Chapter 4
Emerging Fruit Crops

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Abstract Hundreds of fruit species with commercial potential are currently in a status of low economic importance. Some, such as quince, pomegranate, and figs, have been cultivated for thousands of years. Others have only been locally collected and consumed from wild populations of the fruit. The development of these under-appreciated crops depends on a range of factors including the cultivation limitations, yields, uses of the fruit, and marketing potential. Although initially many crops are developed using selections from the wild, as they are developed, breeding programs work toward improving the crop for both production and quality. This chapter examines nine emerging crops chosen among hundreds of potential crops

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which are currently showing much promise as commercial crops. These include five tree fruits, namely, pawpaw, quince, mayhaw, pomegranate, and fig, and four berry crops, namely, blue honeysuckle, elder, goji, and ‘ōhelo.

Keywords Underutilized genetic resources • Specialty crops • Local crops • Heritage fruit cultivars • Potential new fruit

1 Introduction

As Darrow and Yerks (1937) state, “All of our present cultivated plants, it must be remembered, have been derived from wild plants.” Those that were outstanding or most readily adaptable were taken from forest and field and grown at the dooryard; others were left in the wild so that products could be gathered and used. Yet, the definition of an ‘emerging crop’ is vague from a temporal sense. Some crops require millennia while others centuries or decades to achieve notoriety.

Internationally, economically important fruit crops, such as grapes, apples, cherries, and pears, date to Western antiquity with cultivation over millennia. Quince (*Cydonia oblonga* L.), pomegranates (*Punica granatum* L.), and figs (*Ficus carica* L.) fit that timeframe, but are still ‘emerging’ crops, despite their documentation in ancient references; their development is expanding in today’s markets.

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The European history of many present-day economically important berry crops, such as raspberries (*Rubus idaeus* L.), blackberries (*Rubus* subgenus *Rubus*), currants and gooseberries (*Ribes* L), and strawberries *Fragaria* × *ananassa* Duchesne ex Rozier, is counted in centuries. Elderberry (*Sambucus* L), among them, now has increasing demand for production in juice, wine, and processed products. American pawpaw (*Asimina triloba* (L.) Dunal) and mayhaw (*Crataegus aestivalis* (Walter) Torr. & A. Gray) were recognized by early European settlers and have continued to emerge as cultivated crops over the past several centuries.

American blueberries (*Vaccinium corymbosum* Ait.) and cranberries (*Vaccinium macrocarpon* Ait.) are recent and have been selected, developed, and bred from the wild over decades. Their relative the Hawaiian ʻōhelo *V. reticulatum* Sm. has now surfaced as another with cultivation potential.

Two Asian berries, the goji (*Lycium barbarum* L.), mentioned in Chinese medicinal texts of antiquity, and the blue honeysuckle (*Lonicera caerulea* L.), also touted in Russian and Chinese folk medicinal traditions, have made a recent splash as new crops for Western production. These two crops, grown near their center of origin by traditional farmers, remain important for the subsistence of local communities. With the advent of the nutraceutical industry, international interest in expanding cultivation for these crops has increased and encouraged breeding and commercial cultivation.

This chapter examines only nine emerging crops: five tree fruits, namely, pawpaw, quince, mayhaw, pomegranate, and fig, and four berry crops, namely, blue honeysuckle, elder, goji, and ʻōhelo. A much more extensive list of neglected berries, potential new berries, and crops with unmet potential has been discussed (Darrow 1975; Finn 1999). Many additional horticultural crops appear on the horizon of development in horticultural compendia such as *Stuartevant*'*s Notes on Edible Plants* (Hedrick 1919), *Hortus Third* (L. H. Bailey Hortorium 1999) or the *Encyclopedia of Fruits and Nuts* (Janick and Paul 2008). These references have a more complete listing and summary of potential crops beyond the scope of this chapter.

Diversification of local production is the key to save small farmers and resolve the food shortage (Lumpkin 2007). Locally produced horticultural crops are the key to success in the United Nations millennium development goals (http://www.un.org/millennium/declaration/ares552e.htm) to eradicate extreme poverty and develop environmental sustainability. Emerging crops will serve to strengthen local economic success through diversification of crop species.

