10 Family Cucurbitaceae

Origin and History

The cucurbits are largely tropical in origin with different genera originating in Africa, tropical America, and Southeast Asia. Commercial cucurbits are primarily herbaceous annuals that produce distinctive tendril-bearing vines and are commonly grown in temperate regions with long growing seasons. Some are adapted to humid conditions while others are found in arid regions. Most are frost-intolerant although some species are more tolerant of low temperature than others.

Taxonomy

The Cucurbitaceae family is well defined but taxonomically isolated from other plant families. The family Cucurbitaceae consists of about 120 genera and more than 800 species. Two subfamilies, Zanonioideae and Cucurbitoideae, are well characterized: the former by small, striate pollen grains and the latter by styles united into a single column. The food plants all fall within the subfamily Cucurbitoideae and belong to two tribes: the Cucurbiteae and Sicyoideae. (Maynard and Maynard, 2000). The genera *Cucurbita*, *Cyclanthera* and *Sechium* are of New World origin. All other genera originated from the African or Asian tropics. In this chapter, the production of cucumber (*Cucumis sativus*), netted and non-netted melons (*Cucumis melo*), watermelon (*Citrullus lanatus*), and squash and pumpkin (*Cucurbita* spp.) will be discussed. Whitaker and Davis (1962), Robinson and Decker-Walters (1997) and Rubatzky and Yamaguchi (1997) provide information about other crops in the family Cucurbitaceae.

CUCUMBER

Origin and History

The center of origin of cucumber is believed to be India where it has been grown for thousands of years (Zeven and Zhukovsky, 1975). The ancient Egyptians also cultivated cucumbers. *Cucumis sativus* var. *hardwickii*, a wild taxon native to India, has been proposed as the wild progenitor of the domesticated forms of *C. sativus*. Cucumbers spread to China and Greece from India about 2,000 years ago (Whitaker and Davis, 1962; Robinson and Decker-Walters, 1997). The Sikkim cucumber has been grown in the Himalayas as food for centuries.

The cucumber also spread to Italy, and was a significant crop during the Roman Empire. In classical Rome, Pliny reported greenhouse production of cucumbers by the 1st century, and the Emperor Tiberius was said to have eaten them throughout the year (Sauer, 1993). Cucumbers were probably spread to the rest of Europe by the Romans. The earliest records of cucumber cultivation appear in France by the 9th century, Great Britain by the 14th century and the Caribbean at the end of the 15th century. Colonists introduced the cucumber to North America by the mid-16th century (Hedrick, 1919). Interaction between Europeans and Native Americans spread cucumbers throughout North America. Less than a century later, European explorers observed a wide range of Native American peoples cultivating cucumbers along the east coast of North America from Montreal to Florida. Slaves also introduced cucumber directly to the Americas from Africa in the early 1600s. By the 17th century, Native Americans living in the Great Plains region were also cultivating cucumbers (Wolf, 1982).

Botany

Cucumber (*C. sativus*) has a chromosome number of n = 7, West Indian Gherkin (*C. anguira*), n = 12, and Armenian cucumber (*C. melo*), n = 12. Commercial cucumber cultivars are warm-season, frost-sensitive annuals that are cross-pollinated by bees.

Plants commonly have a trailing or climbing growth habit, although some bush cultivars with shortened internodes also exist. Root systems are extensive but shallow. Stems are square with stiff bristle hairs, unbranched tendrils and generally range in length from 0.4 to 3 m (1.3 to 9.8 ft). Tendrils at each node help anchor plants and allow climbing on supports. Cucumber petioles are 3–15 cm (1.2–5.9 in) long. Rough leaf blades have a triangular ovate shape from 5 to 25 cm (2.0 to 9.8 in) wide with three- to five-angled regions or shallow-lobed sinuses and a pointed apex (Rubatzky and Yamaguchi, 1997).

Cucumber plants exhibit monoecious (separate male and female flowers on a plant), andromonoecious (separate perfect and male flowers on the same plant) or gynoecious (all female) sex expression. Sex expression is genetically controlled but modified by the environment and chemicals. Application of auxin or ethephon favors both earlier and a higher percentage of female flowers, while gibberellin delays female flower formation and percentages. Auxin and ethephon favor female flower development while gibberellin stimulates the formation of male flowers. In monoecious cultivars, staminate flowers appear first and are several times more abundant than pistillate flowers. Flowers occur at the nodes, staminate in clusters or singly with only one flower in a cluster opening at a time. Pistillate flowers are borne singly on the main stem and lateral branches in monoecious types and singly or in clusters on the main stem and lateral branches on gynoecious types. The large inferior ovary of pistillate flowers resembles a miniature fruit. Both staminate and pistillate flowers are 1–3 cm (0.4–1.2 in) in diameter with a yellow, showy five-lobed corolla. Flowers are open for a single day and if not adequately pollinated rapidly abort.

Flowering is influenced by photoperiod with regard to the number and sex of the flowers formed. During short days, there is a tendency for earlier and more frequent pistillate flowering. Low temperatures may cause a similar response. Conversely, high temperature and long days promote male flower formation (Rubatzky and Yamaguchi, 1997). High nitrogen promotes vegetative growth and inhibits flower formation. Environmental stress (water, nutrient, etc.) promotes female flower formation.

Fruits can be spherical, blocky, oblong or elongated in shape and variable in size. Fruit surfaces vary in the number and size of spiny warts, which are usually more apparent on young fruit. Cucumber fruit are consumed immature when their flavor is mild and seeds are small and underdeveloped. Cucumbers are used for different purposes depending on their characteristics (Fig. 10.1).

Cultivars are often divided into the general categories of "fresh market" or "processing" to describe their intended uses. Cultivars grown for fresh market usually have a fruit length-to-width ratio of at least 4:1, dark-green color when immature, thick skin, slightly tapered stem and blossom ends. The seed cavity of fresh market types is usually larger than processing cultivars.

Cultivars developed for processing often have smaller vines, fruit with a length-to-width ratio of about 2.5:1, bicolored pale and darker green immature color, thin skins, blocky shape and more prominent warts. The warts bear white or black loosely attached spines (spicules) in their centers. Fruit with white spines turn from green to white or yellow at full physiological maturity when seeds have fully developed. The color of black-spined fruit changes from green to orange at maturity. Black-spined fruit have thinner skin and lighter fruit color compared to white-spined fruit and for many years were preferred for processing because they have a more attractive appearance after pickling. However, black-spined cucumbers tend to prematurely develop their mature orange color at the stem and blossoms ends under environmental stress or when over mature, so more white-spined cultivars have been developed for processing in recent years.

West India gherkin

Small-fruited cultivars of pickling cucumbers are sometimes sold as gherkins. However, the West India or true gherkin (*Cucumis anguria*) belongs to a different species and has a different appearance and characteristics than *C. sativus*. West India gherkin is an annual, monoecious climbing vine with flowers, leaves, tendrils and fruit smaller than cucumber. Fruits, which are spiny, yellow, oval and about 5 cm (2 in) long, are eaten fresh, cooked or pickled. The plant may self-seed, escape from cultivation, and become an aggressive weed (Whitaker and Davis, 1962).

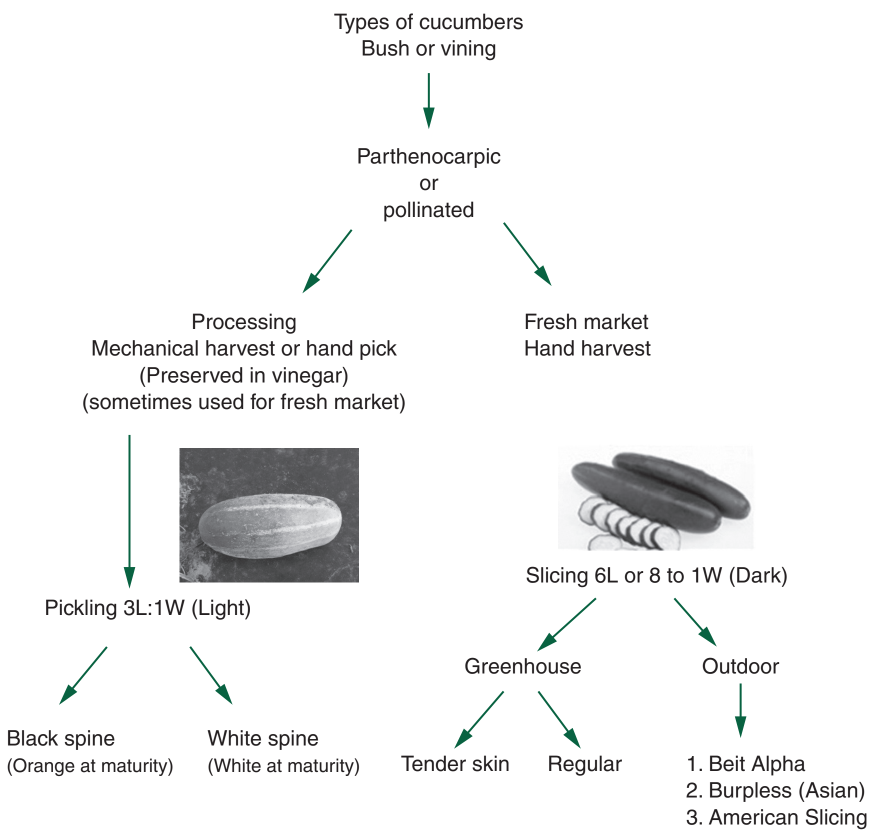

Fig. 10.1. Cucumber cultivars come in many different shapes and sizes that were developed for specific uses and markets. This figure summarizes some of the major commercial types.

Types and Cultivars

There are many diverse cultivars of cucumber grown throughout the world. Cultivars differ in their degree of bitterness caused by cucurbitacins that accumulate in tissues of plants in the family Cucurbitaceae. The function of cucurbitacins is believed to be defense against herbivores. Cucurbitacins are chemically classified as steroids but often occur as glycosides (Chen *et al*., 2005). Non-bitterness in fruit is inherited as a simple recessive trait. Since plant breeders have been selecting against bitter flavor for many years, fruits of most modern cultivars are free of bitterness. Some older heirloom cultivars may develop bitter taste, particularly when grown under environmental stress.

Pickling

Immature pickling cucumber cultivars are processed with vinegar, spices and herbs (such as dill seed) to make pickles and other products (Fig. 10.2).

Pickling cultivars have special characteristics that make them suitable for processing in vinegar (Motes, 1975). Resistance to carpel separation and bloating allow pickling cucumbers to retain their shape and integrity during the brining process. Fruit are harvested for processing while immature and not more than 12.5 cm (5 in) long. Cucumbers for processing may be open-pollinated or F-1 hybrids and are either hand or mechanically harvested, maturing 55–60 days from seeding. To ensure a concentrated set for mechanical harvesting, gynoecious cultivars are often preferred. The first flowers developing on a gynoecious cultivar are female, so every flower has the potential to produce fruit resulting in a concentrated early set and uniform crop maturation. However, to provide a source of pollen, a monoecious cultivar must be added so

Fig. 10.2. Pickling-type cucumber fruit at harvest maturity.

that 12–18% of the plants are pollinators. The male flowers of the monoecious cultivar are sufficient to pollinate gynoecious plants (Rubatzky and Yamaguchi, 1997).

Total yields of gynoecious and monoecious cultivars are comparable because not all of the female flowers on the gynoecious plants develop into fruit. The gynoecious plant cannot produce enough photosynthates, so some female flowers abort. Applying gibberellic acid to small plants induces some male flower formation on gynoecious cultivars for seed production. The gynoecious character may not always be stable, so some plants may be monoecious in a gynoecious cultivar. Crowding may increase the percentage of monoecious plants in a gynoecious field depending on the stability of the cultivar. Pickling cultivars are sometimes marketed fresh for use in salads or fresh consumption without pickling.

American slicing

Fresh market cultivars popular for slicing as a side dish or in salads are sometimes referred to as American types. Cultivars are usually monoecious F-1 hybrids that require bee pollination and mature in about 80–85 days from seeding. These cultivars have comparatively solid dark-green skin and a length-to-width ratio of 5:1 or greater, 8–10 cm (3–4 in) in diameter and 20–25 cm (8–10 in) long (Fig. 10.3).

The fruits are harvested immature well before physiological maturity, which occurs at approximately 120 days when the fruit are white or creamy yellow in color with fully mature seeds.

Plant breeding has improved the quality of the American slicing cucumber. Modern cultivars are uniformly dark green over the entire fruit with no white striped ends. The fruit shape is nearly cylindrical with blunt ends and fruits appear circular in cross section. The pericarp (fruit) walls are thicker and the seed cavity greatly reduced. Modern cultivars tend to have fewer warts and spines compared to older cultivars (Rubatzky and Yamaguchi, 1997). Many modern cultivars are resistant to virus diseases and mildew.

Parthenocarpic types

Parthenocarpic slicing cultivars are also called seedless, English or greenhouse cucumbers. Seedless or parthenocarpic cucumbers have traditionally been grown in greenhouses to prevent bees from introducing foreign pollen, which would cause seed development (Fig. 10.4).

Many cultvars are gynoecious, producing long, straight, smooth fruit at each axil, with thin-skins and medium to dark-green color. A slightly restricted "neck" at the stem end of the fruit serves to readily identify this unique type. Parthenocarpic cucumber fruit have a length-to-width ratio of about 6:1. The skin is so thin that greenhouse cucumber cultivars are often film wrapped to protect against physical damage and prevent shriveling (Rubatzky and Yamaguchi, 1997).

More recently, parthenocarpic cultivars have been developed for field production of both processing and fresh market cucumbers. Parthenocarpic pickling cucumber cultivars are not dependent on bee pollination and produce uniform fruit for mechanical harvest when conditions are unfavorable for pollination. For the processing of larger whole fruit, parthenocarpic cultivars are less desirable because they lack seed development, which contributes to texture and flavor components associated with quality.

'Beit Alpha' cucumbers were developed in Israel but are gaining popularity in other parts of the world as a fresh-market type. 'Beit Alpha', also known as 'Beta Alpha', are a type of parthenocarpic, all female, multi-fruited, dark-green hybrid that do not require pollination and offer high yield potential. The seedless fruit is 14–19 cm (5.5–7.5 in) long, with a thin smooth skin with few warts that does not need to be peeled before eating or film wrapping to prevent postharvest dehydration. Fruits can be harvested when 3–4 cm (1.2–1.6 in)

Fig. 10.3. Slicing cucumbers after harvest waiting to be washed and graded.

Fig. 10.4. Greenhouse-grown parthenocarpic cucumbers from the Netherlands.

in diameter or for the specialty markets with the flowers still attached.

Oriental types

Oriental cultivars are usually long, contain seeds, have thin dark-green skins and considerable warts and spines. They are popular in Asian markets and are grown to a limited extent in other parts of the world. Oriental cultivars are often divided into two groups: the day-neutral North China group and the short-day South China group that is grown primarily for winter production. The South China group produces primarily pistillate flowers under short-day conditions and many staminate flowers under long-day conditions.

The Sikkim cucumber, also called the Concombre apple, is popular in India and is unique because the fruit has reddish brown skins. The Sikkim cucumber is a fat, large fruit reaching 38 cm (15 in) long and 15 cm (6 in) wide. The ripe fruit is eaten cooked, fermented or raw and has a mild flavor (Tamang *et al*., 1988).

Armenian

The Armenian cucumber, also called the serpent or snake cucumber, is a type of melon (*C. melo*) that is eaten fresh like a slicing cucumber when immature. The annual vine is creeping, with slender pubescent stems and rounded leaves with five lobes. The sex expression is monoecious with small and pale yellow flowers with five petals similar to other melons. The Armenian cucumber is long and slender with pale to dark green skin that is wrinkled longitudinally without spines. The slender fruit have their best flavor when 25–35 cm (10–15 in) in length but if allowed to grow will reach a length of about 0.9 m (3 ft) and up to 15 cm (6 in) in diameter. Fruit are rarely straight and often bent and twisted. The fruit color changes to yellow when ripe with a mature odor similar to cantaloupe (Rubatzky and Yamaguchi, 1997).

