table 6.2. Common parasitic nematodes of cut flowers, lifestyle and habitat.

Nematode	Lifestyle	Habitat	Crops affected
Meloidogyne	Sedentary	Endoparasite	Carnation, china aster, chrysanthemum, dendrobium, gerbera, gladiolus, gypsophila, lily, peony, rose, snapdragon, sunflower
Heterodera	Sedentary	Endoparasite	Carnation, gypsophila
Pratylenchus	Migratory	Endoparasite	Chrysanthemum, gypsophila, lily, peony, rose, snapdragon, sunflower, tulip
Rotylenchus	Migratory	Ecto/endo parasite	Carnation, china aster, rose
Aphelenchoides	Migratory	Ecto/endo parasite	Carnation, china aster, chrysanthemum, lily, peony, tulip
Ditylenchus	Migratory	Ecto/endo parasite	Carnation, lily, tulip
Paratylenchus	Migratory	Ectoparasite	Alstroemeria, carnation
Xiphinema	Migratory	Ectoparasite	Carnation, gerbera, rose, sunflower
Longidorus	Migratory	Ectoparasite	Lily
Trichodorus	Migratory	Ectoparasite	Tulip
Paratrichodorus	Migratory	Ectoparasite	Sunflower, tulip
Hoplolaimus	Migratory	Ectoparasite	Carnation
Helicotylenchus	Migratory	Ectoparasite	Carnation, rose, sunflower
Criconemella	Migratory	Ectoparasite	Carnation, rose
Mesocriconema	Migratory	Ectoparasite	Carnation
Belonolaimus	Migratory	Ectoparasite	Sunflower

Important hosts

Carnation, chrysanthemum, gerbera, gladiolus, gypsophila, peony, rose and sunflower.

Symptoms and signs

Infected roots are knotted or galled as a result of feeding females developing inside the roots (Horst and Nelson, 1997). Wilting, stunting and nutrient deficiencies appear in aerial portions of the plant.

Disease cycle

Second-stage juveniles present in the soil are mobile and penetrate the roots, migrating into the vascular system, where they establish permanent feeding sites and become sedentary. Only females feed, thus under favorable conditions more mature females develop at the adult stage, while under non-favorable conditions more males are produced. Females develop specialized feeding sites called giant cells. As they feed, their width increases inside the roots, which results in gall formation. Females secrete egg masses in a gelatinous matrix that becomes the inoculum source for new infections.

REFERENCES

Aissat, K., Nicot, P.C., Guechi, A., Bardin, M. and Chibane, M. (2008) Grey mould development in greenhouse tomatoes under drip and furrow irrigation. *Agronomy for Sustainable Development* 28, 403–409.

Ajayi-Oyetunde, O.O. and Bradley, C.A. (2018) Identification and characterization of *Rhizoctonia* species associated with soybean seedling disease. *Plant Disease* 101, 520–533.

Anaïs, G., Darrasse, A. and Prior, P.H. (2000) Breeding anthuriums (*Anthurium andreanum* L.) for resistance to bacterial blight caused by *Xanthomonas campestris pv. dieffenbachiae. Acta Horticulturae* 508, 135–140.

Andersen, T.F. and Rasmussen, H.N. (1996) The mycorrhizal species of *Rhizoctonia*. In: Sneh B., Jabaji-Hare S., Neate S. and Dijst G. (eds) *Rhizoctonia Species: Taxonomy, Molecular Biology, Ecology, Pathology and Disease Control*. Springer, Dordrecht, the Netherlands, pp. 379–390.

Ann, P.J., Kunimoto, R. and Ko, W.H. (1990) Phytophthora wilt of carnation in Taiwan and Hawaii. *Plant Protection Bulletin* 32, 145–157.

Bardin, M. and Gullino M.L. (2020) Fungal diseases. In: Gullino M.L., Albajes R. and Nicot P.C. (eds) *Integrated Pest and Disease Management in Greenhouse Crops*. Springer, Cham, Switzerland, pp. 55–81.

Bélanger, R.R. and Labbé, C. (2002) Control of powdery mildews without chemicals: prophylactic and biological alternatives for horticultural crops. In: Bélanger R.R., Bushnell W.R., Dik A.J. and Carver, T.L.W. (eds) *The Powdery Mildews: A Comprehensive Treatise*. American Phytopathological Society, St. Paul, Minnesota, pp. 256–267.

Benson, D.M. and Parker, K.C. (2011) Efficacy of fungicides and biopesticides for management of phytophthora crown and root rot of gerbera daisy. *Plant Health Progress* 12, 13.

Ben-Ze'ev, I.S., Elkind, G. and Levy, E. (2006) Two *Peronospora* species causing downy mildew of carnation and gypsophila (Caryophyllaceae) in Israel. *Phytoparasitica* 34, 265–268.

Bhat, H.A., Ahmad, K., Ahanger, R.A., Qazi, N.A., Dar, N.A. and Ganie, S.A. (2013) Status and symptomatology of Alternaria leaf blight (*Alternaria alternata*) of gerbera (*Gerbera jamisonii*) in Kashmir valley. *African Journal of Agricultural Research* 8, 819–823.

Blair, J.E., Coffey, M.D., Park, S.-Y., Geiser, D.M. and Kang, S. (2008) A multi-locus phylogeny for *Phytophthora* utilizing markers derived from complete genome sequences. *Fungal Genetics and Biology* 45, 266–277.

Blancard, D. (2012a) Diagnosis of parasitic and nonparasitic diseases. In: Blancard D. (eds) *Tomato Diseases*, 2nd Edition. Academic Press, San Diego, California, pp. 35–411.

Blancard, D. (2012b) Principal characteristics of pathogenic agents and methods of control. In: Blancard D. (eds) *Tomato Diseases*, 2nd Edition. Academic Press, San Diego, California, pp. 413–650.

Brahamanage, R. (2018) Are pathogenic isolates of *Stemphylium* host specific and cosmopolitan? *Plant Pathology and Quarantine* 8, 153–164.

Brahmanage, R., Wanansinghe, D.N., Dayarathne, M.C., Jeewon, R., Yan, J. *et al.* (2019) Morphology and phylogeny reveal *Stemphylium dianthi* sp. *nov*. and new host records for the sexual morphs of *S. beticola*, *S. gracilariae*, *S. simmonsii* and *S. vesicarium* from Italy and Russia. *Phytotaxa* 411, 243–263.

Braun, U. and Takamatsu, S. (2000) Phylogeny of *Erysiphe*, *Microsphaera*, *Uncinula* (Erysipheae) and *Cystotheca*, *Podosphaera*, *Sphaerotheca* (Cystotheceae) inferred from rDNA ITS sequences – some taxonomic consequences. *Schlechtendalia* 4, 1–33.

Brisco-McCann, E.I. and Hausbeck, M.K. (2018) Diseases of gerbera. In: McGovern R.J and Elmer W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International, Dordrecht, the Netherlands, pp. 533–559.

Broadbent, A.B. and Matteoni, J.A. (1990) Acquisition and transmission of *Pseudomonas chichorii by Liriomyza trifolii* (Diptera: Agromyzidae). *Proceedings of the Entomological Society of Ontario* 121, 79–84.

Chardonnet, C.O., Sams, C.E., Trigiano, R.N. and Conway, W.S. (2000) Variability of three isolates of *Botrytis cinerea* affects the inhibitory effects of calcium on this fungus. *Phytopathology* 90, 769–774.

Chitambar, J. (2016) *Phytophthora tentaculata* Kröber and Marwitz 1993. In: *Pest Rating Proposals and Final Ratings – Fungi, Plant Pathogens*. California Department of Food and Agriculture, Sacramento, California.

Cook, R.T.A. (2001) First report in England of changes in the susceptibility of *Puccinia horiana*, the cause of chrysanthemum white rust, to triazole and strobilurin fungicides. *Plant Pathology* 50, 792.

Dahmen, H. (1992) Protective, curative, and eradicant activity of difenoconazole against *Venturia inaequalis*, *Cercospora arachidicola*, and *Alternaria solani*. *Plant Disease* 76, 774.

Dallagnol, L.J., Rodrigues, F.A., Tanaka, F.A.O., Amorim, L. and Camargo, L.E.A. (2012) Effect of potassium silicate on epidemic components of powdery mildew on melon. *Plant Pathology* 61, 323–330.

Darras, A.I. (2018) Postharvest disease management. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International, Dordrecht, the Netherlands, pp. 253–279.

Datnoff, E.L. and Rodrigues, A.F. (2015) Highlights and prospects for using silicon in the future. In: Rodrigues, F.A. and Datnoff, L.E. (eds.) *Silicon and Plant Diseases*. Springer International Publishing, Cham, Switzerland, pp. 139–145.

Dheepa, R., Vinodkumar, S., Renukadevi, P. and Nakkeeran, S. (2016) Phenotypic and molecular characterization of chrysanthemum white rust pathogen *Puccinia horiana* (Henn) and the effect of liquid based formulation of *Bacillus* spp. for the management of chrysanthemum white rust under protected cultivation. *Biological Control* 103, 172–186.

Dicklow, M.B. (2015) Leaf spot diseases of floricultural crops caused by fungi and bacteria. Center for Agriculture, Food and the Environment. Extension Greenhouse Crops & Floriculture Program, University of Massachusetts.

d'Oliveira, B. (1949) Life-cycle of *Puccinia gladioli* cast. *Nature* 164, 239–240.

Domínguez-Serrano, D., García-Velasco, R., Mora-Herrera, M.E., Salgado-Siclan, M.L. and González-Díaz, J.G. (2016) La cenicilla del rosal (*Podosphaera pannosa*). *Agrociencia* 50, 901–917.

Dordas, C. (2008) Role of nutrients in controlling plant diseases in sustainable agriculture. A review. *Agronomy for Sustainable Development* 28, 33–46.
Duan, C.F., Long, Y.Q., Chen, H., Yang, G.H, Gui, M. and Liu, G.H. (2015) First report of *Alternaria dianthicola* causing flower blight on carnation in China. *EPPO, Bulletin* 45, 195–198.
Elad, Y. (2016) Cultural and integrated control of *Botrytis* spp. In: Fillinger, S. and Elad, Y. (eds) *Botrytis – The Fungus, The Pathogen and Its Management In Agricultural Systems*. Springer International Publishing, Cham, Switzerland, pp. 149–164.
Elmhirst, J.F., Haselhan, C. and Punja, Z.K. (2011) Evaluation of biological control agents for control of botrytis blight of geranium and powdery mildew of rose. *Canadian Journal of Plant Pathology* 33, 499–505.
EPPO (2008) *Plasmopara halstedi*. *EPPO Bulletin* 38, 343–348.
Fillinger, S. and Walker, A.S. (2016) Chemical control and resistance management of botrytis diseases. In: Fillinger, S. and Elad, Y. (eds) *Botrytis – The Fungus, The Pathogen and Its Management In Agricultural Systems*. Springer, Dordrecht, the Netherlands, pp. 189–216.
Fiori, M. (1992) A new bacterial disease of chrysanthemum: a stem rot by *Pseudomonas corrugata* Roberts et Scarlett. *Phytopathologia Mediterranea* 31, 110–114.
Gachomo, E.W. (2004) Studies of the life cycle of *Diplocarpon rosae* Wolf on roses and the effectiveness of fungicides on pathogenesis. Thesis. Rheinischen Friedrich-Wilhelms-Universität Bonn, Nyeri, Kenya, pp. 129–157.
Gachomo, E.W., Dehne, H.-W. and Steiner, U. (2006) Microscopic evidence for the hemibiotrophic nature of *Diplocarpon rosae*, cause of black spot disease of rose. *Physiological and Molecular Plant Pathology* 69, 86–92.
Gamliel, A., Hadar, E. and Katan, J. (1993) Improvement of growth and yield of *Gypsophila paniculata* by solarization or fumigation of soil or container medium in continuous cropping systems. *Plant Disease* 77, 933–938.
Goethals, K., Vereecke, D., Jaziri, M., Van Montagu, M. and Holsters, M. (2001) Leafy gall formation by *Rhodococcus fascians*. *Annual Review of Phytopathology* 39, 27–52.
Gohlke, J. and Deeken, R. (2014) Plant responses to *Agrobacterium tumefaciens* and crown gall development. *Frontiers in Plant Science* 5, 155.
Götz, M., Ulrich, R. and Werres, S. (2017) First detection of *Phytophthora chrysanthemi* on *Chrysanthemum indicum* in Germany. *New Disease Reports* 35, 6.
Gould, A. (2012) Disease control recommendations for ornamental crops, 2012. Rutgers NJAES Cooperative Extension. Available at: https://njaes.rutgers.edu/pubs/publication.php?pid=E036 (accessed 15 April 2020).
Gullino, M.L. (2012) Fusarium wilt of bulb crops. In: Gullino, M.L., Katan, J. and Garibaldi, A. (eds) *Fusarium Wilts of Greenhouse Vegetable and Oramental Crops. APS, St. Paul*, Minnesota, pp. 199–204.
Gullino, M.L. and Garibaldi, A. (2007) Critical aspects in management of fungal diseases of ornamental plants and directions in research. *Phytopathologia Mediterranea* 46, 135–149.
Gullino, M.L. and Garibaldi, A. (2018) Environment modification for disease management. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 119–136.
Gullino, M.L., Daughtrey, M.L., Garibaldi, A. and Elmer, W.H. (2015) Fusarium wilts of ornamental crops and their management. *Crop Protection* 73, 50–59.
Gwynn R.L. (2014) *The Manual of Biocontrol Agents*, 5th Edition. BCPC, London.

Harrison, N.A. and Helmick, E.E. (2008) First report of a '*Candidatus* Phytoplasma asteris'-related strain associated with little leaf disease of *Helianthus debilis* in Florida, USA. *Plant Pathology* 54, 772.
Harrison, U.J. and Shew, H.D. (2001) Effects of soil pH and nitrogen fertility on the population dynamics of *Thielaviopsis basicola*. *Plant and Soil* 228, 147–155.
Hausbeck, M.K. and Glaspie, S.L. (2008) *Control of Phytophthora Root Rot of Gerbera Daisy with Fungicide Drenches*. PDMR Crop Protection and Management Collection. The American Phytopathological Society, St. Paul, Minnesota.
Henderson, D.M. (2004) *The rust fungi of the British Isles*. British Mycological Society, Kew, Richmond, 1–20.
Hikichi, Y., Wali, U.M., Ohnishi, K. and Kiba, A. (2013) Mechanism of disease development caused by a multihost plant bacterium, *Pseudomonas cichorii*, and its virulence diversity. *Journal of General Plant Pathology* 79, 379–389.
Hollomon, W.D. and Wheeler, E.I. (2002) Controlling powdery mildews with chemistry. In: Belanger, R.R, Bushne, R.W., Dik, J.A. and Carver, W.L.T. (eds) *The Powdery Mildews. A Comprenhensive Treatise.* APS Press, St. Paul, Minnesota, pp. 249–255.
Hoppe P.E. (1966) Pythium species still viable after 12 years in air-dried muck soil. *Phytopathology* 56, 1411.
Horita, H. and McGovern, R.J. (2018) Diseases of china aster. In: McGovern R.J. and Elmer W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 419–437.
Horst, R.K. and Cloyd, R.A. (2007) *Compendium of Rose Diseases and Pests*, 2nd Edition. The American Phytopathological Society, St. Paul, Minnesota.
Horst, R.K. and Nelson, P.E. (1997) *Compendium of Chrysanthemum Diseases*. APS Press, St. Paul, Minnesota.
Jarvis, W.R. (1962) The dispersal of spores of *Botrytis cinerea* fr. in a raspberry plantation. *Transactions of the British Mycological Society* 45, 549–559.
Jarvis, W.R. (1992) *Managing Diseases in Greenhouse Crops.* The American Phythopathological Society, St. Paul, Minnesota.
Jones, D.R. (1972) In vitro culture of carnation rust, *Uromyces dianthi*. *Transactions of the British Mycological Society* 58, 29–36.
Jones, J.B., Engelhard, A.W. and Raju, B.C. (1983) Outbreak of a stem necrosis on chrysanthemum incited by *Pseudomonas cichorii* in Florida. *Plant Disease* 67, 431–433.
Kado, C.I. (2002) Crown gall. The Plant Health Instructor. Available at: https://www.apsnet.org/edcenter/disandpath/prokaryote/pdlessons/Pages/CrownGall.aspx (accessed 13 May 2020).
Khalil, S. (2011) Influence of electrical conductivity on biological activity of *Pythium ultimum* and Binab T in a closed soilless system. *Journal of Plant Diseases and Protection* 118, 102–108.
Khouader, M., Benkirane, R., Touhami, A.O., Boussalwa, E.H. and Douira, A. (2011) The endemic plant *Limonium mucronatum* L. (Fil.) Chaz., a new host for *Uromyces limonii* (DC.) Lev., 1849 in Morocco. *Atlas Journal of Biology* 1, 66–69.
Kimishima, E. and Goto, M. (1992) Foot rot of gerbera caused by *Phytophthora cryptogea* Pethyb. andamp; Laff. in Japan. *Annals of the Phytopathological Society of Japan* 58, 87–90.
Kiss, L. (2003) A review of fungal antagonists of powdery mildews and their potential as biocontrol agents. *Pest Management Science* 59, 475–483.
Kiss, L., Russell, J.C., Szentiványi, O., Xu, X. and Jeffries, P. (2004) Biology and biocontrol potential of *Ampelomyces* mycoparasites, natural antagonists of powdery mildew fungi. *Biocontrol Science and Technology* 14, 635–651.

Le, D.P., Smith, M., Hudler, G.W. and Aitken, E. (2014) Pythium soft rot of ginger: detection and identification of the causal pathogens, and their control. *Crop Protection* 65, 153–167.

Leroux, P. (2007) Chemical control of *Botrytis* and its resistance to chemical fungicides. In: Elad, Y., Williamson, B., Tudzynski, P. and Delen, N. (eds) *Botrytis, Pathology and Control.* Springer, Dordrecht, the Netherlands, pp. 192–222.

Lichatowich, T. (2007) The plant growth enhancing and biocontrol mechanisms of *Streptomyces lydicus* WYEC 108 and its use in nursery and greenhouse production. In: Lichatowich, T. (eds) *Proceedings RMRS-P-50 Reforestation, Nurseries and Genetics Resources*. USDA Forest Service, Rocky Mountain Research Station, Eugene, Oregon, pp. 61–62.

Liu, Y., Xin, J., Liu, L., Song, A., Zhiyong, G., Fang, W. and Chen, F. (2020) A temporal gene expression map of chrysanthemum leaves infected with *Alternaria alternata* reveals different stages of defense mechanisms. *Horticulture Research* 7, 1–14.

Mackenzie, S.J. and Peres, N.A. (2012) Use of leaf wetness and temperature to time fungicide applications to control botrytis fruit rot of strawberry in Florida. *Plant Disease* 96, 522–528.

Malandrakis, A.A., Apostolidou, Z.A., Markoglou, A. and Flouri, F. (2015) Fitness and cross-resistance of *Alternaria alternata* field isolates with specific or multiple resistance to single site inhibitors and mancozeb. *European Journal of Plant Pathology* 142, 489–499.

Markell, S.G., Harveson, R.M., Block, C.C. and Gulya, T.J. (2015) Sunflower diseases. In: Martínez-Force, E., Dunford, N.T. and Salas, J.J. (eds) *Sunflower*. AOCS Press, Urbana, Illinois, pp. 93–128.

Mathur, K., Ram, D., Poonia, J. and Lodha, B.C. (2012) Integration of soil solarization and pesticides for management of rhizome rot of ginger. *Indian Phytopathology* 55, 345–347. Available at: https://agris.fao.org/agris-search/search.do?recordID=DJ2012075781 (accessed 20 July 2020).

McGovern, R.J. (2018) Diseases of lisianthus. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International, Cham, Switzerland, pp. 583–632.

McGovern, R.J., Horita, H., Stiles, C.M. and Seijo, T.E. (2006) Host range of *Itersonilia perplexans* and management of itersonilia petal blight of china Aster. *Plant Health Progress* 7, 1.

McGovern, RJ. and Seijo, T.E. (1999) Petal blight of *Callistephus chinensis* caused by *Itersonilia perplexans*. *Plant Disease* 83, 379.

Melero-Vara, J.M. and Lopez-Herrera, C.J. (2012) Use of poultry manure combined with soil solarization as a control method for *Meloidogyne incognita* in carnation. *Plant Disease* 96, 990–996.

Michel, J., Samarakoon, U.C., Virnston, B., Horst, L. and Altland, J. (2019) *Effect of calcium chloride on powdery mildew in lettuce* (Poster). American Society of Horticultural Science, Las Vegas, Nevada.

Mohan, S.K. and Bijman, V.P. (2010) Bacterial cane blight of rose caused by *Pseudomonas syringae*. *Acta Horticulturae* 870, 109–114.

Mullen, J.M., Hagan, A.K. and Carey, D.K. (2001) First report of Phytophthora blossom blight of Chrysanthemum caused by *Phytophthora nicotianae. Plant Disease* 85, 923.

Muñoz, M., Faust, J. and Schnabel, G. (2019) Characterization of *Botrytis cinerea* from commercial cut flower roses. *Plant Disease* 103, 1577–1583.

Nguyen, L.T.T., Ja, J.Y., Kim, T.Y., Yu, N.H., Park, A.R., *et al.* (2018) Nematicidal activity of verrucarin A and roridin A isolated from *Myrothecium verrucaria* against *Meloidogyne incognita*. *Pesticide Biochemistry and Physiology* 148, 133–143.

Nicot, P.C., Stewart, A., Bardin, M. and Elad, Y. (2016) Biological control and biopesticide suppression of *Botrytis*-incited diseases. In: Fillinger, S. and Elad, Y. (eds) *Botrytis – The Fungus, The Pathogen and Its Management in Agricultural Systems*. Springer International Publishing, Cham, Switzerland, pp. 165–187.

Nishi, N., Muta, T., Ito, Y., Nakamura, M. and Tsukiboshi, T. (2009) Ray speck of chrysanthemum caused by *Stemphylium lycopersici* in Japan. *Journal of General Plant Pathology* 75, 80–82.

Norman, D.J. and Ali, G.S. (2012) *Anthurium Diseases: Identification and Control in Commercial Greenhouse Operations*. University of Florida IFAS Extension, Gainesville, Florida.

O'Keefe, G. and Davis, D.D. (2015) Morphology of *Puccinia horiana*, causal agent of chrysanthemum white rust, sampled from naturally infected plants. *Plant Disease* 99, 1738–1743.

Ongena, M., Henry, G. and Thonart, P. (2009) The roles of cyclic lipopeptides in the biocontrol activity of *Bacillus subtilis*. In: Gisi, U., Chet, I. and Gullino, M.L. (eds) *Recent Developments in Management of Plant Diseases*. Springer, Dordrecht, the Netherlands, pp. 59–69.

Palmer, C.L. and Vea, E. (2018) Fungicides and biocontrols for management of florists' crops diseases. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 137–166.

Park, M.J., Choi, Y.J., Hong, S.B. and Shin, H.D. (2010) Genetic variability and mycohost association of *Ampelomyces quisqualis* isoletes inferred from phylogenetic analyses of ITS rDNA and actin gene sequences. *Fungal Biology* 114, 235–247.

Perombelon, M.C.M. and Burnett, E.M. (1991) Two modified crystal violet pectate (CVP) media for the detection, isolation and enumeration of soft rot erwinias. *Potato Research* 34, 79–85.

Pscheidt, J.W. and Rodriguez, T.G. (2018) Diseases of rose. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 713–742.

Putnam, M.L. and Miller, M.L. (2007) *Rhodococcus fascians* in herbaceous perennials. *Plant Disease* 91, 1064–1076.

Reddy, P.P. (2014) Ornamental crops. In: Reddy, P.P. (ed.) *Biointensive Integrated Pest Management in Horticultural Ecosystems*. Springer India, New Delhi, pp. 185–200.

Reid, T.C., Hausbeck, M.K. and Kizilkaya, K., (2002) Use of fungicides and biological controls in the suppression of fusarium crown and root rot of asparagus under greenhouse and growth chamber conditions. *Plant Disease* 86, 493–498.