2 The North American Pawpaw

2.1 Botany

The North American pawpaw, *Asimina triloba* (L.) Dunal, grows wild as an understory tree, often in large patches due to root suckering, in hardwood forests in the eastern USA (Kral 1960) (Fig. 4.1). Trees may reach 30 ft in height and assume a

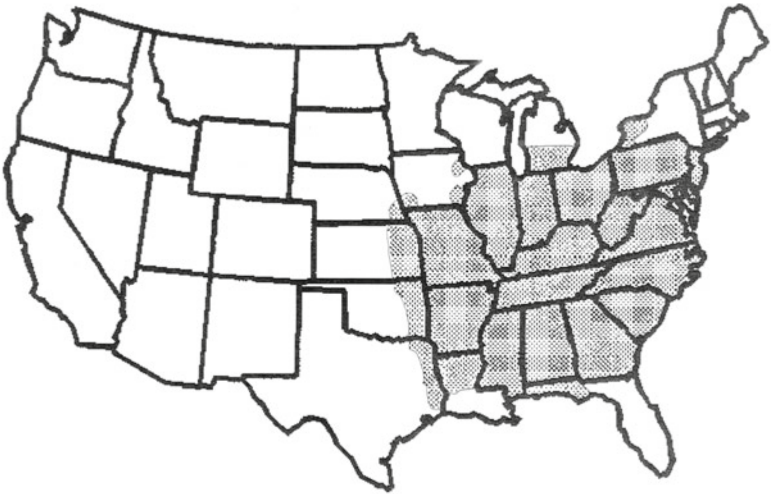

Fig. 4.1 Native distribution of *Asimina triloba* (L.) Dunal, the North American pawpaw, prepared by Kirk Pomper, Kentucky State University

pyramidal habit in sunny locations. This plant can be grown successfully in USDA plant hardiness zones 5 through 8 (Kral 1960). Fruits weigh up to 2 lbs and may be borne in clusters of up to 13 fruit or singly (Fig. 4.2). The fruits are highly nutritious, have a strong aroma, and have a unique flavor that resembles a combination of banana, mango, and pineapple (Pomper and Layne 2005; Duffrin and Pomper 2006). The fruit has both fresh market and processing potential.

2.2 Origin and Domestication

Pawpaw has a well-established place in folklore and American history. The traditional American folk song, "Way down, yonder in the pawpaw patch" is still known to children and fall pawpaw hunting in the woods is still a common tradition for rural families in the eastern USA. In 1541, the Spanish explorer Hernando de Soto reported Native Americans growing and eating pawpaws in the Mississippi valley. Native Americans also used the bark of pawpaw trees to make fishing nets. Daniel Boone and Mark Twain were reported to have been pawpaw fans. In 1806, Lewis and Clark recorded in their journal how pawpaws saved their party from starvation. There was interest in pawpaw as a fruit crop in the early 1900s; however, the rapid perishability of fruit likely decreased interest in this fruit (Peterson 1991). Interest in pawpaw grew between 1950 and 1985, and recently, the appeal of pawpaw as a gourmet food has increased (Pomper and Layne 2005).

Fig. 4.2 Pawpaw fruit. Photocredit: Kirk Pomper, Kentucky State University

2.3 Production and Uses

Pawpaw is in the early stages of commercial production as a new high-value tree fruit crop. The greatest market potential for pawpaw currently is for sales at Farmers' markets and direct sales to restaurants and other gourmet food clientele. Pawpaw fruits are mainly collected from natural stands in the forest or from production from small plantings. Sellers often have difficulty finding sufficient pawpaws to meet the demand. Wild fruits collected from some trees can have a bitter aftertaste, while fruits from grafted trees of named cultivars are of a higher quality, do not have a bitter aftertaste, and have greater market potential.