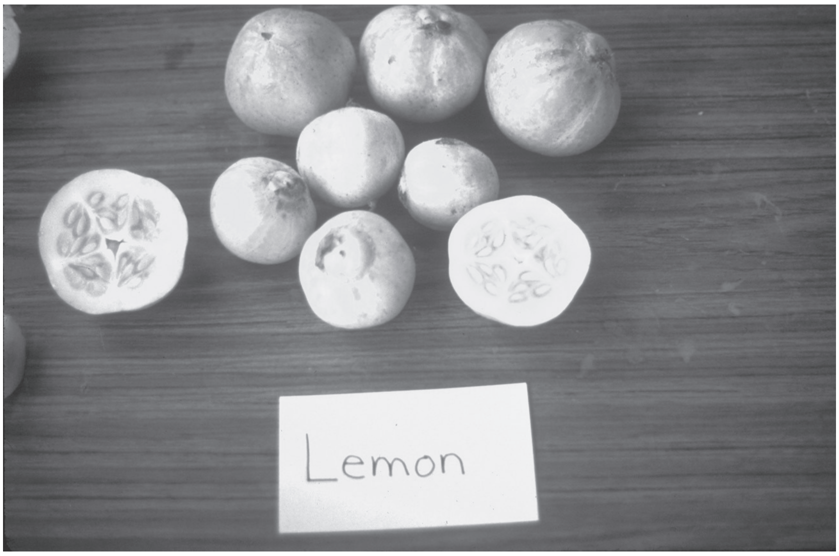

Fig. 10.5. 'Lemon' cucumber fruit.

Novelty types

Novelty cultivars have a unique appearance that appeals to some consumers but generally have limited marketability. 'Lemon' or 'Apple' is a novelty or heirloom open-pollinated cultivar that has been passed along for many generations without significant genetic improvement. The fruits are round, have black-spines, and pale yellow-green color at the immature eating stage before turning bright orange at physiological maturity when the seeds are fully developed (Rubatzky and Yamaguchi, 1997; Fig. 10.5).

'Lemon' is andromonoecious (separate male and perfect flowers on the same plant) like cantaloupe. A hundred years ago, some botanists incorrectly identified this cultivar as a cantaloupe. The seed area is large and the pericarp wall is very thin compared to modern cucumber cultivars.

'White Wonder' is a white novelty pickling cucumber cultivar that lacks chlorophyll in the fruit epidermis during immature and mature stages of development. The color is the primary characteristic that makes 'White Wonder' unique. The shape, texture and flavor are similar to other pickling cultivars.

Economic Importance and Production Statistics

Total world production of cucumbers and gherkins in 2011 was estimated to be 1,958,000 ha (4,836,260 acres). The average world yield was 30,927 kg/ha (27,613 lb/acre) in 2011. Compared with other vegetables, cucumber occupies fourth place in importance in the world, following tomato, cole crops and onion. In 2011 total production of cucumbers and gherkins, according to FAO, was 37.6 million metric tonne (t); Africa producing 847,737 t, North America 1.2 million t, South America 78,570 t, Asia 30.8 million t and Europe 3.9 million t. China alone produced 23.6 million t. For the most current information on cucumber production, please consult the latest FAO Crop Production Statistics.

Nutritional Values

Cucumbers are mainly water and do not contribute a great deal to the human diet. Cucumbers are a good source of certain minerals like potassium but are a poor source of protein, carbohydrates, fat, fiber or most vitamins (Table 10.1).

Production and Culture

Temperature requirements and crop management

Cucumbers are a warm-season, frost-sensitive crop requiring warm soil temperatures for germination and reliable field emergence. The minimum, optimum and maximum soil temperatures for germination are

Table 10.1. Nutritional composition of cucumber (USDA, 2011).

Nutrient	Amount/100 g edible portion
Water (%)	96
P (mg)	17
Energy (Kcal)	13
Fe (mg)	0.3
Protein (g)	0.5
Na (mg)	2
Fat (g)	0.1
K (mg)	149
Carbohydrate (g)	2.9
Ascorbic acid (mg)	4.7
Fiber (g)	0.6
Vitamin A (mg)	45
Ca (mg)	14

60°F (15.5°C), 95°F (35°C) and 105°F (40.5°C), respectively. The optimum range of soil temperatures for stand establishment is 15.5–35°C (60–95°F) (Masabni *et al*., 2011).

Little vine growth occurs when temperatures fall below 15.5°C (60°F). The growth rate increases steadily as temperatures rise above 21.1°C (70°F) (Curwen *et al*., 1975). Crops planted in early spring when soils are cool may take 8–9 weeks or more to reach harvest-stage, while later plantings may require only 6 weeks. Under optimal conditions, pickling cultivars mature approximately 55–60 days after seeding depending on the cultivar and the fruit size required. Slicing cultivars require an average of 80 days to harvest from seeding depending on the cultivar and environmental conditions.

Cucumbers should not be planted in a rotation after related cucurbit species like melons, squash and pumpkins because of the build-up of various insects and diseases, which live on crop residues and are common among these related species. Cucumbers are very sensitive to some herbicides, so carryover from previous crops must be considered when selecting fields for conventional production.

Soil requirements

Cucumbers can be grown profitably on most fertile, well-drained soils. Loam-textured soils with organic matter are well suited for cucumber production. Light, sandy soils are acceptable provided they are adequately fertilized and irrigated. A pH of 6.0–7.0 is suggested for cucumbers for optimum growth. Acid soils with pH <5.5 should be avoided (Lorenz and Maynard, 1988).

Fertilizer and nutrition

Cucumbers respond favorably to fertilizer, so proper fertility management is a key to maximizing productivity. Fertilizer requirements vary, depending on the soil type, the environment and cultivar. There is no single recommendation that will fit all production situations. Fertilization is most efficient and effective if based on preplant soil test recommendations and foliar analyses made throughout the season. Most soil testing labs will rate essential minerals as being high, medium or low and recommend how much fertilizer should be applied to successfully grow the crop. It is important to determine how many nutrients a cucumber crop is likely to remove during a season. The nutrients removed from a field by a typical cucumber crop would be 196 kg/ha (175 lb/acre) of nitrogen (N), 28 kg/ha (25 lb/acre) of phosphorus (P) and 196 kg/ha (175 lb/acre) of potassium (K) (Masabni *et al*., 2011). Soil test recommendation for N and K often are less than this amount to account for release of nutrients for organic matter and inputs from the nitrogen cycle. Recommendations for P additions often exceed the amount removed by the crop because some P fertilizer will be fixed or immobilized in soil. An adequate supply of micronutrients should also be provided, especially for hydroponic production.

Nitrogen is a very important nutrient for cucumber production. Early in the season, adequate nitrogen promotes vegetative growth and canopy formation that is needed to maximize photosynthesis to support later fruit development. Lower available nitrogen a little later in the season promotes flower formation and fruit set, while excessive nitrogen fertilization may delay flowering and reduce fruit set.

Petiole or plant tissue analysis can be used to assess crop nutrient status during the growing season to know if adjustments in the fertility program are required. Later in the season, side dressing or fertigation with nitrogen, and possibly other nutrients, may correct deficiencies and maximum yields on sandy soils, especially when crops are handpicked over an extended period. Additional nitrogen applications are often needed following heavy, leaching rains on light, sandy soils. Side dressing is usually not necessary for crops grown for once-over mechanical harvesting because of the relatively short crop maturation time.

Seedbed preparation

Field production of cucumbers may be with or without mulch. Plasticulture is the most popular mulch and is often used in areas with short growing seasons to enhance early production of slicing cucumbers for fresh market. Plasticulture is rarely used for the production of earlier maturing pickling cucumbers because the added cost is not warranted and the mulch interferes with mechanical harvesting.

If cucumbers are not grown on plastic, production on raised beds is recommended to improve drainage and to reduce belly rot of the fruit. If fertigation is not used, mineral nutrients should be incorporated into the bed prior to planting. The soil should be tilled so that it is friable and free of clods to provide good seed to soil contact for direct-seeded crops.

Field establishment

There are approximately 1100 cucumber seeds/oz (30–35/g) (Lorenz and Maynard, 1988). Precision planting of cucumber seeds to the right spacing and depth will encourage uniform emergence of seedlings. A uniform stand will lead to concentrated fruit set for efficient hand or mechanical harvesting. Precision seed spacing produces the desired stand of plants, saves seed and eliminates the need for thinning after establishment. This is particularly important for once-over destructive machine harvests of pickling cucumbers. Cucumbers are normally planted at a depth of 0.5–2 in, depending on soil type, time of season and soil moisture availability. Many growers use precision planters and coated seed helps deliver fungicides, biologicals or small amounts of fertilizer.

In short season areas, cucumbers particularly for fresh market are transplanted. Transplanting may reduce the time to first harvest by 10 days to 2 weeks depending on environmental conditions. Cucumbers are sensitive to transplant shock and are best transplanted from plug transplants rather than with bare roots. To reduce transplant shock, plants should be hardened before transplanting and irrigated more frequently until plants are properly established.

Spacing

Spacing is dependent on cultivar, environments and cultural practices. Generally recommendations for fresh-market cucumbers are in-row spacing of 23–31 cm (9–12 in) with row spacing of 0.9–1.8 m (36–72 in). This results in populations of 18,000–29,600 plants/ha (7,300–21,780 plants/acre) (Fig. 10.6).

Pickling cucumbers usually have smaller vines than the slicer type and are grown at high populations. Depending on environmental conditions, maximum yields for hand-harvest may be obtained with in-row spacing of 15–31 cm (6–12 in) with 0.9–1.8 m (36–72 in) between rows. This spacing results in populations of 18,000–71,700 plants/ha

Fig. 10.6. A field of slicing cucumbers grown without plastic mulch, destined for fresh-market sale.

(7,300–29,040 plants/acre). Populations of 50 plants/m^2 gave higher yields compared to lower plant populations of pickling cucumbers (O'Sullivan, 1980). High yields of destructively harvested pickling cucumbers are obtained from plant populations of 123,500–222,300 plants/ha (50,000–90,000 plants/acre) (Curwen *et al.*, 1975). These populations are achieved with in-row spacing of 10–15 cm (4–6 in) with 31–71 cm (12–28 in) between rows.

Irrigation

Cucumber crops require large amounts of water. In many locations where the average rainfall during the growing season is appreciably less than 15 in or erratic during the growing season, irrigation is necessary to maximize both fruit quality and yields. Fruits contain about 95% water. The rule of thumb for at least 1 in of water per week applies to cucumber production. Even this amount may be insufficient to sustain growth during prolonged drought and/or high temperatures. In areas where environmental stress is common, 2 in/week may be required. Wilting decreases yields and may reduce fruit quality depending on the severity. The most critical need for water is during the fruiting when drought may cause "nubbing" (small fruit that are shriveled at one end). In crops being grown for once-over mechanical harvest, the last irrigation should be timed to allow the soil to dry sufficiently to allow equipment into the field.

Where possible, irrigation should be applied early in the day to permit the soil and leaf surfaces to dry before nightfall. Prolonged periods of wet soil and leaves promote infection by mildew, *Alternaria*, angular leaf spot, and other various fruit-rotting and foliage diseases. Overhead irrigation will prohibit bee activity and should not be used in the early morning hours when bees are most active.

Cucumbers can be successfully irrigated by furrow, trickle and overhead sprinkler methods. Furrow irrigation is limited to areas where the land is level. Surface irrigation is preferable to overhead, which tends to spread various diseases to the foliage and fruit. Trickle or drip irrigation is commonly used with plasticulture but can be used on bare soil as well.

Pollination

Bees are extremely important for field production of non-parthenocarpic cultivars. In most areas, native bee populations are insufficient to pollinate a commercial crop. Motes (1975) recommends at least one colony per 50,000 plants. Most cucumber flowers are open for only 1 day and a successful pollination event requires multiple bee visits. Cool wet weather significantly reduces bee activity and pollination resulting in low yields and/or a high percentage of misshapen fruit. Pesticides that harm bees should not be used and when necessary spray applications should be scheduled for late afternoon or early evening.

Greenhouse production

Cucumbers are important greenhouse crops in North America, western Europe and Japan. Cucumbers are grown during the winter in unheated greenhouses in temperate regions. Parthenocarpic cultivars are usually grown in greenhouses to avoid the use of bees since standard field cultivars must be cross-pollinated. Most parthenocarpic greenhouse cucumbers are gynoecious F-1 hybrids. The cost of parthenocarpic greenhouse cucumber seed is significantly higher than seed of standard field cultivars (Hochmuth, 2013).

Plants are transplanted into a wide range of synthetic rooting media including rockwool, gravel, sand or bagged media to avoid the buildup of disease in native greenhouse soils. Greenhouse soils may be sterilized with steam or chemical fumigants. Cucumbers may also be grafted on to special disease-resistant rootstocks such as *Lagenaria siceraria* (Molina) Standl. and a *Cucurbita moschata* (Duchesne ex. Pow) × *C. maxima* (Duchense ex. Lam.) hybrid for greenhouse production in native soils if soil fumigation/sterilization is not used (Hochmuth, 2013).

Temperature control is important with an optimum recommended temperature of 25–28°C (77–82°F) and night temperatures of 17–18°C (63–64°F). Lower temperatures tend to favor vegetative growth while higher temperatures promote flowering. High light intensities are necessary to obtain maximum yields. Greenhouse CO_2 levels should be maintained between 400 and 1500 ppm to maximize photosynthesis (Hochmuth, 2013).

Harvesting and marketing

Fields of slicing cucumbers are repeatedly hand-harvested during the season. Fruit are harvested by carefully cutting or snapping fruit from the vine by hand to avoid damaging the plant. Cucumbers develop rapidly and must be harvested every other day or daily under favorable growing conditions.

Delayed harvest results in excessively large fruit and inhibits the production of new fruit. Fruit are carefully handled and graded after harvest.

Cucumbers for fresh use are often individually film wrapped or grouped in a plastic tray and wrapped to preserve freshness and prevent shriveling. Nontoxic water-soluble wax is sometimes added to the wash water to provide a thin coating on the fruit surface to reduce desiccation and give fruit an attractive glossy appearance. The parthenocarpic greenhouse slicing cucumbers are usually wrapped in plastic film because of their very tender delicate skin that is easily damaged.

Cucumbers are generally stored at 13–15°C (55–59°F) and 90–95% relative humidity (RH) and have a postharvest shelf life of 1–2 weeks. Like all cucurbits, storage at temperatures less than 13°C (55°F) causes chilling injury. Fruits injured by chilling will deteriorate more rapidly when returned to room temperature and cause the formation of off-flavor. Short-term chilling before serving in salads or for fresh use improves crispness. In contrast, freezing injury will be initiated at –0.5°C (31°F). Symptoms of freezing injury include a water-soaked pulp becoming brown and gelatinous in appearance over time (Suslow and Cantwell, 2013).

Cucumbers are highly sensitive to exogenous ethylene. Accelerated yellowing and decay will result from low levels (1–5 ppm) of ethylene during distribution and short-term storage. Do not mix commodities such as bananas, melons and tomatoes with cucumber (Suslow and Cantwell, 2013).

Controlled or modified atmosphere storage and/or shipping offer moderate to little benefit for maintaining cucumber quality. Low O_2 levels (3–5%) delay yellowing and the onset of decay for a few days. Cucumber tolerates elevated CO_2 up to 10% in controlled atmosphere storage but storage life is not extended beyond the benefit of reduced levels of O_2 (Suslow and Cantwell, 2013).

Pickling cucumbers may also be repeatedly hand-harvested but the trend has been toward greater use of once-over destructive mechanical harvesting, particularly for processing, to cut labor costs. A mechanical harvester cuts the vines at the soil surface and conveys the plants up a conveyer to a set of rollers that pinch the fruit from the vine as the plants are fed between the rollers. The vines and immature fruit are returned to the field and fruit of the desired size are conveyed to an adjacent vehicle or wagon and taken to the processing facility for washing, grading and processing.

Diseases

There are many diseases that affect cucumbers. Cucumber mosaic virus, watermelon mosaic 1 potyvirus and zucchini yellow mosaic potyvirus are some of the most important viral diseases (Zitter *et al.*, 1996). The use of disease-free seed and sprayings to control aphids may help prevent the spread of virus diseases. Some cultivars are resistant to viruses.

Some of the most important fungal diseases are downy mildew (*Peronospora cubensis*), powdery mildew (*Erysiphe cichoracearum*) and damping-off (*Pythium*, *Rhizoctonia*) (Fig. 10.7).

Treating seed with thiram, fungicide applications to soil at planting, and spraying emergent seedlings with metalaxyl controls damping-off.

Mildew is common on cucumber leaves, particularly late in the season and in areas with high humidity. Cultural control measures include: removing plant debris at the end of the season to reduce overwintering of the fungus, reducing plant populations to improve air circulation, and avoiding excess nitrogen fertilization. Several fungicides, such as trifloxystrobin, azoxystrobin and chlorothalonil + myclobutanil control the mildew diseases. Some cultivars are resistant to mildew. Biorational compounds can reduce the incidence of powdery mildew on cucurbits. Biorational materials include natural and mineral oils, peroxigens, cow's milk, silicon, and salts of monovalent cations such as sodium, potassium and ammonium (Bélanger and Labbe, 2002).