Rodríguez-Alvarado, G., Fernández-Pavía, S.P., Valenzuela-Vázquez, M. and Loya-Ramírez, J.G. (2006) First report of gladiolus rust caused by *Uromyces transversalis* in Michoacán, México. *Plant Disease* 90, 687–687.

Rosskopf, E.N., Kokalis-Burelle, N., Fennimore, S.A. and Wilen, C.A. (2018) Soil/media disinfestation for management of florists' crops diseases, In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases.* Springer International Publishing, Cham, Switzerland, pp. 167–199.

Samson, R., Legendre, J.B., Christen, R., Fischer-Le Saux, M., Achouak, W. and Gardan, L. (2005) Transfer of *Pectobacterium chrysanthemi* (Burkholder *et al.* 1953) Brenner *et al. 1973* and *Brenneria paradisiaca* to the genus *Dickeya gen. nov.* as *Dickeya chry-*

santhemi comb. nov. and *Dickeya paradisiaca comb. nov*. and delineation of four novel species, *Dickeya dadantii* sp. nov., *Dickeya dianthicola* sp. nov., *Dickeya dieffenbachiae sp. nov*. and *Dickeya zeae sp. nov*. *International Journal of Systematic and Evolutionary Microbiology* 55(4), 1415–1427.

Satta, E., Paltrinieri, S. and Bertaccini, A. (2019) Phytoplasma transmission by seed. In: Bertaccini, A., Weintraub, P., Rao, G. and Mori, N. (eds) *Phytoplasmas: Plant Pathogenic Bacteria-II*. Springer, Singapore, pp. 131–147.

Schilder, A. (2013) *Botector: A New Biofungicide for Control of Botrytis Bunch Rot in Grapes*. Michigan State University Extension. Dept. of Plant, Soil and Microbial Sciences. Available at: https://www.canr.msu.edu/news/botector_a_new_biofungicide_for_control_of_botrytis_bunch_rot_in_grapes (accessed 14 May 2020).

Schneider, J.H.M., Schilder, M.T. and Dijst, G. (1997) Characterization of *Rhizoctonia solani* AG 2 isolates causing bare patch in field grown tulips in the Netherlands. *European Journal of Plant Pathology* 103, 265–279.

Seijo, T.E., McGovern, R.J. and de Blandino, A.M. (2000) Petal blight of sunflower caused by *Itersonilia perplexans. Plant Disease* 84, 1153.

Sendall, B.C., Kong, G.A., Goulter, K.C., Aitken, E.A.B., Thompson, S.M., *et al*. (2006) Diversity in the sunflower: *Puccinia helianthi* pathosystem in Australia. *Australasian Plant Pathology* 3, 35–40.

Shirai, K., Nishiwaki, Y., Kobayashi, S. and Satou, M. (2016) First report of downy mildew of statice caused by *Peronospora statices* in Japan. *Journal of General Plant Pathology* 82, 212–215.

Simón-Mateo, C., Depuydt, S., Manes, C.L.D.O., Cnudde, F., Holsters, M., Goethals, K. and Vereecke, D. (2006) The phytopathogen *Rhodococcus fascians* breaks apical dominance and activates axillary meristems by inducing plant genes involved in hormone metabolism. *Molecular Plant Pathology* 7, 103–112.

Spencer, D.M. (1980) Parasitism of carnation rust (*Uromyces dianthi*) by *Verticillium lecanii*. *Transactions of the British Mycological Society* 74, 191–194.

Staats, M., van Baarlen, P. and van Kan, J.A.L. (2005) Molecular phylogeny of the plant pathogenic genus *Botrytis* and the evolution of host specificity. *Molecular Biology and Evolution* 22, 333–346.

Stanghellini, M.E. (1971) The sporangium of *Pythium ultimum* as a survival structure in soil. *Phytopathology* 61, 157.

Stanghellini, M.E., Rasmussen, S.L. and Kim, D.H. (1999) Aerial transmission of *Thielaviopsis basicola*, a pathogen of corn-salad, by adult shore flies. *Phytopathology* 89, 476–479.

Stes, E., Francis, I., Pertry, I., Dolzblasz, A., Depuydt, S. and Vereecke, D. (2013) The leafy gall syndrome induced by *Rhodococcus fascians*. *FEMS Microbiology Letters* 342, 187–194.

Strider, D.L. (1980) Control of bacterial leaf spot of zinnia with captan. *Plant Disease* 64, 920.

Takamatsu, S., Niinomi, S., Harada, M. and Havrylenko, M. (2010) Molecular phylogenetic analyses reveal a close evolutionary relationship between *Podosphaera* (Erysiphales: Erysiphaceae) and its rosaceous hosts. *Persoonia* 24, 38e48.

Tepedelen Ağaner, G. and Uysal, A. (2018) First report of downy mildew caused by *Peronospora chlorae* on lisianthus in Turkey. *New Disease Reports* 37, 7.

Thinggaard, K. and Andersen, H. (1995) Influence of watering frequency and electrical conductivity of the nutrient solution on Phytophthora root rot in pot plants of gerbera. *Plant Disease* 79, 259–263.

Thomma, B.P.H.J. (2003) *Alternaria* spp.: from general saprophyte to specific parasite. *Molecular Plant Pathology* 4, 225–236.

Toome-Heller, M. (2016) Latest developments in the research of rust fungi and their allies (Pucciniomycotina). In: Li, D.-W. (ed.) *Biology of Microfungi, Fungal Biology.* Springer International Publishing, Cham, Switzerland, pp. 147–168.

Toppe, B. and Thinggaard, K. (1998) Prevention of Phytophthora root rot in gerbera by increasing copper ion concentration in the nutrient solution. *European Journal of Plant Pathology* 104, 359–366.

Torres, D.E., Rojas-Martínez, R.I., Zavaleta-Mejía, E., Guevara-Fefer, P., Márquez-Guzmán, G.J. and Pérez-Martínez, C. (2017) *Cladosporium cladosporioides* and *Cladosporium pseudocladosporioides* as potential new fungal antagonists of *Puccinia horiana* Henn., the causal agent of chrysanthemum white rust. *PLoS ONE* 12, e0170782.

Trolinger, J.C., McGovern, R.J., Elmer, W.H., Rechcigl, N.A. and Shoemaker, C.M. (2018) Diseases of chrysanthemum. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 439–502.

Troisi, M., Bertetti, D., Gullino, M.L. and Garibaldi, A. (2013) Race differentiation in *Fusarium oxysporum* f.sp. *chrysanthemi. Phytopathology* 161, 675–688.

Tzotzos, G.T., Head, G.P. and Hull, R. (2009) Setting the context: agriculture and genetic modification. In: Tzotzos, G.T., Head, G.P. and Hull, R. (eds) *Genetically Modified Plants*. Academic Press, San Diego, California, pp. 1–32.

Uchida, J.Y. and Aragaki, M. (1991) *Fungal Diseases of Dendrobium Flowers*. University of Hawaii, College of Tropical Agriculture and Human Resources, Research Extension, 8.

Uddin, W., McCarter, S.M. and Gitaitis, R.D. (1996) First report of oakleaf hydrangea bacterial leaf spot caused by a pathovar of *Xanthomonas campestris*. *Plant Disease* 80, 1–5.

Vakalounakis, D.J. and Malathrakis, N.E. (1987) Occurrence of *Uromyces savulescui* on statice (*Limonium sinuatum*) in Crete, Greece. *Plant Pathology* 36, 600–601.

Vartapetian, B.B., Dolgikh, Y.I., Polyakova, L.I., Chichkova, N.V. and Vartapetian, A.B. (2014) Biotechnological approaches to creation of hypoxia and anoxia tolerant plants. *Acta Naturae* 6, 19–30.

Verhaar, M.A., Kerssies, A. and Hijwegen, T. (1999) Effect of relative humidity on mycoparasitism of rose powdery mildew with and without treatments with mycoparasites. *Journal of Plant Diseases and Protection* 1062, 158–165.

Wang, B. and Jeffers, S.N. (2002) Effects of cultural practices and temperature on fusarium root and crown rot of container-grown hostas. *Plant Disease* 86, 225–231.

Water, J.K. (1981) Chrysanthemum white rust. *Invasive species compendium. EPPO Bulletin* 11, 239–242.

Wegulo, S.N. and Chase, A.R. (2018) Diseases of snapdragon. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 743–766.

Wick, R.L. (2018) Diseases of kalanchoe. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 1007–1019.

Williamson, B., Duncan, G.H., Harrison, J.G., Harding, L.A., Elad, Y. and Zimand, G. (1995) Effect of humidity on infection of rose petals by dry-inoculated conidia of *Botrytis cinerea*. *Mycological Research* 99, 1303–1310.

Williamson, B., Tudzynski, B., Tudzynski, P. and van Kan, J.A.L. (2007) *Botrytis cinerea*: the cause of grey mould disease. *Molecular Plant Pathology* 8, 561–580.

Wolcan, S.M. (2010) First report of downy mildew caused by *Bremia lactucae* on *Gerbera jamensonii* in Argentina. *Australasian Plant Disease Notes* 5, 98.

Wolcan, S.M., Malbrán, I., Mourelos, C.A., Sisterna, M.N., González, M. del P., Alippi, A.M., Nico, A. and Lori, G.A. (2018a) Diseases of carnation. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 317–378.

Wolcan, S.M., Mourelos, C.A., Sisterna, M.N., González, M. del P., Alippi, A.M., Nico, A. and Lori, G.A. (2018b) Diseases of Gypsophila. In: McGovern, R.J. and Elmer, W.H. (eds) *Handbook of Florists' Crops Diseases*. Springer International Publishing, Cham, Switzerland, pp. 561–582.

Wu, H.C. and Wu, W.S. (2003) Sporulation, pathogenicity and chemical control of *Alternaria protenta,* a new seedborne pathogen on sunflower. *Australasian Plant Pathology* 32, 309–312.

Xu, X.-M. and Pettitt, T. (2017) Downy mildew. In: *Reference Module in Life Sciences*. Elsevier, Amtserdam, pp. 154–158.

Yeriyahu, U., Shamai, I., Peleg, R., Dudai, N. and Shtienberg, D. (2006) Reduction of *Botrytis cinerea* sporulation in sweet basil by altering the concentrations of nitrogen and calcium in the irrigation solution. *Plant Pathology* 55, 544–552.

7

Biological Control of Pests

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INTRODUCTION

Biological control has made huge strides forward since Hussey and Scopes (1985) wrote their seminal book, *Biological Pest Control: The Glasshouse Experience*, over 35 years ago. The two largest commercial biological control companies that exist today (Koppert Biological Systems and Biobest Group NV) have their roots in this period. Initially, biological control focused on greenhouse vegetables such as tomatoes and cucumbers. However, in the past 10 years significant developments have taken place that have stimulated adoption of biological control products in a range of crops and situations. The main challenge in using biological controls in cut flowers is that stems, leaves and flowers are generally all harvested and represent 'the product'. Therefore, there is almost zero tolerance for damage or the presence of pests, or indeed the presence of the biological control agent. Despite this potential drawback, biological control is now widely practiced in cut flower production through augmentative biological control using invertebrate and microbial organisms (natural enemies and biopesticides) applied seasonally or prophylactically.

WHY USE BIOLOGICAL CONTROL?

In the past decade, many of the factors that encourage adoption of biological control have become more prominent in both cut flowers and food crops. Van Lenteren (2012) identified some of these factors, the most important of which has been the build-up of arthropod resistance to chemical pesticides. The issue of resistance has been further compounded by a significant reduction in the range of chemical active ingredients available to growers. Manufacturers have withdrawn many of the older, more toxic pesticides owing to pressure from national regulators. The maximum residue levels (MRLs) permitted for chemical pesticides have influenced growers' crop protection programs on edible crops.

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For cut flowers, retailers and supermarkets have imposed their own controls on the use of chemical pesticides by their suppliers, both in terms of numbers of detectable residues of any amount and the actual residue level on cut flowers. These actions are because of concerns about using pesticides in the production process and the possible harmful effect from the exposure of workers in the supply and production chains to any residues on the crop. Retailers are also concerned about negative publicity arising owing to the impact of pesticide use on environmental issues such as bumble bee deaths and water pollution. In a study in Belgium (Toumi *et al.*, 2016), many pesticide residues were found in roses, gerberas and chrysanthemum flowers, which raised concern about florists handling the flowers. However, they noted that the main residues were the less toxic fungicides. In the past 5 years, the use of the neonicotinoid group of insecticides globally has been severely restricted by international regulators owing to their harmful effect on bees. For those production zones outside Europe that supply the European markets, most producers have voluntarily withdrawn the use of neonicotinoids because of retailer pressure, despite neonicotinoids being legal to use.

Legislation is another reason for adoption. The European Union Directive on the Sustainable Use of Pesticides – Directive 2009/128/EC – has had a significant impact on pesticide use in Europe. The directive requires all professional users of pesticides to adopt the eight general integrated pest management (IPM) principles; however, the development of crop-specific IPM guidelines remains voluntary (Lamichhane *et al.*, 2016).

Initially growers found the use of biological control use challenging, but this has become easier as commercial biological control companies have developed more reliable, higher-quality products and designed more robust IPM programs. They provide growers with a greater level of technical support and knowledge transfer. Growers are now appreciating the numerous additional benefits accrued when using biological controls in a cut flower crop. The re-entry interval (REI) after the use of a biopesticide spray or application of a natural enemy is zero hours. This means there is no delay in re-entering the crop after application of a biopesticide, whereas harvesting operations can be restricted up to 48 h after the application of a chemical pesticide.

The re-entry period can be critical as some cut flowers need to be harvested two or three times a day to ensure the correct cut stage. The crop quality is often higher using biological control agents as pesticides are well documented to stress the plant. As a consequence, under an IPM program the cut flowers produce longer stems and glossy foliage. There is much less risk of phytotoxic damage to plants when biological control agents are used. Biological control agents can be used frequently without the risk of resistance and hence, provide a more sustainable production system without chemical residues (van Lenteren *et al.*, 2018).

Accurately quantifying the amount of biological control used in cut flower production is difficult. Globally, biological control usage is increasing at a faster rate than conventional pesticides across all crops (Dunham Trimmer, 2017). The use of biological control in cut flowers depends on a variety of factors including the type of crop, the pests that are prevalent and require control, the willingness of individual managers to adopt the technology and also the country where production occurs.

Biological control of spider mites is possible without the need for chemical acaricides to support the program, whereas the control of thrips is likely to require a combination of biological controls integrated with compatible pesticides. Biological control options for the control of fungal diseases are more limited. Large differences exist in the availability and cost of biological control agents in different countries. As an example, the cost of 1000 *Phytoseiulus persimilis* is about US$1 in Kenya, while in Europe it could be US$5. Unit costs have a major influence on the introduction rates and strategies for *Phytoseiulus*-based programs and consequently on whether the objective is to virtually eliminate spider mites or simply to create an acceptable balance in the numbers of pest and predators in the crop. In terms of budget, typically, a rose grower in the Netherlands may spend in excess of 70% of their crop production budget on biological controls, while in Kenya this might be 30–50% and in Colombia this might be less than 25%. In Colombia, the low figure spent on biological controls is partly due to the fact that fewer biological control agents are commercially available at an affordable price and fungal disease pressure is much higher than in other production zones. Intensive use of chemical fungicides leaves residues that make the use of predatory mites for spider mite control more complicated.

MAJOR PESTS AND THEIR BIOLOGICAL CONTROL

A major consequence of the cut flower industry moving away from broad-spectrum pesticides toward IPM programs is that the pest pressure has changed. For example, mealybug was rarely considered a pest in cut flowers, but is now a major secondary pest in roses. This has presented evolving challenges for the growers, the biological control industry, and the researchers who need to develop new solutions and programs. The following section examines some of the major biotic stresses cut flowers face and reviews the biological control solutions. It is not possible to cover every pest encountered by every cut flower, and Doğan *et al.* (2019) have also compiled a comparative list of pests and their biological control solutions in cut flowers.

Two-spotted mite (*Tetranychus urticae*)

The most common pest of cut flowers is *Tetranychus urticae*, a spider mite, which feeds on the sap of a very wide range of plants and can reproduce rapidly enough to severely damage or kill plants. It is known commonly as the two-spotted spider mite because the plant sap that concentrates in its gut can be seen as two spots. When stressed, owing to high or low temperatures or because of competition for plant sap reserves in high mite densities, this mite can turn red in color giving rise to its other common name – red spider mite. Normally these mites are yellow-green to dark red in color, partly dependent on the plant they are feeding on, and will turn bright orange-red when they enter diapause under unfavorable climatic conditions.

Even low levels of feeding damage will downgrade the quality of the cut flower. If mite populations are allowed to build up, leaf desiccation can occur, and the mites will produce copious webbing that can drop down from the plant containing masses of mobile spider mites. This dispersal mechanism allows them to move to other less populated leaves, spreading in air currents or on the clothing of greenhouse workers. Two-spotted mite is not the only mite that attacks cut flowers, and others include tarsonemid mites and bulb scale mites.

Twenty years ago, two-spotted mite was probably the number one pest in many cut flower crops. Yet in a relatively short period, control has almost completely moved away from pesticides to biological control and physical action products. Two-spotted mite became a successful pest for multiple reasons: it reproduced rapidly, it was difficult to target on the underside of leaves with sprayed pesticides, it easily developed resistance to pesticides, it was easily transferred from plant to plant by air movement and on the clothes of workers, and it was hosted by many plant species.

Biological control was successfully achieved by using the predatory mite *P. persimilis* (Fig. 7.1). This predator has been found in 36 countries from all the continents. Today this predatory mite is mass produced by biological control companies throughout the world (Migeon *et al.*, 2019). *Phytoseiulus persimilis* is a successful biological control agent because it feeds entirely on two-spotted mite, and it feeds on all its life cycle stages, eggs to adults. This focus makes it more efficient at controlling spider mites than other generalist predatory

Fig. 7.1. Adult predatory mite *Phytoseiulus persimilis*. (Photo: H. Wainwright.)

species such as *Amblyseius* mites. *Phytoseiulus persimilis* also has the ability to search out the pest wherever it might be on the plant, and it reproduces more rapidly than two-spotted spider mite.

The disadvantages of *P. persimilis* are that the population declines quickly in a crop when pest levels are low, and it does not reproduce well under conditions of low humidity. Therefore, *P. persimilis* is often used in combination with the predatory mite *Neoseiulus californicus* (syn. *Amblyseius californicus*), a generalist predator that can withstand lower humidity and exists in the crop for longer periods even when there is low pest pressure. Other predators of two-spotted spider mite that are used commercially include the gall midge, *Feltiella acarisuga*, which is used to manage hot-spot areas with high spider mite populations.

Biopesticides produced commercially from naturally occurring insect-killing fungi have also been used to manage spider mite populations. This option is particularly valuable after incompatible pesticides have been sprayed, leaving harmful chemical residues that last for several days and make it impossible to introduce predatory mites, e.g. *Metarhizium anisopliae* icipe 78 (Bugeme *et al.*, 2014).

Western flower thrips (WFT) (*Frankliniella occidentalis*)

Adult thrips are small winged insects ranging from golden yellow to black in color. With over 6000 species, the main thrips in floriculture is the *Frankliniella occidentalis* (western flower thrips, WFT). However, there are other crop-specific thrips such as *Thrips simplex* (gladiolus thrips) and increasingly species such as *Thrips setosus* (japanese flower thrips), which are spreading across the globe. Thrips can damage leaves, petals and stems by piercing and then sucking out the content of the cells leaving gray/silver patches. Some species of thrips are quarantine pests, while others transfer viruses. A quarantine pest is defined by the Food and Agriculture Organization of the United Nations (FAO, 2017) as 'A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled' (ISPM 5, FAO).

Whereas two-spotted spider mite has declined in importance as a pest of cut flowers, thrips species, and especially WFT, have probably become the most important pest of cut flowers and one of the most difficult to control. Thrips are a successful pest because, like spider mite, they develop rapidly (typically 12 days at 25°C), have high fecundity (up to 250 eggs per female), have a wide host range and can develop resistance to pesticides. Thrips are difficult to control chemically because of their complex life cycle that takes place on both the plant and in the soil. Thrips are difficult to target with sprays owing to their cryptic habits and thigmotactic behavior. Thrips are relatively weak flyers but can be blown into a greenhouse over considerable distances, escalating the resident thrips populations in a matter of hours. The attractiveness of flowers to thrips varies with the colors, odors and development stage of the crop. For instance, yellow roses are more susceptible than some of the other colored roses, and flowers that are harvested fully open, such as chrysanthemums and gerberas, present thrips with an easy target to invade.

Unlike *P. persimilis* for two-spotted spider mite control, there is no single thrips predator that can control all stages of thrips. The complexity of the life cycle of thrips has also made control particularly difficult. Consequently, researchers and the biological control industry have developed a large range of commercial biological control agents for thrips that need to be used in combination (Table 7.1). Growers of cut flowers do not just use a single control agent, but a plethora of biological control tools to manage thrips. These often have to be integrated with the use of selective pesticides. In Fig. 7.2, these biological controls are shown in relation to the life cycle stage of thrips they are attempting to control. Good control of thrips can be achieved using mainly biological control methods when production occurs in thrips-proof netted greenhouses that prevent the influx of adult thrips on air currents. However, the mesh size of the netting is very small and this reduces ventilation, thus

Table 7.1. Examples of commercially available biological control agents for thrips control.

Biological control organism	Common name	Life cycle stage targeted
Arthropods and mites		
Amblydromalus limonicus (syn. *Typhlodromalus limonicus*)	Predatory mite	Larvae
Amblyseius barkeri	Predatory mite	Larvae
Amblyseius cucumeris (syn. *Neoseiulus cucumeris*)	Predatory mite	Larvae
Amblyseius degenerans	Predatory mite	Larvae
Amblyseius montdorensis (syn. *Transeius montdorensis*)	Predatory mite	Larvae
Amblyseius swirskii	Predatory mite	Larvae
Atheta coriaria	Predatory beetle	Pupae
Macrocheles robustulus	Predatory mite	Pupae
Macrolophus pygmaeus	Predatory bug	Larvae
Orius laevigatus	Predatory bug	Larvae
Stratiolaelaps scimitus (syn. *Hypoaspis miles*)	Predatory mite	Pupae
Nematodes		
Steinernema feltiae	Entomopathogenic nematode	Larvae and pupae
Fungi (biopesticides)		
Beauveria bassiana	Entomopathogenic fungi	All life cycle stages
Metarhizium anisopliae	Entomopathogenic fungi	All life cycle stages

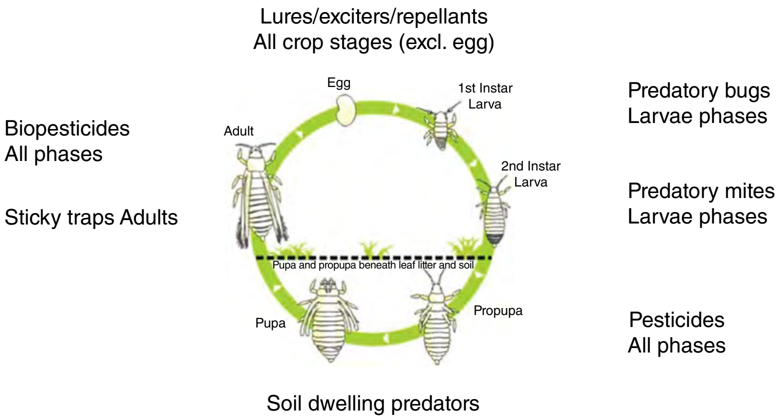

Fig. 7.2. The thrips life cycle showing the stage of when different control measures are applied**.** (Used with permission from M. Hoddle**.**)

requiring changes in environmental control of temperature and humidity. Other non-pesticide techniques for reducing thrips populations include sticky traps, often blue in color, and pheromone lures (Sampson and Kirk, 2013).

An extensive range of predatory mites is used for the management of thrips. None gives as good control as *P. persimilis* does for spider mite control. This is partly because these thrips predatory mites are generalists and no predator consumes all life cycle stages of thrips. McMurtry *et al.* (2013) described four groups of predatory mites with regard to their feeding behavior. Type I are the specialized mite predators of *Tetranychus* species, which include *P. persimilis*. Type II and Type III are generalist predators that include a wide and diverse group of general feeders that consume a varied diet. Many species in Type III have been shown to be able to feed and reproduce well on pollen. They can utilize plant exudates, fungi and honeydew as survival food in the absence of prey. Many of the thrips mite predators fall into Type III. The advantage of using predatory mites in Type III is that they can survive when the pest (prey) is absent but remain as a low population in the background until the pest reappears. The disadvantage is that the Type III mite predators are not dedicated to consuming the pest as a priority food source and are, therefore, less efficient at controlling high populations of the pest.