Pawpaw production challenges have been reviewed by Pomper and Layne (2005) and included the need for high quality cultivars, poor pollination, and fruit perishability issues. A number of high-quality pawpaw cultivars with large fruit (over 5 oz) have been selected since 1950. Some of these cultivars have been evaluated at Kentucky State University and cultivars that can be recommended based on large fruit size and production (about 20 lbs/tree/year) are: 'NC-1,' 'Overleese,' 'Potomac,' 'Shenandoah,' 'Sunflower,' 'Susquehanna,' and 'Wabash.' Grafted trees usually begin reliable fruit production at 5–6 years after planting (Pomper et al. 2003a, b, 2008). Pawpaws need to cross-pollinate and flies and beetles are the main pollinators (Faegri and van der Pijl 1971). Efforts to attract these pollinators to pawpaw plantings can improve fruit set. Perishability is still a problem for pawpaw; ripe fruits soften rapidly and have 5-to-7-day shelf life at room temperature (Archbold and Pomper 2003). However, fruits that are just beginning to soften can be stored for about 3 weeks at 4°C and maintain a good eating quality.

Initial investments include land preparation, purchase of plants, installation of an irrigation system, and tree establishment. The recommended density is 295 pawpaw trees per acre. Grafted trees usually cost between $10 and $25 each. Growers may not recover the cost of establishing a pawpaw planting until about 7 years after planting. According to estimates by the University of Kentucky, production costs for pawpaw are estimated at $884 per half-acre, with harvesting and marketing costs at $720 per half-acre (University of Kentucky 2008). Total expenses per half-acre come to approximately $2,075. Presuming gross returns of $3,500 per half-acre, returns to land, capital and management are approximately $1,490 per half-acre. These returns could be substantially higher than the $1 per pound wholesale price used in estimates; pawpaws sold at the Lexington and Frankfort, Kentucky, farmers' markets for $3 per pound in 2009. Other challenges to expanding a pawpaw industry include: developing a grower base, improving orchard establishment rates, rootstock development, improving clonal propagation methods, new cultivar development, increasing yields, postharvest handling of fruit, and developing an overall marketing strategy.

2.4 Breeding Potential

From about 1900 to 1960, at least 56 clones of pawpaw were selected and named. Fewer than 20 of these selections remain, with many being lost from cultivation through neglect, abandonment of collections, and loss of records necessary for identification (Peterson 1991, 2003). Since 1960, additional pawpaw cultivars have been selected from the wild or developed as a result of breeding efforts of hobbyists. More than 40 clones are currently available (Pomper and Layne 2005). The loss of cultivars over the last century may have led to erosion in the genetic base of current pawpaw cultivars (Huang et al. 1997). New breeding efforts by The PawPaw Foundation have led to the release of several new cultivars (Peterson 2003). Additionally, fruit to fruit consistency in ripeness and quality, longer cold storage ability, and higher yields would be desirable in new pawpaw cultivars.

Since 1994, Kentucky State University has served as a satellite site of the USDA National Clonal Germplasm Repository, Corvallis, Oregon, Genebank for *Asimina* species (Pomper et al. 2003a, b). The collection contains over 2,000 accessions from 17 states. Assessing genetic diversity and evaluating pawpaw germplasm for the repository collection is a top priority and will hopefully conserve current pawpaw germplasm and serve as a source of new germplasm for breeding new cultivars in the future.

Fig. 4.3 *Cydonia* distribution, prepared by Joseph Postman, USDA ARS

3 Quince

3.1 Botany

Cydonia oblonga Mill. is a monotypic genus belonging to family Rosaceae, subfamily Spiraeoideae, tribe Pyreae and subtribe Pyrinae (USDA 2009a). It grows as a multistem shrub or small tree and has pubescent to tomentose buds, petioles, leaves, and fruit. Leaves are ovate to oblong, about 5 cm across and 10 cm long. The white, solitary flowers are 4–5 cm across, have 5 petals, 20 or more stamens, 5 styles, an inferior ovary with many ovules, and are borne on current season growth. Bloom time overlaps with that of apples, usually beginning in mid April in the middle latitudes of the northern hemisphere. The fruit is a fragrant, many-seeded pome about 8 cm in diameter. Shape ranges from round to pear-like, flesh is yellow, and the Bailys refer to it as 'hard and rather unpalatable' (Bailey and Baily 1976; Rehder 1986). Fruit size and leaf size of cultivated varieties can be many times larger than the wild type described above.