Stripped and spotted cucumber beetles transmit bacterial (*Erwinia tracheiphila*) wilt among plants during feeding. Cucumber beetle feeding does little direct damage to plants but the bacteria introduced during feeding proliferate in the xylem reducing water flow between the roots to leaves. Bacterial wilt symptoms

Fig. 10.7. Cucumber leaf with powdery mildew infection.

are similar to drought stress and in severe cases will kill plants. Some cucumber cultivars are more resistant to bacterial wilt than others. Other cucumber pathogens include: angular leaf spot (*Pseudomonas syringae* pv. *Lachrymans*), gummy stem blight (*Didymella bryoniae*), common anthracnose (*Colletotrichum* spp.), fruit wet-rot (*Choanephora cucurbitarum*), Fusarium wilt, Cladosporium scab and bacterial soft rot (*Erwinia* spp.) (Zitter *et al*., 1996). Cucumber growers should consult local recommendations for tested and approved control measures as well as disease-resistant cultivars.

Insect Pests

Some of the most troublesome insects of cucumber include cucumber beetles (*Diabrotica* and *Acalymma* spp., vector of bacterial wilt), *Epilachna* spp. beetles, greasy worm (*Agrotis ipsilon*), the melon fruit fly (*Dacus* spp.) and aphids. These pests can be controlled with insecticides. Control with natural enemies is highly developed in greenhouses but less so for field cultivation. Please consult local recommendations for effective control measures.

NETTED AND MIXED MELONS

Origin and History

Netted melons, also called muskmelons or cantaloupes, appear indigenous to Africa (Zeven and Zhukovsky, 1975). The oldest record appears to come from Egypt were muskmelon cultivation occurred as early as 2400 BC. Netted melons were known to Greeks about 300 BC. Truly wild forms are found only in eastern tropical sub-Saharan Africa. The related wild forms reported in India are likely undomesticated escapes derived from local cultivars. Once domesticated, melon diversity expanded into numerous cultivars, especially in India, which is considered a secondary center of origin (Zeven and Zhukovsky, 1975). Cultivars were rapidly dispersed throughout Europe and fairly early into the Americas. Columbus reportedly carried seed to the New World in 1494 and the Spaniards introduced melons into the Americas in the late 1500s. North American natives were growing muskmelons during the 1660s (Rubatzky and Yamaguchi, 1997).

The term muskmelon is derived from musk, which is a Persian word for a kind of perfume. The name cantaloupe is believed to have arisen from the city of Cantaluppi in Italy or from the estate and castle of Cantalupo also in Italy (Rubatzky and Yamaguchi, 1997).

Modern-day cultivars share main characteristics of earlier cultivars but greatly improved for uniformity, size, shape, flesh thickness, sugar content and quality. ‘Netted Gem’ introduced by W. Atlee Burpee Seed Company from France in about 1880 made an important contribution to cultivar development in North America. Shipping and storage characteristics were of no importance until after 1900. Today melons are most commonly eaten fresh, as a salad or as a dessert (Rubatzky and Yamaguchi, 1997).

Botany and Life Cycle

Melon is a general term for fruit produced by various members of the family Cucurbitaceae. In some areas the term is applied to both netted and non-netted members of *C. melo* but not watermelon. In other regions of the world, the terms cantaloupe and/or muskmelon are used to describe the netted melon while other types of *C. melo* are called “melon”, “mixed melon” or sometimes “winter melon”. Cucumber and melon are both members of the genus *Cucumis* but different species, so they do not cross-pollinate. Since cucumber and melons are related, some of the information on cucumber also applies to melon.

Naudin classified different forms of *C. melo* into separate botanical varieties in 1859. Although Naudin’s classification was not recognized taxonomically, it was useful for many years to delineate obvious horticultural differences among fruit types within *C. melo*. Many of the botanical variety designations are now classified into eight horticultural groups under *C. melo* (Table 10.2; Rubatzky and Yamaguchi, 1997).

Table 10.2. Groups of *Cucumis melo* (Rubatzky and Yamaguchi, 1997).

Group name	Common name/characteristics
Cantaloupensis (formerly Reticulatus)	Netted melons (muskmelon and cantaloupe) as well as lightly or non-netted cultivars. Perishable
Inodorus	Winter melons or mixed melons. Some may be stored for several weeks
Flexuous	Armenian cucumber, snake or serpent melons
Comonon	Oriental pickling melon
Chito	Mango melon or vine peach melon
Dudaim	Queen Anne’s pocket melon
Momordica	Snap melon
Agrestis	Wild types

Fruit size and characteristics vary widely among groups and cultivars (Table 10.2). Fruit shape varies from spherical to oblong. Many fruits are covered with corky reticulate netting while others are smooth. The vein tracts or sutures are longitudinal indentations or stripes on the fruit surface associated with vascular bundles, which may not be visible in fruits that are heavily netted. The edible melon flesh is actually the fruit pericarp, which varies in thickness, color and texture. Pericarp colors maybe white, green, pink or orange. Aroma varies from strong to odorless and depends on the quantity and quality of volatile compounds produced. Melon fruits produce from 300 to 500 seeds each arising from separate fertilization events. The seeds are smooth, range from 5 to 15 mm in length and have yellow or beige coloration. On average there are approximately 30 seeds/g.

Types and Cultivars

This section focuses on the most widespread and economically important Groups Cantaloupensis and Indorous. Cultivars in the Inodorous and Cantaloupensis Groups can be intercrossed. The Group Inodorus contains the so called "winter melons" such as 'Casaba', 'Canary', 'Honeydew', 'Honeyloupe', 'Crenshaw', 'Canary' and 'Santa Claus' that do not abscise from the vine at maturity, lack heavy netting, are generally less aromatic, and have longer storage life than the Cantaloupensis group. One exception to this description is the 'Crenshaw' melon, which has a short shelf-life and can be very odoriferous. Winter melons generally require a growing season that is several weeks longer than most members of the Cantaloupensis Group. Best fruit quality is obtained at high temperatures from 30 to 35°C (86–95°F) in semi-arid environments with low humidity.

'Honeydew' fruit have pale green rinds that turn creamy white when mature (Fig. 10.8). The firm, thick, juicy flesh is pale green to white at maturity. Fruit do not abscise when ripe so judging maturity can be more difficult than for netted melons that slip. 'Honeydew' fruit have moderate storage life of up to several weeks under the right conditions. Honeydew can accumulate high sugar contents and when fully ripe may have a soluble solids content in excess of 16%, among the highest of any melon. 'Honeydew' was selected from the French cultivar 'White Antibes' in the state of Colorado in the USA (Rubatzky and Yamaguchi, 1997).

'Crenshaw' originated by chance in a muskmelon field (Rubatzky and Yamaguchi, 1997). The 'Crenshaw' fruit is smooth and oblong with some ribbing at the tapered stem end (Fig. 10.9). 'Crenshaw' fruit exhibit intermediate stem abscission, are very susceptible to sunburn, and have poor shipping and storage qualities. The immature fruit rind is dark green.

Fig. 10.8. 'Honeydew' fruit in a California production field.

Rind color change is not uniform and ripe fruit often have sections of both green and pale yellow. The ripe fruit have moderately firm, salmon-colored flesh with a mild perfume-like aroma. The flesh is sweet with 12–14% soluble solids (Rubatzky and Yamaguchi, 1997).

'Casaba' fruit have a greenish yellow, thick, relatively hard rind with shallow ribs and no netting. Fruits are round but tapered at the stem end (Fig. 10.10). The white flesh is moderately firm with an aroma reminiscent of cucumber. The fruit do not abscise at maturity and have a long storage life of up to a couple of months at cool temperatures. The flesh has a soluble solids content of 6–8%.

'Juan Canary' fruit are oblong, smooth, and intense yellow. The flesh has little aroma and is whitish green. The flesh has a soluble solids content of 6–8%. The fruit do not abscise at maturity, are well adapted to shipping and can be stored for several weeks.

Fig. 10.9. 'Crenshaw' fruit in a California field. The yellow fruit on the left is ripe and the green fruit is immature. The rind is very sensitive to sunburn and fruits not protected by the canopy are sometimes protected with bags.

Fig. 10.10. Mature bright yellow 'Casaba' fruit in a California production field.

'Santa Claus' is an oblong slightly warted melon with a hard rind that is green and yellow, vaguely striped, and has little aroma. The flesh is firm and whitish green with a soluble solids content of 6–8%. The fruit are suitable for shipping and under cool temperatures can be stored for approximately 3 months if the rind is not damaged.

The netted fruit of group Cantaloupensis (formerly Reticulatus) are called muskmelon and/or cantaloupe in many markets. A unique feature of some muskmelon/cantaloupe cultivars is that they detach from the vine at maturity in a series of stages known as "slip". The slip stages are useful for characterizing maturity. Fruits progress from complete stem attachment to ¼, ½, ¾ and finally full slip during ripening, becoming increasingly aromatic and yellowish orange in color (Fig. 10.11; Rubatzky and Yamaguchi, 1997).

The name cantaloupe is often associated with fruit produced in North and Central America in arid regions with low humidity and high temperatures. Cantaloupe fruit characteristics are desirable for long-distance shipping and include: round and small shape, weight of approximately 1.5–2 kg (3.3–4.5 lb), uniform heavy netting, indistinct ribbing, firm thick flesh and small, relatively dry seed cavity (Fig. 10.12).

In contrast, muskmelon cultivars grown for local markets in the eastern USA and Canada are adapted for production under humid conditions, have spherical or elongated fruit shape, prominent vein tracts and ribbing, larger size (2.3–3.6 kg; 5–8 lb), strong flesh, strong aroma, large moist seed cavities, and relatively soft flesh. Most muskmelons have relative poor shipping and storage characteristics and are better adapted to local or regional markets (Fig. 10.13).

Many modern muskmelon cultivars developed for the eastern USA and Canada have incorporated the beneficial fruit characteristics of western cantaloupes to improve shipping and storage life but with larger fruit size and tolerance of high humidity. This trend has blurred the distinction between muskmelon and cantaloupe cultivars. Today, older large-fruited aromatic muskmelon cultivars are popular in some markets as heirlooms. Melon retailers are making a conscious effort to eliminate the word "muskmelon" from marketing because of the negative connotations associated with the term "musk" and the strong aromas the name implies.

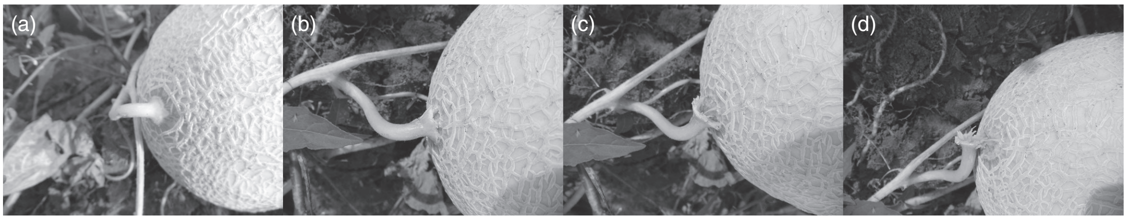

Fig. 10.11. Cantaloupe fruit naturally separate from the vine in a series of stages described by the percentage of stem attachment. Before the fruit begins to ripen, the stem is securely attached to the fruit (a). As ripening commences, the stem begins to separate so that when ¼ of the stem is free of the fruit it is often called ¼ slip stage (b), half separation is ½ slip (c) and total separation is full slip (d).

Fig. 10.12. A western shipping-type melon commonly grown in California, Arizona, Texas, Mexico or Central America for distant markets.

Increasingly the word cantaloupe is used exclusively for marketing netted melons in the USA.

Not all netted melons abscise at maturity. Some Japanese cultivars have netting and vein tracts like western cantaloupe cultivars but ripen without abscission like members of the Inodorus Group. Fruit of these cultivars are often sold with stems attached to the fruit in a T configuration (Fig. 10.14).

Persian melon cultivars produce large-round netted fruit that resemble western shipping-type cantaloupes. Persian fruit do not detach at maturity and are usually classified in the Inodorus Group despite their shallow netting, mild aroma, small moist seed cavity and firm salmon-colored flesh. Persian melons can be crossed with other Cantaloupensis types to create melons with good shipping characteristics and longer shelf life.

Cultivars of other Cantaloupensis melons have either sparse netting or lack netting entirely but have vein tracts and thin rinds. Examples include 'Charentais', 'Ananas', 'Ha-ogen' and 'Valencia'.

Plant characteristics

Commercial cultivars of *C. melo* types are warm-season, frost-sensitive annuals that are cross-pollinated by bees. Sex expression is andromonoecious or sometimes monoecious. Commercial cultivars are day-neutral. Plant habit is vining with varied internode length. Bush cultivars have been developed for some types. Many cultivars have tendrils at each node and flowers have five yellow petals that are open for a single day, like cucumber. However, leaves differ from cucumber in being circular, oval or kidney shaped with five to seven rounded lobes. Many commercial cultivars are F-1 hybrids. The main advantages of F-1 hybrids are uniformity and hybrid vigor. Most commercial cultivars are andromonoecious so F-1 hybrid seed production requires emasculation of the hermaphrodite flowers and cross-pollination by hand. Manual labor increases the cost of hybrid seed by several times compared to open-pollinated. It is estimated that at least 80% of the netted melons grown in the USA are F-1 hybrids. A lower percentage of winter melon cultivars are F-1 hybrids.

Production and Culture

According to FAO, in 2011 the total annual world production of melons was about 25.5 million t from 1,008,700 ha. Major melon-producing countries were China (12.2 million t), followed by Turkey (1.7 million t), Iran (1.2 million t), the USA (1.1 million t) and Spain (1.0 million t). In the USA, California was the leading producer of all melons, accounting for 33% of total acreage in 2005, followed by Texas, Georgia and Arizona. By acreage and weight, California leads the USA in cantaloupe and honeydew production.

In the past, melons were considered "seasonal delights" because of their limited availability throughout the year.

Fig. 10.13. A classic muskmelon cultivar traditionally grown for local markets in the eastern USA and now as heirlooms.

Fig. 10.14. Japanese melons grown in tunnels early in the season and then uncovered later so the structure supports vine growth. These fruit resemble cantaloupe but do not abscise at maturity and have characteristics similar to the Winter Melon Group (Table 10.2).

Production for export has developed in Mediterranean countries, Australia, Costa Rica, Guatemala, Taiwan and Japan, using F-1 hybrid cultivars with improved shelf life. Today, not only is the USA a net importer of melons (imports minus exports) but it is the largest importer of cantaloupes and mixed melons in the world. Many of the US imports come from Costa Rica and Guatemala. France and the UK are also large import markets for melons. In tropical Asia, melons are more of a luxury crop for urban markets, grown in the drier lowlands and highlands.

Site selection

Melons grow well in a wide range of fertile and well-drained soils. Maximum yields are achieved on medium-textured soils with high water-holding capacity and good internal drainage. Peat and heavy clay soils should be avoided because their poor aeration and restricted drainage inhibit root growth and fruit quality. Melons are sensitive to saline and acid soils but will grow well on slightly acidic (pH 6.8) to moderately alkaline (pH 8.0) conditions.

A crop rotation cycle of several years without growing other members of the family Cucurbitaceae (cucumber, pumpkin, watermelon, etc.) is recommended if pathogen populations are high and fumigation is not used. When possible, grasses, corn or sorghum are good rotation crops. Carryover from herbicides, such as atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine), may inhibit melon growth.

Seedbed preparation

In many regions, melons are generally grown on raised beds 15–20 cm (6–8 in) high. Final spacing of the beds in furrow-irrigated culture is generally 203 cm (80 in) center-to-center. Beds can be created and shaped to final spacing before planting or to one-half final spacing (102 cm; 40 in). In the latter procedure, every other bed is seeded at planting. When plants begin to vine, unplanted beds are broken open and the field is reworked to position the plant row in the middle of the final 203 cm (80 in) bed.

Plastic mulch

In short-season areas, plastic mulches heat cold soil to stimulate early season growth. In other areas, mulch is popular for fumigation, moisture conservation, reducing fruit rot, preventing the leaching of nutrients following heavy rains, and providing weed control. Plastic film is installed over a 203 cm (80 in) bed and secured at the edges with soil. Planting is by direct seeding or transplanting through holes punched or burned in the mulch. Water is applied under the plastic by drip irrigation or fertigation.

Trenches

For early-season plantings in some areas, seeds are planted in the bottom or on the north slope of a plastic-covered trench dug approximately 46 cm (18 in) wide and 15–20 cm (6–8 in) deep in the center of a standard east-west, 203 cm (80 in) raised bed. After planting, the trench is covered with clear plastic and secured at the edges with soil. The plastic cover is cut open or removed entirely when the melon plants begin to vine and temperature control is no longer required. The plastic cover protects from fly-in insects while intact.