Tobacco whitefly (*Bemisia tabaci*) and the greenhouse whitefly (*Trialeurodes vaporariorum*)

Whiteflies are small winged insects (1.25–2 mm) that are serious pests owing to their ability to transmit plant viruses for which there are no control options. Whiteflies suck the sap of host plants, reproduce rapidly and can produce copious quantities of sugary solution or 'honeydew', which drips from their bodies as they feed. Black sooty molds will grow on the areas where the honeydew has collected, causing cosmetic damage to the cut flower crops.

Whiteflies are an important pest on certain cut flowers including gerbera, verbena, hypericum and roses. They are a major pest of Solanaceous crops. Whitefly development stages include the crawler stage, which is the only mobile stage, apart from the winged adult. The three sedentary larval stages, referred to as scales, are usually found on the underside of leaves, where they plug into the plant and feed on the sap. Scales are covered in a waxy layer that repels liquids and makes them difficult to control with pesticides.

Biological control of whitefly was probably one of the earliest examples of biological control. The rearing of *Encarsia formosa*, a parasitic wasp of whitefly, occurred as early as 1926. *Encarsia formosa* is a tiny wasp and a parasitoid of whitefly. The female lays an egg in the third- or fourth-instar whitefly larvae. Parasitized whitefly scales are black and therefore, easily distinguished from the white, unparasitized whitefly scales (Fig. 7.3). *Encarsia formosa* females can lay up to 300 eggs at a rate of about 10–15 per day. *Encarsia formosa* is generally introduced into crops as parasitized whitefly scales, often stuck onto cards to make them easy to distribute evenly in the crop canopy. The adult *E. formosa* wasps then emerge from these parasitized scales and begin searching the crop for whitefly scales in which to lay their eggs. Plants with hairy leaves, such as cucumbers, can restrict the movement of *E. formosa*. Ideally, temperatures for the application of *E. formosa* should be above 18°C. *Encarsia formosa* is also particularly sensitive to chemical pesticide use.

A similar parasitoid of whiteflies is the wasp *Eretmocerus eremicus*. *Eretmocerus eremicus* is used during periods of continuous high temperatures

Fig. 7.3. Whitefly scales parasitized with *Encarsia formosa* shown as black in color. (Photo: H. Wainwright.)

and low humidity, since *E. formosa* does not flourish under these environmental conditions. The life cycle of *E. eremicus* is very similar to *E. formosa* except that *E. eremicus* is an ectoparasite that lays its egg under the whitefly scale, whereas *E. formosa* is an endoparasite that lays its egg inside the whitefly scale. As the *E. eremicus* wasp eggs hatch, the larvae burrow into the whitefly larvae.

Encarsia formosa populations are generally 99% female, making them a particularly effective biological control agent since the act of parasitization kills the whitefly scale. *Eretmocerus eremicus* populations have a sex ratio of 50:50 but compensate for this lower number of females by engaging in aggressive host feeding involving the probing of scales with their formidable mouth parts to draw out the contents. When parasitized by *E. eremicus* the scales turn yellow and the *E. eremicus* larvae can be clearly seen inside the whitefly scale. The tobacco whitefly is usually the predominant whitefly species found at higher temperatures, and growers tend to use *E. eremicus* with this whitefly species as it is also adapted to higher temperatures.

Macrolophus pygmaeus is a polyphagous predatory mirid that has been used against whitefly, particularly in tomato crops. The predatory mite *Amblyseius swirskii* has been used for whitefly scale control often in combination with *E. formosa*. In the small black ladybird *Delphastus pusillus*, both the adult and larvae can be used against whiteflies *B. tabaci* and *T. vaporariorum*. Numerous biopesticides are on the market including the fungus *Isaria fumosoroseus*, strain Apopka 97 (syn. *Paecilomyces farinosus*), which is highly efficient against all whitefly stages (egg, larva, pupa and adult) (Biobest, 2020b). Yellow sticky cards are also very effective at trapping whiteflies (Fig. 7.4).

Fig. 7.4. Sticky card used for trapping flying pests such as whitefly, aphids and thrips. (Photo: H. Wainwright.).

Aphids (Aphididae)

There are numerous species of aphid, and they come in all colors, e.g. black, green, gray, pink, brown. Sizes range from 0.5 to 6.5 mm, and they have different common names, e.g. blackfly, greenfly. Aphids are soft-bodied insects and are differentiated from other Hemiptera by their ability to produce active young (viviparous birth) from unimpregnated females (parthenogenesis). A single species of aphid can be present on the same plant as either the winged form (alate) or wingless form (apterae). The winged form is often produced when adverse conditions are experienced, such as poor-quality plant sap, overcrowding or the onset of winter (short days and lower temperatures). Aphids feed by inserting their stylets into the plant cells. The aphid injects saliva as it probes the plant and in turn sucks up partially digested plant sap. During this feeding process, numerous plant viruses can be transferred. Some plants react to feeding damage by forming galls in leaves, which encompass the aphid colony. Large quantities of honeydew can be excreted by aphids during feeding, providing a substrate for the growth of sooty molds. Ants are often associated with aphids, attracted by the honeydew excreted during feeding. Aphids have a large number of natural enemies including several parasitic wasps, including *Aphidius* spp. (Fig. 7.5), numerous predatory insects and mites, and a range of fungal pathogens.

Banker plants as an open-rearing system are most often used for aphid biological control though they have been evaluated for many crop pests. This technology relies on aphids being very crop-specific. Aphids that feed on grasses (monocots) will often not attack other crop plants (dicots). Banker plants consist of a plant in the grass (Poaceae, formerly Gramineae) family, such as wheat, which is inoculated with cereal grain aphids that do not attack the crop plant.

Fig. 7.5. The mummies of aphids that have been parasitized by *Aphidius colemani*. (Photo: H. Wainwright.)

Table 7.2. Examples of commercially available biological control agents for aphid control.

Name	Common name	Mode of control
Coleoptera		
Adalia bipunctata	Two-spotted ladybird	Predator
Coccinella septempunctata	Seven-spotted ladybird	Predator
Delphastus pusillus	Black ladybird	Predator
Hippodamia convergens	Convergent lady beetle	Predator
Propylea quatuordecimpunctata	Fourteen-spot ladybird	Predator
Cecidomyiidae		
Aphidoletes aphidimyza	Gall midge	Predator
Hymenoptera		
Aphelinus abdominalis	Wasps	Parasitism
Aphidius colemani	Wasps	Parasitism
Aphidius ervi	Wasps	Parasitism
Aphidius matricariae	Wasps	Parasitism
Ephedrus cerasicola	Wasps	Parasitism
Praon volucre	Wasps	Parasitism
Syrphidae		
Sphaerophoria rueppellii	Hoverfly	Predator
Heteroptera		
Macrolophus pygmaeus	Bugs	Predator
Neuroptera		
Chrysoperla carnea	Lacewings	Predator
Fungi (biopesticides)		
Beauveria bassiana	Entomopathogenic fungi	Pathogen
Lecanicillium lecanii (syn. *Verticillium lecanii*)	Entomopathogenic fungi	Pathogen

The banker plant is also inoculated with an aphid parasitoid (see Table 7.2) that attacks both the non-pest and pest aphids occurring on crop plants. A common commercially available banker plant system that targets pest aphids in controlled environments uses the bird cherry oat aphid, *Rhopalosiphum padi*, as an alternative host for the parasitic wasp *Aphidius colemani*. *Rhopalosiphum padi* only feeds on monocots, reducing the risk of an unintentional, secondary infestation in most ornamentals, while *A. colemani* will breed on both the non-pest aphids (*R. padi*) and the pest aphids (*Myzus persicae* and *Aphis gossypii*) (Payton-Miller and Rebek, 2018). Typically, one pot of cereals is grown in every 1000 m^2 of greenhouse. The use of the banker plant system reduces the need for regular augmentative releases of parasitoids. However, the banker plants need to be maintained and replaced during the growing season, because they can become contaminated with hyperparasites such as *Dendrocerus* spp. and *Alloxysta* spp. Hyperparasites are parasites of the parasites within the aphid, and these organisms can result in a breakdown of aphid control in the crop.

Mealybugs (Pseudococcidae)

Mealybug species originate from tropical and subtropical locations. They are sap-sucking and associated with perennial, long-season crops or slow-growing plants including many ornamentals, of which cut roses are particularly susceptible. A waxy layer coats their bodies and protects them from contact insecticides. As sap-feeders, they can weaken the plant and in some cases can cause shoot distortion. Mealybugs also excrete honeydew during feeding, which results in black sooty mold. Mealybugs are mobile but tend to remain in clusters of females. The male mealybugs are very delicate-winged flies that only exist for about 48 h before dying. Mealybugs will spread slowly in a cut flower crop and can also be distributed in rose greenhouses moving plant debris, such as pruned stems, during crop hygiene operations. Mealybugs can also remain in the soil to infect a newly planted crop. Mealybugs have increased in importance as a pest in recent years owing to the reduction in use of broad-spectrum insecticides and the adoption of IPM crop protection programs that have focused on other pests. The two most common pest mealybugs in cut flowers are *Planococcus citri* (citrus mealybug) and *Pseudococcus longispinus* (long-tailed mealybug).

Cryptolaemus montrouzieri (Fig. 7.6) is one of the most established biological control agents for mealybug control. Kairo *et al.* (2013) report that this ladybird was introduced into California in 1891 for control of citrus mealybug. Since then, the beetle has been introduced into many countries around the world and is widely available commercially both as adults and larvae. As with other ladybirds this is a generalist that feeds on a large host range and not only on pests. Interestingly, *C. montrouzieri* was first introduced into Kenya in 1924 in an unsuccessful attempt to control coffee mealybug. More recently, this predator was again introduced in an augmentative program into cut rose production in Kenya and again failed to give economic control. The generalist predator *Chrysopa carnea* Stephens

Fig. 7.6. The adult predatory ladybird *Cryptolaemus montrouzieri*. (Photo: H. Wainwright.)

(green lacewing) is commercially available for use against mealybug as are the parasitoid wasps *Anagyrus pseudococci* and *Leptomastix dactylopii* among others. *Anagyrus pseudococci* is the most common commercial parasitoid reared for mealybug control (Triapitsyn *et al.*, 2007). It is a solitary, internal parasitoid and lays one egg per host, with the larva developing inside the host's body. In the greenhouses of Kenya, the natural occurrence of a tropical midge, *Diadiplosis megalamellae*, has been reported on rose plants predating on citrus mealybug (Hoogendoorn *et al.*, 2019).

Leaf miner

Leaf miners are small flies about 2 mm in length. Many species have a distinct yellow spot on their backs. Under greenhouse conditions, breeding is continuous year-round. Feeding causes cosmetic damage to leaves, and high populations can severely stunt plants. The critical issue is that some species are quarantine pests and any detection can lead to the rejection of shipments.

Chrysanthemum is the most susceptible cut flower to leaf miners, in particular *Phytomyza syngenesiae* (chrysanthemum leaf miner). However, a range of leaf miner species attack chrysanthemums, including *Liriomyza huidobrensis* (South American leaf miner, pea leaf miner), *Lirimyza trifolii* (American serpentine leaf miner) and *Liriomyza sativae* (South American vegetable leaf miner). Gerbera are also highly susceptible to leaf miner attack. The female fly punctures the leaves to feed and to lay their eggs. Feeding marks appear as very small pale spots on the leaf. The eggs hatch into larvae that begin to feed inside the leaf lamina and make narrow serpentine mines that are whitish in color.

Biological control of leaf miner is well established and reviewed in detail by Liu *et al.* (2009). *Diglyphus isaea* is an ectoparasitic wasp. Once the wasp has located the larva inside the leaf, the wasp stings the larva to paralyze it and then lays one to three eggs immediately beside the young larva. The *D. isaea* larva then begins to feed on the leaf miner larva until it is fully developed into an adult wasp. The adult of *D. isaea* emerges from the leaf to search for new leaf miner larvae in which to lay its eggs. *Diglyphus isaea* have an excellent searching capability making them effective even at low pest densities. A single female *D. isaea* wasp will lay 60–100 eggs.

The wasp *Dacnusa sibirica* is a slightly larger wasp than *D. isaea* and can be mistaken for the aphid parasitoid (*Aphidius* spp.). *Dacnusa sibirica* is an endoparasitoid, which lays its egg directly into the leaf miner larvae. Unlike *D. isaea*, the infection of *D. sibirica* in the leaf mine is difficult to detect without dissecting the leaf. *Dacnusa sibirica* works well at low pest densities and can be used at the first sign of pest damage and then followed up with *D. isaea* introductions. *Dacnusa sibirica* is also reported to be tolerant of lower light levels and shorter days than *D. isaea*.

The nematodes *Steinernema feltiae* and *Heterorhabditis bacteriophora* are used against leaf miner larvae. When the infective juvenile nematodes are applied as spray to plant foliage, they enter the leaf mines through the leaf miner feeding punctures or exit holes made by the leaf miner adults. Once inside the mine the nematodes swim to find a leaf miner maggot; nematodes then penetrate into the maggot body cavity via natural openings such as mouth, anus and spiracles. Infective juveniles of *H. bacteriophora* also enter through the intersegmental members of the larval cuticle. Once in the body cavity, infective juveniles release symbiotic bacteria (*Xenorhabdus* spp. for Steinernematidae and *Photorhabdus* spp. for Heterorhabditidae) from their gut in the maggot blood. In the blood, multiplying nematode–bacterium complex causes septicemia and kills maggots usually within 48 h after infection. The predatory bug *Macrolophus pygmaeus* can also be used in the canopy against leaf miner larvae.

Nematodes

Nematodes or roundworms or eelworms constitute the phylum Nematoda. They are a diverse animal phylum inhabiting a broad range of environments. Horticulturally, they are significant in two ways: the plant pathogenic nematodes and the beneficial, entomopathogenic nematodes that are discussed later.

The two important plant pathogen nematodes with regard to cut flowers are root-knot nematodes (*Meloidogyne* spp.) that form galls on the roots of cut flower crops such as chrysanthemum and rose. The other group is the stem nematode (*Ditylenchus dipsaci*), which causes discoloration of the stems and can lead to distortion on narcissus and tulips. For root-knot nematodes, infested soil is a major source of infection of the roots while river and lake irrigation water can contaminate the crop; therefore, it is important to identify the source of infestation. Soil sterilization using either steam or chemicals has been the traditional method of control. Various biopesticides have been developed and Marrone (2019) lists six different organisms that are now commercially available as bionematicides. Marrone (2019) also adds that bionematicides are the fastest growing category sparked by market need owing to loss of toxic chemical nematicides, e.g. methyl bromide. For bulb and stem nematodes, the major source of infestation is planting infected bulbs. Hot-water treatment is an established method of control for bulb and stem nematode, and no biological control methods are used routinely. Pest nematodes have declined in importance in cut flowers as the industry has moved toward soilless cultivation, clean water sources and healthy planting material.

Caterpillars (Order: Lepidoptera)

The larval stages of moths and butterflies have been a relatively minor pest of cut flowers. However, in recent years, various crops are seeing greater presence of three moths: *Thaumatotibia leucotreta* (false codling moth), *Duponchelia fovealis* (European pepper moth) and *Helicoverpa armigera* (cotton bollworm).

False codling moth caterpillars (larvae) attack more than 70 host plants, mainly in Africa. False codling moth has become a serious pest of cut roses in Kenya. The European Commission includes false codling moth on its list of harmful organisms and it is a quarantine pest to prevent its introduction into Europe, where it could attack outdoor or glasshouse crops. The EU issued new and stricter EU import requirements for false codling moth in March 2019 with their Implementing Directive 2019/523.

European pepper moth is distributed worldwide. The caterpillars are pests of cut flower crops such as lisianthus, limonium, gerbera and rose.

The cotton bollworm is a pest of carnation, rose and chrysanthemum, and it is present in southern Europe, Africa and Asia but not North or South America. A feature of these three Lepidoptera is that they can fly long distances and can easily infest a flower crop. Though their presence is often seasonal, under tropical conditions they can be present throughout the year.

Pheromones are chemicals produced as messengers that affect the behavior of other individuals of insects and in the case of moths they attract the moth to a trap. Commercial pheromones are available to monitor the pest populations of all three moths. In some instances, these pheromones can be used for mass trapping. Typically, a pheromone will last about 4–6 weeks in a trap. Pheromones can have increased evaporation caused by exposure to elevated heat and direct sunshine and may be cross-contaminated by field operators when setting up the traps, leading to mixed catches of moth species. The Delta trap is mostly used for the false codling moth and the cotton bollworm. The water trap is recommended for the European pepper moth, although the Delta trap is also used. For water traps the pheromone is positioned over a pan of water that has a thin layer of oil on the top of the water. The moths land on the surface of the water, where they remain trapped.

The bacterium *Bacillus thuringiensis* Berliner (*Bt*) produces highly specific protein toxins. *Bt*-based products have become the most widely used biopesticides against certain groups of pests such as caterpillars and mosquitoes. *Bt* products are most effective when applied preventatively against early life cycle phases (instars) of caterpillar pests. When ingested by the caterpillar larvae, the *Bt*-delta-endotoxins that possess toxic properties dissolve in the insect's gut. The resulting toxic liquid dissolves the gut cells of the insect, creating holes in the lining. The *Bt* spores spread through the caterpillar and germinate, causing death within 1–2 days; however, the caterpillar will probably cease to feed shortly after infection.

Many strains of *Bt* exist, but three of the most common biopesticides are based on the strains *Bt israelensis*, *Bt kurstaki* and *Bt aizawai*. *Bt* biopesticides suffer from poor product stability, easy inactivation under visible light, short residual effect period and slow speed of killing. In addition, insect resistance can develop; therefore, a resistance management strategy should be used. *Bt*-toxin genes have been incorporated into agronomic crop plants, i.e. transgenic *Bt* crops, but this technology has not been used for any flower crops (Xiao and Wu, 2019). Generalist predators such as the soil-dwelling predatory mite *Stratiolaelaps scimitus* (syn. *Hypoaspis miles*) and *Dalotia coriaria* (syn. *Atheta coriaria*) (rove beetle) consume Lepidoptera pupa in the soil. The egg parasitoid (*Trichogramma*) will attack Lepidoptera eggs, but it is not used in cut flower crops.

INTEGRATED PEST MANAGEMENT

The vast majority of cut flower growers use various IPM strategies for the management of their pest and diseases. There are many definitions of IPM, but for our purposes, IPM is defined as 'an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment' (Dreistadt, 2001).

Certified organic cut flower production is minimal; however, both IPM and organic approaches use biological control agents. The adoption of biological control is primarily through augmentative release; this is the supplementary release of the biological control agents at regular intervals during the crop life based on pest pressure. As cut flower production systems use IPM, the success of the biological control programs within IPM is dependent on the use of other pest management techniques (cultural, physical and compatible pesticides). As biological control of insects is better developed than that of diseases, many cut flower growers remain dependent on fungicide programs for disease management. The cultural techniques for disease management are fully discussed by van Lenteren and Nicot (2020).

Conservation of predator populations

Considerable effort and research have focused on conserving the predatory mite populations within the crop to provide a reserve corps of predators to prevent the resurgence of pests. Messelink *et al*. (2014) have comprehensively reviewed this strategy. For *P. persimilis*, this approach has limited potential because they can only feed on two-spotted spider mite and, in the absence of spider mite, their population in the crop will decline rapidly. *Phytoseiulus persimilis* will even become cannibalistic in the absence of spider mite as prey. To overcome the difficulty of establishing *P. persimilis* in a crop where spider mite levels are still low, the concept of introducing the live two-spotted spider mites as prey into the crop before the *P. persimilis* is introduced was tested. Known as 'Pest-in-First' this strategy has had limited commercial uptake owing to the risks involved. For Type III predator mites the addition of a supplementary food, such as pollen, into the crop has proved more successful (Vangansbeke *et al.*, 2016). However, the concern remains as to whether the predatory mites will prefer the supplementary food source rather than consuming the pest. Various studies have investigated whether the boost in mite numbers from the consumption of pollen outweighs the risk that the predators fail to prey on the pest quickly enough to prevent pest damage to the crop. There is the possibility that the pest itself may also eat the supplementary food and survive longer. In spite of these questions, supplementary foods are being used in commercial practice.

Another method of conserving the predators in the crop is the development of mini rearing systems in the crop. Examples include the use of *banker plants*, as discussed earlier in the chapter (e.g. for aphid biological control agents), where a potted plant infested with a species of aphid that does not attack the commercial crop is placed within the commercial crop itself. The banker plant is also infested with aphid parasitoids that hatch from parasitized aphids and fly into the commercial crop in search of other aphids.

The *slow-release sachet* (Fig. 7.7) has been developed for Type III predatory mites and it also addresses the problem of high labor costs associated with the need for frequent applications of predatory mites by hand into the crop. These sachets are small predatory mite breeding systems, suitable for *Amblyseius* spp., that contain proprietary diets including bran, saprophytic fungi, fungal-feeding astigmatic mites (prey), and the prey's food sources including sugars, starch and yeast. Proprietary sachet technology has been developed by the biological control industry and is patent protected. Such sachets are usually hung in the crop and release predatory mites over a period of 4–6 weeks. The concept of creating ecosystems that support the conservation and multiplication of biological control agents, such as certain predatory mites in a crop, is an exciting development that offers considerable advantages.

More recently, growers are using the same prey mites from the sachets as a food for predatory mites by scattering them directly over crops such as cut chrysanthemums. The benefit of this is that this predator food can be provided at a low cost. The industry is seeing many new types of distribution tools such as blowers to apply this type of food for predators. The concern with this strategy is whether the prey mite causes damage by feeding on the plant, which has been observed in cucumber crops. This is a topic for further biological control development in the future.

Beneficial, entomopathogenic nematodes

Beneficial, entomopathogenic nematodes are capable of infecting a wide range of insect pests. Their free-living infective juveniles penetrate host insects through natural openings or through the cuticle and release their

Fig. 7.7. The slow-release sachet used as breeding systems for *Amblyseius swirskii* in a rose crop. (Photo: H. Wainwright.)

symbiotic bacteria into the body cavity of the insect. The host is rapidly killed, and its cadaver is converted to nematode production, where they multiply freely. New infective juveniles emerge from the cadaver, dispersing and seeking fresh hosts to infect. The two families Heterorhabditidae and Steinernematidae are widely used as biological control agents. Though there are many species in these families, the main commercial species are *Steinernema carpocapsae*, *Steinernema feltiae*, *Steinernema kraussei* and *Heterorhabditis bacteriophora*. There have been major improvements in recent years in the nematode's efficacy through strain selection and improved methods of production, formulation and application (Labaude and Griffin, 2018). In cut flowers, the control of thrips larvae is commercially undertaken through the use of applications of *S. feltiae* to the crop canopy, while the control of sciarid flies and *Otiorhynchus sulcatus* (black vine weevil) larvae is achieved through the application to the growing media. Moth caterpillars are also killed by foliar application of *S. feltiae*. Similarly, black vine weevil can be controlled by soil drenches of *H. bacteriophora*. The parasitic nematode *Phasmarhabditis hermaphrodita* is widely recommended for use against slugs.

Integrated use of pesticides

To ensure that biological control agents are successfully used within an IPM program, the pesticides must be compatible with the biological control agents. The International Organization for Biological and Integrated Control (IOBC) has defined two main parameters of a pesticide that determine its compatibility with biological control agents: (i) the toxicity of the pesticide against the biological control agent, and (ii) the persistence of the toxic effect of the pesticide against the biological control agent. The pesticide effect is scored according to four toxicity categories: 1 = harmless: <25% mortality of biological control agent; 2 = slightly harmful: 25–50% mortality; 3 = moderately harmful: 51–75% mortality; or 4 = harmful: >75% mortality (Hassan *et al*., 1985). The persistence of any pesticide against a biological control agent is measured in days or weeks. There are extensive data published on the side effects of pesticides against biological control agents and most commercial biological control companies have side effect databases that are available on their websites. The toxicity and persistence of a pesticide is dependent on many factors: the stage of the life cycle of the biological control agent, the method of application of the pesticide (foliar spray or drench), the direction of nozzles (upper or lower leaf surface), the part of plants sprayed (foliage or flowers), the pesticide formulation and the location of the application (laboratory, greenhouse or open field). The persistence of a pesticide is influenced by the growth phase of the plant, the temperature, exposure to UV radiation and the method of irrigation (overhead or drip). Even a water spray can reduce the population of some natural enemies by as much as 25%, but such ‘products’ are still classified as harmless to the biological control agent.