3.2 Origin and Domestication

Cydonia is native to western Asia, and the center of origin is considered to be the Trans-Caucasus region including Armenia, Azerbaijan, Iran, SW Russia, and Turkmenistan (Fig. 4.3; USDA 2009a). During ancient times, it spread from its wild center of origin to the countries bordering the Himalaya Mountains to the east, and throughout Europe to the west. It has many uses and traditions associated with it throughout this range.

The quince of Persia attains a weight of 1.5 kg (more than 3 lbs), ripens on the tree or in the store, and can be eaten like a soft ripe pear; according to the 'Horticulturist' of 1849 (Meech 1908). This is hardly the quince known in America today, or rather the quince which is hardly known today. In Colonial America it was a rarity in the gardens of the wealthy, but was found in nearly every middle class homestead (Roach 1985). The fruit was an important source of pectin for food preservation and a fragrant addition to jams, juice, pies and candies. However, by the early twentieth century quince production declined as the value of apple and pear production increased. Today's consumers prefer the immediate gratification provided by sweet, ready-to-eat fruits. Charles Knox introduced powdered gelatin in the 1890s and the use of quince pectin for making jams and jellies declined. U.P. Hedrick lamented in 1922 (Hedrick 1922) that "the quince, the 'Golden Apple' of the ancients, once dedicated to deities and looked upon as the emblem of love and happiness, for centuries the favorite pome, is now neglected and the least esteemed of commonly cultivated tree fruits."

Luther Burbank took credit for helping to transform this neglected fruit from a commodity that was "altogether inedible before cooking" into a crop he likened to the best apple. He half-jokingly cited a formula to make quince fruits edible: "Take one quince, one barrel of sugar, and sufficient water" (Whitson et al. 1914). Burbank released several improved cultivars in the 1890s that he hoped would raise the status of the fruit. While two Burbank cultivars 'Van Deman' and 'Pineapple' are important commercially in California today, quince fruit production in the USA is so small that it is not even tracked by the USDA National Agricultural Statistics Service (McCabe 1996; USDA 2009b). Both of these Burbank quinces, however, have found their way to other parts of the world where they are among the handful of cultivars considered worthy of production (Campbell 2008).

Meech described 12 varieties important in the USA of 1909, although some 'varieties' such as 'Orange' (syn. = 'Apple') were as often as not grown from seed rather than propagated as clones. Quince is easily grown from either hard-wood or soft-wood cuttings, and is readily grafted onto another quince rootstock. Although quince is an important dwarfing rootstock for pear, the reverse graft is not reliable and therefore pear should not be used as a rootstock for quince.

Quince has a very extensive history in the Middle East, and may have even been the fruit of temptation in the Garden of Eden. The ancient Biblical name for quince translates as 'Golden Apple' and cultivation of *Cydonia* predates cultivation of *Malus* in the region once known as Mesopotamia, now Iraq. Juniper and Mabberly (2006) relate how this region is well adapted to cultivation of quince, pomegranate and other fruits, but is much too hot and dry for the cultivation of all but the most recently developed low-chill apple cultivars. Quince was revered in ancient Greece where a fruit was presented to brides on their wedding day as a symbol of fertility. It was mentioned as an important garden plant in Homer's Odyssey and Pliny the Elder extolled its valuable properties.

3.3 Production and Uses

Worldwide, there are about 43,000 ha of quince in production with a total crop of 335,000 MT. Turkey is the largest producer with about 25% of world production. China, Iran, Argentina, and Morocco each produce less than 10%. The USA is a very minor player in terms of growing quince for fruit with only about 100 ha in production, mainly in California's San Joaquin Valley. Burbank's 'Pineapple' is the most widely grown in that state and is said to be more flavorful than 'Smyrna' (McCabe 1996). Membrillo, or Quince Paste, is popular in several European countries, particularly Spain, and in parts of Latin America. This fragrant, sweet, jelly-like confection is cut into slices and often served with cheese. Quince is also served poached in either water or in wine and develops a rich aroma and deep purple-red color. In Armenia, quince is used in many savory as well as sweet dishes, and is often cooked with lamb (Ghazarian 2009).