Low row covers

Plastic tunnels are suspended over melon beds by tightly stretching clear plastic film over wire hoops for temperature modification in short-season areas. Row covers can be used longer in the season than with trenches but are more expensive and may require ventilation on sunny days. Beds under clear plastic tunnels may be covered with plastic mulch to provide weed control and to conserve water.

Fertilizer and nutrition

Melons develop extensive root systems that efficiently explore the soil for water and available nutrients. For this reason, fertilizer requirements are moderate compared with many other vegetable crops. An effective nutrient management program provides sufficient quantities of N, P, K, S, Ca, Mg, B, Cu, Fe, Mn, Mo and Zn so that plants develop and maintain a large canopy of healthy leaves throughout the season. Fertilizer should be applied in accordance with both soil and foliar test results when possible. Nitrogen is the most commonly required fertilizer, although P is sometimes needed to promote good seedling vigor, maximum productivity and high fruit quality, especially in alkaline soils. Mineral soils may contain adequate K but losses through leaching necessitate annual additions, especially in areas with light soils. The approximate absorption of N-P-K by a melon crop is 174 kg/ha (155 lb/acre), 28 kg/ha (25 lb/acre) and 174 kg/ha (155 lb/acre), respectively. Soil test recommendation for N and K often are less than these amounts to account for nutrient release for organic matter and inputs from the nitrogen cycle. Recommendations for P additions often exceed the amount removed a melon crop because some P fertilizer will be fixed or immobilized by certain soil types (Lorenz and Maynard, 1988).

For conventional production, granular phosphorus fertilizer may be applied preplant, as 10-34-0 or 0-52-0 for example, in twin bands 15 cm (6 in) deep and 10–15 cm (4–6 in) to either side of the planted row or in drip irrigation lines as part of a fertigation program. Phosphorus can also be banded and lightly incorporated before beds are formed, but alkaline mineral soils chemically tie up phosphorus, making it unavailable to the plants. Thus, banding the fertilizer near the seed is preferred over broadcast application (Lorenz and Maynard, 1988).

Nitrogen is often applied in two side-dressings or through fertigation, the first at the two- to four-leaf stage and the second at vine proliferation. Melon leaf petiole tissue analysis provides an effective diagnosis of crop nutrient status and allows continuous monitoring of crop fertility throughout the season so inputs can be applied only if required to maximize fruit yields and quality. Over-fertilization, especially with N, favors vegetative growth over reproductive growth and may inhibit fruit set. The N level, especially ammoniacal N, must be relatively low at flowering to encourage fruit set and development over the production of new leaves and vines. Moderate N tissue levels favor sugar accumulation in the fruit rather than additional vegetative development.

Field establishment

The minimum, optimum and maximum soil temperatures for seed germination are 16°, 35° and 38°C (60°, 95° and 100°F), respectively. Germination is slow and erratic when soil temperature is below 20°C (68°F). Fruit maturing when daily mean air temperatures are below 21°C (70°F) have poorer quality. Melons grow best in hot weather but very high temperatures (43–46°C/110–115°F) may cause temporary vine wilting and softer ripe fruit with reduced shelf life (Lorenz and Maynard, 1988).

Melons are often planted in single rows spaced 203 cm (80 in) apart (Fig. 10.15). Seeds are planted from 1.25 cm (0.5 in) to 2.5 cm (1.0 in) deep. In-row spacings of 7.5–15 cm (3–6 in) are common. After plants reach the two- to four-leaf stage, they are sometimes thinned to an in-row spacing of approximately 20 cm (8 in) for a final stand of about 4,000 plants/ha (10,000 plants/acre). In some areas on small plots, melons are planted in hills 1.3–1.8 m (4–6 ft) apart with three or four seeds per hill (Lorenz and Maynard, 1988).

Vacuum planters optimize use of expensive hybrid seed by precision placement. Under ideal conditions, seeds are planted to a final stand at 15–20 cm (6–8 in) spacing and not thinned (Table 10.3).

Narrow spacing reduces fruit size while wider spacing increases it. Hybrids usually are less affected by close spacing than open-pollinated cultivars. Melon seeds are often film coated. Film coating offers several advantages, such as less abrasion and clogging of planter parts, easier cleanup and maintenance of equipment, addition of fungicide or small quantities of fertilizer to seeds, and checking of seed placement in soil.

Fig. 10.15. Canteloupe field on raised beds in the Central Valley of California during harvest season.

Table 10.3. Number of seeds needed to plant 0.4 ha (1 acre) when rows are spaced 203 cm (80 in) apart (Lorenz and Maynard, 1988).

In-row spacing cm (in)	Seeds/ha (seeds/acre)
5 (3)	26,150 (10,460)
10 (4)	19,600 (7,840)
15 (6)	13,050 (5,220)
20 (8)	9,800 (3,920)
25 (10)	7,850 (3,140)

Transplants are used primarily in areas with short growing seasons to reduce development time. Melons do not easily produce adventitious roots and are considered difficult to transplant, especially with bare roots. Melons are most easily transplanted from plug trays with soil around the roots. Transplants are grown in protective structures until they have two to four true leaves and conditions are sufficiently warm for rapid field growth. Prior to field planting, transplants should be hardened to increase dry matter and stress tolerance by withholding water, mechanical conditioning or exposure to suboptimal temperatures. Plants should be kept well watered to minimize stress after field planting. A liquid fertilizer or "starter" solution is often applied to the root zone at transplanting to encourage rapid growth.

Irrigation

Muskmelon have extensive, moderately deep, root systems that efficiently remove water from soil, so irrigations may be less frequent than with some other vegetables. However, the general recommendation for at least 2.5 cm (1 in) of water per week still applies particularly during pollination and rapid fruit development. Post-plant irrigations ensure seed germination, emergence and stand establishment. However, when possible, irrigation may be withheld or carefully managed until the pre-vining stage to avoid cooling the soil, to discourage damping-off diseases and to encourage deep rooting. The final irrigation is typically 7–10 days prior to harvest, but may vary depending on environmental factors such as soil type, air temperature and humidity.

Drip irrigation, either with or without plastic mulch, is common in the eastern and increasingly the western USA as well as other areas where irrigation is required. Drip conserves water and provides uniform application to the root zone. Melon fields are often established with sprinkler irrigation but this may increase foliar and fruit disease in mature plants.

Furrow irrigation is a relatively inefficient method that is still used in some flat desert areas. When using furrow irrigation, care must be taken to ensure that water reaches the seed or root zone, and that after vines start to run, the top of the bed does not become wet and encourage fruit rot. Poor drainage, flooding or standing irrigation water may damage melon crops. Common problems associated with excessive water are weak root systems that may lead to vine collapse as the crop reaches maturity, poor fruit netting and low fruit sugar content.

Flowering and pollination

Melon sex expression is most commonly andromonoecious because separate male and perfect flowers occur on the same plant. Both male and perfect flowers are open for only 1 day. Male flowers rapidly senesce and dehisce after closing, but fruiting flowers often remain attached for several days. If pollination is successful, the ovary rapidly enlarges and "set" fruit, while the remaining fruiting flowers senesce and abscise. Most vines only support a few developing fruit at once and most later fruiting flowers will not set.

Melon pollen is sticky and must be transferred from stamens to the pistil by insects. The most effective pollinators are bees. Several hundred pollen grains must be uniformly transferred to each lobe of the stigma of each fruiting flower. Poor or inadequate pollination of each lobe will result in misshapen and/or small fruit. Adequate pollination requires 10–15 bee visits during the single day a flower is open. The grower and beekeeper must time colony placement with the start of flowering. If colonies are placed prematurely before flowering, bees will migrate to another source of pollen and will not work the intended field. Conversely, if bees are placed in the field too late, the first flowers will not be pollinated. One or two strong colonies per acre are required to ensure sufficient bee visits to adequately pollinate a melon field and maximize yield and quality.

Bee colonies are often placed around the periphery of the field, but placement within a field may increase the frequency of flower visits with the same number of colonies. Communication between the grower and beekeeper is essential to minimize bee kill if harmful chemicals are used and colony disruption by cultural practices.

Environmental and disease factors may significantly influence flowering, pollination and fruit set.

Plants under stress will have fewer flowers and will not set as many fruit as healthy plants. Rain, fog, strong winds and extreme temperatures will reduce bee activity and consequently yields.

Fruit quality

Soluble solids (sugars) accumulation depends upon the plant's ability to produce sufficient quantities of sugars by photosynthesis to meet metabolic needs plus excess for fruit storage. For high fruit sugar content, it is important to have a large leaf canopy prior to fruit set to maximize photosynthesis and support fruit growth. Any factor that limits photosynthesis will also decrease sugar accumulation in fruit. Factors that limit fruit sugar content include: reduced leaf area (leaf size and number, disease, insects, mechanical damage); reduced photosynthesis (insufficient leaf area due to viral infection, foliage disease, insect damage, mechanical damage, chemical damage or air pollutants such as nitrogen oxides or ozone, cloudy weather, dust, shading by other plants, opaque sprays); water stress (dry soil, restricted root growth); and competing needs for sugar compounds within the plant (vegetative growth, repair of damaged tissue, combating disease). The highest melon sugar content is produced during warm sunny days and cool clear nights when plants are not diseased or stressed. Sugar content of melons are easily measured by expressing a few drop of fruit juice on to a refractometer. By some standards, 9% soluble solids, reported as °Brix, is the minimum industry standard allowed for shipment to preserve quality and reputation. Soluble solids of 9% are needed to achieve a grade of USA No.1, and USA Fancy Grade requires 11% along with other criteria. A good tasting netted melon contains about 14% soluble solids (Suslow *et al*., 2013).

Besides sugar accumulation, other characteristics associated with cantaloupe fruit quality are netting, flesh color, flesh thickness, flesh texture, aroma and cavity size. During netted fruit enlargement, certain cells in the fruit epidermis divide to form a layer of corky tissue under the fruit surface. This corky tissue eventually protrudes through fissures on the rind surface that forms the fruit net. Favorable temperatures, plant nutrition and moisture as well as freedom from disease, insects or other stresses help produce a rugged attractive net that also protects the fruit from abrasion during shipment. Examples of stress conditions that reduce net formation are: insufficient or excess nutrients or moisture; poor root development; reduced photosynthetic capacity; and unfavorable growing conditions such as extreme temperatures, high humidity, excess moisture or competition from weeds. When selecting a fruit, consumers should avoid "slick" cantaloupes with poor netting. These are considered off-types because they have an abnormal appearance. The best quality cantaloupe fruit are true-to-type with heavy netting, uniform shape and good size.

Fruit color is more stable under environmental changes than soluble solids, especially when stress occurs close to harvest. However, color intensity is decreased by plant stress during the earlier stages of fruit development. Disease, poor nutrition, waterlogged root systems, extensive insect or mechanical damage and strong weed competition (shading) reduce color. Interestingly, mild water stress, as might be present under semi-desert or desert conditions, seems to enhance fruit flesh color intensity (Rubatzky and Yamaguchi, 1997).

Flesh thickness is largely genetically controlled and is one of the most stable fruit quality characteristics. Fruit cavity size is a factor in shipping and holding ability of fruit. Fruit with a small tight cavity ships better. Rough handling of fruit, especially throwing, causes loose seed cavities, sometimes caused "shakers" because of the sound the dislodged seeds make when the fruit is rapidly moved back and forth. Large cavities may result in softer fruit that does not ship or hold as well as fruit with a small solid seed cavity.

Harvesting and marketing

The time to harvest netted melons is easily determined because the vine and the fruit naturally separate or "slip" as ripening progresses (Fig. 10.11). For local markets, netted melons are harvested at 1/4 or 1/2 "slip". In other words, the fruit is harvested when the stem is only 1/4 or 1/2 attached to the fruit. This varies somewhat because certain cultivars are riper at a particular slip stage than others (Suslow *et al*., 2013).

For distant markets, melons are sometimes harvested preslip, which is before full maturity. Consumers should avoid buying cantaloupe fruit with the stems still attached because they usually have lower sugar content and crunchy texture due to premature harvest. A "wet nose" (moist stem end of the fruit) is a good indication that the fruit was recently harvested.

Optimum harvest is more difficult to determine for melons that do not "slip" from the vine at maturity.

For example, honeydew fruit are often harvested as they reach mature size. The plant hormone ethylene is sometimes applied to ripen honeydew after harvest. Ethylene is a natural gaseous plant hormone that triggers ripening in many fruit including both netted and winter melons. Rates of ethylene production vary from 40 to 80 µl/kg/h at 20°C (68°F) for intact fruit and 7–10 µl/kg/h at 5°C (41°F) for fresh cut fruit (Suslow *et al*., 2013).

Fruits that are signaled to ripen by ethylene are called climacteric. The climacteric response includes increased fruit respiration, fruit softening, a change immature to mature fruit color, and increased aroma. In the USA, cantaloupes with altered ethylene response have been genetically engineered to ripen more slowly to prolong shelf life and decrease storage losses. These cultivars were tested but never brought to market.

Controlled atmosphere storage or shipping offer only moderate benefits for cantaloupes under most conditions. With extended transit times of 14–21 days, cantaloupes are reported to benefit from delayed ripening, reduced respiration and associated sugar loss, and inhibition of surface molds and decay. Modified atmospheres of 3% O_2 and 10% CO_2 at 3°C (37.4°F) are effective. Elevated CO_2 at 10–20% is tolerated but will cause effervescence in the fruit flesh. This carbonated flavor is lost on transfer to air. Low O_2 (<1%) or high CO_2 (>20%) will cause impaired ripening, off-flavors and odors and other condition defects (Suslow *et al*., 2013).

Postharvest cooling

Postharvest cooling is very important to maintain fruit quality by slowing the rate of fruit respiration and ripening after harvest. In some areas, melons are harvested at night or in the early morning when fruit temperatures are naturally low to reduce field heat. After harvest, melons are forced-air cooled to 50–55°F (10–13°C) but no lower since they are chilling sensitive.

Because melons, and particularly netted melons, can harbor harmful bacteria in the corky tissues of the rind, melon fruit should be washed thoroughly before cutting. This is especially important for crops produced using animal manures, which can be a source of biological contamination along with poor worker sanitation. Fruit should be stored for less than 3 days after cutting to reduce the risk from *Salmonella* or other bacterial pathogens. A chlorinated postharvest dip treatment can provide some control of fruit rot diseases as well as human pathogens such as *Listeria*, *E. coli* and *Salmonella*.

Diseases

There are a number of important diseases that affect melons. Growing resistant cultivars effectively prevents Fusarium wilt (*Fusarium oxysporum* f.sp. *melonis*) (races 0, 1, 2 and 1-2). Powdery mildew (*Sphaerotheca fuliginea* and *Erysiphe cichoracearum*) is controlled by fungicide applications, but modern F-1 hybrids are tolerant of most races. Downy mildew (*Peronospora cubensis*) is important in hot and humid climates and is controlled by fungicides. Gummy stem blight (*Didymella bryoniae*) is also a disease in humid and hot conditions. Seed treatment, crop rotation and fungicides control anthracnose (*Glomerella cingulata*). Damping-off (*Pythium* sp. and *Rhizoctonia* sp.) is prevented by treating seed with fungicides, such as thiram. Bacterial wilt (*Erwinia tracheiphila*) causes symptoms similar to drought stress because bacteria clog the xylem, reducing the flow of water through the plant. Bacterial wilt is controlled by removing affected plants and by controlling the striped and spotted cucumber beetles, which vector the bacteria (Fig. 10.16).

Other diseases include: angular leaf spot (*Pseudomonas syringae* pv. *lachrymans*), Cercospora leaf spot (*Cercospora citrullina*), Alternaria leaf spot (*Alternaria cucumerina*) and scab (*Cladosporium cucumerinum*) fruit and foliage disease (Zitter *et al*., 1996).

Cucumber mosaic virus cucumovirus, watermelon mosaic 2 potyvirus and zucchini yellow mosaic potyvirus all affect melon and are transmitted by aphids, in particular *Aphis gossypii*. Sources of resistance to these three viruses and also

Fig. 10.16. Bacterial wilt of cantaloupe.

to the vector *A. gossypii* are available. Other virus diseases in melon are papaya ringspot potyvirus (aphid transmitted), melon necrotic spot carmovirus (transmitted by the soil fungus *Olpidium* sp.) and beet curly top hybrigeminivirus (BCTV) (transmitted by leafhoppers) (Zitter *et al.*, 1996).