In Table 7.3, examples of the side effects of commonly used pesticides are provided as an illustration. There is variation between different databases on the side effects of pesticides and many side effects have not yet been identified. Biological control companies based upon internal research, research results from IOBC’s Pesticides and Beneficial Organisms working group, published research journals and the agrichemical companies have compiled databases summarizing the side effects pesticides. Accessible databases are available from Koppert Biological Systems (www.koppert.com/global/), Biobest Group NV (www.biobestgroup.com) and Agrobio (www.agrobio.es). Similar side effects data exist for microbial biological control agents. Many insecticides and fungicides have no or limited harmful effect on microbial biopesticides even when tank mixed; however, growers are recommended to check compatibility. Most bacteria-based biological control agents such as *Bacillus subtilis* are compatible with nearly all chemical pesticides.

Table 7.3. The side effects of some pesticides on different life cycle stages of the biological control agent *Phytoseiulus persimilis*.

Pesticide active ingredient	Pesticide type	Application method	Pesticide persistence (weeks)	Side effect rating		
				Life cycle stage		
				Egg	Nymph	Adult
Deltamethrin	Insecticide	Spray	8–12	4	4	4
Imidicloprid	Insecticide	Spray	3–5	–	–	4
Imidicloprid	Insecticide	Drench	2	–	2	2
Spinosad	Insecticide	Spray	1	–	2	2
Spinosad	Insecticide	Drench	0	–	–	1
Azoxystrobin	Fungicide	Spray	0	–	–	1
Mancozeb	Fungicide	Spray	0	1	3	2
Metalaxl	Fungicide	Spray	Unknown	–	3	3

1 = harmless: <25% mortality; 2 = slightly harmful: 25–50% mortality; 3 = moderately harmful: 51–75% mortality; or 4 = harmful: >75% mortality.

Choice of biological control agent

Currently, growers have numerous options in the choice of biological control agents for different pests and diseases threatening their crops. In the recent past, viable options were restricted to insect and mite biological control agents for pest control, but now nematodes and microbials, sometimes referred to as biopesticides, are widely available. Factors that can influence the choice of control agent include effectiveness, cost, speed of control, persistence of the agent in the crop, season, environmental conditions, crop type (and even variety) and the application method of the biological control agent. For instance, mechanical air blowing of some predatory mites has significantly reduced the cost of application (Fig. 7.8) (Lanzoni *et al.*, 2017). Much of this information is gained through personal experience of the grower and their unique situation, especially since cut flower production spans a huge list of plant species and varieties grown in many unique locations.

Resistance of pests to biological control agents is very low; therefore, the rotation of different biological control agents is not necessary unlike chemical pesticides to which many pests are displaying varying degrees of resistance. There has been a rise in the use of biological control generalists (polyphagous predators), but this is mainly in greenhouse vegetable crops. Their polyphagy is advantageous as it allows them to survive when the target pest is reduced to low densities. Some generalist predators are also omnivores, so they can also feed on plant material. Examples of the feeding behavior of predatory mites are shown in Table 7.4. The anthocorid *Orius laevigatus* and the mirids, *M. pygmaeus*, *Dicyphus tamaninii* and *Nesidiocoris tenuis* are all omnivores (van Lenteren

Fig. 7.8. A mechanical air blower for the application of predatory mites**.** (From Lanzoni *et al*., 2017**.**)

Table 7.4. The feeding behavior of predatory mites. Facultative leaf-feeding refers to behavior that occurs but is not required for survival. Obligatory leaf-feeding refers to behavior that is required for survival. (From van Lenteren *et al*., 2020.)

Non-leaf-feeding	Facultative leaf-feeding	Obligatory leaf-feeding
Phytoseiulus persimilis	*Amblyseius limonicus*	*Iphiseius degenerans*
Neoseiulus californicus	*Typhlodromus pyri*	*Euseius gallicus*
Amblyseius swirskii		*Euseius stipulatus*
Transeius montdorensis		
Neoseiulus cucumeris		
Amblyseius andersoni		

et al., 2020). In the future, more omnivorous biological control agents will be used in cut flowers.

THE FUTURE

New pests

The types of pests and diseases that cut flower growers face are in a constant state of flux. The decrease in the use of broad-spectrum pesticides has resulted in an increase in what had been historically thought of as secondary pests, e.g. mealybugs. Invasive pests, such as *Tetranychus evansi* (red tomato spider-mite) and *Tuta absoluta* (tomato leaf miner) are an increasing challenge to cut flower growers (Parrella *et al.*, 2015). False codling moth is a quarantine pest and special measures are required to ensure that it does not spread with the movement of cut flowers. In such cases, the easiest and fastest option is to revert to conventional pesticide use. Yet with research and development, biological control solutions will be found and adopted.

Barriers and drivers

The adoption of new technology for any agricultural activity should consider the two paradigms: the barriers and the drivers for adoption. The adoption of biological control technology is no different. Typical barriers to adoption have included lack of knowledge of the grower, lack of suitable biological control agents, costs, availability in cut flower production areas, and registration and legal aspects of their use. The search and development for new biological control agents have also been restricted by increased regulatory requirements and the implementation of the Nagoya protocol concerning access- and benefit-sharing. The Nagoya protocol objective is to ensure fair and equitable sharing of benefits arising from the utilization of genetic resources, but implementation of the protocol without availability of clear guidelines has resulted in a bureaucratic nightmare for researchers. As a result, this has led to a dramatic decrease in bioprospecting for biological control agents (van Lenteren *et al.*, 2020). However, none of these barriers is permanent and barriers will change and evolve over time. Progress will occur through greater knowledge, better training, improved mass production techniques and improved communication with regulatory agencies.

The drivers for adoption of non-pesticide solutions to crop protection issues in cut flowers continue to gain international momentum. This includes customer preference for flowers free from pesticide residues, safer working conditions with less pesticide use in the production environment, and greater attention to environmental protection issues and factors contributing to climate change. It is highly likely that these drivers will continue to increase in importance in the coming years.

Research and development

The cut flower industry will continue to benefit from ongoing developments in biological control research led by academic and industry researchers. These efforts include: bioprospecting for new natural enemies (Ravensberg, 2011; van Lenteren *et al.*, 2018), the improvement of quality control protocols (van Lenteren, 2003), and the greater availability of biological control agents through improved production and storage technology. The use of biological control agents in cut flower production is now well established for some pests, such as two-spotted spider mite. However, pesticides are still needed in combination with biological control agents for pests such as thrips and many diseases.

Extensive research is ongoing to find biological solutions to difficult-to-control pests and diseases. This will not only involve new biological control agents but also new techniques to increase the effectiveness of biological control implementation. Examples include the expansion of in-crop breeding systems for predators, such as *Ambyseiulus* spp., as well as more efficient methods for delivering biological control agents into the crop, such as drone technology.

Tools to improve scouting accuracy will also play a part in targeting biological controls directly to the problem areas of the crop and research is already looking at robotic solutions to identify pests and diseases, and to further develop 'precision agriculture' techniques with the help of artificial intelligence. The potential of drones for scouting through advanced imaging technologies and application of biological control agents is just one example of novel approaches (Filho *et al.*, 2020).

For biopesticides, improvements in formulation, persistence and application methods are forthcoming. For example, the concept of auto-dissemination, which utilizes an infected insect as a disseminator of an entomopathogen among the insect population, is being evaluated for the management of various pests (Guimapi *et al.*, 2020). Linked to this are the bee vectoring systems that use managed bee hives to efficiently deliver naturally derived plant treatment products for crop protection, such as the use of bumble bees through the 'Flying Doctors®' concept (Biobest, 2020a).

When pests attack plants, the plants release herbivore-induced plant volatiles (HIPVs) and these play an important role in signaling information for natural enemies to be attracted to the damaged plant. The utilization of this phenomenon may be by either by (i) intercropping plant species that emit endogenous HIPVs, or (ii) applying HIPVs exogenously on the crop. Therefore, HIPVs could offer an excellent tool to increase the presence of natural enemies in crops (van Lenteren *et al.*, 2020). These concepts are recent novel ideas that may well expand to become routine commercial practice in the coming years. Whichever new biological control technologies enter the cut flower industry, this is an exciting time for crop protection. There will be challenges and the management skills of the producer will have to increase, but to remain competitive, growers must be rapid adopters of new technologies.

REFERENCES

Biobest (2020a) Biobest presents the innovative 'Flying Doctors®' concept. Available at: https://www.biobestgroup.com/en/news/biobest-presents-the-innovative-flying-doctors%C2%AE-concept (accessed 12 April 2020).

Biobest (2020b) PREFERAL WG. Available at: https://www.biobestgroup.com/en/biobest/products/biological-pest-control-4463/biopesticides-4482/preferal-wg-4621/ (accessed 12 April 2020).

Bugeme, D.M., Knapp, M., Ekesi, S., Chabi-Olaye, A., Boga, H.I. and Maniania, N.K. (2014) Efficacy of *Metarhizium anisopliae* in controlling the two-spotted spider mite *Tetranychus urticae* on common bean in screenhouse and field experiments. *Insect Science* 22, 121–128.

Doğan, E., Kazaz, S., Kaplan, E., Kılıç, T., Ergür, E.G. and Aslansoy, B. (2019) Biological control in cut flowers. *Acta Horticulturae* 1263, 315–323.

Dreistadt, S. (2001) *Integrated Pest Management for Floriculture and Nurseries.* Publication No. 3402. University of California. Oakland, California.

Dunham Trimmer (2018) Biological Products Markets Around the World. BIPA 2018 Spring conference and International Meeting. Available at: http://www.bpia.org/wp-content/uploads/2018/03/Biological-Products-Markets-Around-The-World.pdf (accessed 16 March 2021).

Filho, F.H.I., Heldens, W.B., Kong, Z. and de Lange, E.S. (2020) Drones: innovative technology for use in precision pest management, *Journal of Economic Entomology* 113, 1–25.

Food and Agriculture Organization of the United Nations (FAO) (2017) Glossary of phytosanitary terms. ISPM 5. Food and Agriculture Organization of the United Nations (FAO), Rome.

Guimapi, R.A., Mohamed, S.A., Ekesi, S., Biber-Freudenberger, L., Borgemeister, C. and Tonnangad, H.E.Z. (2020) Optimizing spatial positioning of traps in the context of integrated pest management. *Ecological Complexity* 41, 1–13.

Hassan, S.A., Bigler, F., Blaisinger, P., Bogenschutz, H., Brun, J., Chiverton, P. and Zon, A.Q. (1985) Standard methods to test the side-effects of pesticides on natural enemies of insects and mites developed by the IOBC/WPRS Working Group 'Pesticides and Beneficial Organisms'. *EPPO Bulletin* 15, 214–255.

Hoogendoorn, A.H.J., Murunde, R, Otieno, E. and Wainwright, H. (2019) Natural occurrence of *Diadiplosis megalamellae* (Barnes) in mealybugs on roses in Kenya. *African Journal of Agricultural Research* 14, 18–23.

Hussey, J. and Scopes, N.E.A. (eds) (1985) *Biological Pest Control: The Glasshouse Experience*. Blandford Press, London.

Kairo, M.T.K., Paraiso, O., Gautam, R.D. and Peterkin, D.D. (2013) *Cryptolaemus montrouzieri* (Mulsant) (Coccinellidae: Scymninae): a review of biology, ecology, and use in biological control with particular reference to potential impact on non-target organisms. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 8, 1–20.

Labaude, S. and Griffin, C.T. (2018) Transmission success of entomopathogenic nematodes used in pest control. *Insects* 9, 72.

Lamichhane, J.R., Dachbrodt-Saaydeh, S. Kudsk, P. and Messéan, A. (2016) Toward a reduced reliance on conventional pesticides in European agriculture. *Plant Disease* 100, 10–24.

Lanzoni, A., Martelli, R. and Pezzi, F. (2017) Mechanical release of *Phytoseiulus persimilis* and *Amblyseius swirskii* on protected crops. *Bulletin of Insectology* 70, 245–250.

Liu, T.X., Le Kang, Heinz, K.M. and Trumble, J. (2009) Biological control of Liriomyza leafminers: progress and perspective. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 4, 1–16.

Marrone, P.G. (2019) Pesticidal natural products – status and future potential. *Pest Management Science* 75, 2325–2340.

McMurtry, J.A., De Moraes, G.J. and Sourassou, NF. (2013) Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. *Systematic & Applied Acarology* 18, 297–320.

Messelink, G.J., Bennison, J., Alomar, O., Barbara L. Ingegno, B.L., Luciana Tavella, L., Shipp, L., Palevsky E. and Wäckers, F.L. (2014) Approaches to conserving natural enemy populations in greenhouse crops: current methods and future prospects. *Biological Control* 59, 377–393.

Migeon, A., Tixier, M.-S., Navajas, M., Litskas, V.D. and Stavrinides, M.C. (2019) A predator-prey system: *Phytoseiulus persimilis* (Acari: Phytoseiidae) and *Tetranychus urticae* (Acari: Tetranychidae): worldwide occurrence datasets. *Acarologia* 59, 301–307.

Parrella, M.P., Wagner, A. and Fujino, D.W. (2015) The floriculture and nursery industry's struggle with invasive species. *American Entomologist* 61, 39–50.

Payton-Miller, T.L. and Rebek, E.J. (2018) Banker plants for aphid biological control in greenhouses. *Journal of Integrated Pest Management* 9, 1–8.

Ravensberg, W.J. (2011) Implementation of a microbial pest control product in an integrated pest management programme. In: *A Roadmap to the Successful Development and Commercialization of Microbial Pest Control Products for Control of Arthropods*. Series: Progress in Biological Control. Springer Netherlands, Heidelberg, Germany, pp. 235–293.

Sampson, C. and Kirk, W.D.J. (2013) Can mass trapping reduce thrips damage and is it economically viable? Management of the western flower thrips in strawberry. *PLoS ONE* 8, e80787.

Toumi, K., Vleminckx, C., van Loco, J. and Bruno Schiffers, B. (2016) Pesticide residues on three cut flower species and potential exposure of florists in Belgium. *International Journal of Environmental Research and Public Health* 13, 943.

Triapitsyn, S.V., González, D., Vickerman, D.B., Noyes, J.S. and White, E.B. (2007) Morphological, biological, and molecular comparisons among the different geographical populations of *Anagyrus pseudococci* (Hymenoptera: Encyrtidae), parasitoids of *Planococcus* spp. (Hemiptera: Pseudococcidae), with notes on *Anagyrus dactylopii*. *Biological Control* 41, 14–24.

Vangansbeke, D., Nguyen, D.T., Audenaert, J., Gobin, B., Tirry, L. and de Clercq, P. (2016) Establishment of *Amblyseius swirskii* in greenhouse crops using food supplements. *Systematic & Applied Acarology* 21, 1174–1184.

van Lenteren, J.C. (ed.) (2003) *Quality Control and Production of Biological Control Agents: Theory and Testing Procedures*. CAB International, Wallingford, UK.

van Lenteren, J.C. (2012) The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. *Biological Control* 57, 1–20.

van Lenteren, J.C. and Nicot, P.C. (2020) Integrated pest management methods and considerations concerning implementation in greenhouses. In: Gullino, M., Albajes, R. and Nicot, P. (eds) *Integrated Pest and Disease Management in Greenhouse Crops*. Series: Plant Pathology in the 21st Century. Springer International, Cham, Switzerland, pp. 177–193.

van Lenteren, J.C., Bolckmans, K., Köhl, J., Ravensberg, W. and Urbaneja, A. (2018) Biological control using invertebrates and microorganisms: plenty of new opportunities. *Biological Control* 63, 39–59.

van Lenteren, J.C., Alomar, O., Ravensberg, W.J. and Urbaneja, A. (2020) Biological control agents for control of pests in greenhouses. In: Gullino, M., Albajes, R. and Nicot, P. (eds) *Integrated Pest and Disease Management in Greenhouse Crops.* Series: Plant Pathology in the 21st Century. Springer International, Cham, Switzerland, pp. 409–439.

Xiao, Y. and Wu, K. (2019) Recent progress on the interaction between insects and *Bacillus thuringiensis* crops. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 374(1767), 20180316.

8

Postharvest Management

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INTRODUCTION

Proper postharvest handling is critical to customer satisfaction. Nothing disappoints a customer more than buying beautiful flowers that die quickly. While many customers may complain, others may not and simply take their business elsewhere or stop buying flowers altogether. Providing customers with the longest-lasting flowers possible requires constant attention at each step of the marketing chain, whether that be directly from the producer to the final customer or via one or more intermediates.

Six main issues must be considered at every step in the postharvest handling system: temperature, water, sanitation, carbohydrates, disease and ethylene. Of these factors, temperature is generally the most critical, because it affects each of the other five factors. Nonetheless, all six can be limiting factors for various species and at various points in the marketing chain.

One of the best ways to ensure a positive customer experience is to conduct on-farm postharvest testing. In-house testing will allow producers to detect postharvest problems as they occur and potentially before the flowers reach customers. An in-house testing process can be set up in a separate room or on a tabletop anywhere in the operation where the temperature and light can be controlled (Fig. 8.1). A simple system is generally best and most sustainable. Pull sample bunches, label with relevant production information and date. If enough capacity is available, regularly conduct comparisons, such as treating flowers with the current flower food and comparing those with untreated flowers and those treated with a new product. A scout should check flowers daily, recording those that are no longer attractive to the typical consumer. It is best to have the same personnel running the testing to ensure consistency.

PREHARVEST CARE

Optimizing the postharvest life of cut flowers and foliage begins before planting with proper cultivar selection and continues through production.

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Fig. 8.1. In-house vase-life testing is necessary to monitor postharvest handling practices and performance. (Photo: J. Faust.)

Cultivar

Vase life among cultivars can vary greatly. For example, a study with 38 rose cultivars showed that vase life ranged from 5 to 19 days (Macnish *et al.*, 2010) and in a more recent study vase life ranged from 6 to19 days for 26 cultivars (Bergmann and Dole, 2020). In a separate study, 47 lisianthus cultivars grown at the same location had a vase life that ranged from 11 to 24 days (Harbaugh *et al.*, 2000).

Light

High light levels promote high endogenous carbohydrate levels, which in turn promote a long vase life. Maximize the light level for each crop based on their optimum conditions, which in some cases may dictate the use of supplemental lighting in the winter, if economical. Note that some species have a relatively low optimum light level and shading may be required. In addition, some foliage species need a lower light level to increase visual quality of the leaves.

Temperature

Low temperatures during production tend to promote high endogenous carbohydrate levels and a long vase life. Thus, it is best to grow a crop with the coolest temperatures that will still keep crop time fairly short. Temperature and light often interact in that high light will raise greenhouse temperatures. In lilies, high air temperatures decrease vase life and shade is recommended to reduce temperatures (Locke, 2010). However, excessively low light will reduce quality and yield.

Nutrition

Improper nutrition reduces visual quality of cut flowers, especially foliage. Vase life of cut flowers may be reduced directly through poor nutrition or indirectly if the foliage on cut flowers turns yellow before the flowers begin to decline.

Pests

Botrytis can be a major problem during postharvest and it typically infects flowers and foliage during production. If not controlled, it can rapidly develop during postharvest handling and shipping. In addition, insects and diseases reduce visual quality and often reduce vase life through ethylene generation. The presence of pests can lead to rejection of the product by customers and may result in the product being rejected, destroyed or fumigated during the importation process. If fumigated, the producer will pay for the fumigation and the product might be unmarketable thereafter.

Water

Cuts should be irrigated long enough before harvest that the surfaces are dry, but recently enough that the tissues are well-hydrated to delay wilting after harvest.

HARVEST

Developmental stage

The cut stage varies greatly with the species and the market. Flowers that do not open up much after harvest, such as astilbe (*Astilbe*), cymbidium orchid (*Cymbidium*) or gerbera (*Gerbera*), are cut more open than those that continue to develop after harvest, which are the majority of the most popular species. Flowers that will be stored or shipped are cut at a younger stage than those being sold directly to the final consumer. Species with large petals, such as gladiolus (*Gladiolus*) and lilies (*Lilium*), need to be harvested before they are open, otherwise the petals will be damaged during transport.

Species that have flower buds that rapidly open, such as roses (*Rosa*) peonies (*Paeonia*) and Dutch iris (*Iris* × *hollandica*), might have to be harvested multiple times per day to ensure that the flower are not too open at harvest. This is especially true during periods of high temperatures.

Flowers harvested when immature will generally not open up well or will not develop proper pigmentation. Flowers harvested when too old will have a short vase life. Cut greens are generally harvested when foliage is mature and attractive. Cut branches with berries are harvested when as many berries are well colored as possible but before the oldest berries start to fall. In some cases, branch tips with immature berries are removed during harvest. Decorative branches without leaves or berries can be harvested any time that they look attractive and have a long harvest period.

Time of day

Flowers that are susceptible to wilting are best harvested in the morning when tissues are turgid and water content is high. Flowers that need to open up after harvest or must be stored for a long period are best harvested in the afternoon when carbohydrate content is high (Ahmad *et al.*, 2014) (Fig. 8.2). However, the commercial reality is that flowers are harvested all day long in many operations. Thus, sensitive species should be harvested at their optimal time of day.

Harvest method

Most stems are cut with sharp shears or knives to ensure a fast, clean cut; however, the stems of a few species are pulled, such as gerbera and cyclamen

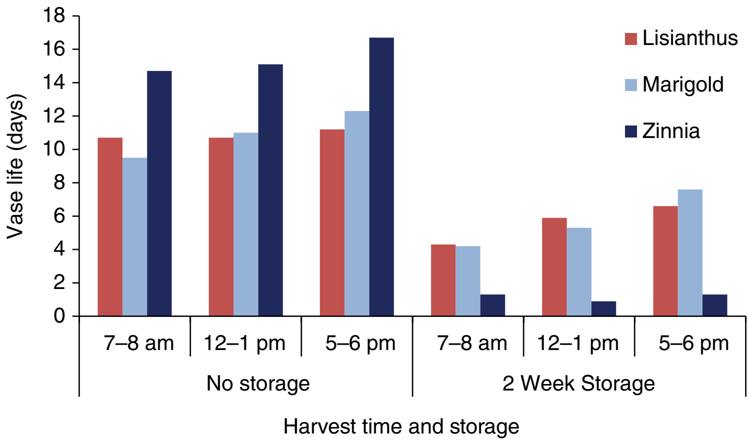

Fig. 8.2. Afternoon harvest resulted in the longest vase life for lisianthus (*Eustoma*), marigolds (*Tagetes*) and zinnia (*Zinnia*). (From Ahmad *et al.*, 2014.)

(*Cyclamen*). Tulips (*Tulipa*) can be pulled with the bulb attached, which allows the stems to better handle the stress of storage and processing. The bulb is then removed before boxing and shipping.

Foliage removal and bunching

Most cut flowers and foliages have lower leaves that need to be removed, which is often done in the production area. Leaves that are below the water line in buckets tend to decay rapidly and contaminate the water. In some cases, the flowers and foliages are durable enough that the stems are bunched at the same time the lower foliage is removed in the production area. With many species, additional foliage is removed mechanically during processing in the packing area. In situations where the foliage has a shorter vase life than the flowers, all foliage may be removed during processing.

Transport from field/greenhouse to packing house

Growers have two methods of transporting freshly cut stems from the field or greenhouse to the packing house. The stems can be transported dry, meaning they are not in any solution. In this situation, the stems are collated in the main aisle of the greenhouse, placed horizontally or hung vertically and transported to the packing house via monorails or vehicles (Fig. 8.3A and B) where they usually go to a cooler until they are processed. Alternatively, the stems are transported wet, meaning they are placed in a field postharvest bucket solution and taken to the cooler or processing room (Fig. 8.3C). The flowers are typically protected from receiving direct sunlight during transport with a covering positioned over the tractor or monorail (Fig. 8.3B and C).