While quince is still grown for its fruit in some parts of the world, in other places including England, France, and the USA, it is primarily grown for use as a dwarfing pear rootstock. In the region around Angers, France, quince has been used as a pear rootstock since before 1500. The French were growing quince from cuttings and in stool beds by layering by the early 1600s and France became an important source of rootstocks around the world. Quince rootstocks grown near Angers were known as 'Angers Quince' and those propagated near Fontenay were known as 'Fontenay Quince' (Roach 1985; Tukey 1964). Confusion arose as to the identities of various quince rootstocks, and in the early 1900s researchers at East Malling in England collected rootstocks from various nurseries and designated clones with letters of the alphabet. Quince rootstock clones now available in the USA include Quince A and Quince C, which came from East Malling–Long Ashton (EMLA); and Provence Quince (= Quince BA 29-C) from France. A pear tree grafted onto Quince A will be about half the size of a tree grafted onto pear seedling rootstock. The tree will also be more precocious and fruit size will be larger. Quince C produces a tree slightly smaller and more precocious still. Province Quince rootstock produces a pear tree slightly larger than Quince A or C. Some pear varieties are not graft compatible with quince and require a compatible interstem pear cultivar such as 'Comice,' 'Old Home' or 'Beurre Hardy' as a bridge.

3.4 Breeding Potential

A collection of quince germplasm was established in Izmir, Turkey beginning in 1964 that includes many regionally developed cultivars and landraces (Sykes 1972). In Karaj, Iran a collection of more than 50 *Cydonia* accessions are maintained, including both cultivated and wild types (Amiri 2008). A large fruit tree collection in Kara Kala, Turkmenistan was once a part of the Vavilov Institutes during Soviet times. Many fruit accessions, including quince, were rescued from that station and brought to other genebanks for safe keeping. A dozen quince accessions from that collection are now growing at the USDA genebank in Oregon. The USDA Agricultural Research Service maintains several important fruit germplasm collections at the National Clonal Germplasm Repository (NCGR), in Corvallis Oregon. The NCGR *Cydonia* collection includes more than 100 clones with origins from 15 countries maintained as self-rooted trees in a field collection (Postman 2008). About half of this collection represents cultivars for fruit production, and the other half are pear rootstock selections, wild types and seedlings. Observations made at the genebank have revealed a wide diversity of genotype resistance to Fabraea leaf and fruit spot [*Fabraea maculata* Atk. (anamorph = *Entomosporium mespili* (DC.) Sacc.)], and a range of ripening seasons that may make it possible to produce quince fruit in short season production areas (Postman unpublished). Several recent USDA-funded plant collecting expeditions to Armenia, Georgia, and Azerbaijan returned with quince seeds and cuttings from these countries. The availability of *Cydonia* germplasm available in the USA increased significantly from 2002 to 2006 as a result of these collections (McGinnis 2007). Selections made in Bulgaria after fire blight invaded that country have shown resistance to the disease, and some of this Bulgarian quince germplasm was recently introduced into the USA by NCGR.

Quince is adapted to hot, dry climates and to acid soils. Under favorable conditions ripe fruit can become quite fragrant, juicy and flavorful. When grown in high pH soils, however, trees can become stunted and chlorotic due to iron deficiency, a disorder referred to as “lime induced chlorosis.” In northern latitudes or colder climates, the fruit of many cultivars does not fully ripen prior to the onset of winter, and in places where it rains during the time when fruit is ripening, fruit cracking can be a big problem. Quince, whether grown for fruit production or for use as a pear rootstock, is impacted by several disease problems. Fire blight (*Erwinia amylovora* (Burrill) Winslow) limits the cultivation of quince for either fruit or rootstock, especially in regions with warm, humid summers. The genus *Cydonia* is one of the most susceptible to fire blight in the family Rosaceae, which includes many genera that are hosts for this disease (Postman 2008). Leaf and fruit spot caused by can result in tree defoliation and production of disfigured, unmarketable fruits if not controlled. Powdery mildew caused by *Podosphaera leucotricha* (Ell. & Ev.) Salmon and various rust diseases can also impact quince production.