Insect Pests

Pests in melon are thrips (*Thrips palmi* and *Frankliniella* spp.), spider mite (*Tetranychus urticae*), melon aphids (*Aphis gossypii*), melon fruit fly (*Bactrocera cucurbitae*), cucumber beetles (*Diabrotica* spp.), leaf folder (*Diaphania indica*) and the leaf feeder (*Aulacophora indica*). Root knot nematodes (*Meloidogyne* spp.) can be a serious problem when melons are grown without proper crop rotation. Control by wide-spectrum soil fumigants can be effective, but these are expensive and hazardous to the environment. Other pests include squash bugs (*Anasa tristis*), leaf miners (*Liriomyza sativae*), melon worm (*Diaphania hyalinata*) and whiteflies (*Trialeurodes vaporariorum*). Please consult local recommendations for effective pest control measures in your area (Cornell, 2004).

Nutritional Values

Netted melons are a good source of carbohydrate in the form of sugar. They are also a reasonably good source of potassium and vitamin A (Table 10.4; USDA, 2011).

Table 10.4. Nutritional composition of netted melons (USDA, 2011).

Nutritional value	Amount/100 g edible portion
Energy	141 kJ (34 kcal)
Carbohydrates	8.16 g
– Sugars	7.86 g
– Dietary fiber	0.9 g
Fat	0.19 g
Protein	1.84 g
Water	90.15 g
Vitamin A equivalent	169 µg (21%)
– β-carotene	2020 µg (19%)
Thiamine (vitamin B1)	0.041 mg (4%)
Riboflavin (vitamin B2)	0.019 mg (2%)
Niacin (vitamin B3)	0.734 mg (5%)
Pantothenic acid (vitamin B5)	0.105 mg (2%)
Vitamin B6	0.072 mg (6%)
Folate (vitamin B9)	21 µg (5%)
Vitamin B12	0.00 µg (0%)
Vitamin C	36.7 mg (44%)
Vitamin E	0.05 mg (0%)
Vitamin K	2.5 µg (2%)
Ca	9 mg (1%)
Fe	0.21 mg (2%)
Mg	12 mg (3%)
K	15 mg (2%)
Zn	0.18 mg (2%)

Percentages are relative to USDA recommendations for adults.

WATERMELON

Origin and History

The origin of watermelon is unclear but it was cultivated at least as early as 2000 BC based on evidence from the Nile Valley (Zohary *et al.*, 2012). Watermelon seeds were found in the tomb of Pharaoh Tutankhamen, as well as in other sites of the 12th Egyptian Dynasty, even though no literature or hieroglyphics depict or describe the eating of watermelons. One theory is that watermelon was derived from a perennial relative, *C. colocynthis*, which is endemic to Africa and was found in early archaeological sites before watermelon (Zohary *et al.*, 2012). However, some believe that watermelon was domesticated in Africa from putative wild forms of *C. lanatus*. The Kalahari Desert in south central Africa is a region where wild forms are still found, some of which do not have bitter fruit. The related species, *C. lanatus* var. *citroides*, known as citron, tsamma melon or preserving melon, is apparently native to the Kalahari Desert region as well. David Livingstone found extensive areas covered with wild watermelon vines in central Africa during his explorations in the mid-1800s. Watermelons were also cultivated in China as early as the end of the 9th century AD (Zohary *et al.*, 2012).

Watermelon was largely unknown in Mediterranean countries until introduction by the Moors in the 13th century. The word "watermelon" first appeared in English dictionaries in the early 1600s (Mariani, 1994). Watermelons were apparently introduced to North America in 1500s, because Native Americans were found cultivating them by French explorers in the Mississippi valley.

Botany and Life Cycle

Watermelon is in the family Cucurbitaceae (Gourd Family) and the genus and species are *Citullus lanatus* (Thunb.) Matsum & Nakai, having formerly been classified as *C. vulgaris* or *C. citrullus* L. Watermelons are annual with monoecious sex expression although some andromonoecious forms exist. The long-trailing stems or vines may exceed 5–6 m (16–20 ft) in length and short internode "bush" cultivars require less space. Stems are thin, angular, grooved and hairy, with branched tendrils that anchor the vines. Root systems are extensive, deeper than some other cucurbits, although still relatively shallow compared to deeply rooted crops such as tomato. The majority of the roots are within 60 cm (24 in) of the surface (Rubatzky and Yamaguchi, 1997).

Leaves are large, 5–20 cm (2–8 in) long, and deeply and prominently lobed. Solitary, yellow flowers range in size from 2 to 5 cm (0.8–2 in) in diameter and are open for only 1 day (Rubatzky and Yamaguchi, 1997).

Relatively large flat, smooth watermelon seed may be colored white, tan, green, red or black and 10–15 seeds weigh about 1 g (0.04 oz) (Lorenz and Maynard, 1988). Large-fruited cultivars may contain 500 seeds. The large cotyledons make up much of the seed volume. Watermelon seedlings like other cucurbits are epigeal with the cotyledons becoming photosynthetic organs after germination. Cotyledons are oblong in shape with an inconspicuous epicotyl developing between them.

Types and Cultivars

Watermelon fruit vary in size, shape, flesh color and surface color among cultivars (Fig. 10.17).

Sizes range from 1 to 3 kg (2.2–5.5 lb) for small-fruited cultivars, sometimes referred to as "icebox" or "midget", to more than 24 kg (55 lb) for large-fruited types. Fruits of some cultivars, like 'Tom Watson', may weigh as much to 60 kg (132 lb). Most icebox cultivars are similar in size to cantaloupe and most have a thin rind that is not well suited for long-distance shipping. Birds can also peck seeds through the thin rind of some small-fruited cultivars. Icebox types are popular with home gardeners and in short-season areas because of their quick maturity. Many commercial markets prefer fruit in the 15–25 lb (7–11 kg) range, that are easier to handle and refrigerate. Fruit shapes range from round, oblong or elongated with blocky or relatively pointed ends. The rind of mature fruit is usually smooth and can vary in thickness from less than 1 cm (0.4 in) to 4 cm (1.6 in). Exterior rind colors range from blackish green to yellow with solid, striped or mottled coloring. Wax accumulation on the outer rind surface increases with maturity. The seed are scattered and imbedded in the edible placental tissue and there is no central cavity.

Fig. 10.17. Diverse sizes, shapes and colors of watermelon fruit at the Taiwan Watermelon Festival.

Cultivars differ with regard to flesh texture, color and sugar content. The placental tissue of modern culitvars is sweet and watery. The flesh texture of some fruit is fairly stringy or fibrous, particularly when over ripe. Flesh colors range from red, orange, pink, yellow, to white (Rubatzky and Yamaguchi, 1997). Red flesh color is due to the pigment lycopene while yellow color mostly comes from β-carotene and xanthophylls (Maness *et al*., 2003). The flavor and sugar content of yellow-fleshed and red-fleshed melons are usually the same. Occasionally, flesh bitterness occurs in some heirloom fruit due to the presence of cucurbitacins, but seldom in modern cultivars. Most modern cultivars have black seeds because some consumers think a fruit with white seeds is immature. Black seeds make an attractive contrast with red or yellow flesh.

Usage

Watermelons are grown primarily for the sweet juicy fruit pericarp tissue that is chilled and eaten as slices or chunks, added to fruit salads or juiced. The rind maybe preserved in vinegar as a sweet or brined pickled product. Some watermelon cultivars and *Citrullus colocynthis*, a related species, are grown exclusively for their abundant and large seeds that are roasted or boiled with flavorings such as licorice. In both Asia and the Middle East, roasted or boiled watermelon seeds are a popular snack food (Fig. 10.18).

Some watermelons are used for livestock feed and extracted juice is fermented into an alcoholic beverage. Watermelon fruit are an important source of water in some desert areas, during drought, or where drinking water is contaminated.

Citron is also called preserving melon and is a distinct inedible flesh type of watermelon that resembles small edible cultivars. 'Green Citron' *Citrullus lanatus* var. citroides has a hard tough rind that can be used for pickling or animal feed. Citron melon flesh is white, light green or slightly pink but generally inedible due to its hard flesh and bitterness. The seed color is greenish tan. Citron melons grow wild in some sections of North America and can be weeds in commercial watermelon fields. Citron watermelons should not be confused with the candied diced citron that is an ingredient in fruitcake and made from the peel of *Citrus paradisi*, a tropical tree fruit also called citron.

Fig. 10.18. This small-fruited watermelon in Israel is grown for its edible seeds.

Production and Culture

Watermelon is a warm-season, frost-sensitive crop that requires a relatively long growing season from 75 to 120 days depending on the cultivar and environment. The optimum day and night temperatures are 32° and 20°C (90° and 68°F), respectively. Crop rotation helps control soil-borne diseases like *Fusarium* or nematodes. Plastic mulch, row covers or low tunnels help increase soil and air temperatures in short-season areas. Some cultivars, like 'Klondike' and 'Peacock', are tolerant of low humidity, are better suited for production in desert areas, and have moderate drought tolerance. F-1 hybrid cultivars are more uniform, more productive and popular despite their extra cost, although open-pollinated cultivars are still widely grown commercially in many areas.

Site selection and field preparation

Soil compaction restricts root growth, so friable, deep and well-drained sandy loam or loam soils are preferred for watermelon production. Watermelons are often grown on raised beds to improve drainage and support plasticulture production. Beds are formed so they are 15–20 cm (6–8 in) above the bottom of the adjacent furrow. Final spacing of the beds is generally 203 cm (80 in) center-to-center although other bed sizes may also be used.

Watermelons can be grown without irrigation or mulch but this is not recommended for commercial production because most areas experience water deficits sometime during the growing season that lower yields and reduce fruit quality. Watermelon is often produced on plastic mulch for weed control, to warm soil in short-season areas, to preserve soil moisture and to reduce the leaching of fertilizer that occurs following heavy rainfall. Plasticulture can significantly increase watermelon yields. Establishment is by direct seeding or plug transplanting, especially for seedless production, through holes punched or burned in the plastic mulch. Drip irrigation or fertigation is used with plastic mulch to get sufficient water to the seed and root zone. Watermelon production with conservation tillage is technically feasible but not widely practiced in North America.

Fertilizer and nutrition

Watermelons tend to develop extensive root systems in the upper profile of the soil allowing efficient extraction of nutrients. For this reason, fertilizer requirements are moderate compared with many other vegetables. A fertility program should be developed with input from preplant soil tests and foliar analysis during the season. Nitrogen is the most commonly required fertilizer, although P is sometimes needed to promote seedling growth and maximum productivity and fruit quality. Potassium increases rind thickness and cracking resistance and fertilization is often needed on lighter soils. A watermelon crop will remove approximately 196, 28 and 196 kg/ha (175, 25 and 175 lb/acre) of N, P and K, respectively, from the soil. General fertilizer recommendations for watermelon production range from 67 to 168, 45 to 168 and 112 to 224 kg/ha (60–150, 40–150 and 100–200 lb/acre) for N, P and K, respectively (Lorenz and Maynard, 1988). The actual fertilization requirement depends on soil test results and plant utilization during the season. The difference between the amount applied and the actual crop need is due to leaching losses for N and K, soil binding which renders a portion of the P unavailable, and N gained from organic matter decomposition, the nitrogen cycle and microbial fixation. The ideal soil pH is between 6.0 and 6.5 although a range from 5 to 7 is acceptable.

Fertilizer, as liquid or granular, is commonly applied as twin bands 15 cm (6 in) deep and 10–15 cm (4–6 in) to either side of the seed lines before planting, at planting, or in drip irrigation lines as part of a fertility program. Banding of fertilizer near the seed is preferred over broadcasting since the rows are far apart making broadcast applications inefficient. Nitrogen is commonly applied as a side dressing or as fertigation, particularly when vines start to spread. Petiole is the most effective means of diagnosing the nutrient status of the crop during the season. Sufficient values for N in the petioles sampled from the sixth leaf from the growing tip during early fruit development range from 5,000 to 7,500 ppm, P values range from 1,500 to 2,500 and K values range from 3 to 5%.

The goal for optimized production is to grow plants with a large canopy, while maintaining healthy leaves as long as possible. This strategy maximizes the photosynthetic capacity of the plant, which maximizes yield potential and fruit sugar content. Canopy development and health is aided by maintaining sufficient levels of N, P, K, S, Ca, Mg, B, Cu, Fe, Mn, Mo and Zn throughout the growing season. Watermelons should not be over-fertilized especially with N. Excessive N increases production costs, may damage the environment by leaching into the water table, and may inhibit fruit set and delay harvest. The N level must be low enough at flowering that the plant will form fewer new leaves once fruit development begins. This allows more sugars to accumulate in the fruit, rather than being used for new vegetative growth.

Field establishment

Seeded watermelon cultivars are often direct-seeded in warm-season areas. Seedless watermelons are transplanted from plugs because they germinate poorly in the field under suboptimal conditions and seeds are very expensive. Bare-rooted watermelons do not survive well in the field because they are sensitive to shock, so most are established with plug transplants. However, both seeded and seedless cultivars are often transplanted in short-season areas. Watermelon transplant scions may be grafted on to squash or gourd rootstocks to increase resistance to soil-borne diseases and nematodes, improve drought resistance or enhance plant growth (Fig. 10.19).

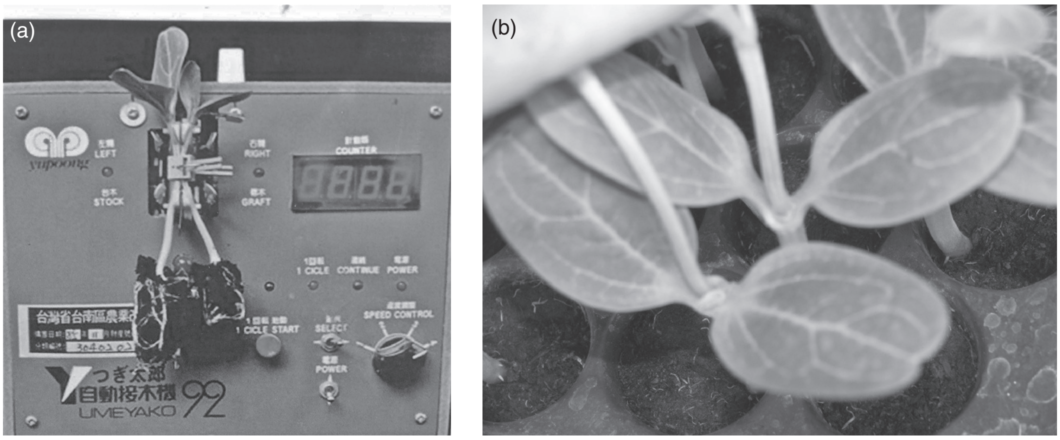

Fig. 10.19. Simple machines can joint rootstocks and scions to make a successful graft union and reduce labor (a). A watermelon seedling grafted just above the cotyledons by removing the apical meristem of the rootstock and replacing it with a scion of a production cultivar (b).

Grafting has long been used as a disease control strategy for greenhouse production of cucurbits and in the Middle East and parts of Asia where acreages are relatively small. With greater emphasis on sustainable production using fewer synthetic chemicals and decreased availability of soil fumigants, grafting of cucurbits is rapidly gaining popularity in other countries as well. The use of machines to aid the grafting process reduces labor.

Watermelon seeds are planted 2–4 cm (0.8–1.6 in) deep. Most cultivars have a germination optimum between 25 and 35°C (77° and 95°F), which will result in emergence in less than 1 week, but between 12° and 20°C (54–68°F) germination is slow and erratic and may require 2 weeks or more depending on seed vigor. Seed fungicide treatments are recommended to control damping-off disease, especially when planting into cool wet soils (Lorenz and Maynard, 1988).

Watermelon vines spread rapidly once established so wide spacing is typical for watermelon production (Fig. 10.20). Except for brush-type cultivars, spacing ranges from 2.5 to 5.0 cm (1–2 in) in-row and from 2 to 3 m (6.5–10 ft) between rows. Seeds can also be planted in hills rather than rows. Hills of three or four seeds can be planted at equidistant spacing 2–3 m (6.5–10 ft) apart. Cultivars with long vines require wide row spacing and are susceptible to wind damage. Short internode or bush-type cultivars can be spaced closer at half the distance of vining cultivars. Fields may be seeded at higher density to ensure a good stand before thinning to a final spacing at the two- to four-leaf stage. Closer spacing generally produces smaller fruit and wider spacing larger fruit. Plant populations can range from 3,200 to 8,000/ha (1,296–3,239/acre) (Lorenz and Maynard, 1988). Vines are sometimes trained toward row centers to facilitate cultivation and harvesting.

Flowering and pollination

Watermelon is "day neutral" and flowers when plants are sufficiently large. Most commercial watermelon cultivars have monoecious sex expression producing separate male and female flowers on a plant. The most effective pollinators are bees. Hundreds of pollen grains must be equally deposited on all lobes of the stigma of each female flower to ensure set and full fruit development. Environmental and disease factors can significantly influence flowering, pollination and fruit set. Plants under stress will have fewer flowers and will not set as many fruit as healthy plants. Rain, strong winds and high or low temperature extremes also will reduce bee activity, fruit set and yields. To transfer sufficient pollen, about ten bee visits are required on the day the flower is open. If pollination is inadequate or if fruit load is excessive, flowers will abort. Poorly pollinated fruit may sometimes set but are often misshapen.