Dry transport from greenhouse to packing house has the benefit of efficiency, i.e. less handling, less weight and increased uptake of the pre-packaging bucket solution. However, dry transport requires efficient handling systems because dry stems held at warm temperatures for any significant time will negatively impact vase life. Thus, dry transport works well if the time from harvest until the stems are in the cooler is minimal and in cooler climates. Dry handling can be used for the more durable species, such as carnation, rose and alstroemeria.

Wet transport from the greenhouse to packing house provides an opportunity to provide a disinfection treatment to species that may have a particularly high occurrence of bacterial contamination, e.g. gerbera and sunflower. Wet transport also provides an insurance policy if the time of transport is occasionally less than optimal or when handling species that are highly susceptible to dehydration. Optimizing the transport logistics is challenging because many factors play into this operation, e.g. the time from harvest to the collation

Fig. 8.3. Cut flowers can be transported from the greenhouses to the packing house by various means, including: (**A**) in canvas lonas on monorails (photo: J. Dole); (**B**) in hanging cones covered and pulled by a tractor; (**C**) in buckets on monorails (photos: J. Faust).

of stems in the main aisle of the greenhouse, the transport of the stems from the production area to the packing house, the time to move the stems into the cooler and the time it takes for the field heat to be removed from the cut stems. If any of these steps are delayed, the plants suffer and vase life will be negatively affected. Field postharvest bucket solutions provide a buffer so that the cuts experience less stress when logistical delays occur.

POSTHARVEST BUCKET AND VASE SOLUTIONS

From the time of harvesting the stem in the greenhouse to when the consumer discards the stem, the stem is placed into three or four different solutions to maximize its postharvest performance (Fig. 8.4). Each solution has a unique set of components chosen to meet the needs of the specific species at

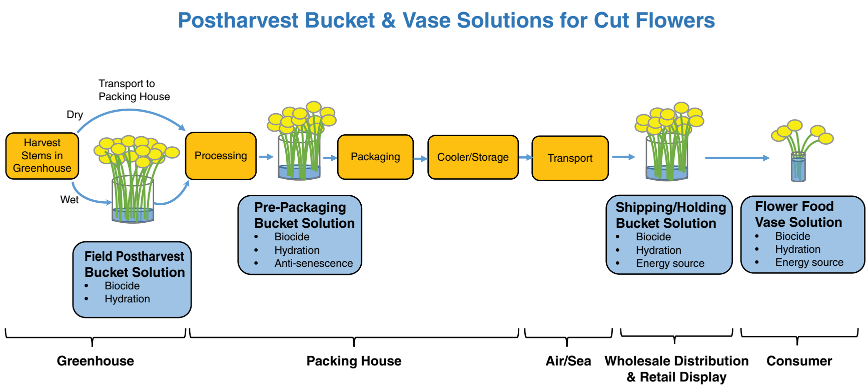

Fig. 8.4. Postharvest bucket and vase solutions for cut flowers from harvest to customer. Over the years, a large number and range of compounds and processes have been tested as ways to improve cut flower vase life or quality (Table 8.1). While a number of them have become commercialized, others have not as they are not effective enough, effective only on a limited number of species or not consistent (Illustration: J. Faust and J. Dole.)

the specific time in the postharvest process. Various names are used to describe these solutions, and these names can be confusing. For example, processed stems (graded, recut, leaf removal, sleeved or bunched) are placed in a solution prior to packaging the stems for long-distance transport. This solution is often referred to as the hydration solution. Hydration is one of the purposes of this solution, but it is not the only purpose. Also, solutions used during other steps in the postharvest life of the cut flowers contain an acidifying agent whose purpose is to improve hydration. The terminology presented in Fig. 8.4 is meant to describe each of the four postharvest solutions; however, the industry and other texts may use different terms.

Greenhouse/field harvest bucket solution

The solutions in which freshly harvested stems are placed are also known as hydration solutions in some firms (Fig. 8.5). Field postharvest bucket solutions typically contain two components: an acidifier to improve hydration and a biocide for disinfection. These solutions are frequently mixed at the greenhouse, but commercially blended products are also available. Citric acid is the most common acidifier, and the pH is typically reduced to 3.5–4.5. Common biocides include sodium hypochlorite (liquid bleach), and calcium hypochlorite (swimming pool chlorine). Hypochlorite products rapidly loses efficacy as the chlorine reacts with organic matter, so these solutions require daily replacement. Chlorine tablets of sodium dichloroisocyanurate dihydrate are also available and provide a more water-stable source of chlorine.

Table 8.1. Numerous compounds have been tested in the quest to extend cut flower vase life and quality.

Anti-ethylene agents

- 1-methylcyclopropene (1-MCP)
- Activated charcoal
- Aminooxy acetic acid (AOS)
- Aminoethoxyvinylglycine (AVG)
- Ethanol
- Ethylene absorbent compounds/scrubbers
- Methanol
- Silver nitrate
- Silver thiosulfate (STS)

Biocides

- 8-hydroxyquinoline citrate (8-HQC)
- 8-hydroxyquinoline sulfate (8-HQS)
- Aluminum sulfate
- Bacterial species (e.g. *Escherichia coli* K12)
- Calcium hypochlorite
- Chlorine dioxide
- Cobalt chloride
- Hydrogen peroxide
- Isopropyl alcohol
- Isothiazolinone (methylchloroisothiazolinone + methylisothiazolinone)
- Nano-silver (NS)
- Quaternary ammonium chloride (C-QA)
- Silver nitrate
- Sodium hypochlorite
- Sodium dichloroisocyanurate

Carbohydrates

- Dextrose
- Fructose
- Galactinol
- Glucose
- Maltodextrin
- Mannitol
- Mannose
- Pinitol
- Raffinose
- Sorbitol
- Sucralose
- Sucrose
- Trehalose

Fungicides and compounds with fungicidal action

- Essential oils (e.g. *Cinnamomum zeylanicum*, *Thymus vulgaris*, *Thymus zygis*)
- Fungicides (e.g. chlorothalonil, cyprodinil, fenhexamide, fludioxonil, fluxapyroxad, iprodione, prochloraz, etc.)
- Potassium bicarbonate
- Stylet oil (paraffin oil)

Nutrients

- Ammonium nitrate
- Boron
- Calcium chloride, calcium nitrate, calcium sulfate, calcium oxalate
- Copper sulfate
- Fluoride
- Iron sulfate
- Magnesium sulfate
- Manganese sulfate
- Nickel
- Potassium chloride, potassium nitrate, potassium sulfate
- Silicon
- Sodium chloride, sodium sulfate
- Zinc sulfate

Continued

Table 8.1. Continued.

Plant growth regulators

- Abscisic acid (ABA) and analogues
- Auxins (e.g. 2,4-dichlorophenoxyacetic acid (2,4-D), 3-indole butyric acid (IBA), indole-3-acetic acid (IAA) and alpha-naphtalene acetic acid (NAA))
- Cytokinins (e.g. benzylaminopurine (BAP), benzyladenine (BA), dihydrozeatin (DHZ), isopentenyladenine (2iP), kinetin (K), thidiazuron (TDZ) and zeatin (Z))
- Ethephon
- Gibberellic acid (GA)
- Gibberellic acid synthesis inhibitors (e.g. ancymidol, chlormequat chloride, daminozide, paclobutrazol)

Plant resistance enhancers/Biostimulants/Antioxidants

- Acetylsalicylic acid
- Acibenzolar-S-methyl (ASM)
- Bacterial species (e.g. *Bacillus subtilis* strain QST)
- Chitosan
- Jasmonic acid (JA), methyl jasmonate (MeJA)
- Methyl salicylate (MeSA)
- *Moringa* leaf extract
- Nitric oxide, nitric oxide donors
- Quercetin
- Salicylic acid

Solution acidifiers

- Aluminum sulfate
- Ascorbic acid
- Citric acid
- Lemon juice
- Vinegar

Miscellaneous

- Anti-transpirants
- Copper coins
- Cycloheximide
- Flaming of cut stem ends
- Hot/boiling water dips of cut stem ends
- Soda drinks
- Wetting agents/surfactants (various formulations)

Pre-packaging bucket solution

After stems have been processed, which includes grading, recutting, bunching and sleeving, they are placed into a bucket solution until they are packaged for transport (Fig. 8.6). These solutions are the first-stage commercial products, e.g. Chrysal #1, Floralife 100 series, that contain an acidifier for improved hydration and a biocide for bacterial control. These hydration solutions may be the same as those used during harvest.

This is the stage at which various species-specific and/or anti-senescence treatments might be applied for species such as alstroemeria, bouvardia, bulbous flowers, gerbera, lilac, lily, narcissus, rose, tulip and ethylene-sensitive species (Fig. 8.7). The commercial products are proprietary, but typically

Fig. 8.5. Roses placed in boxes with holes in the bottom and placed in a greenhouse harvest bucket solution prior to transport to the packing house or cooler. (Photo: J. Faust.)

Fig. 8.6. Following processing (grading, cutting, bunching and sleeving), roses are placed in a pre-packaging bucket solution in the packing house prior to boxing and cooling. (Photo: J. Faust.)

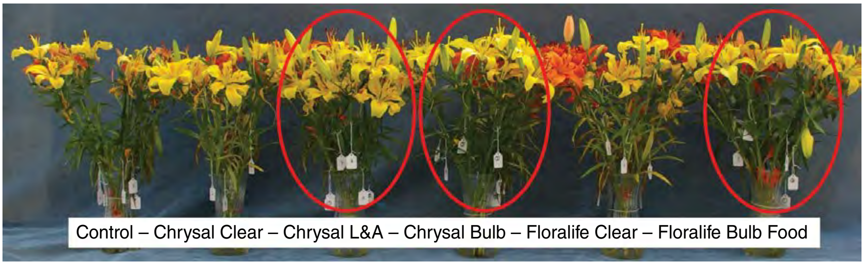

Fig. 8.7. The use of lily-specific commercial bucket/vase solutions improves flower longevity and delays foliar yellow. (Photo: J. Dole.)

include plant hormones that delay senescence, such as cytokinins, or anti-ethylene compounds, such as silver thiosulfate (STS) or aminoethoxyvinylglycine (AVG). Unique formulations have been developed for individual species or groups of species to maximize vase life. Also, liquid and powdered products are available for stimulating bud-opening of immature flowers, e.g. carnations and gypsophila.

The duration of this bucket treatment is temperature-dependent. If the buckets are in an ambient temperature room in the packing house, then the flowers will be in the solution for several hours. For this reason, these solutions may also be referred to as pulse solutions. If the buckets are located in a cooler, then the flowers may stay in the solution overnight (<24 h) before being packaged dry.

Shipping/holding bucket solution

The shipping/holding bucket solution is also known as the storage and transport, or transport and display solution. After flowers have been transported from the grower to the wholesale distributor, the stems are placed in this solution. These solutions are the second-stage commercial products, e.g. Chrysal #2, Floralife 200 series, that contain an acidifier for hydration, a biocide of bacterial control and an energy/food source, which is typically sugar. Thus, these solutions promote water uptake, minimize bacterial growth and provide energy for continued floral development. The flowers typically stay in these solutions for one to several days as they are transported to local distributors and retailers and are used for retail displays. The solutions can last for 1 week.

Vase solution

The vase solution is also known as the vase and foam, or flower food solution (Fig. 8.8). These solutions are the third-stage commercial products, e.g.

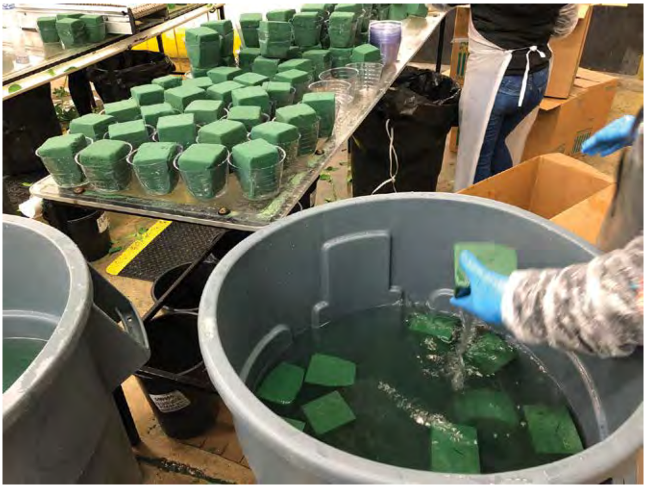

Fig. 8.8. Floral foam being soaked in a vase solution prior to making arrangements. (Photo: J. Faust.)

Chrysal #3, Floralife 300 series, for use by retail floral shops or consumers. The three components of vase solutions include: an acidifier for hydration, a biocide for bacterial control and an energy/food source for continued plant development. The amount of carbohydrates provided is generally higher than that in holding solutions. Specific products have been developed for flowers displayed in floral foam. Flower food packets are conveniently provided to retail customers to mix into the final vase solution. These packets are developed to be mixed into 0.5 or 1 l of water. Improper mixing may be detrimental to vase life, e.g. excess dilution will reduce the activity of the biocide, allowing the bacteria to thrive on the supplied sugar.

Adding to the complexity of postharvest solutions available in the marketplace are products with long-lasting, antimicrobial compounds that reduce or eliminate the need for flower stems to be recut. Unique versions of these products are available for each of the pre-packaging/hydration, shipping/holding and vase solutions.

POSTHARVEST HANDLING

Processing

The processing of cut flowers, foliage and branches can be a complex series of steps that need to occur rapidly and in a cool, if not cold environment. The processing steps are not typically difficult to do, but must be done as efficiently as possible. Processing stations are set up with a number of tools, often color coordinated, that allow workers to quickly determine stem length, head size, stem strength, etc. (Fig. 8.9). Each time a person must stop and think about the next step, the process is slowed down and mistakes are more likely to occur.

A number of flowering species are particularly prone to opening up too fast in warm processing environments, including anemone, iris, peony, rose and tulip, so these are handled exclusively in refrigerated environments. More durable species may be handled in a cool, but not cold environment that is more comfortable for the staff. Buckets or lonas of cuts are placed in the cool or cold environments until they can be processed.

Grading

Stems are graded and sorting based on stem length, flower (head) size, degree of openness, stem caliper and strength, and presence of defects: curved stems,

Fig. 8.9. (**A**) Flower processing and grading (note the color-coded sections used to determine flower grades); (**B**) rose grading system; and (**C**) processing room. (Photos: J. Faust.)

damaged petals or foliage that cannot be removed, off-type flowers, insects or diseases. Flowers are quickly accessed and cleaned up, if necessary, by removing damaged petals, discolored foliage and so forth before grading. Extra lower foliage is removed at this time. The soft tips of some woody species might be removed if they are prone to wilting. Processing stations usually have easy-to-use markings for determining stem length and strength. The grading system varies with the species, customer and use. High-volume customers might govern the standards for the products they purchase. Smaller grades might be used for bouquets or pre-made arrangements or may be sold to local markets.

Bunching

After grading stems are bunched, the ends are recut to a uniform length and any stray lower foliage is removed. The cut is made perpendicular to the stem, not at an angle. Cutting at an angle leaves points of tissue that will become damaged when the stems are placed in bucket, resulting in more microbial growth. The number of stems per bunch varies with the species and the market. Ten stems per bunch is quite common and up to 20–25 stems/bunch for roses. Flowers packaged for direct sales to consumers may have any number of stems, usually an odd number for aesthetic reasons. With large flowers, single-stem ‘bunches’ are also sold. If bouquets are created in-house, the stems may not be bunched. Foliages and some filler flowers, such as gypsophila, are typically sold in bunches with a minimum weight.

Treatment with solutions

Most species are treated with one or more of the solutions indicated in the ‘Postharvest Bucket and Vase Solutions’ section above. Treatment time will vary, usually from a minimum of 4 h to overnight.

Sleeving

Most cut products are sleeved to reduce mechanical damage during the subsequent storage and shipping process. Even direct-market growers will usually wrap bouquets in paper to help the customer safely transport it home. The bunches may be sleeved after bunching or after treatment with solutions. If botrytis is especially problematic, sleeving may be delayed as the material can trap moisture around the foliage and petals. For flowers prone to botrytis, packing paper and sleeves impregnated with antimicrobial compounds are available.

Packing

After bunches are treated and sleeved, they are packed into boxes, unless they are being shipped in water. It is a common tendency to try to pack a lot of plant material into a box for cost-effective shipping. However, overpacking will damage the flowers and make it difficult to lower the temperature of the plant material. This is especially important for species such as gerbera, larkspur, lisianthus and tulips that are prone to growth tropisms and will turn up if laid flat for too long. The longer the stems are subjected to warm temperatures and the warmer the temperature, the more the stems will turn up after the customer receives the flowers. The packing of boxes is an important skill that must be learned well to allow the flowers to be successfully shipped.

Similarly, for flowers shipped in buckets, be sure not to overpack the buckets, which can damage the flowers and foliage. For species prone to tropisms, stems should be packed tightly, but carefully, in buckets to ensure that none are leaning.

Sanitation

After temperature, sanitation is the next most important factor affecting postharvest performance of most cut flowers. The main side effect of microbial growth is the plugging of stem xylem, which reduces or stops water uptake. However, in some situations, microorganisms can directly discolor and decay stems. Strict sanitation is necessary to prevent the build-up of microbial growth in buckets and on clippers and work surfaces. Regularly clean and wipe down clippers and surfaces with disinfecting agents. Use cleaners with a residual effect to maximize the duration of effectiveness.

Bucket sanitation is most critical, and buckets should be thoroughly cleaned between every use. Both the insides and the outsides of the bucket should be cleaned as they are often stacked one within another (Fig. 8.10). While display buckets are often black or some other color to show the flowers well, buckets for processing and handling should be white as that color makes it easy to see when they are clean. Buckets should be replaced if they have a lot of gouges or indentations in the plastic that make them difficult to clean. Commercial bucket-washing equipment is necessary for medium to large operations owing to the volume of buckets to be cleaned. Flower foods with antimicrobial compounds or chlorine tablets help to keep buckets free of microbial growth, but are not a replacement for good sanitation practices. The take-home message: *would you drink out of the buckets after they are clean?* If not, they should not be used for flowers as well.

Fig. 8.10. Commercial bucket-washing equipment is necessary to clean the large number of buckets needed each day. (Photo: J. Dole.)

Water quality

Cut flowers last longest in solutions with a low pH, approximately 3.1–4.0, and low to moderate soluble salt levels, 0.25–2.0 dS/m. Acidifiers are typically required to lower the water pH; however, the products may not work well if the water has an exceptionally high pH or alkalinity. In such cases, the water must be treated via acid injection or reverse osmosis or an alternative water source must be found.

The use of flower foods during processing can help overcome the negative effects of high or low soluble salts, but water that has too high a level of soluble salts may need to be treated with reverse osmosis. Cut flowers and foliage tend to be less sensitive to high or low soluble salts than to high pH, but the effect varies with the species. For example, zinnia can be quite sensitive to high water EC.

The presence of specific ions, such as fluoride or boron, might also cause problems. In particular, fluoride damages gladiolus and freesia flowers. Gladiolus is especially sensitive to fluoride, which causes transparent outer margins of the petal, failure of the flowers to open, burning of the floret sheath, marginal leaf scorch and premature wilting.

Ethylene control

The presence of ethylene can greatly shorten the vase life of species sensitive to the gas. Ethylene is a naturally occurring plant hormone that regulates a number of processes within plants, including ripening and senescence. Ethylene is produced by plant tissues when plants are damaged either by harvest or by processing. This ethylene, known as wound ethylene, generally increases rapidly after harvest and declines within 24 h. Some plant species produce relatively high levels of ethylene regardless of wounding. Also, pollination of flowers induces ethylene production and the subsequent senescence processes, since pollinators no longer need to be attracted to the flower.

Cut flowers can be damaged by ethylene from external sources, such as malfunctioning heaters, fruits and vegetables, decaying plant material, space heaters, engine exhaust, welding and cigarette smoke.

Besides reduced vase life, a number of symptoms indicate ethylene damage include abscission of leaves, buds and flowers, bud abortion, foliar chlorosis and epinasty (twisting and turning of foliage and/or stems). Symptoms often appear within 24 h, but can be delayed if stems are quickly stored or shipped at cold temperatures, since ethylene production decreases as temperature decreases.

Sensitivity to ethylene varies with the species, ethylene level, duration of exposure and temperature. Exposure to low levels of ethylene at warm temperatures or for long durations (a couple of days) can cause as much damage as high levels of ethylene for a few hours or at colder temperatures. There are innumerable combinations of conditions that can either result in damage or leave cuts unharmed. However, as a general guideline, sensitive plants can be damaged if exposed to ethylene concentrations as low as 0.1 ppm for 24 h or 0.25 ppm for 12 h. Exposure to 10 ppm for a few hours can lead to plant death. The threshold concentration for significant damage to many cut species appears to be in the range of 0.01–0.1 ppm.

One of the key strategies for preventing ethylene damage is temperature management. Generally, temperatures in the range of 1–2°C will prevent damage from low to moderate concentrations of ethylene. For those species sensitive to cold damage, keep the harvested stems as cold as possible for the species. A number of other preventative strategies include:

- Provide excellent ventilation in processing, packing, holding and shipping areas, while ensuring the flowers do not dehydrate. In coolers, provide good ventilation to prevent the build-up of endogenous ethylene in the air near the stems.
- Be sure that coolers and processing, packing, holding and shipping areas are regularly cleaned to remove decaying plant material. Strip old foliage from stems before storing.
- Do not store flowers with fruits and vegetables.
- Avoid engine exhaust, use electric-powered vehicles wherever possible. Use combustion engines only in areas with excellent ventilation.
- Provide excellent botrytis-control measures.
- Store ethylene-sensitive flowers in separate coolers from those that produce ethylene, such as cut evergreens.
- Delay packing of ethylene-sensitive flowers as boxes can allow ethylene to build up.
- Pack and ship flowers as soon as possible.

When prevention is insufficient, anti-ethylene agents may be needed. The two most commonly used compounds are STS and 1-methylcyclopropene (1-MCP), and both block ethylene receptor sites within the plant tissue. This prevents the plant tissue from 'sensing' ethylene and prevents ethylene damage from both internal and external sources.

STS is applied to cut flowers as a pre-packaging, pulse solution from 4 h to overnight. The STS is taken up the stems, moving through the plant tissue and blocking receptors. Follow directions carefully as phytotoxicity can occur. In addition, left-over solution must be disposed of properly and according to directions as silver is a toxic, heavy metal that can contaminate water supplies. Delivery systems can be devised to ensure that all, or almost all, of the solution is taken up by the stems, greatly reducing the need for silver disposal. STS stays within the plant tissue and continues to block new receptor sites as they develop; thus, STS is suitable for either single-bloom flowers or those that also develop new florets in the postharvest environment.

1-MCP is a powder that produces a gas when mixed with water or the solution provided by the manufacturer. The gas penetrates the plant tissue, blocking the receptors (Blankenship and Dole, 2003). For effective applications, the gas must be released into an enclosed chamber and the flowers treated for 4 h to overnight. The application rate is determined by the temperature, exposure time and flower species. The gas can be released into holding rooms, coolers, delivery truck containers or chambers constructed specifically for 1-MCP treatment. 1-MCP is considered to be very safe for both humans and plants. 1-MCP does not stay within the plant tissue for a long time as it can diffuse out of the tissue as easily as it diffuses into the tissue; thus, 1-MCP is most effective on single-bloom flowers that do not develop additional receptor sites in the postharvest environment. However, repeated applications of 1-MCP do not cause phytotoxicity, allowing flowers to be treated more than once, if necessary. Sachets containing 1-MCP powder can be placed in boxes with the flowers. The high humidity within the boxes causes the release of the 1-MCP. Sometimes the process is jump-started by dipping the sachets in water before placing them in the boxes.

Anti-transpirants and moisture-retentive packaging

Anti-transpirants are compounds applied to the leaves of cut flowers or cut foliages to reduce water loss, delay wilting, reduce yellowing and, in some cases, increase vase life. Most anti-transpirants are oil-based, which has the added advantage of making the foliage glossy and more attractive while hiding minor visual imperfections. Anti-transpirants should be tested before use as the products can cause unsightly dark spots from the oil penetrating the leaf tissue. Damage can take a while to appear, so be sure to monitor the foliage for its entire vase life. If damage occurs, reduce the application rate. Some crops, such as cast-iron plant (*Aspidistra*), are prone to damage and should not be treated with anti-transpirants.