Genetic improvements needed for expanding the use of quince as a dwarfing pear rootstock include increased resistance to fire blight for warm and humid summer climates, and increased winter cold hardiness for northern climates. Adaptation to alkaline soils will allow quince production to expand to more diverse soil conditions both as a rootstock for pear and for production of quince fruit. Very slight progress in soil adaptation was achieved by selecting somoclonal variants of rootstock clone Quince A in high pH tissue culture (Bunnag et al. 1996). Quince for fruit production will benefit from earlier ripening, and elimination of summer ‘rat-tail’ blooms, which predispose a tree to attack by fire blight. Most quince genotypes are adapted to regions with long, hot growing seasons and will not ripen properly without adequate heat units. Fruits that are picked too green may never ripen in storage

(McCabe 1996). Resistance to the fungal rusts and mildews will allow quince to be produced with fewer pesticide applications.

For nearly a century, the quince has been ignored for fruit production in North America, while many improvements have been made in the Middle East and central Asia. Germplasm is available in the USA for expanding the use of *Cydonia* both as a rootstock for pear and as a fruit producing tree in its own right. As Luther Burbank concluded a hundred years ago, "The quince of today is, indeed, a half wild product that has waited long for its opportunity. It remains for the fruit growers of tomorrow … to see that the possibilities of this unique fruit are realized" (Whitson et al. 1914).

4 Mayhaws: A Multiuse Native Fruit

4.1 Botany

The genus *Crataegus* is a complex group of deciduous shrubs and small trees native to northern temperate zones (Mabberley 1997), mostly between latitudes 30° and 50°N (Phipps 1983). *Crataegus* belongs to the subfamily Maloideae in the Rosaceae, a natural group originally occurring as suppressed, understory trees in the virgin forests with the ability to interbreed (hybridize) freely because they possess the base haploid chromosome number of $x=17$. Following the clearing of the dominant trees for human colonization, *Crataegus* underwent rapid proliferation and are now abundant in clearings, along streams, sloughs, river bottoms, and abandoned fields (Phipps et al. 1991; Robertson 1974; Robertson et al. 1991).

The genus has vexed so many authors that early experts on the group termed the situation "the *Crataegus* problem" (Eggleston 1910; Palmer 1932). Quantification of hawthorn species is controversial because of hybridization and unusual factors relative to reproduction, including (1) apomixis, (2) polyploidy, and (3) aneuploidy (Duncan and Duncan 2000; Phipps 1988; Talent and Dickinson 2007b). Apomixis, polyploidy, and hybridization blur the boundaries between species. At the end of the nineteenth and the early years of the twentieth century, workers described hundreds of species in ignorance of the occurrence of apomixis and polyploidy (Dickinson et al. 2007). Several recent studies now demonstrate that both apomixis and polyploidy are implicated in the complex variation seen in this genus in North America (Dickinson 1985; Muniyamma and Phipps 1979, 1984, 1985; Phipps 1984).

4.2 Origin and Domestication

Over 100 species of hawthorn have been described from North America (Phipps 1983; Phipps et al. 2003), but only those early ripening, edible southern US

Crataegus species including *Crataegus aestivalis* [Walter] Torrey & Gray, *C. opaca* Hook. & Arn., and *C. rufula* Sarg, are considered mayhaws (Bush et al. 1991; Payne et al. 1990). Mayhaws are atypical among the hawthorns in their early flowering period (from late February through late-March) and their early fruit ripening dates (late April to mid-May, central Louisiana, Zone 9A) (Craft et al. 1996). This arborescent shrub has outstanding ornamental characteristics such as, attractive foliage, showy blossoms, and clusters of brilliantly colored fruits. Mayhaws are native to the alluvial acid soils of rivers, streams and swamps from North Carolina to Florida and west to Arkansas and Texas (Clewell 1985; Craft et al. 1996; Godfrey and Wooten 1981; Phipps 1988; Radford et al. 1974; Sargent 1965; Vines 1977).