If pollination is successful, the ovary of the female flowers will enlarge rapidly. Early developing fruit have an inhibitory influence on the development of late-formed fruit. Most vines of large-fruited cultivars can only support two or three fruit at a time and female flowers forming

Fig. 10.20. Watermelon production field with full vine cover and developing fruit.

after fruit set will abort. Fruit thinning is sometimes practiced to improve the size and sugar accumulation of remaining fruit. Small-fruited cultivars may support more fruit per vine.

The bee population needed to maintain that frequency of flower visitations is normally four to five strong colonies per hectare (1–2/acre). Placement of bee colonies within a field rather than along the periphery may double the flower visitation frequency with the same number of colonies. Good cooperation between the grower and beekeeper is essential for making sure the bees are present in time for flowering and to minimize bee kill from insecticide applications if used.

Seedless watermelon

Kihara (1951) first developed seedless watermelons in Japan during the early 1950s. Tetraploid (4n) and diploid (2n) plants are crossed to produce triploid (3n) seed (Kihara, 1951). Diploid watermelons are treated with colchicine, a natural product from autumn crocus that doubles the chromosome number, to create tetraploid plants (Deppe, 1993). When performing the 4n × 2n cross, pistillate flowers of the 4n plant are pollinated with 2n pollen. Fertilization produces fruit with 3n seeds that are planted for seedless crop production. Fruits of watermelon are seedless because they are triploid and normally sterile so fertilization does not occur. On the rare occasions that fertilization does occur, the embryo usually aborts. Small, aborted seeds may be found in the placental tissue of seedless fruit, but they are soft with no embryo, and can be eaten like the seeds in an immature cucumber.

Pollination is still required with a diploid cultivar to stimulate ovary growth for parthenocarpic fruit development. About 12–18% of the field must be interplanted with a diploid cultivar that serves as a pollen source for the seedless triploid cultivar. Sometimes a standard diploid cultivar is planted to pollinate two to four rows of triploid plants. When this approach is used, a pollinator cultivar should be of a contrasting color or shape to distinguish the seedless fruit from the selfed diploid that are sold as seeded watermelon. Recently, diploid pollinator lines that only produce male flowers have been developed for seedless watermelon production (Freeman *et al.*, 2007).

Since the male pollinator only produces staminate flowers, fewer plants are required for adequate pollination. These pollinator lines make seedless production more efficient because a portion of the field does not need to be devoted to a lower-value seeded fruit pollinator cultivar.

The chromosome imbalance caused by triploidy does not significantly affect plant or fruit development. Early seedless cultivars had a higher percentage of fruit defects such as triangular shape, large blossom scars, hollow heart, light flesh color, off flavors and delayed maturity. However, modern seedless cultivars have higher quality and greater uniformity with few if any defects.

Because triploid seeds germinate poorly, particularly at low temperatures, the seeds are more expensive and seedlings are not vigorous, seedless fields are often established by plug transplants to minimize shock. Seedless transplants are often germinated at a high temperature (32°C, 90°F) and the temperature is then lowered to 22–23°C (72–73°F) for seedling growth. The coats of triploid seed tend to adhere to the seed coats of emerging cotyledons, which can distort and cause poorly developed seedlings. Orienting seed with the radicle end up when planted may help seedlings lose their coats during emergence.

Irrigation

Despite the fact that watermelon has an extensive root system, a consistent supply of water particularly during fruit development maximizes both yield and fruit quality. Preplant or post-plant irrigations will ensure rapid seed germination, emergence and stand establishment. Irrigation is often applied sparingly until the pre-vining stage to avoid cooling the soil, inhibit damping-off diseases, and encourage deep-root formation. Watermelon crops require from 400 to 700 mm (16–28 in) of rainfall or irrigation for maximum productivity. The general recommendation for at least 2.5 cm (1 in) water/week either from rain, irrigation or both applies and more water is required on sandy soils or when mulch is not used.

Drip irrigation, either with or without the use of plastic mulch, conserves water and provides uniform application directly to the root zone at a slow rate. Sprinkler irrigation is often used for stand establishment, but this is not the best system once the vine canopy has developed because it may increase vine and fruit disease. Level production fields in the southwestern USA, western USA and Mexico are furrow irrigated but this traditional inexpensive system uses water inefficiently and may lead to salt accumulation in soil.

Harvesting and marketing

Cultivars differ greatly in their times to fruit maturity. Some small-fruited cultivars mature 75 days after planting while others may require 140 days or longer depending on the environment. Ideally, fruit are harvested when the sugar concentration is highest. Sugar is the primary determinate of quality along with flesh texture. There are no other well-defined flavor components other than sugar. Soluble solids (sugar) readings should be taken from the center because sugars are not always evenly distributed within the fruit. Higher sugar accumulation often occurs on the side of the fruit facing the sun away from the ground. Soluble solids of 12% to more than 13% can be achieved by some cultivars. Fruits with less than 7% soluble solids generally do not have good flavor. Fruit maturing when daily mean air temperatures are below 21°C (70°F) has poor quality. Sugar content does not increase after harvest. Watermelon do not ripen once harvested so it is important to allow fruits to fully mature on the vine to achieve their maximum sugar content.

Watermelons do not abscise from the vine when ripe like cantaloupe. In commercial fields, harvesting crews determine maturity by examining the color of the fruit's ground spot. The ground spot is white where the fruit rests on the soil and the rind does not develop chlorophyll. As the melon ripens, the ground spot changes from white to pale yellow. When the fruit is ready for harvest the ground spot will be pale yellow, and will turn dark yellow when overly ripe (Fig. 10.21).

The ground spot color of ripe fruit varies somewhat with cultivar. Also during ripening the color of the rind will fade from glossy to dull green and the tendril dies at the node where the fruit is attached to the vine. These are the most reliable indications of maturity. Tapping or thumping to hear a dull sound is subjective and not a reliable method for determining fruit maturity. A dull sound may be the result of "hollow heart", a common disorder that occurs when an open space forms in the fruit tissue. Soluble solids measurements or tasting, although destructive, are the best ways to evaluate fruit maturity and quality. When sampled fruit are sufficiently ripe, it is assumed that fruit of similar size and age in the same field are of equivalent maturity and ready for harvest.

Fruit tissue becomes "grainy" around the seed when overripe. Delayed harvest or prolonged storage causes the flesh texture to become mealy and stringy as cells collapse when over mature.

Postharvest handling

Fruit should be cleanly cut at the stem end rather than pulled from the vine. Fruit rinds may give the appearance of strength but actually are susceptible to cracking from compression or impact shock and should not be stacked on the stem or blossom ends. Watermelons may be shipped in bulk or in cardboard or plastic pallets. Small-fruited cultivars can be packed in cardboard pallets to prevent fruit damage from compression.

Fig. 10.21. Observing the change of ground spot color from white to yellow is a reliable way of determining ripeness.

Fruit are most turgid and susceptible to cracking during early morning hours. Flesh firmness and rind toughness are important cultivar characteristics for shipping without damage. To maintain harvest quality, fruit should be quickly cooled and stored at 13–16°C (55–61°F). Watermelons are not suited to long-term storage, but can be held at 80% RH for 2–3 weeks with little loss of quality if optimum temperatures are maintained. Extended storage at 10°C (50°F) or less results in quality loss due to chilling injury. The waxy rind limits desiccation. Watermelons are not climacteric, and immature fruit cannot be ripened off the vine with ethylene treatment. Watermelons should, ideally, not be stored or transported together with climacteric fruit that give off ethylene at harvest such as apple, cantaloupe or tomato because ethylene will cause pitting of the skin, flesh breakdown and black rot, shortening the storage life.

Sale of precut watermelons has increased dramatically in some markets. Precut-watermelons offer greater convenience and an appropriate quantity for single people and couples. Precut watermelons are sold ready-to-eat in resealable containers with the rind removed. Precutting reduces preparation time and waste that the consumer must deal with. Precut products also allow the consumer to evaluate the flesh color and texture prior to purchase.

In Japan, watermelons are sometimes grown in square molds (Fig. 10.22a). Molded watermelons command a premium price and are often given as presents for special occasions. Watermelons are also used for carving to make table decorations. Very complex designs and figures can be sculpted using the different colored layers of a watermelon fruit (Fig. 10.22b).

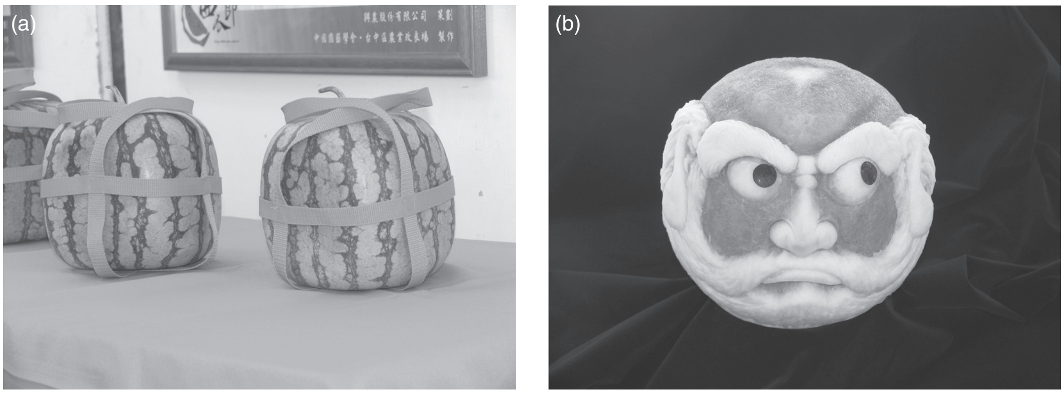

Fig. 10.22. Watermelons can be molded into different shapes by placing rigid containers around the developing fruit (a). Watermelon fruit may become elaborate art objects when carved (b).

Diseases

A number of different diseases affect watermelon, many of which are most prevalent under humid conditions. Damping off is favored by cold wet conditions and is caused by *Phythium* spp., *Rhizoctonia* spp. or *Fusarium* spp. Damping off can infect seedlings in the field as well as greenhouse transplants. Fungicide seed treatments and limiting moisture can effectively control damping off. Phytophthora root and fruit rot (*Phytophthora capsici*) can infect maturing fruit (Noh *et al*., 2007). Gummy stem blight (*Didymella bryoniae*) is a major fungal disease that can cause a numbering of disorders in watermelon fields or greenhouse transplants including damping off, crown rot, leaf spot, stem canker and fruit rot (Gusmini *et al*., 2005). Gummy stem blight causes round or irregular, brown lesions on the leaves and may also attack the stem causing elongated water-soaked areas that become gray. Gum may ooze from the stem cracks and plant dieback is another identifying feature.

Anthracnose (*Glomerella cingulata* var. *orbiculare*) attacks watermelon foliage and fruit. In severe cases, leaves die back leaving only bare stems. Anthracnose is most common under warm rainy conditions.

Downy mildew (*Pseudoperonospora cubensis*) occurs on watermelons worldwide and attacks the foliage giving rise to yellow spots, which coalesce into brown areas causing leaf curl and resulting in a scorched appearance of the crop. Powdery mildew (*Sphaerotheca fuliginea* and *Erysiphe cichoracearum*) is a widespread watermelon foliage disease (Tomason and Gibson, 2006). Fusarium wilt (*Fusarium oxysporum*) causes infected vines to wilt. In severe cases, the entire root system may become brown and a soft rot may develop near the crown.

Watermelon is also susceptible to virus diseases that are often transmitted by aphids. Watermelon mosaic virus causes leaf mottling and stunted plant growth. Other virus diseases that affect watermelon include: cucumber green mottle mosaic, cucumber mosaic, cucumber vein yellowing, cucurbit aphid-borne yellows, cucurbit chlorotic yellows, squash leaf curl, squash mosaic, tomato spotted wilt, watermelon chlorotic stunt, watermelon silver mottle, zucchini yellow mosaic and cucurbit yellow stunting disorder.

Fruit blotch is a particularly devastating disease throughout the world caused by the bacterium *Acidovorax avenae* subsp. *citrulli*. There are several symptoms, including leaf lesions and fruit spots that may cover the entire fruit surface in severe cases. Fruit blotch bacteria may eventually cause the fruit to rot and can be transferred by infected seed, transplants or weeds (Lessl *et al*., 2007). Another bacterium that may affect watermelon is *Xanthomonas cucurbitae*, which causes bacterial pumpkin spot. Other significant watermelon diseases include black root rot (*Chalara elegans*), fruit rot (*Choanephora cucurbitarum*), Alternaria leaf spot (*Alternaria alternata*) and cucumber blight (*Alternaria cucumerina*) (Zitter *et al*., 1996).

Insect Pests

Several species of cucumber beetle attack watermelon, including *Diabrotica undecimpunctata*. Both the beetles and larvae damage watermelon; the beetles feed on the stems and foliage and larvae feed on roots. Cucumber beetles are vectors of bacterial wilt but watermelon is not as susceptible to the disease as *C. melo* or *C. sativum*. In India, the red pumpkin beetle (*Aulacophora foveicollis*) is a significant pest, which feeds on the immature leaves and flowers. *Epilachna* beetles (*Epilachna* spp.) are common pests of watermelon in Africa. The larvae and adults feed on the leaves and chew holes in the stems and fruit (Cornell, 2004).

The melon aphid, *A. gossypii*, and the green peach aphid, *Myzus persicae*, may infest watermelon crops. Heavy aphid populations seriously weaken the plant and cause yellowing and wilting. Aphids also vector several viruses, which reduce plant growth and fruit quality. Several species of thrips may also infect watermelon crops (Cornell, 2004).

Melon fruit fly (*Bactrocera cucurbitae*) is a pest of watermelon in some countries. Adult flies lay eggs, which hatch into larvae within 1 week and feed on the fruit, causing damage and also allowing entry of fruit-rot pathogens. Watermelon crops may be covered with netting to protect against fruit flies. Mites (*Tetranychus urticae* and related species) are pests of watermelon, particularly when conditions are warm and dry. Mites cause distortion of new growth and chlorotic spotting as well as fine webbing on the foliage. Armyworms, sometimes referred to as melonworm or rindworms, feed on the rind of developing fruit. There are several types of armyworms that feed on watermelon fruit including southern (*Spodoptera eridania*), beet (*Spodoptera exigua*) and fall (*Spodoptera frugiperda*) (Cornell, 2004).

Seed corn maggots (*Delia platura*, formerly *Hylemya platura*) are a pest favored by early planting dates, heavy cover crops and cool-wet weather. Seed corn maggots attack a wide range of horticultural crops including beans, peas, cucumber, melon, onion, corn, pepper, potato and watermelon. Although these maggots feed primarily on decaying organic matter, they will feed on seeds and seedlings of watermelon and other crops. Similarly cutworms (*Agrotis segetum* and *A. ipsilon*) reduce watermelon stands by feeding on young seedlings (Cornell, 2004).

Economic Importance and Production Statistics

According to the United Nations Food and Agricultural Organization (FAO), watermelon is the most widely grown cucurbit with an estimated 3,413,750 ha (8,435,560 acres) worldwide in 2011 and production totaling 98,047,947 t of fruit (FAO, 2011). An estimated 1,200 watermelon cultivars are grown in at least 96 countries. Asia leads the world in watermelon production with two-thirds of the volume, followed well behind by European (13%) and African (6%) production. China, with 23% of the world's watermelon production, provides most of the Asian volume. In 2009, China produced 65,002,319 t of watermelon on 1,776,579 ha (4,390,022 acres). Other major producing countries were Turkey (3,810,210 t), Iran (3,074,580 t), the USA (1,819,890 t) and Egypt (1,500,000 t).

Watermelon consumption per person in the USA for 2011 was 6.8 kg (15 lb)/year. In the USA, per capita watermelon consumption has steadily declined over the past 50 years likely due to competition from a wide range of convenience-packaged beverages and frozen snacks. The per capita consumption of watermelon remains highest in countries of the Middle East. In Egypt for example, consumption per person is nearly 45 kg (100 lb)/year. Of the watermelons used in the USA, 22% were imported primarily from countries in Central America. Texas produces the largest acreage of watermelons in the USA followed by Florida, while California, Georgia and Arizona are other major producing states.

Nutritional Values

As the names suggests, watermelon consists mostly of water (Table 10.5). Watermelon fruit also contain soluble sugar and significant concentrations of some minerals. Lycopene, a pigment response for red flesh color, is also an antioxidant.

Table 10.5. Nutrient composition of watermelon fruit tissue (USDA, 2011).