On a large scale anti-transpirants are applied by dipping stems into large tanks. Avoid overpacking the tanks to ensure that stems are uniformly and adequately covered. If a species is prone to disease, replace the solution regularly to reduce spread. The dipping process can be combined with the cooling by refrigerating the solution.

Water loss can also be reduced by maintaining high humidity in the cooler and packing stems into water-retentive boxes. These boxes are coated in wax or other substances to retain the humidity in the boxes and prevent the cardboard from getting wet and losing integrity.

Coloring, glitter and other enhancements

Increasingly, cut flowers and foliages are being colored, glittered, beaded or otherwise enhanced to provide colors not found in nature or just to provide a unique appearance (Fig. 8.11). One common enhancement is the use of floral

Fig. 8.11. Value added enhancements include (**A**) rainbow-dyed roses (photo: J. Faust); (**B**) dyed chrysanthemums (photo: J. Faust); and (**C**) dyed and glittered roses (photo: J. Dole).

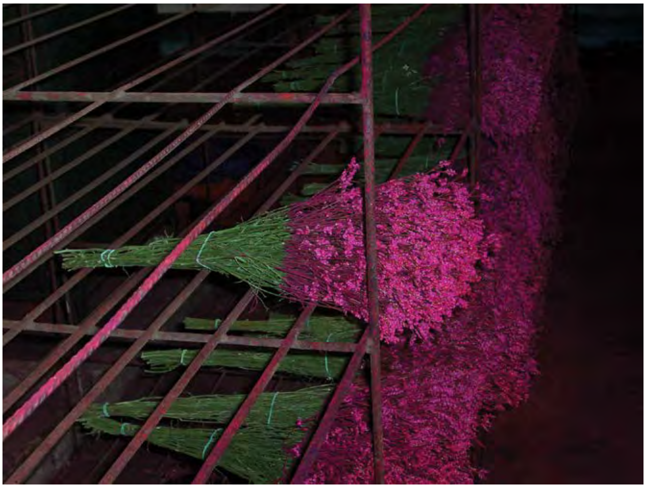

Fig. 8.12. Statice flowers dipped in colorant on drying racks. (Photo: J. Dole.)

sprays that make flowers or foliage glossy. Glitter and beads are applied by first dipping or spraying the flowers with a non-toxic adhesive and then adding the glitter or beads. Products are available that combine adhesive and glitter, and sometimes color, simultaneously.

Flowers and foliage can be colored by infusing them systemically with dyes or coating them. In systemic dyes, fresh flowers or foliages are placed in buckets with colorants and allowed to take up the solution. Be sure to use fresh flowers or those that have been dry-stored to ensure proper uptake of solution. Old flowers or those that have been stored in water may not take up enough solution to generate a vibrant color. Recut the stems and place the flowers in warm (40°C) solutions for 30–60 min. Wash off excess dye, then place in other postharvest solutions, such as a flower food, if needed. While many species can be colored, carnations, chrysanthemums, hydrangeas, roses and sunflowers are most commonly used.

Flowers and foliages can also be colored by dipping them into solutions or spraying them with colorants (Fig. 8.12). Commercially, many bunches are dipped into large vats at one time, allowed to drain and then hung or placed on a rack to dry. Be sure to test products to ensure that they do not reduce vase life and that the colors do not fade or bleed out of the tissue.

STORAGE AND SHIPPING

Temperature

The general rule for storage and shipping temperature is to be as cold as possible without damaging the plant (Fig. 8.13). Low temperatures greatly reduce

Fig. 8.13. A cooler with boxed cut foliages being held prior to shipping. (Photo: J. Faust.)

respiration, slow the decline in carbohydrate levels, and reduce botrytis development, water loss and ethylene sensitivity. For most species, the optimum temperature is 1–2°C. Closer to 0°C would be best, but this temperature is difficult to maintain without cold spots in the cooler that might freeze the flowers. Tropicals and a few annuals or temperate species are sensitive to cold temperatures. In particular, some lilies, zinnias and celosia are damaged by temperatures below 5°C. Tropicals are quite cold-sensitive and should be held at 12–16°C.

Unfortunately, coolers are often too warm, because the temperature has been set too high, the temperature-control system is not properly calibrated or too much warm product has been regularly placed in the cooler. The first two situations are easy to correct, the latter one may require a pre-cooling area that removes much of the field heat before the plant materials are placed in the cooler.

Temperature control during shipping is more problematic owing to the potential lack of control. Producers can cool the product and maintain cold temperatures until handing the product over to the shipper. Unfortunately, shipping delays can occur and product is sometimes left in hot locations too long. The best defense against temperature issues during shipping is to ensure that the product is properly packaged and cold when it leaves the production facility and shipping times are as short as possible. Additional protection can be provided with the use of ice or frozen gel packs for high-value flowers, which work if the boxes are well insulated.

Humidity

Relative humidity should be kept high, around 95%, to keep flowers and foliages from drying out during cold storage. Humidity is often too low in coolers, around 85%. To increase humidity temporarily, spray water on the floor and pack flowers close together. If spraying water on the floor repeatedly, clean floors regularly to keep them from getting slippery from algal growth. The best long-term solution is to use coolers with humidity control. The humidity in boxes usually rises rapidly owing to transpiration of the plant materials in the enclosed environment.

Unfortunately, a number of flower species, such as roses and peonies, are especially sensitive to botrytis and high humidity during storage can accentuate botrytis development. In such cases, reduce humidity to around 85–90% and provide excellent air movement.

Disease control

While any number of diseases can occur on cut flowers after harvest, gray mold (botrytis) is by far the most common. Botrytis has a very broad host range and, unfortunately, is ubiquitous in most production greenhouses, tunnels and fields. Botrytis is common on fallen leaves, petals and other debris, producing spores that can infect petals under the right conditions. Optimal conditions for botrytis spore germination and infection are 13–24°C, greater than 93% relative humidity, and 8–12 h of free water exposure (Sosa-Alvarez *et al.*, 1995; Zhang and Sutton, 1994), which also happens to be the production environment for many cut flowers.

Typically, botrytis spores infect petals during production, but develop and spread during postharvest handling, storage and shipping (Fig. 8.14). During postharvest handling, flowers may become wet from filling buckets, handling or condensation, leading to spore germination and hyphal growth. Packing stems into high-humidity boxes further exacerbates the issue. Keeping temperatures as cold as possible during processing, packing, holding and shipping will slow the development of botrytis, but warm temperatures resulting from breaks in the cold chain from producer to customer can cause rapid development of latent infections. Prevention is the best strategy by controlling botrytis as much as possible during production. In addition, be sure to control diseases, insects and nutritional problems during production as they

Fig. 8.14. Progression of *Botrytis* blight symptoms from initial infection to spore formation (Photo: J. Dole.)

can result in dead tissue, such as leaf edges, which then become infection sites for botrytis.

Postharvest sprays or dips can be used to control botrytis after harvest, but they run the risk of making the disease worse if they are not close to 100% effective. The added moisture can encourage botrytis growth so be sure to allow petals to dry before further handling and test fungicides for effectiveness and lack of phytotoxicity before treating large numbers of flowers.

A number of other diseases can occur during postharvest handling, most of which develop during production and continue during postharvest handling, including sclerotinia, erwinia and itersonilia. For example, itersonilia can cause severe petal blight damage on gerbera and chrysanthemum. Symptoms begin as small, pinpoint, brown lesions on the petals, which enlarge and coalesce, leading to necrosis of the entire blossom. Petal blight can develop at 1–20°C, allowing for postharvest damage of cut flowers.

Environmental monitoring

Large amounts of product can be lost quickly owing to malfunctions, and environmental monitoring systems and processes are critical. The best systems are automatic, keeping a record of temperature and humidity in the cold storage facilities and sending out alerts if the temperature rises or falls below a set point. These systems generally allow real-time monitoring of temperatures from off-site. At the other end of the spectrum are older systems without automated monitoring that need to be checked regularly during the day and evening to ensure they are working. Temperature logs should be maintained to verify temperature and spot the beginnings of any potential malfunctions. With any monitoring system the sensors should be placed where the flowers are to ensure accurate temperatures and humidity.

Air movement

Air movement is needed in cold storage areas to prevent cold and warm spots. Cold spots may be particularly problematic if they are below freezing and damage flowers quickly. Warm spots cause less obvious problems, but reduce the vase life of flowers. Also, air movement can disperse ethylene molecules from flowers, reducing their impact. However, too much air movement can desiccate flowers.

Light

Sufficient light needs to be provided to allow workers to manage the flowers, read labels, etc. While most cut flowers and foliages can be stored in the dark, the foliage of a few species, including alstroemeria, chrysanthemum and protea, can yellow if stored in the dark and not held cold enough. The foliage yellowing can be prevented by providing enough light to allow a low level of photosynthesis, which is about the intensity of a bright office. However, it is easier and more effective to provide the appropriate cooler temperature, anti-yellowing flower foods or other anti-senescence treatments.

Forced-air cooling

Boxes packed with flowers and foliage can be difficult to cool down owing to the large amount of plant material in a small space with limited room for air circulation. In fact, high respiration rates of the plant material can cause the temperature to actually increase after boxes are placed in cold storage. The best solution is to cool flowers first and then pack. However, even then the plant material will need to be cooled further. In addition, during shipping boxes may warm up and have to be cooled down. Forced-air coolers pull cold air through holes in the ends of boxes by positioning the boxes in front of large horizontal air handlers (Fig. 8.15). Air is much more easily pulled than pushed; hence, a negative pressure is applied. Monitor the temperatures of the plant material in the boxes using probe thermometers and remove as soon as the proper temperature is reached. Excessive forced-air cooling will dehydrate the flowers.

Controlled-atmosphere (CA) storage

Controlled-atmosphere (CA) storage balances low oxygen, elevated carbon dioxide and low temperatures to reduce respiration and delay the decline in vase life caused by storage. Currently, CA storage appears to be most applicable for sea shipping where the environment in the containers can be strictly controlled and shipping durations are extensive. The balance of gases in CA storage can be maintained either actively or passively through the use of selectively gas-permeable films.

Fig. 8.15. Forced-air cooling allows rapid removal of heat from within boxes of flowers. (Photo: J. Faust.)

Wet vs. dry storage and shipping

It is preferred to use dry storage and/or shipping whenever this can be done for cut flowers and foliage without reducing vase life. However, wet storage and/or shipping, i.e. placing stems in a solution, is often done for logistical reasons or because many species do not tolerate dry postharvest conditions.

Logistically, water is difficult to work with because it is heavy, making it difficult for workers to carry, and it is expensive to ship. Flowers in buckets of water cannot be easily stacked vertically, thus they take up more space than those held dry. Water has tremendous thermal mass, so it takes a lot more energy to remove the field heat from buckets of flowers brought from the greenhouses to the cooler. Also, water accelerates microbial growth and distribution, resulting in a decline in vase life.

For species that do not tolerant dry shipping conditions, the stems can be inserted into floral tubes filled with a postharvest solution. This technique works well for high-value flowers, such as orchids or gerbera. Other high-value flowers can be air shipped in Procona® or similar buckets. These are rectangular buckets that are constructed to be boxed and stay upright during shipping. They allow flowers to be shipped in water. Moderate- or low-value flowers may have to be locally grown so that they can be shipped by truck.

POSTHARVEST FUTURE DIRECTIONS

The importance of flowers having a long vase life will continue to drive postharvest improvements. Maximizing vase life starts with postharvest testing and selection of cultivars and proper preharvest care. Gene-editing tools, such as CRISPR (clustered regularly interspaced short palindromic repeats), now allow breeders to strategically modify commercially important cultivars to increase postharvest life. We can expect continued refinement of production and postharvest procedures to prevent water and temperature stress during the handling, storage and shipping processes. All of this must occur in a cost-effective manner while still providing customers with a minimum vase life of 7 days. Thus, sea shipping and mechanization will become increasingly common. Ensuring customer satisfaction requires retailer buy-in as well as vase life guarantees.

REFERENCES

Ahmad, I., Dole, J.M. and Blazich, F.A. (2014) Effects of daily harvest time on postharvest longevity, water relations, and carbohydrate status of selected specialty cut flowers. *HortScience* 49, 297–305.

Bergmann, B.A. and Dole, J.M. (2020) Ethylene exposure exacerbates botrytis damage in cut roses. *Journal of Environmental Horticulture* 38, 80–90.
Blankenship, S.M. and Dole, J.M. (2003) 1-Methylcyclopropene: a review. *Postharvest Biology and Technology* 28, 1–25.
Harbaugh, B.K., Bell, M.L. and Liang, R. (2000) Evaluation of forty-seven cultivars of lisianthus as cut flowers. *HortTechnology* 10, 812–815.
Locke, E. (2010) Extending cut flower vase life by optimizing carbohydrate status: preharvest conditions and preservative solution. PhD Dissertation, North Carolina State University. Available at: https://repository.lib.ncsu.edu/bitstream/handle/1840.16/6166/etd.pdf?sequence=1&isAllowed=y (accessed 5 January 2020).
Macnish, A.J., Leonard, R.T., Borda, A.M. and Nell, T.A. (2010) Genotypic variation in the postharvest performance and ethylene sensitivity of cut rose flowers. *HortScience* 45, 790–796.
Sosa-Alvarez, M., Madden, L.V. and Ellis, M.A. (1995) Effects of temperature and wetness duration on sporulation of *Botrytis cinerea* on strawberry leaf residues. *Plant Disease* 79, 609–615.
Zhang, P.G. and Sutton, J.C. (1994) Effects of wetness duration, temperature, and light on infection of black spruce seedlings by *Botrytis cinerea*. *Canadian Journal of Forest Research* 24, 707–713.

Index

Note: Page numbers in **bold** type refer to **figures**
Page numbers in *italics* type refer to *tables*

Abies spp. *186*
Acacia 166
  baileyana 166
  cultriformis 166
  merinthophora 166
  spp. *203*
Achillea cvrs. *203*
acid-injection systems 232
acidifiers 357
Aconitum napellus *203*
Africa 18–20
African fern pine 166–167
African marigold 32
African rose mallow *186*
Afrocarpus 166–167
Agapanthus praecox *203*
Agastache cvrs. *203*
Ageratum houstonianum *203*
Aglaonema 158–159
Agonis 167
agri-tourism 42
Agrobacterium
  radiobacter strain K84 291
  tumefaciens 126–127, 289, **290**
Agrostemma githago *203*
air
  blowing, mechanical 335, **336**
  movement, in storage and shipping 364
air freight 9–10
airport logistics and availability 10
air–water balance, in soils and substrates *228*, 233–234, *234*
Alchemilla mollis *203*
alkalinity, of irrigation water 232
Allium, spp. and cvrs. *203*
Alpinia 160
  purpurata *203*
alstroemeria (*Alstroemeria* x *hybrida*) 48–54
  cultivars 49, 52
    Alstresia 49
    Florinca 49
  irrigation and nutrition 52–53
  market 49
  pests 53, *294*
  postharvest management 54
  production practices 49–52
    environmental requirements 50–52, **51**
    protected cultivation 49, **50**
  propagation 49–50
  storage 54
Alternaria
  dianthicola 60
  leaf spot, flower spot, speck and blight 59, 276–277
    disease cycle 277
    management practices 277
    symptoms and signs 276–277
  spp. 276–277
Amaranthus
  caudatus *203*
  cruentus *203*
amaryllis *209*
Amazon lily *208*
Amblyseius
  spp. 332, 338
  swirskii 324
American basket flower *205*

American Gladiolus Council 86
Americas, trade routes, cut flowers 21, **22**
Ammi cvrs. *203*
Ammobium alatum *203*
ammonium 239, **240**, 245
Anagyrus pseudococci 328
Andalusia (Spain) 17
Andean countries–USA free-trade agreements 9
Andean Trade Preference Act (1991) 23
Anemone coronaria *203*
Anethum graveolens *204*
Anigozanthus cvrs. *204*
annuals 155
- cool-season 155
- plant spacing 199
- warm-season 155

anthracnose 133
Anthurium 160
- *clarinervium* 160
- *crystallinum* 160
- cvrs. *204*

anti-ethylene agents *349*
anti-transpirants 156, 159, 160, 161, 359–360
Antioquia (Colombia) 25–26
Antirrhinum **215**
- cvrs. *204*
- *majus* *204*

ants 107, 108, 325
Aphididae 66, 147, 288, 325–326
Aphidius
- *colemani* **325**, 326
- spp. 325

aphids 66, 147, 288, 325–326
- biological control agents 325–326, *326*

apple *211*
Apuglia (Italy) 17
Aquilegia, cvrs. *204*
Arachniodes 168
arborvitae *188*
Artemisia ludoviciana *186*
arthropods
- biological control *321*
- resistance to chemical pesticides 316

Asclepias cvrs. *204*
Asia 28–29
- trade patterns, cut flowers **30**, 31

Asia and Pacific 28–37
Asiatic lilies 96, 97, 98, 100, 102
Asocolflores 26
Asparagus 167–168
- *aethiopicus* 167
- *asparagoides* 168
- *densiflorus* 167
- *falcatus* 168
- *retrofractus* 168
- *setaceous* 167
- *virgatus* 167–168

Aspidistra 168–169
aster annual *205*
Aster cvrs. *204*
aster yellows disease 133, 140, 289
Asteraceae 263, 274, 275
Astilbe cvrs. *204*
Astrantia major *204*
atmometers 233
auctions 12–14, 31, 37, 39
- clock 13, **13**, 39
- Germany 16
- Japan 31
- marketing costs 14
- Netherlands 13, **13**, 18
  - Royal FloraHolland 11, **11**, 12, 39, 96, 103
- Taiwan 35

Aucuba 168
Australia 36
- commercial crop of *Chamelaucium* **217**

auto-dissemination concept, for biopesticides 338

bachelor's button *205*
Bacillus
- *subtillis* 287
- *thuringiensis* (*Bt*) 330

bacterial disease 83, 89, 94, 147
- affecting root, crown and stem tissues 289–292
- and phytoplasma diseases, affecting foliar and floral tissues 285–289

bacterial soft rot (*Dickeya* and *Pectobacterium*) 140
Baden-Wurttemberg (Germany) 17
balloon flower *213*
balloon plant *209*
Baloskion
- *pallens* *186*
- *tetraphyllum* *186*

bamboo *186*
Bambusa spp. *186*
banana *211*
Bangkok Flower Market 40
banker plants 325–326, 332
Banksia, spp. *204*
Baptisia spp. and cvrs. *204*
Barker bush *187*

basil 181, *182*, *212*
basketflower *206*
Bavaria (Germany) 17
bayberry *187*
beads 361
beargrass 184
beautyberry *205*
bee balm *211*
bee vectoring systems 338
bees 317
beetles 141
Belarus 18
Belgium 17–18
bells of Ireland *211*
Bemisia tobacci 322–324
bent neck 44, 79, 84, 127, 129
benzyladenine 70, 93, 168
bigleaf hydrangea *209*
Billy buttons *207*
biocides 83–84, 90, 348, *349*
biological control 316–341
  for botrytis blight 265
  for powdery mildew 269
  rose 121, **123**, 126
biomass, and evapotranspiration relationship, roses 226, **226**
bionematicides 329
biopesticides 320, *321*, 324, 329, 335, 338
  auto-dissemination concept 338
  Bt 330
  microbial 334
bioprospecting 337
bird-of-paradise *214*
bittersweet *205*
black mold, *Thielaviopsis* 284–285
black spot, rose 278–279
black vine weevil 333–334
black-eyed Susan *213*
blackberry lily *210*
bleeding heart *210*
blue lace flower *214*
blue mist *205*
boron
  deficiency 59, 82
  uptake behavior 239, **240**
Botrytis
  cinerea **259**, 261, **263**
  tulipae 147, 261
botrytis blight 44, 53, 59–60, 78, 83, 84, 90, 261–267, 363
  disease cycle 264
  during storage and shipping 363–364, **364**
  hosts 262, 363
  and humidity in storage 363
  lily 101
  management practices 264–267, 363–364
  pathogen description 261–262
  peony 107–108
  preharvest care 344
  ranunculus 114
  rose 122–124, 125, 127, *128*, **128**, 129
  and sleeving 35
  statice 132–133
  symptoms and signs 262–263, **263**, 363, **364**
bouncing bet *213*
bouquet makers 41, 43
Bouvardia cvrs. *204*
boxwood *186*
Brassica oleracea *204*
Bribie pine *186*
brodiaea *214*
brokers 37, 39
broom *207*
Brunia spp. *205*
Bt-based products 330
Bt-toxin genes 330–331
bucket
  sanitation 356
  solutions *see* postharvest bucket solutions
  -washing equipment 356, **357**
buckthorn *187*
bud, nets, rose 124, **124**
budding, rose 117, **119**
Buddleia davidii *204*
bulb rot 101
bunches and bunching 156, **157**, 355
Bupleurum rotundifolium *204*
butterfly bush *204*
butterfly weed *204*
Buxus
  microphylla *186*
  sempervirens *186*

Calathea 160–161
  lancifolia 161
  louisae 161
  makoyana 161
calcium 127, 267
Calendula officinalis *205*
California (USA), cut flower production 23
calla *215*

Callicarpa spp. *205*
Callistephus **192**
- *chinesis* *205*

Callitris columellaris *186*
calyx splitting, carnation 58
Camellia 178–179
- *japonica* *205*

Campania (Italy) 17
Campanula **216**
- cvrs. *205*

Canada 23, 25
Candidatus Phytoplasma asteris 289
canopy thinning 52
cape rush 174
Capsicum **220**
- cvrs. *205*

Captan 2878
carbohydrates *349*
carnation (*Dianthus caryophyllus*) 54–61, 227
- cultivars and related species 55–57, **56**
  - petite spray 57
  - spray 57, 60
  - standard 56–57, 60
- exporters 55
- market 55
- novelty (*D. barbaratus*) 57, **57**
- pests 59–60, *294–295*, 305
- postharvest management 60–61
- production practices 57–58
- propagation 57–58
- storage 60, 61

Carthamus tinctorius *205*
Caryopteris x *clandonesis* *205*
cast iron plant 168–169
catchfly *214*
caterpillars 141, 156, 329–331
- biocontrol 330–331

Cattleya cvrs *205*
Caustis
- *blakei* *186*
- *flexuosa* *186*

cedar *186*
Celastris scandens *205*
cell walls, and water pressure potential 230
Celosia **193**, **216**
- *argentea* *205*

Centaurea
- *americana* *205*
- *cyanus* *205*
- *macrocephala* *206*

Centranthus ruber *206*
Cercis
- *canadensis* *206*
- *chinensis* *206*

certification 44–45
- eco-label 45, 236, 247

certified organic production 331
Chaenomeles cvrs. *206*
Chamaecyparis spp. *186*
Chamaedorea 169
- *elegans* 169
- *ernesti augusti* 169
- palm leaves 150
- *tepejilote* 169

Chamelaucium **217**
- cvrs. *206*

charcoal rot 140
Chelone, spp. *206*
chemical pesticides 316, 317
chemical weed control 201
chilling *see* cold
China 5, 31–32
Chinese arborvitae *187*
Chinese evergreen 158–159
Chinese lantern *213*
chlamydospores 274, 275, 280, 283
chlorine tablets 348
chlorothalonil 276
Chondropetalum elephantinum 174
Christmas fern 183
chrysanthemum (*Chrysanthemum* x *morifolium*) 61–67, 280
- cultivars and types 62–63, 64–65
- market 61–62
- pests 66, *295–296*, 328
- and photoperiod 6
- postharvest management 66–67, **67**
- production practices 63–65
- propagation 63, **64**

chrysanthemum white rust (CWR) 270–271
Chrysopa carnea 327–328
Cirsium japonicum *206*
citric acid 348
city markets 42
cladodes 167
Clarkia cvrs. *206*
Clematis cvrs. *206*
climate change 224
climate data 233
climatic zones 152–153
club stores 41
Cocculus 170
coconut husks/fiber (coir) 68, 71, **72**, 99, 245