Nutrient	Amount/100g edible portion
Water (g)	92.6
Protein (g)	0.5
Fat (g)	0.2
Carbohydrate (g)	6.4
Fiber (g)	0.3
Ca (mg)	0.7
P (mg)	10
Fe (mg)	0.5
Na (mg)	1.0
K (mg)	100
Ascorbic acid (mg)	7.0
Vitamin A (IU)	590
Thiamine (mg)	0.03
Riboflavin (mg)	0.03
Niacin (mg)	0.2

PUMPKINS AND SQUASH

Origin and History

The genus *Cucurbita* is believed to be native to tropical America. Archaeological evidence suggests squash may have been first cultivated in Mesoamerica some 8,000 to 10,000 years ago (Roush, 1997; Smith, 1997). *Cucurbita pepo* likely originated in what is today the southwest USA and Mexico. *Cucurbita argyrosperma* may have originated in Central America and southern Mexico, while *C. moschata* may have developed further south in Central America and northern South America. Similarly, *C. maxima* apparently originated in central and southern regions of South America (Zeven and Zhukovsky, 1975).

Species of *Cucurbita* are among the most ancient crops cultivated in the Americas. The four species *C. pepo*, *C. argyrosperma*, *C. moschata* and *C. maxima* only exist in cultivation. The close relationship with humans along with evidence of these species in the ruins of ancient American civilizations, indicate their importance in the development of Native American agriculture. Squash was one of the “Three Sisters”, maize (corn), beans and squash, planted by Native Americans.

Botany and Life Cycle

Cucurbita spp. are generally warm-season, frost-sensitive annuals, although *Cucurbita foetidissima* HBK is a perennial. *Cucurbita foetidissima* includes buffalo gourd, which has a variety of common names including calabazilla, chilicote, coyote gourd, fetid gourd, Missouri gourd, stinking gourd, wild gourd and wild pumpkin. The buffalo gourd is a xerophytic tuberous plant found in the southwestern USA and northwestern Mexico. The fruit is eaten cooked like a squash when very young but becomes too bitter for vegetable use at maturity. The buffalo gourd grows fast, requires little water, and produces a large massive underground tuber that has medicinal properties and has been proposed as a feedstock for biofuel production (Curtin *et al*., 1997). The seeds can be used as food and are high in both lipid and protein (Berry *et al*., 1976).

Cucurbita ficifolia, known as Bouche, malabar or figleaf gourd, is a climbing vine that reaches from 5 to 15 m (16–49 ft) in length. The figleaf gourd is a frost-sensitive annual in temperate climates and a perennial in tropical zones (Andrés, 1990). In nature, the figleaf gourd grows in moist regions at altitudes from 1,000 to 3,000 m (3,281–9,843 ft), but it can be cultivated in other climates because of its hardy root system and disease resistance. The figleaf gourd is used as a disease-resistant rootstalk for grafting to cucurbits that are susceptible to root disease. The flowers and tender shoots are used in Mexico as vegetables. The most nutritional part of *C. ficifolia* is its fat- and protein-rich seeds (Andrés, 1990).

Other species of *Cucurbita* have been identified growing wild. These are not commercially important on an international scale, although they may be grown and consumed locally and may cross with other species. Three of the most significant species include *C. lundelliana* Bailey, which is native to Central America, *C. andreana* Millan, which is cross-fertile with *C. maxima* and is believed to be its wild progenitor from South America, and *C. texana* Gr. Millan, which is cross-fertile with *C. pepo* and native to southern USA and northern Mexico (Robinson and Decker-Walters, 1997).

The primary species of economic importance include: *C. pepo* L., which includes many diverse types including pumpkin, winter squash, summer squash, gourds; *C. moschata* Duch., which includes pumpkin and winter squash; *C. maxima* Duch., which includes pumpkin and winter squash; and *C. argyrosperma* Pang., which includes pumpkin, winter squash and gourds (Robinson and Decker-Walters, 1997).

Summer squash are defined as fruits harvested in an immature stage before the rind becomes hard (Fig. 10.23).

Winter squash are physiologically mature fruit with a hard rind that cannot be penetrated with a fingernail, and contains viable seeds at harvest. They can be stored for several months at room temperature if properly cured and are free of mechanical damage and disease. Pumpkin is another term for winter squash in much of the world. However, in North America pumpkins are essentially a winter squash with a bright orange rind and stringy flesh grown as a decoration for the fall festival Halloween or made into pies. For Halloween celebrations, orange or white mature pumpkin fruits of predominately *C. pepo* and *C. maxima* are decorated or carved (Fig. 10.24).

Differences among the various species of *Cucurbita* are subtle based on seed anatomy and leaf and stem characteristics (Table 10.6). Although leaf shape and surface marking can vary within a species, a combination of stem, androecium, peduncle, flesh texture and seed features is used to differentiate the species. Seed colors can be white, tan,

Fig. 10.23. ‘Zucchini’, an example of a bush type summer squash, grown on plastic mulch and drip irrigation in Nova Scotia. Fruits are classified as summer squash because they are harvested when immature a few days after anthesis.

Fig. 10.24. In parts of North America, pumpkin refers to orange cultivars of winter squash that are decorated or carved like this jack-o'-lantern to celebrate the Halloween holiday on 31 October. A jack-o'-lantern is a pumpkin whose insides have been removed and replaced with a light or candle.

brown or black depending on the species. Examples of characteristics that differentiate the major cultivated species of *Curcurbita* are listed in Table 10.6.

The cutivated *Cucurbita* described in Table 10.6 are monoecious and most have long trailing vines and a prostrate growth habit unless supported. Certain summer squash cultivars of *C. pepo* have short internodes and a bush growth habit (Fig. 10.23). Taproots are moderate to deep with extensive shallow horizontal development. Flowers are bright yellow, borne singly in leaf axils, and seldom open for more than 1 day. Most *Cucurbita* species are day neutral, although in a few flowering is affected by day length.

Uses

Cucurbita fruit may be very large, particularly fruit of *C. maxima* and *C. argyrosperma*. Large-fruited cultivars of *C. maxima* bred for exhibition have weighed greater than 800 kg (1,700 lb; Fig. 10.25).

Cucurbita pepo is probably the most versatile and widely used species. Cultivars of both summer and winter squash exist in *C. pepo*. Some bush cultivars of squash are grown for their immature fruits (summer squash, courgettes, vegetable marrow) or at anthesis (baby squash) that are steamed, boiled, baked or fried. The time-to-harvest for this stage of development depends on the environment and cultivar but generally ranges from 35 to 50 days.

Table 10.6. Characteristics that differentiate species of *Curcurbita* (Rubatzky and Yamaguchi, 1997).

Cucurbita species	Leaves	Fruit stems (peduncle)	Seeds
C. pepo	Prickly, deep sinuses between lobes	Not noticeably flaring or enlarged at attachment to fruit	Tan colored Seed scar horizontal or rounded
C. moschata	Not prickly, sinuses indistinct or absent, lobes pointed; with rare exceptions, leaves soft hairy, with white spots at the intersections of veins	Distinctly five-sided, regularly grooved, hard Flaring at attachment to fruit Roughly cylindrical, not definitely, irregular grooves, not flaring or noticeably enlarged at attachment to fruit; hard	Color, grayish white to tan; margin thickened deeper in color and different texture from body of seed; seed scar slanting, rounded or horizontal
C. maxima	Lobes rounded; rough hairy, kidney shaped, white spots never present	Cylindrical, soft and spongy, yielding readily to thumbnail	Margin, when present, identical in color and texture with body of seed; white or brown to bronze, seed scar slanting

Fig. 10.25. Prize-winning *C. maxima* fruit in a large pumpkin competition in Bradford, Ohio. The fruit in the background weighed 910 lb (413 kg).

Cucurbita pepo includes many cultivars of pumpkin and gourd that are widely used as ornamentals. Gourds have distinctive shapes and color, but are not edible because of their very hard, thin rinds. Ornamental gourds of *C. pepo* with considerable variation in color and shape are also used as decorations to celebrate Halloween and Thanksgiving holidays in North America. The flesh of physiologically mature pumpkin and squash fruits may be boiled, steamed or baked for consumption (winter squash). The flesh may also be creamed, mixed with spices and eaten as a pudding or as pie filling. Pumpkin pies are traditionally made for fall and winter holidays in North America. While pumpkin pies are often made from small and medium-sized fruit of *C. pepo* or *C. maxima* some prefer using butternut squash (*C. moschata*) because they have less fiber, small seed cavity, mild flavor and intense orange color (Fig. 10.26).

Some *C. pepo* cultivars such as 'Lady Godiva', 'Streaker', 'Triple Treat', 'Eat All', 'Sweetnut' and 'Hull-less' produce "naked seed". The naked-seeded pumpkin was derived from natural mutants whose seed coats include all tissue layers, but secondary wall thickening is reduced in the outer tissues (epidermis, hypodermis and sclerenchyma). As mature hull-less seed dry, the outer tissues collapse, producing a thin seed coat that can be eaten without decoating

Fig. 10.26. Butternut is a popular and distinctive winter squash type that has excellent qualities for making pies and baking.

(Stuart and Loy, 1983). Because the seed coat is formed from maternal tissue, cross-pollination of naked-seeded cultivars does not affect coat development. Although the feature improves seed edibility, the characteristic makes seed more susceptible to mechanical damage and decay after planting.

'Spaghetti squash' also called "vegetable spaghetti" is another unique edible cultivar of *C. pepo*. After cooking, the edible pericarp tissue can be divided into loose strands resembling spaghetti but with crisp texture different from pasta.

Economic Importance and Production Statistics

World production of pumpkin, squashes and gourds in 2009 was estimated at 22.1 million t produced on 1.6 million ha (3,953,686 acres) (FAO, 2011). The greatest production was in Asia (14.4 million t), with China being the leading producer (6.5 million t). Total production in Europe was about 2.8 million t, with the Russian Federation, Ukraine, Italy and Spain as the top four producers (FAO, 2011). Africa produced 1.9, South America 0.7 and North and Central America 1.4 million t, respectively. In North America, the USA is a significant producer with 0.7 million t. Winter squash and pumpkin are grown primarily in the northern USA. Illinois, New Jersey, California, Indiana, New York, Ohio, Michigan and Pennsylvania are leading producers. Illinois has significant processing industry for producing pumpkin pie filling and other products totaling about 3,600 ha (8,000 acres) (Fig. 10.27).

Summer squash are grown throughout the USA with Georgia, Florida and California being the leading producers.

Nutritional Values

Except for vitamin C, winter squash are generally more nutritious than summer squash (Table 10.7). Winter squash are a typically a good source of carbohydrates and vitamin A.

Production and Culture

Growth and development

Winter and summer squash and pumpkins are warm-season crops that are sensitive to cool temperatures and frost intolerant. Most cultivated *Cucurbita* are well adapted for growth at temperatures from 18 to 30°C (64–86°F) and are damaged by chilling at temperatures below 13°C (55°F). Although most are day neutral, *Cucurbita* spp. generally do not grow well in the wet tropics, although certain forms of *C. moschata* are adapted to tropical conditions. Summer squash production is more widely dispersed than winter squash (Rubatzky and Yamaguchi, 1997).

Fig. 10.27. A pumpkin field windrowed for mechanical collection and processing into pumpkin pie filling.

Pumpkins and squash can be grown on a wide range of moderately fertile and well-drained soils. Peat and heavy clay soils are not recommended. Clay soils generally have poor aeration and restricted drainage, which inhibit root growth and increase fruit rot. Maximum yields are achieved on medium-textured soils with high water-holding capacity.

A crop rotation cycle of several years between planting members from the family Cucurbitaceae is recommended if pathogen populations are high and soils are not fumigated between crops. When possible, grasses, corn or sorghum are good rotation crops. However, care must be taken that there are no carryover herbicide residues, which might inhibit growth. Pumpkins and squash are sensitive to acid conditions and salinity. A pH range from 6.5 to 7.5 is ideal for good growth and yields (Rubatzky and Yamaguchi, 1997).

Seed are planted about 2.5 cm (1 in) deep in heavy soils and about 5 cm (2 in) deep in sandy soils. Soil temperatures should be above the minimum of 15°C (59°F) for seed germination and at 30–35°C (86–95°F) emergence can occur within 1 week for high vigor seeds. In some tropical areas, plants occasionally are propagated from cuttings (Rubatzky and Yamaguchi, 1997). Pumpkins and squash are sometimes transplanted from plug trays with a root ball intact in short-season areas.

Plastic mulch is sometimes used for pumpkins and winter squash production primarily for weed control, to keep fruit clean and for moisture conservation since earliness is not a big issue except for summer squash production. Clear or infrared transmitting IRT is used in northern areas to increase soil temperatures especially for early season planting of summer squash (Fig. 10.28). Planting through mulch is by direct seeding or occasionally transplanting through holes punched or burned through the plastic. Drip irrigation or fertigation is used with plasticulture.

No-till pumpkin production works well and is rapidly gaining popularity. No-till pumpkins are direct seeded or transplanted when soil is sufficiently warm in the early summer directly into killed cover-crop residue, such as small grain-straw mulch, which serves as a weed barrier, conserves moisture and keeps fruit clean.

Spacing depends on whether cultivars are bush or vining. Wide plant spacing accommodates spreading vine growth. Spacing within rows varies greatly depending on plant growth habit and the desired fruit size, number and yield. Thus, spacing from 50 to 150 cm (20–59 in) in rows and from 2 to 3 m (6.6–9.8 ft) between rows is common. Wide spacing enables intercropping cultivation, which is used

Table 10.7. Nutritional composition of summer and winter squash (amount/100 g edible portion; USDA, 2011).

Nutrient	Summer squash	Winter squash
Water (%)	94	89
Energy (Kcal)	20	37
Protein (g)	1.2	1.5
Fat (g)	0.2	0.2
Carbohydrate (g)	4.4	8.8
Fiber (g)	0.6	1.4
Ca (mg)	20	31
P (mg)	35	32
Fe (mg)	0.5	0.6
Na (mg)	2	4
K (mg)	195	350
Ascorbic acid (mg)	14.8	12.3
Vitamin A (mg)	196	4,060

Fig. 10.28. A maturing pumpkin production field using black plastic mulch and drip irrigation.

with cucurbits in some areas. Pumpkins and squash can also be planted in "hills" of three to five seeds each spaced 2–3 m (6.6–9.8 ft) apart. Bush cultivars are spaced closer with populations as much as two to three times greater than for vining cultivars.

The large leaf area of *Cucurbita* results in high evapotranspiration. However, many cultivars are drought tolerant due to their moderately deep root system and extensive horizontal root proliferation near the surface. Nevertheless, because of the high moisture requirements of these crops, soils with high water-holding capacity supplied with at least 2.5 cm (1 in) of moisture per week during active periods of growth is needed. Vining *Cucurbita* crops require from 500 to 900 mm (20–35 in) of water to produce a high-yielding crop. Summer squash with less extensive root systems are more easily stressed during periods of drought.

Fertilizer and nutrition

Since pumpkins and squash efficiently explore the soil for water and available nutrients, fertilizer requirements are moderate compared to many other vegetable crops. A high yielding crop of winter squash will remove roughly 168N-28P-168K kg/ha (150N-25P-150K lb/acre) from the soil depending on the cultivar, soil and environment (Lorenz and Maynard, 1988). A summer squash crop may remove slightly less nutrients. Fertilizer should be applied in accordance with soil tests before planting and foliar test during the season. Plant tissue analysis of petioles is the most effective means of diagnosing the nutrient status of the crop in the field.

Nitrogen is the most commonly required fertilizer, although P is sometimes needed to promote early-season growth particularly in cool soils, maximize production and achieve high fruit quality, especially in alkaline soils. Nitrogen is applied as fertigation in response to tissue analysis or as two side-dressings, the first at the two- to four-leaf stage and the second at vine spread. Care must be taken to not over-fertilize with N, particularly early in the season prior to flowering and fruit set. Excessive N favors vegetative growth over reproductive growth, which can inhibit fruit set. The N level must be low enough by the time of flowering so that the plant will form fewer new leaves after fruit set and growth begins. This allows more sugars to go to the fruit, rather than excessive vegetative growth.

Some mineral soils contain adequate K, but deficiencies are common on light or infertile soils. Potassium should be applied in conjunction with soil and foliar test results and can be made by row banding or through fertigation during the season.

Phosphorus fertilizer, as liquid or granular, is commonly injected in twin bands 10 cm (6 in) deep and 10–15 cm (4–6 in) to the side of a row before planting or as liquid by fertigation. Banding of fertilizer near the seed is more efficient than broadcasting since the rows are very far apart with vining cultivars.