Codiaeum 161
cold
  chilling 74
  chilling-sensitive species 152, 159
  coolers 362, **362**
  hardiness 198
  precooling 145
  treatment 98, 144–145
cold-chain management 10, 19
collar rot 83
Colombia 9, 25–27
  biological control budget 318
  exports from 25, **26**
  industry consolidation 43
  production 25–26
  production area 5
  US imports from 21–23
coloring 2, 360–361, **360**, **361**
columbine *204*
common myrtle *187*
Community-Supported Agriculture (CSA) 43, 44
Compositional Nutrient Diagnosis (CND) 250–252
conebush 20, **154**, 172–173, **173**
coneflower *207*
conidia 264, 267–268, 278
  macro-/micro- 280
Consolida ambigua *206*
consolidation 43
consumption, Europe 12, **12**
contamination, of propagation material 288
controlled-atmosphere (CA) 366–367
Convallaria majalis *206*
cool-season annuals 155
coolers 362, **362**
coontie *188*
cooperatives, marketing 38, 40
Cootamundra wattle 166
copper 279, 283
Cordyline 161–162
Coreopsis spp. *206*
corm rots 89
corncockle *203*
Cornus
  alba **217**
  florida *206*
  spp. *206*
Corylus spp. *207*
Cosmos bipinnatus *207*
Costa Rica 28
Cotinus spp. *207*
cotton bollworm 329–330
cottony rot 140
cover crops 194–196
Craspedia globosa *207*
Crataegus svrs. *211*
crates, tulip planting 145–146
Crocosmia x *crocosmiiflora* *207*
croton 161
crown buds 65
crown gall 126–127, 289–291
crown rot 108, 114, 133
Cryptolaemus montrouzieri 327, **327**
cultural symbolism 150
Culver's root *215*
Cupressus spp. *186*
Curcuma alismatifolia *207*, **218**
currency exchange rates 8
cuttings 57–58, 63, 198
Cycas 170
Cyclamen hybrida *207*
cyclic lighting 92
Cymbidium (cymbidium orchid) **219**, *297*
  cvrs. *207*
Cyperus 162
  alternifolius 162
  papyrus 162
cypress *186*
Cyrtomium 170
Cytisus cvrs. *207*
cytokinins 160
cytoplasm, plant cell 229

Dacnusa sibirica 328
daffodil *212*
Dahlia 219
  cvrs. *207*
daily light integrals (DLI) 7, **7**, 154
daminozade 64
Danaë 170–171
dancing ladies orchid *212*
Davallia 171
de-methylation inhibitors 279
decorative branches 345
dehydration 162
Delphastus pusillus 324
Delphinium cvrs. *207*
Delta trap 330
dendrobium orchids (*Dendrobium* x *hybrida*) 68–75
  cultivars 68, 69
    flower sizes 69
  D. gouldii 69
  irrigation and nutrition 71–72, *72*

dendrobium orchids (*Dendrobium* x *hybrida*) (*continued*)
  pests 72–73, *296–298*
  D. phalaenopsis 69
  postharvest management 73–74
  propagation 69–71, **70**, **71**, **72**
  storage 74
desalination 231–232
desiccation 156, 161
designers 4
Deutzia cvrs. *207*
developing countries, production 14
Diadiplosis megalamellae 328
Diagnosis and Recommendation Integrated System (DRIS) 250–252
Dianthus
  barbatus 57, **57**, *207*
  caryophyllus see carnation (*Dianthus caryophyllus*)
didgery sticks *186*
diffusion, nutrient 238
Digitalis purpurea *207*
Diglyphus isaea 328
dill *204*
dingo fern *186*
Diplocarpon rosae 278
direct (-to-consumer) sales 4, 14, 42–43, 44, 156
disbudding, carnation 58
disease 114
  bacterial 83, 89, 94, 147
  components 258–259
  control, storage and shipping 363–364, **364**
  difficult-to-control 338
  eradication 259–260, **260**
  exclusion 259
  exotic 44
  fungal 93, 102, 318
  management, general principles and strategies 258–261, 293
  triangle 259, **259**
distribution
  pathways 44
    for flowers 37, **38**
  systems 37
    producer to consumer, direct 42–43, 44
    producer to customer, via intermediates 37–41
Ditylenchus dipsaci 329
dogwood
  flowers *206*
  stems *206*
downy mildew 83, 272–273
  disease cycle 272–273
  hosts 272
  management practices 273
  pathogen description 272
  resistant (DMR) 136, 140
  symptoms and signs 272, **273**
Draecana
  fragrans 162–163
  marginata 163
  surculosa 163
drip irrigation 53, **53**, 77, 101, 107, **197**, 199, 267
drip tapes/emitters 199
drone technology 338
Duponchelia fovealis 329–330
dusty miller 183–184
Dutch iris *210*
dwarf umbrella tree 163
dyes 92, 117, 156, **158**, 178

East Indian holly 168
Echinacea cvrs. *207*
Echinops
  bannaticus *207*
  ritro *207*
eco-label certification 45, 236, 247
eCommerce 29, 31
ectoparasites 305
ectoparasitic wasps 328
Ecuador 21–23, 28
Elaeagnus
  x *ebbingei* *186*
  pungens *186*
electrical conductivity (EC) 229, 232
  of fertigation/nutrient solution 247–248, 282
Elegia
  capensis 174
  tectorum 174
elm *215*
emerging countries 3, 5, 5
emu feather *186*
emu grass *187*
Encarsia formosa 323–324, **323**
endoparasites 305
English ivy 180
enhancements 156, **158**, 360–361, **360**
environmental impact, of irrigation and fertilization 224–225
environmental monitoring systems, storage and shipping 365

environmental requirements,
alstroemeria 50–52, **51**
equatorial climate 18
equatorial countries 2, 6, 14, 52, 58, 63, 64
photoperiod 6, 58
Equisetum hyemale *186*
Eremus cvrs. *208*
Eretmocerus eremicus 323–324
Erwinia
bacterial soft rot 291–292
disease cycle 291
hosts 291
management practices 291–292
pathogen description 291
carotovora 156
streak disease 60
Eryngium cvrs. *208*
Ethiopia 19
ethylene 66, 146
control 357–359
damage 358, 359
sensitivity to 60–61, 73, 78, 114, 358
aglaonema 159
anti-ethylene compounds 129
lily 102
rose 127–129
statice 133–134
tulip bulbs 144
ethylene scrubbers 74
Eucalyptus 171–172
Eucharis amazonica *208*
Eucomis cvrs. *208*
Euonymus 179
fortunei 179
Eupatorium spp. *208*
Euphorbia
fugens *208*
marginata *208*
pulcherrima *208*
Europe 12–18
European pepper moth 329–330
European Union (EU)
Directive on the Sustainable
Use of Pesticides (2009/128/
EC) 317
false coddling moth stricter import
restrictions 330
Eustoma **220**
grandiflorum *208*
evapotranspiration 226, **226**, 233
exporters
carnation 55
Kenya 18
exporting
countries, cut foliage 150
leading nations 2
exports
emerging countries in 21st century 3,
5, 5
markets 2–5
value 3–4, **4**
foliage 150
global 2

false coddling moth 329–330, 337
fan palm 178
far-red light 93
farmer florists 42
farmers' markets 42, 44
fasciation 288
Fatsia 172
bunches **157**
shade house production **154**
Feltiella acarisuga 320
Feria de las Flores (Festival of Flowers,
Medellin) 26, **27**
fertigation 194
closed systems 247
solution
EC of 247–248
inline pH monitoring 232
osmotic potential 229
fertilization
environmental impact 224–225
osmotic effects 243
fertilizer 89, 101, 107
festivals, religious 32
field
postharvest bucket solutions 348, **351**
production 193–196, **195**
filbert *207*
fir *186*
fish-tail palm 169
flame weeding 201
flax lily 181–182
flexi grass *187*
floral solutions 134
floral tissues *see* foliar and floral tissues
florists, farmer 42
Florverde 26
flower food 352–353, **353**, 357
flower markets 37, 39–40
flower spot
Alternaria 59, 276–277
Stemphylium 275–276

flowering quince *206*
fluoride 357
Flying Doctors® concept 338
foliage 150
  categorizing 151–155
  exporter, Italy 16–17
  greens 20, 345
  minor species 185–188, **185**, *186–188*
  removal and bunching 346
foliage-producing countries 150
foliar feeding 71
foliar and floral tissues
  bacterial and phytoplasma pathogens 285–289
  fungal and oomycete pathogens 261–279
foliar nutrient range 249
forced-air cooling, storage and shipping 365–366, **366**
forcing, tulip bulbs 144, 145, 146, *146*, 147
forest lace *188*
Forsythia x *intermedia* *208*
foxglove *207*
foxtail fern 167
foxtail lily *208*
fragrance 76
Frankliniella occidentalis 320–322
free-trade agreements 9
freesia (*Freesia* x *hybrida*) 75–78
  cultivars 76
  irrigation and nutrition 77
  market 75, **75**
  pests 78, *298*
  postharvest management 78
  production practices 76–77
  propagation 76–77, **77**
fungal disease 93, 102
  biological control 318
fungal leaf spot 89
fungal pathogens 126, 156
  see also pathogens, fungal and oomycete
fungi
  biological control, biopesticides *321*
  tulip problems 147
fungicidal baths 156, **159**
fungicides 112, 114, 264, 271, 273, 280, 283, 284, *349*
  multi-site 279
  programs 331
  resistance 264–265, 271
  resistance management 277
  sprays 127, **128**
  systemic 273, 277
fungus gnat larvae 83
Fusarium
  bulb, corm, stem rot and wilt 59, 66, 279–280
  oxysporum 279
    formae speciales 279–280
  spp. 140, 146, 279
fynbos 20

GA *see* gibberellic acid (GA)
Galax 179
galls 288
  leafy 288
  see also crown gall
garden roses 117, 118
Gardenia jasminoides *208*
garlands, India 32, **33**
gene-editing 367
gentian *208*
Gentiana spp. *208*
geophytes 155, 197
gerbera daisy (*Gerbera jamesonii* and hybrids) 79–85, 283
  cultivars 80
    flower forms 80
  irrigation and nutrition 82, *82*
  market 79
  pests 83, *298–299*, 328
  postharvest management 83–84
  powdery mildew **268**
  production practices 80–82, **81**
  propagation 80–81, **81**
Germany 16
gibberellic acid (GA) 58, 70, 93, 105, 131
ginger *203*
ginger lily 160
gladiolus (*Gladiolus hortulanus* hybrids) 85–91
  corms, botrytis blight 263
  cultivars 85–87, **86**
  fluoride sensitivity 357
  irrigation and nutrition 89
  market 85
  pests 89–90, *299*, 320
  postharvest management 90
  production practices 87–89, *87*
  propagation 87–88
Gleichenia dicarpa *186*
glitter 156, **158**, 360–361, **360**
global trends, industry consolidation 43
globalization 1–2
globe thistle *207*
globeflower *215*

Gloriosa superba *209*
godetia *206*
gold dust plant 168
goldenrod *214*
Gomphocarus physocarpus *209*
Gomphrena cvrs. *209*
gooseneck loosestrife *211*
governmental incentives 9
grading, postharvest handling 354–355, **354**
grafting, bud, rose 117, **119**
grasses, South Africa 20
grasshoppers 141
gray mold *see* botrytis blight
greenhouse production 192, **192**
greenhouse whitefly 322–324, **323**
greens 20, 345
Grevillea 172
  baileyana 172
  hookeriana 172
  robusta 172
grocery stores 41
ground beds, solarization of 260, **260**
growth
  regulators *350*
  retardants 149
  room, for gypsophila 94, **94**
Guatemala 28, **29**
gum trees 171–172
gypsophila (*Gypsophila paniculata*) 91–95
  cultivars 92
  irrigation and nutrition 93
  market 91–92
  pests 93–94, *299*
  and photoperiod 6
  postharvest management 94–95, **94**
  production practices 92–93
  propagation 92–93

hairy balls *209*
Hamamelis cvrs. *209*
hand irrigation 199
hand weeding 200, 201
handling *see* postharvest handling
hardiness, cold 198
hardiness zones 153, *154*, 218–223
harvest 223, 344–347
  developmental stage 344–345
  foliage 156–158
    generalizations 150–151
    removal and bunching 346
  method 345–346
  peony stages 108–109
  ranunculus 114
  rose 124–125, 127
  statice 133, **134**
  sunflower 141
  time of day 345, **345**
  transport from field/greenhouse to packing house 346–347, **347**
  tulip 147
  wounds created **261**
hawthorn *211*
head rots 140
head-clipper weevil 141
heavenly bamboo 180–181
Hedera 180
Heliconia **220**
  spp. *209*
Helicoverpa armigera 329–330
hellebore *209*
Helleborus cvrs. *209*
Heptacodium miconioides *209*
herbaceous perennials, temperate/tropical 155
herbicides 201
herbivore-induced plant volatiles (HIPVs) 338
herbs, culinary 181
Heterorhabditidae 333
Heterorhabditis bacteriophora 328–329
Heuchera cvrs. *209*
Hibiscus
  acetosella *186*
  sabdariffa *209*
Himalayan honeysuckle *211*
Hippeastrum cvrs. *209*
holiday markets 116
holly *186*, *210*
holly fern 170
honeydew 325
horsetail *186*
hot-water treatment 329
huckleberry 184
humid chambers 264, **266**
humidity 52, 69, 71, 81
  and rose production 122–124
  storage and shipping 363
hyacinth *209*
Hyacinthus orientalis *209*
hybrid tea roses 117
Hydrangea
  arborescens *209*
  macrophylla **195**, *209*
  paniculata *210*
  quercifolia *210*
hydration solutions 348, 350, **351**

hydroponics 58, 59, 63, 81, **81**
nutrients in fertilization solution 59
rose 118, **120**, 125–126
fertigation solutions 126, *126*
nutrient uptake capacity 239, **240**
nutrient and water uptake 240–241, **241**
system cleaning 200
tulip 145
Hylotelephium cvrs. *210*
Hypericum cvrs. *210*
hyperparasites 326
hypochlorite products 348

ice tulips 145
Iceland poppy *212*
Ilex
spp. *186, 210*
verticillata **221**
impatiens necrotic spot virus 114
importers 37, 38–39
importing countries 12, **12**
imports, annual values 3, **3**
incentives, governmental 9
India 32–34, **33**
exports from 32–34
gladiolus 85
production 32–34
production area 5
indigenous production, South Africa 19–20, **20**
industry consolidation 43
inline acid-injection systems 232
inline pH monitoring 232
integrated management practices
for downy mildew 273
for fungicide resistance 279
for pythium root rot 282
integrated pest management (IPM) 331–336
beneficial entomopathogenic nematodes 332–334
biological control agent choice 335–336
conservation of predator populations 331–332, **333**
definition 331
integrated use of pesticides 334, *335*
principles 317
integrative nutrient diagnosis techniques 250–252, **251**
interception, root 238
intermediaries 38
international agreements 9
international businesses 43
International Flower Bulb Centre, gladiolus categories 86–87
International Organization for Integrated and Biological Control (IOBC)
pesticide parameter definition 334
Pesticides and Beneficial Organisms working group 334
Internet 13, 14
sales 44
invasive pests 336–337
ions 357
absorption 239–240
toxic 232
Iris
chinensis *210*
hollandica *210*
iron deficiency 82
irrigation 267
drip 53, **53**, 77, 101, 107, **197**, 199, 267
environmental impact 224–225
hand 199
management 225–227, **226**
water volume and frequency 232–233
overhead 101, 132, 199
water
alkalinity 232
application rates 224, *225*
pH 232
quality 230, *231*
sources 247–248
Ischyrolepsis subverticillata 174
Israel 21
Israeli ruscus 177–178, **177**
Italian ruscus 170–171
Italy 16–17
itersonilia 83
petal blight 274–275, 364
disease cycle 275
hosts 275
management practices 275
pathogen description and morphologies 274
symptoms and signs 274, **274**
Itersonilia perpexans 274
ivy 180

Japan 29–31
auctions 31
chrysanthemums 60–61
imports to 31

Japanese peony 104
Japanese pittosporum 174
Joe-pye-weed *208*
juniper *186*
Juniperus spp. *186*

kangaroo paw *204*
Kenya 2, 18–19, 236
Kenya Flower Council (KFC) 19
Kerria japonica *210*
king sago 170
knife-leaf wattle 166
Kniphofia uvaria *210*
koala fern *186*

labor
  cost and availability 8–9
  shortages 34
laceleaf 160
lady palm *187*
lady slipper orchid *212*
lady's mantle *203*
Laitai Flower Market (Beijing) 40
lamb's ear *188*
Lamprocapnos spp. *210*
landscape fabric 106, 200
larkspur *206*
latex sap 159, 160
Lathyrus odoratus *210*
laurel-leaved snail tree 170
Lavetera trimestris *210*
leaf
  chlorosis 67
  distortion 82
  nutrient concentration value 249
  pests
    leaf hoppers 133
    leaf miners 83, 328–329
  water potential *228*, 230
  yellowing 53, 54, 66
leaf shine 156, 161
leaf spot 102, 108
  Alternalia 59, 276–277
  fungal 89
  see also Pseudomonas, bacterial wilt, bacterial leaf spot; *Stemphylium*, leaf and flower spot and ray speck
leafy gall 288
leatherleaf fern 176–177
  shade houses **176**
  shrink-wrapping 156, **157**
legislation, and pesticide controls 317
legume cover crops 196
lemonleaf 183
Lepironia articulata *187*
lesions 264
  pythium root rot 281
Leucadendron 20, 172–173, **173**
  cvrs. *210*
  outdoor production **154**
Leucanthemum x *superbum* *210*
Leucospermum cvrs. *211*
Leycesteria formosa *211*
Liatris **221**
  cvrs. *211*
light 7, **7**, 69, 112, 153–154
  daily integrals (DLI) 7, **7**, 154
  far-red 93
  full sun 153
  preharvest care 343
  storage and shipping 365
lighting 58, 64, 88
  cyclic 92
  photoperiodic 92
  supplemental 52, 76, 94, 100, **100**, 121–122
Liguria (Italy) 17
Ligustrum
  japonicum *187*
  lucidum *187*
lilac *214*
lily (*Lilium* hybrids) 95–103
  botrytis blight 263
  cultivars 96–97, **97**, 98, 100, **100**, 102
  irrigation and nutrition 101
  L. longiflorum 96, 97, 100
  market 96
  pests 102, *300–301*
  postharvest management 102
  production practices 97–101
  propagation 98–100
  specific bucket/vase solution **352**
lily-of-the-valley *203*, *206*
lilygrass/lilyturf 173–174
Linaria maroccana *211*
liners 197
Liriomyza trifolii 286
Liriope 173–174
lisianthus *208*
Lobelia cvrs. *211*
logistics, Netherlands 13, **13**
loose flowers 32, **33**, 73, **73**
love-in-a-mist *212*
love-lies-bleeding *203*

Lunaria annuua *211*
lupine *211*
Lupinus spp. *211*
Lysimachia clethroides *211*
lysimeter, weighing/leaching 233

Macrolophus pygmaeus 324, 329
Macrophomina phaseolina 140
magnesium deficiency 53, 82
Magnolia 180
Malaysia 34
Malus *211*
manganese toxicity 82
manual weeding 200, 201
manures 194
marigold *214*
market
demand 11
domestic 5, **6**
Europe 12–18
export 2–5
holidays
China 31
India 32
US 23
traditional 44
marketing cooperatives 38, 40
marketplace, retail 1
mass flow 238
Matthiola **222**
incana *211*
Maximillian's sunflower (*Helianthus maximilliani*) 136
maximum residue levels (MRLs) 316
meadow-rue *214*
mealybugs 327–328
biocontrol agents 327–328, **327**
mechanical air blowing 335, **336**
mechanical cultivation 200–201
Medellin (Colombia) 26
Feria de las Flores (Festival of Flowers) 26, **27**
Meloidogyne
incognita 305
spp. 305–307, 329
mesh **51**, 196, **197**
1-methylcyclopropene (MCP) 359
Mexican fan palm 178
Mexico 5, 25
Miami 38–39
Miami International Airport, imports through 23, **24**
microbial biopesticides 334
microbial growth 356
microtubes 199
Middle East 21
migrant workers 8–9
migratory parasites 305
mildew *see* downy mildew; powdery mildew
mimosa 166
mineral nutrients 239–241
mineral nutrition 267
minerals, essential 236
misting 71
mites 66, 83
biological control *321*
predatory 322, 331
feeding behavior 335, *336*
mock orange 174, *212*
moisture-retentive packaging 360
x *Mokara* cvrs. *211*
mokara orchid *211*
Molineria 163
Moluccella laevis *211*
Monarda cvrs. *211*
moneyplant *211*
monitoring, nutrients and plant nutrient status 248–250
monkshood *203*
Monstera 163
Montezuma 25
moth orchid *212*
moths, caterpillars 329–330, 333
mulch 200
organic 194
Multiflora Flower Market (Johannesburg, South Africa) 19
Musa cvrs. *211*
mycelia 140, 262, **263**, 268, 282, 283, 284
mycoparasites 269
Myrica
cerifera *187*
gale *187*
pennsylvanica *187*
Myrothecium verrucaria 305
myrtle, common *187*
Myrtus communis *187*

Nageia 174
nagi 174
Nagoya protocol 337
Nairobi Airport (Kenya) 19, 20
Naivasha Lake (Kenya) 18, 19, 235, *235*

Nandina 180–181
domestica *211*
Narcissus cvrs. *212*
nematicides 305
nematodes 66, 83, 90, 102, 329
beneficial entomopathogenic 332–334
biological control *321*, 329
diseases 293–307
description and importance 293, 305
general management practices 305
effects on plants 293, 305
parasitic 293, 305
classification 305, *306*
of leaf miner larvae 328–329
pathogenic 329
peony 108
root-knot 305–307, 329
rose 127
sunflower 141
tulip 147
vectors 292
neonicotinoids 317
Neoseiulus californicus 320
Nephrolepsis exaltata *187*
Nerine bowdenii *212*
Netherlands 9, 39
exports/imports **15**
logistics 13, **13**
production 14–16, 116
netting
bird **221**
greenhouses, to inhibit thrips 321–322
support **51**, **197**
New Covent Garden Flower Market (London) 39
New England Flower Exchange 40
New Zealand 36–37
New Zealand flax 181–182
New Zealand pittosporum 174
Nigella spp. *212*
ninebark 182, *213*
nitrate 239, **240**, 246, 254
nitrification 246
nitrogen 93, 194, 242–243
application to roses 242–243, **242**
concentration 267
forms in nutrient solutions, and pH management 245–246, **245**
nutrition study, greenhouse roses 249–250, **250**
non-indigenous production, South Africa 19
non-pesticide solutions 337
North America 21–25
North American Free Trade Agreement (NAFTA) 21
North-Rhine-Westphalia (Germany) 17
nutrient balance index (NBI) 251–252, **251**
nutrient solution
EC of 247–248
management 243–245, *244*
nitrogen forms in, and pH management 245–246, **245**
osmotic effect 244–245
recipes 243–245, *244*
recirculating and recycling 246–248
nutrients *349*
availability 236–238, **237**
deficiencies 53, 54, 82
delivery 238
integrative diagnosis techniques 250–252, **251**
and plant nutrient status, monitoring 248–250
supplies, plant responses 242–243, **242**
uptake
factors affecting **237**, 238–239
response to nutrient concentrations 239–241, **240**
uptake capacity and behavior 239–241
nutrition
field production 194
preharvest care 344

oak *187*
oakleaf hydrangea *210*
obedient plant *213*
Ocimum 181, *182*
cvrs. *212*
Olea 174
olive 174
on-farm sales 42
Oncidium cvrs. *212*
online firms 43
online vendors 41
oomycetes 272
pathogens 156
oospores 273, 281, 282, 283
Ophiopogon 174
orchids
cymbidium *207*, **219**
dancing ladies *212*
lady slipper *212*
mokara *211*
moth *212*

orchids (*continued*)
production 34
see also dendrobium orchids (*Dendrobium* x *hybrida*)
oregano *212*
Oreopanax capitatus *187*
organic matter 194
organic production, certified 331
oriental arborvitae *187*
Oriental lilies 96, 98, **100**, 102
Origanum spp. *212*
ornamental cabbage/kale *204*
ornamentals 28, **29**, 31
Ornithagalum spp. *212*
osmotic effects, of (over)fertilization 243
Ota Shijo 39
Otiorhynchus sulcatus 333–334
outdoor insect pests 140–141
outdoor production 16, 23, **154**
field 193–196, **195**
overhead irrigation 101
overpacking 356
oxygen deficiency 234
Oxypetalum caerulea *212*
Ozothamnus diosmifolius *212*