Flowering and pollination

Squash and pumpkin have monoecious sex expression with separate male and female flowers on the same plant. Both kinds of flowers are open a single day. Male flowers rapidly senesce and abscise the day after closing. If female flowers are successfully pollinated, the ovaries will rapidly develop into fruit, but if not they will slowly wither and senesce after a few days. Most vines of large-fruited cultivars can only support two or three developing fruit at a time and later flowers will fail to set. Small-fruited cultivars can support many developing fruit on a single vine.

The most effective pollinators are bees. Several hundred pollen grains must be deposited on the pistil of each female flower to produce a fully developed fruit of marketable size and uniform shape. Full pollination requires 10–15 bee visits during the 1 day the flower is open. The bee population needed to maintain that frequency of flower visitations is normally four to five strong colonies per hectare (1–2/acre). Plants under stress will have fewer flowers and will not set as many fruit as healthy plants. Reduced photosynthetic capacity, rain, strong winds and high or low temperature extremes also will reduce bee activity and consequently reduce yields.

Growing giant pumpkins

In some parts of the world, the size of winter squash and pumpkins is important especially when growing fruit for exhibition (Fig. 10.25). Growing giant pumpkins and squash also illustrates some of the important principles of fruit development. The first step is to select a cultivar that has the genetic potential to grow large fruit such as *C. maxima* cv. Atlantic Giant. Cultural practices help fruit reach their maximum genetic potential. Plants must be grown at extra wide spacing to reduce competition. After the first fruit sets, all other developing fruit and flowers should be removed to eliminate competing "sinks" that draw photosynthetic resources from the single selected exhibition fruit. Minimizing disease and insect attacks on the plant is important because these stresses reduce photosynthetic capacity. Plants should be watered regularly to optimize expansive growth and eliminate water stress that would reduce photosynthesis by causing stomatal closure. Plants should be fertilized weekly with a complete analysis fertilizer after the fruit has set to ensure that essential mineral nutrients are not limiting. Some pumpkin growers inject carbohydrates into the stem with the hope that they will be absorbed, translocated into the fruit, and metabolized to supplement natural dry matter accumulation through photosynthesis. Rotating the developing fruit periodically will help prevent the development of a flat side but this is for cosmetic purposes and will not affect final size or weight.

Harvesting and marketing

Summer squash, such as 'Yellow Straight Neck', 'Zucchini' and 'Patty Pan' are harvested as immature fruit often as soon as 40–50 days after planting. Summer squash should be harvested when fruits are immature and glossy in appearance before significant seed development begins. Preferred size varies among markets. Some summer squash are harvested very early in their development, often just a few days after anthesis with the flower corolla still attached. Other markets prefer larger fruit (Fig. 10.29).

It is important to harvest summer squash regularly to maximize plant productivity because larger developing fruit tend to suppress the development of new pistillate flowers. In some markets, clusters of open male flowers are harvested and sold as a delicacy (Fig. 10.30). The flowers are prepared by cooking in a number of different ways, usually with ingredients like eggs, flour or meat.

Fig. 10.29. A succession of developing fruit with senescing flowers on a bush green zucchini summer squash plant. Flowers are only open for a single day and then rapidly senesce.

Fig. 10.30. Squash flowers for sale at a farmers' market in Hania, Crete, Greece.

The development of most pumpkins and winter squash cultivars falls in the range of 80–150 days although the exact time is very cultivar and environmental dependent. Pumpkins and winter squashes should fully mature before harvesting. Essentially, all *Cucurbita* fruit are hand harvested, and except for summer squash, rind hardness is a usual indication of maturity sometimes accompanied by vine senescence. Fruits for storage should be harvested after the skin is sufficiently hard that a fingernail or similarly sharp object cannot penetrate it. When ready for harvest, fruit are carefully cut off the vine with a sharp knife to minimize peduncle injury, a possible site for disease entry. Pumpkins for ornamental display are usually cut well above the fruit attachment point so the large stem can act as a fruit handle for carrying. Crop yields for winter squash range from 20 to 30 t/ha (9–14 ton/acre) (Lorenz and Maynard, 1988).

Harvesting of bush cultivars of summer squashes is complicated by short internodes that cause fruits to be closely spaced, which interferes with removal. Fruits are harvested by cutting with clippers or a sharp knife or by twisting the soft pedicle or fruit stem, by hand. Having soft skins, the fruit are easily scratched by the stiff foliar trichomes on the leaf petioles and are very susceptible to physical damage and rapid moisture loss. Summer squash are sometimes sold in plastic-wrapped trays to protect fruit. Care must be taken to protect the harvester's arms and hands from abrasion by foliar trichomes as well. Crop yields for summer squash range from 7 to 15 t/ha (3–7 ton/acre). Summer squash has a marketable shelf life of only about 7–10 days at 13°C (55°F) and is chilling sensitive and should not be stored at lower temperatures (Cantwell and Suslow, 2013).

Rough handling damages pumpkins and winter squash despite their relatively hard rind. Fruit should not be exposed to bright sunlight or hard freezes. After harvest, winter squash are often cured at temperatures between 27 and 30°C (81–86°F) at 80% RH for about 10 days to heal wounds that occurred during harvest. Curing helps increase storage life by healing (suberize) cuts and bruises thus inhibiting entry of disease pathogens that cause fruit rot. Undamaged or cured, disease-free winter squash and pumpkins can be stored for several months at 13–15°C (55–59°F) and 55–60% RH depending on the genotype. Squash are chilling sensitive and should not be stored below 13°C (55°F), which can cause off flavors and rapid deterioration, particularly when fruit are returned to room temperature (Cantwell and Suslow, 2013).

Diseases

Anthracnose (*Colletotrichum orbiculare*) is a destructive disease that causes defoliation and lesions on the fruits. Angular leaf spot (*Pseudomonas syringae* pv. *Lachrymans*) is caused by a bacterial pathogen. The bacterium can attack leaves, stems and fruit. Leaf symptoms begin as small, water-soaked lesions that expand to fill the area between veins, giving an angular appearance (Cornell, 2004). Powdery mildew (*Erysiphe cichoracearum*), downy mildew (*Peronospora cubensis*), scab (*Cladosporium cucumerinum*) and leaf-spot (*Alternaria cucumerina*) primarily affect leaves and stems (Fig. 10.31).

The same fungus, *Didymella bryonia*, that causes gummy stem blight in other cucurbits causes black rot (Cornell, 2004). Black rot is the fruit-infecting phase of the disease, and is most common on butternut squash and pumpkins, while gummy stem blight refers to the foliar and stem-infecting phase of the disease. Choanephora wet rot (*Choanephora cucurbitarum*) causes a soft rot of squash fruit. Serious virus diseases include: cucumber mosaic cucumovirus (CMV), watermelon mosaic 2 potyvirus (WMV-2), watermelon mosaic 1 potyvirus, zucchini yellow mosaic potyvirus (ZYMV) and squash leaf curl bigeminivirus (SLCV). Damping off is favored by cold wet conditions and is caused by *Phythium* spp., *Rhizoctonia* spp. or *Fusarium* spp., and can infect seedlings and transplants in the field or greenhouse if disease-free media is not used. Phytophthora blight, caused by the fungal-like organism *Phytophthora capsici*, causes a sudden wilt of infected plants and/or white yeast-like growth on affected fruit. Fusarium wilt and crown rot are diseases caused by several different members of the genus *Fusarium*, which has many subspecies that are host-specific (Cornell, 2004). *Fusarium* species can be seed-borne, but also persist in the soil as spores for many years with no host. The spread of this pathogen often occurs through movement of infested soil and/or plant debris. Bacterial wilt is not as serious a problem with pumpkin and squash as with cucumber and muskmelon because the vascular elements are larger and less susceptible to clogging. Still, this disease, which is spread by cucumber beetles, has been reported in *Cucurbita* and appears cultivar specific.

Insect Pests

Squash vine borer is a major pest. This insect bores small holes that are visible on the outside of the stem to access the interior where if feeds and lives.

Fig. 10.31. Powdery mildew on squash leaves.

The debris surrounding each hole looks as though the stem had been drilled with a small-diameter bit. Once inside the stem the borers are sheltered and difficult to control by conventional means.

Cucumber beetles feed on flowers and young seedlings causing mainly superficial damage. The leaf-feeding *Epilachna* beetles are a serious problem for *Cucurbita* growers. The adult squash bug (*Anasa tristis*) is dark gray and about 5/8 in (16 mm) long and sucks sap from the leaves and stems. In severe cases, the leaf first wilts, turns black and dies. Squash bugs can also feed directly and damage the fruit. Squash bugs live through the winter in protected areas both under debris in the fields and in buildings and lay eggs on the underside of leaves in the spring and summer. Aphids, primarily *A. gossypii*, do not cause serious injury to cucurbits. Aphid feeding may distort leaves. However, some species of aphids transmit virus disease. Resistant cultivars provide the most reliable control of virus diseases. Other insects that may affect *Cucurbita* spp. to varying degrees include cutworms (*Agrotis segetum* and *A. ipsilon*), leafminers (*Liriomyza sativae*) and rindworms (*Spodoptera* spp.).

References

Andrés, T.C. (1990) Biosystematics, theories on the origin and breeding potential of *Cucurbita ficifolia*. In: Bates, D.M., Robinson, R.W. and Jeffrey, C. (eds) *Biology and Utilization of the Cucurbitaceae*. Cornell University Press, Ithaca, New York, pp. 102–199.

Bélanger, R. and Labbe, C. (2002) Control of powdery mildew without chemicals: prophylactic and biological alternatives for horticultural crops. In: Belanger, R.R., Bushnell, W.R., Dik, A.J. and Carver, T.L.W. (eds) *The Powdery Mildews. A Comprehensive Treatise*. The American Phytopathological Society Press, St. Paul, Minnesota, pp. 256–267.

Berry, J., Weber, C., Dreher, M. and Bemis, W.E. (1976) Chemical composition of Buffalo Gourd, a potential food source. *Journal of Food Science* 41, 465–466.

Cantwell, M. and Suslow, T.V. (2013) Pumpkin and Winter Squash: Recommendations for Maintaining Postharvest Quality. Available at: http://postharvest.ucdavis.edu/pfvegetable/PumpkinWinterSquash (accessed 18 November 2013).

Chen, J.C., Chiu, M.C., Nie, R.L., Cordell, G.A. and Qiu, S.X. (2005) Cucurbitacins and cucurbitane glycosides: structures and biological activities. *Natural Product Reports* 22, 386–399.

Cornell (2004) Cornell Pest Management Guidelines for Vegetables 2004. Available at: www.nysaes.cornell.edu/recommends (accessed 31 December 2013).

Curtin, L.S., Moore, M., Kamp, M. and Austin, M. (1997) *Healing Herbs of the Upper Rio Grande: Traditional Medicine of the Southwest*, Revised Edition. Western Edge Press, Santa Fe, New Mexico.

Curwen, D., Powell. R.D. and Schulte, E.E. (1975) *Vine crops*. Cooperative Extension Programs, University of Wisconsin–Extension, Madison, Wisconsin.

Deppe, C. (1993) *Breed Your own Vegetable Varieties*. Little, Brown & Company Publishing, Boston, Massachusetts.

FAO (2011) FAOSTAT Production Crops. Available at: http://faostat.fao.org/site/567/default.aspx#ancor (accessed 12 June 2012).

Freeman, J.H., Miller, G.A., Olson, S.M. and Stall, W.M. (2007) Diploid watermelon pollenizer cultivars exhibit varying degrees of performance with respect to triploid watermelon yield. *HortTechnology* 17, 518–522.

Gusmini, G., Song, R. and Wehner, T.C. (2005) New sources of resistance to gummy stem blight in watermelon. *Crop Science* 45, 582–588.

Hedrick, U.P. (1919) Sturtevant's notes on cultivated plants. *New York Department of Agriculture Annual Report* 27, 1–686.

Hochmuth, R.C. (2013) Greenhouse Cucumber Production - Florida Greenhouse Vegetable Production Handbook, Vol. 3. Publication #HS790. Available at: http://edis.ifas.ufl.edu/cv268 (accessed 18 November 2013).

Kihara, H. (1951) Triploid watermelons. *Proceedings American Society of Horticultural Science* 58, 217–230.

Lessl, J.T., Fessehaie, A. and Walcott, R.R. (2007) Colonization of female watermelon blossoms by *Acidovorax avenae* spp. *citrulli* and the relationship between blossom inoculum dosage and seed infestation. *Journal of Phytopathology* 155, 114–121.

Lorenz, O.A. and Maynard, D.N. (1988) *Knott's Handbook for Vegetable Growers*, 3rd edn. Wiley-Interscience, New York.

Maness, N., Mcglynn, W., Scott, D. and Perkins-Veazie, P. (2003) Alternative uses of watermelons: Progress towards on-farm lycopene production. *Proceedings of Horticultural Industry Show* 2003, 77–80.

Mariani, J.F. (1994) *The Dictionary of American Food and Drink*. Hearst Books, Charlotte, North Carolina.

Masabni, J., Dainello, F. and Cotner, S. (2011) Texas Vegetable Growers' Handbook. Available at: http://aggie-horticulture.tamu.edu/publications/veghandbook/index.html (accessed 27 September 2011).

Maynard, D. and Maynard, D.N. (2000) Cucumbers, Melons, and Watermelons. In: Kniple, K.F. and Orneles, K.C. (eds) *The Cambridge World History of Food*. University Press, Cambridge, UK, pp. 298–313.

Motes, J.E. (1975) Pickling cucumber production-harvesting. Bulletin E837. Available at: http://archive.lib.msu.edu/DMC/Ag.%20Ext.%202007-Chelsie/PDF/e837.pdf (accessed 17 November 2013).

Noh, J., Kim, W., Lee, K., So, S., Ko, B. and Kim, D. (2007) Effect of furrow mulching with PE black film and dripping of phosphorous acid on control of Phytophthora root and fruit rot (*Phytophthora capsici*) occurred in field-grown watermelon. *Korean Journal of Horticultural Science and Technology* 25, 24–28.

O'Sullivan, J.N. (1980) Irrigation, spacing and nitrogen effects on yield and quality of pickling cucumbers grown for mechanical harvesting. *Canadian Journal of Plant Science* 60, 923–928.

Robinson, R.W. and Decker-Walters, D.S. (1997) *Cucurbits*. CAB International, Wallingford, UK.

Roush, W. (1997) Squash Seeds Yield New View of Early American Farming. *Science* 276, 894–895.

Rubatzky, V.R. and Yamaguchi, M. (1997) *World vegetables: Principles, production, and nutritive value*, 2nd edn. Chapman and Hall, New York.

Sauer, J.D. (1993) *Historical Geography of Crop Plants: A select roster*. CRC Press, Boca Raton, Florida.

Smith, B.D. (1997) The initial domestication of *Cucurbita pepo* in the Americas 10,000 years ago. *Science* 276(5314), 932–934.

Stuart, S.G. and Loy, J.B. (1983) Comparison of testa development in normal and hull-less seeded strains of *Cucurbita pepo* L. *Botanical Gazette* 144, 491–500.

Suslow, T.V. and Cantwell, M. (2013) Cucumber: Recommendations for Maintaining Postharvest Quality. Available at: http://postharvest.ucdavis.edu/pfvegetable/Cucumber (accessed 18 November 2013).

Suslow, T.V., Cantwell, M. and Mitchell, J. (2013) Cantaloupe: Recommendations for Maintaining Postharvest Quality. Available at: http://postharvest.ucdavis.edu/pfvegetable/Cantaloupe (accessed 18 November 2013).

Tamang, J.P., Sarkar, P.K. and Hesseltine, C.W. (1988) Traditional fermented foods and beverages of Darjeeling and Sikkim – a review. *Journal of the Science of Food and Agriculture* 44, 375–385.

Tomason, Y. and Gibson, P.T. (2006) Fungal characteristics and varietal reactions of powdery mildew species on cucurbits in the steppes of Ukraine. *Agronomy Research* 4, 549–562.

USDA (2011) National Nutrient Database for Standard Reference 2011. Available at: www.nal.usda.gov/fnic/foodcomp/search (accessed 7 October 2011).

Whitaker, T.W. and Davis, G.N. (1962) *Cucurbits. Botany, cultivation, and utilization*. Interscience Publishers, New York.

Wolf, E.R. (1982) *Europe and the People without History*. University of California Press, Berkeley, California.

Zeven, A.C. and Zhukovsky, P.M. (1975) *Dictionary of Cultivated Plants and their Centers of Diversity*, 2nd edn. Centre for Agricultural Publishing and Documentation, Wageningen, the Netherlands.

Zitter, T.A., Hopkins, D.L. and Thomas, C.E. (1996) *Compendium of Cucurbit Diseases*. APS Press, St. Paul, Minnesota.

Zohary, D., Hopf, M. and Weiss, E. (2012) *Domestication of Plants in the Old World*, 4th edn. Oxford University Press, Oxford, UK.