Pacific and Asia 28–37
packaging
moisture-retentive 360
solution 74
paints 117, 156, **158**, 178
pan evaporation 233
Pandanus 163–164
pansy *215*
Papaver nudicaule *212*
Paphiopedilum cvrs. *212*
parasitic nematodes *see* nematodes
parasitic wasps
Encarsia formosa 323–324, **323**
Eretmocerus eremicus 323–324
parlor palm 169
pathogens 83, 101–102
bacterial and phytoplasma
affecting root, crown and stem tissues 289–292
foliar and floral tissues 285–289
categories 258
fungal 126, 156
fungal and oomycete
foliar and floral tissues 261–279
root, crown, corm, basal and stem rots 279–285
nematode 293–307
oomycete 156
virus and viroid diseases 292–293
peegee hydrangea *210*
Penicillium 147
Peninsular Malaysia 34
pennycress *188*
Penstemon spp. *212*
peony (*Paeonia* hybrids) 103–110
cultivars and types 104–105, **104**
irrigation and nutrition 107
market 103
pests 107–108
exudates 108
postharvest management 108–109
bud opening stages 108
harvest stages 108–109
storage 109
production practices 105–107, **106**
propagation 105–107
shipping 109
viruses 108, *301*
pepper *205*
perennial aster *204*
perennials 155
herbaceous 155
plantings 198, 199
Peronospora spp. 272
Persoonia
longifolia *187*
virgate *187*
pest management techniques 331
pesticides 83, 331
arthropod resistance to 316
and biological control against compatibility, IOBC parameters 334
integrated use 334–335, *335*
residues 317
side-effects 334, *335*
toxicity and persistence 334
withdrawal by manufacturers 316
pests
biological control 318–331
biological control agents, resistance to 335
difficult-to-control 338
exotic 44
insect 292–293
outdoor 140–141
invasive 336–337
new 336–337
outdoor, insect 140–141

preharvest care 344
see also integrated pest management (IPM)
petal blights 140
see also itersonilia
petal curl 60
pH 285
of irrigation water and fertigation solutions, inline monitoring 232
low 246
management, and nitrogen forms in nutrient solutions 245–246, **245**
Phalaenopsis cvrs. *212*
pheromones 330
Phialophora wilt 59
Philadelphus spp. *212*
Philodendron 164
phloem obstruction 289
Phlox paniculata *212*
Phoenix (Phoenix palm) 164–165, **164**
Phoma black stem (*Phoma macdonaldii*) 140
Phomopsis stem canker (*Phomopsis helianthi* and *P. gulyae*) 140
Phormium 181–182
Photinia
x *fraseri* *187*
glabra *187*
photoperiod 6–7, 58, 92
control **195**
Phragmidium 270
phylloclads 167
Physalis alkekengi *213*
Physocarpus 182
opulifolius *213*
Physostegia virginiana *213*
Phytophthora
cryptogea 83, 283
root and stem rot 282–283
disease cycle 283
hosts 282
latent infection 283
management practices 283
pathogen description 282
symptoms and signs 282–283
spp. 282
phytoplasmas 289
phytosanitary obligations 44
Phytoseiulus persimilis 318, 319–320, **319**, 331–332
life cycle stages, pesticide side-effects on *335*
picon *187*
Pieris cvrs. *213*
pinching 52
pincushion *211*
pincushion flower *214*
pine *187*
pineapple lily *208*
Pinus spp. *187*
pitt/pitto 174
Pittosporum 175
tenuifolium 175
plant-parasitic nematodes *see* nematodes
plant–microbe interactions 258
Plasmopara halstedii 272
plastic
film 15
mulches 200
sheeting 88
Platycladus orientalis *187*
Platycodon grandiflorus *213*
plug sizes 197–198
plume thistle *206*
plums, and relatives *213*
podo/podocarpus *187*
Podocarpus
drouynianus *187*
macrophyllus *187*
poinsettia *208*
Polianthes tuberosa *213*
polyphagous predators 335
Polystichum 183
acrostichoides 183
postharvest
challenges 44
foliage 156–158
future directions 367
handling 353–361
see also postharvest bucket solutions
management 147–149, **149**
future 367
in-house testing 342, **343**
main issues 32
postharvest, futures 367
see also harvest; postharvest bucket solutions; preharvest care; shipping; storage
postharvest bucket solutions 81, 83, 95, 102, 134, 367
greenhouse/field 348, **351**
pre-packaging 74, 350–352, **351**, **352**, 359
shipping/holding 352
vase solution 352–353, **353**
shipping/holding 352
and vase solutions 347–353, **348**

pot marigold *205*
powdery mildew 83, 108, 267–269
  disease cycle 267–268
  hosts 267
  management practices 268–269
  pathogen description 267
  symptoms and signs 267, **268**
prayer plant 160–161
pre-packaging bucket solution 74, 350–352, **351**, **352**
  species-specific and/or anti-senescence treatments 350–352, **352**
precision agriculture 338
predators
  generalist, for caterpillars 331
  of mealybugs 327–328, **327**
    Cryptolaemus montrouzieri 327, **327**
  polyphagous 335
  population, conservation 331–332
  of two-spotted mite, *Phytoseiulus persimilis* 318, 319–320, **319**
predatory mirid 324
predatory mites 322, 331
  conservation 331–332
    mini-rearing systems 325–326, 332
    slow-release sachets 332, **333**
    supplementary food 332
  feeding behavior 335, *336*
  to manage thrips 322
preharvest care 343–344
  cultivar 343
  light 343
  nutrition 344
  pests 344
  temperature 343–344
  water 344
preventative practices, for nematode diseases 305
privet *187*
processing, postharvest handling 353–354
Procona® buckets 367
producers
  cut flower 38
  to consumer, direct 42–43
  to customer, via intermediates 37–41
propagation
  bud grafting/stenting 117, **119**
  material, contaminated 288
Protea 20
  spp.and cvrs. *213*
protected cultivation, rose 118
protection, from disease 260, **261**, **262**
pruning, wounds created **261**
Prunus cvrs. *213*
Pseudococcidae, mealybugs 327–328
Pseudomonas
  bacterial wilt, bacterial leaf spot 60, 285–287
    disease cycle 286
    hosts 286
    management practices 287
    pathogen description 285–286
    symptoms and signs 286
  caryophylli bacterial wilt 60
  cichorii 285
    symptoms 286
  spp. 285–286
  syringae 285–286
    symptoms 286
Puccinia spp. 270
pussy willow *213*
pustules, rust 270
puzzle stix *187*
Pythium 147
  root rot 53, 281–282
    disease cycle 281–282
    hosts 281
    management practices 282
    pathogen description 281
    symptoms and signs 281
  spp. 281, 282

quarantine pest 337
  definition (FAO) 320
Queen Anne's lace *203*
Quercus spp. *187*

rabbit's foot fern 171
raised beds 196, *197*, **197**
ranunculus (*Ranunculus asiaticus*) 110–115
  cultivars and types 111, **111**
  irrigation and nutrition 112–114
  market 110–111
  pests 114
  postharvest management 114
  production practices 111–112, *112*, **113**
  propagation 111–112
ray speck *see Stemphylium*, leaf and flower spot and ray speck
recirculation 247–248
  closed systems 247
  economic incentives 247

systems, potential nutrient imbalances 248
technical aspects 247
red cedar *186*
red hot poker *210*
red valerian *206*
redbud *206*
regulatory requirements, of biological control agents 337
religious festivals 32
religious symbolism 150
research and development 337–338
resistance
to biological control 335
to chemical pesticides 316
disease 260
to fungicides 264–265, 271, 277, 279
management strategy, for *Bt* pesticides 330
Restio 175
restricted-entry interval (REI) 317
retail, retailers
florists 38, 40
flower shops, Europe 12
marketplace 1
see also sales
Rhamnus alaternus *187*
Rhapis excelsa *187*
Rhizoctonia
root and stem rot 53, 283–284
disease cycle 283
hosts 284
management practices 284
pathogen description 283–284
solani 284
spp. 283–284
symptoms and signs 284
tuliparum 147, 284
rhizosphere 236–238, **237**
Rhopalosiphum padi 326
rice flower *212*
road systems 9
roadside stand 42
robotics 338
rodents 141
Rodococcus fascians 288
fasciation, leafy gall 288
root rot 101, 108, 114
Phytophthora 282–283
Pythium 53, 281–282
Rhizoctonia 283–284
Thielaviopsis 284–285
root-knot nematodes 305–307, 329
disease cycle 306–307
hosts 306
symptoms and signs 306
rootstocks, rose 118
rootzone 236, **237**
chemistry, monitoring 249
Rosa
spp. and cvrs. *213*
see also rose (*Rosa* x *hybrida*)
rose hips *213*
rose mallow *210*
rose (*Rosa* x *hybrida*) 115–129
annual biomass and flower yield, and nitrogen application 242–243, **242**
black mold 285
black spot 278–279
evapotranspiration and biomass relationship 226, **226**
experimental greenhouse crop 224
fertigation solution *126*, 243, 245
garden 117, 118, **118**
greenhouse
leaf water potential 230
nitrogen nutrition study 249–250, **250**
growing, effective WUEs 226
harvesting 127
hybrid tea classification 117
hydroponic, nutrient uptake capacity 239, **240**
irrigation and nutrition 125–126, *126*
market 116–117, **116**
flower color 116–117, **116**
pests 126–127
Phragmidium spp. 270
planting systems
bending method 121, **123**
traditional method 120, **122**
postharvest management 127–129
production 115–116
Netherlands 14–16, 116
production practices 117–125, *228*
harvest 124–125
outer guard petals 125, **125**
propagation 117–124
bud grafting/stenting 117, **119**
rootstocks 118
root and leaf cells, pressure potential values 230
sustainable practices 117
water footprint 235, *235*
well-watered and drought-stressed 229

roselle *209*
Rosemarinus officinalis *187*
rosemary *187*
Royal FloraHolland 12, 39, 96, 103
  species quantity and pricing 11, **11**
Rudbeckia cvrs. *213*
Rumohra 156, **157**, 176–177, **176**
Ruscus **158**, 177–178, **177**
  aculeatus 177
rust 60, 269–272
  management practices 271–272
  pathogen description 269
    fungi spore types 269
    life cycles 269
  symptoms and signs 269–271

safflower *205*
sage *213*
sago palm 170
Salal 183
sales
  direct 4, 14
    to consumer 44
  holiday, Europe 12
  on-farm 42
  supermarket 44
salinity 231–232
Salix cvrs. *213*
Salvia spp. *213*
San Francisco Flower Market (USA) 40
sanitation
  postharvest 356, **357**
  practices 265, 287, 288
Sansevieria 165
Saponaria officinalis *213*
sapphire grass *187*
Sarah Bernhardt peony 105
saw palmetto 178
scabiosa *214*
Scabiosa
  atropurpurea *214*
  caucasia *214*
scarlet plume *208*
Schefflera 165
  actinophylla 165
  arboricola 165
Schoenus melanostachys *187*
sciarid flies 333
sclerotia 263, 264
Sclerotina diseases 140
  S. sclerotiorum (cottony rot) 140
Sclerotium rolfsii (southern blight) 140
scouring rush *186*
scouting plants 264, 265, **265**
  accuracy, tools 338
screw pine 163–164
sea holly *208*
sea transport 10, 44
  controlled-atmosphere (CA) storage 367
  from Colombia 26
  from Ecuador 28
  rose 129
  to China 32
  see also shipping
sedentary parasites 305
sedges 162
sedum *210*
seeding, direct 198
Senecio 183–184
Serenoa 178
seven-son flower *209*
shade
  cloth 69, **71**, 92
  houses 69, **71**, **154**, 193, **195**
    Rumohra **176**
  light/moderate/heavy 153–154
shasta daisy *210*
shield fern 168
shipping
  ethylene perception prevention, dendrobium 73–74
  long-distance, chrysanthemum 65
  peony 109
  statice 133, 134
  and storage 361–367
  temperature control 361–362
  see also sea transport
shore fly 285
shrink-wrapping, leatherleaf fern 156, **157**
Siam tulip *207*
Silene armeria *214*
silicon 271
silky oak 172
silleteros 26, **27**
site selection, specialty cuts 196
sleeving, postharvest handling 355
slow-release sachets 332, **333**
slugs 334
smoketree *207*
smooth hydrangea *209*
snake grass *186*
snake plant 165
snapdragon *204*
snow-on-the-mountain *208*
snowberry *214*

soft rot, bacterial 291–292
soil
- electronic moisture sensors 233
- field 194
- solarization 291
- sterilization 284, 329
- temperature 52

soil/substrate
- air–water balance 233–234
- moisture monitoring 233
- water potential (Ψ) components 227–229

soil/substrate–plant–atmosphere continuum (SPAC) 227, *228*, 230
soilless production systems 248–249
soilless substrates 118, **120**
solarization 282
- of ground beds 260, **260**
- soil 291

Solidago & x *214*
Solidaster **194**
- cvrs. *214*

solutions
- acidifiers *350*
- flower food 352–353, **353**
- hydration 348, 350, **351**
- *see also* fertigation; nutrient solution; postharvest bucket solutions; pre-packaging bucket solution

South Africa 19–20
South America 23
South and Central America 25–28
South Korea 36
Southeast Asia 85
southern blight (*Sclerotium rolfsii*) 140
southern magnolia 180
spacing, plant 198–199
Spain 17
Spanish moss *188*
specialty cuts 191
- flowers 21, 24–25
- flowers, fruits or stems *203–215*
- plant type 215–218
- production environment 192–196
- species 201–202, *203–215*

speedwell *215*
spider mites 132, 156
- biological control 318, 331–332
- *Tetranychus urticae* 318–320

spineless butcher's broom 177–178, **177**
Spirea cvrs. *214*
sporangia 272–273, 281, 282, 283
sporulation 272–273, 282
spotted Japanese laurel 168
Stachys byzantine *188, 214*
stale bed method 200
star fern *186*
statice (*Limonium* spps. and hybrids) 130–135
- coloring **361**
- cultivars, annual/perennial or hybrid 130
- irrigation and nutrition 132
- market 130
- pests 132–133
- postharvest management 133–134, **134**
- production practices, annual statice 131–132, **131**
- *Uromyces* spp. 270, **271**

steel grass *188*
Steinernema feltiae 328–329, 333
Steinernematidae 333
stem
- bending 44, 79, 84, 148
- rot 53, 140, 279–280
  - *Phytophthora* 282–283
  - *Rhizoctonia* 53, 283–284
- wilts 140
  - *Fusarium* 59, 66, 279–280
  - sunflower 140

Stemphylium
- leaf and flower spot and ray speck 83, 275–276
  - disease cycle 275–276
  - hosts 276
  - management practices 276
  - pathogen description 275
  - ray speck 275
  - symptoms and signs 275
- spp. 275–276

Stenocarpus angustifolius *188*
stenting, rose 117, **119**
Stephanotis floribunda *214*
sterilization, soil 284, 329
sticky card, yellow 324, **324**
stock *211*
storage
- and shipping 361–367
  - air movement 364
  - controlled-atmosphere (CA) storage 366–367
  - disease control 363–364, **364**
  - environmental monitoring 365
  - forced-air cooling 365–366, **366**
  - humidity 363
  - light 365
  - temperature 361–363, **362**
  - wet versus dry 367

storage/transport solution 74, 84
strawflower *215*
streak disease 60
street vendors 40–41
  Thailand **35**
Strelitzia reginae *214*
stress
  and pythium root rot 281
  water and temperature 367
strobilurins 279
STS 60, 359
subscriptions 43
substrates 192
  and fusarium infection 280
  humid/dry 153
  soilless 118, **120**
  tulips in 145, 146
  see also soil/substrate
subtropical climates 153
subtropical foliage species 166–178
suckers, rose 120
sucrose 74
summer flowers 24–25
sunflower (*Helianthus annuus*) 135–142
  cultivars and types 135–138, **137**
  irrigation and nutrition 138–140
  itersonilia petal blight 274, **275**
  market 135
  pests 140–141
  postharvest management 141
  production practices 136–138
    head size and stem thickness 138, **139**
sunlight 153
supermarkets 12, 14, 17, 23, 44
support
  netting **51**
    specialty cuts 196, **197**
sustainability 44–45, 236
sustainable practices
  programs 45
  rose 117
swamp sunflower (*Helianthus angustifolius*) 136
swan plant *209*
sweet pea *210*
sweet William (*Dianthus barbaratus*) 57, **57**, *207*
Swiss-cheese plant 163
sword fern 183, *187*
Sydney Flower Market (Australia) 39, **40**
symbolism, cultural/religious 150
Symphoricarpos spp. *214*
Syringa cvrs. *214*
systemic fungicides 273, 277
systemic herbicides 201

Tagetes erecta *214*
Taiwan 34–35
Tanzania 20
technical aspects, of recirculation and recycling 247
technology
  biological control, new 337
  drone 338
Telopea cvrs. *214*
temperate climates 8, 153
temperate species 8
  cut foliage 178–185
  herbaceous perennials 155
  woody foliage 155
temperature 8, 49–50, 65, 69–70, 81, 88
  for foliage 151–152
  logs 365
  management for ethylene damage prevention 358
  preharvest care 343–344
  storage and shipping 361–363, **362**
  tolerance *154*
    minimum for foliage 151–152
tensiometer 228, 233
tepee palm 169
Tetranychus
  spp. 322
  urticae 318–320
Thailand 34, **35**
  dendrobium growing *see* dendrobium (*Dendrobium x hybrida*)
Thalictrum spp. *214*
Thaumatotibia leucotreta 329–330, 337
therapy, disease 261
Thielaviopsis
  basicola 284
  root rot, black mold 284–285
    disease cycle 285
    hosts 285
    management practices 285
    pathogen description 284–285
    symptom and signs 285
  spp. 147, 285
  thielaviodes 284–285
Thlaspi **185**
  arvense *188*
thrips 66, 83, 90, **220**, 292–293
  biological control 318

commercial agents 321, *321*
in relation to life cycle stage 321–322, **322**
control difficulty 320–321
larvae control 333
see also western flower thrips (WFTs)
Thrips
setosus 320
simplex 320
Thuja
occidentalis *188*
plicata *188*
Ti plant 161–162
tickseed *206*
Tillandsia usneoides *188*
tissue culture 34, 92
dendrobium 69, **70**
gerbera daisy 80
tissues
foliar and floral
bacterial and phytoplasma pathogens 285–289
fungal and oomycete pathogens 261–279
tobacco whitefly 322–324, **323**
toothbrush plant 172
toxic ions 232
trachelium *214*
Trachelium caeruleum *214*
Trachymene coerulea *214*
trade patterns
flowers
Americas 21, **22**, 23
Asia **30**, 31
traditional markets 44
transmission, vector 292
transpiration 230
evapo- 226, **226**, 233
transplants 197
transportation
from field/greenhouse to packing house 346–347, **347**
dry/wet 346, **347**
systems 9–10
see also sea transport; shipping
tree fern 167–168
Trialeurodes vaporariorum 322–324
Trichoderma spp. 265, 284
Triteleia laxa *214*
Trollius spp. *215*
tropical climates 8, 152
lowland/highland 152
tropical species 8, 362
foliage 158–165
woody 155
herbaceous perennials 155
tuberose *213*
tulip (*Tulipa* x *gesneriana*) 142–149
botrytis blight 263
bulb sizes 144, *146*
cultivars and categories 143–144, **143**
irrigation and nutrition 146
market 142
pests 146–147
postharvest management 147–149
production practices 144–146, *146*
tumors 290
tunnels 24–25, 88, 92, 105, 192–193, **193**
turgor pressure 225, 230, 232
turtlehead *206*
Tuscany (Italy) 16–17
Tweedia *212*
two-spotted mite 318–320
biological control 319–320, **319**, 331–332

u-pick operations 42
UK 17
Ulmus alata *215*
umbrella sedge 162
umbrella tree 165
United Flower Growers 39
Uromyces spp., statice 270, **271**
USA 21–25
USA–Andean countries free-trade agreements 9

Vaccinium 184
vector transmission 292
vendors, online 41
ventilation 69
Verbena bonariensis *215*
vernalization, peony 105, 106
Veronica longiflora *215*
Veronicastrum virginicum *215*
Verticillium wilt (*Verticillium dahlia*) 140
Viburnum spp. *215*
Vietnam 35–36
vine weevils, black 333–334
Viola
odorata *215*
x *wittrockiana* *215*
violet *215*

viroids
composition 292
see also viruses
viruses 114
alstroemeria 53
carnation 60
chrysanthemum 66
composition 292
dissemination strategies 292–293
freesia 78, *298*
gerbera daisy *298–299*
gladiolus 90, *299*
gypsophila 94, *299*
lily 102, *300–301*
peony 108, *301*
sunflower 140
tulip 147
and viroid diseases 292–293
general management strategies 293
pathogen description 292
symptoms 292
transmission 292–293, *294–304*
virus–vector associations 293
Vitex spp. *215*

waratah *214*
warm-season annuals 155
Washingtonia 178
wasps
ectoparasitic 328
parasitic 323–324, **323**
water
crop, relations 225–227
desalinized 232
during storage and shipping 367
efficient utilization 236
preharvest care 344
purification systems 231–232
quality, postharvest handling 357
reduced availability 226–227
relations in soil substrates and plants 227
stress 89
traps 330
water footprint (WF) 234–236
components, blue (WF_{blue})/green (WF_{green})/gray (WF_{gray}) 234–236
indexes 236
water potential (Ψ) 227
components in soil substrate ($Ψ^{soil}$) 227–229
components within plants 229–230
of plant tissues, osmotic potential ($Ψ_o$) 229
of plants, pressure potential ($Ψ_p$) 230
of soil ($Ψ^{soil}$)
matric potential ($Ψ_m$) 227–228
osmotic potential ($Ψ_o$) 227, 229
total ($Ψ^{Total}$) 227, *228*
water use efficiency (WUE) 226, 234
effective 226
water-recycling systems 247
economic incentives 247
technical aspects 247
water-retentive boxes 360
wattle 166
waxflower *206*
waxmyrtle *187*
weather stations 233, 265–267
website, direct sales 156
weeding
flame 201
hand/manual 200, 201
weed(s)
barrier **262**
control 275
specialty cuts 200–201
management 194–196
rose 127
removal 289
weeping podo 166–167
Weigela florida *188, 215*
Western Australian peppermint 167
western flower thrips (WFTs) 320–322
biological control 321–322, **322**
commercial biocontrol agents 321, *321*
western sword fern 183
whaleback palm leaf 163, concept 234
white oak 172
whiteflies 83
biological control 323–324, **323**, **324**
tobacco and greenhouse 322–324, **323**
wholesale firms 39
wholesale florists 37, 39
wild-harvesting 156
willow myrtle 167
willowleaf sunflower (*Helianthus salicifolius*) 136
wilt/wilting 225, 228
Fusarium 59, 66, 280
Verticillium 140
see also Pseudomonas bacterial wilt, bacterial leaf spot
winged everlasting *203*
witch hazel *209*
witches' broom 288

woody perennials, native, Australia 36
woody plants, temperate/perennial 155
wound ethylene 357–358
wounds, plant 290, 291

Xanthomonas
  bacterial leaf spot 287
  campestris 287
  spp. 287
Xanthorrhoea
  glauca *188*
  johnsonii *188*
  latifolia *188*
xaté 168
Xerochrysum bracteatum *188, 215*
Xerophyllum 184
xylem 230
  fluid 229

yarrow *203*
Yunnan Province (China) 31

Zamia pumila *188*
Zantedeschia **222**
  cvrs. *215*
zig-zag wattle 166
Zinnia **223**
  violacea *215*
zoospores 272, 273, 281, 283

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CROP PRODUCTION SCIENCE IN HORTICULTURE

CUT FLOWERS AND FOLIAGES

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The cut flower and foliage industry is a global business with major production locations in North America, South America, Central America, East Africa, Europe, the Middle East, Asia, Australia and New Zealand. Few other horticulture crops are as ubiquitous, yet the production techniques and challenges are universal.

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