4.3 Production and Uses

Mayhaw fruit is a small pome (1.4–3.7 g), yellow to dark burgundy, fragrant, acidic, and juicy, of a high culinary value. Over the last 30 years, more than 70 cultivars have been selected from native stands and seedlings for improved color, fruit size, yield, and ease of harvest. Harvested fruit is processed into marmalades, butters, preserves, jellies, condiments, syrups, wines, and desserts (Gibbons 1974; Morton 1963; Payne et al. 1990; Reynolds and Ybarra 1984; Vines 1977). Superior clones are grafted onto rootstocks, but many orchards still consist of seedling trees. Fruits are hand harvested or mechanically shaken onto tarps and catch frames. The fruits can be processed fresh, refrigerated for a few days, or frozen for several months without loss of quality. Thus, the opportunity exists for a greatly expanded market based upon a consistent supply of fruits (Bush et al. 1991; Payne et al. 1990).

There is limited information on the pest management of mayhaws; however, they are susceptible to many of the insects and diseases that attack other pome fruits (Krewer and Crocker 2000; McCarter and Payne 1993; Moore 2006; Scherm and Savelle 2003). Several insects including plum curculio [*Conotrachelus nenuphar* (Herbst)], flower thrips (*Frankliniella spp.*), roundheaded appletree borer (*Saperda candida* F.), leafminers (many different insect species), terrapin scale [*Mesolucanium nigrofasciatum* (Pergande)], and mealybugs (Pseudococcidae family) feed on the foliage, flower, fruit, and wood of mayhaw. The plum curculio in particular has caused extensive damage to fruit in many locations (Krewer and Crocker 2000; Payne et al. 1990).

There are several major diseases of mayhaw including quince rust (caused by *Gymnosporangium clavipes* Cke. and Pk.), fire blight [caused by *E. amylovora* (Burrill) Winslow], and hawthorn leaf blight [caused by *Monilinia johnsonii* (Ellis & Everh.)]. Quince rust attacks both the leaves and fruit of mayhaw trees. Fire blight can be severe in many parts of North America and many mayhaw growers consider it the most limiting factor in mayhaw production. Blossoms, actively growing shoots, and immature fruits are most readily infected, but the trunks and roots may become infected as well (McCarter and Payne 1993). Lack of available chemicals to control insects and diseases continues to be a major deterrent for growers interested in starting new mayhaw orchards. However, great strides have been made in the labeling of pesticides, especially fungicides, for commercial production in the USA (Graham 2000).

4.4 Breeding Potential

4.4.1 Scion

Many selections of mayhaw have been evaluated for fruit quality, growth habit, and disease resistance (Craft et al. 1996; Krewer and Crocker 2000; Graham et al. 2000). While no single selection is resistant to quince rust, a wide range of tolerance exists among *C. opaca* cultivars. Hybridization of the most tolerant cultivars could lead to selections with a greater disease tolerance. Mayhaw cultivars have exhibited a wide range of relative susceptibility to fire blight. 'Maxine' has shown high resistance to fire blight in Louisiana orchards (Craft Personal communication). It has been used in controlled hybridizations, but the progeny are still in the juvenile stage.

Taxonomists are using flow-cytometric DNA measurements to elucidate relationships within and between *Crataegus* populations (Talent and Dickinson 2007a). Lo et al. (2007) used two nuclear and four intergenic chloroplast DNA regions to clarify the phylogeny of many *Crataegus* species. Species grouped with the cultivated species *C. aestivalis* [Walter] Torrey & Gray and *C. opaca* Hook. & Arn included *C. calpodendron* (Ehrh.) Medik., *C. crus-galli* L., *C. lassa* Beadle, *C. mexicana* DC, *C. mollis* Scheele, *C. punctata* Jacq., *C. triflora* Chapm., *C. uniflora* Munchh., and *C. viridis* L. These related species need to be evaluated for horticultural characteristics and disease resistance. Hybridization of these species with mayhaws may lead to novel fruit types with better disease resistance.

4.4.2 Rootstock

Currently, mayhaws are grown on seedling rootstock of *C. opaca* and *C. aestivalis* in the southern USA. Although mayhaw appears to be initially compatible on most *Crataegus* rootstocks, our knowledge of mayhaw rootstocks is rudimentary at best. 'Royalty' mayhaw was tested on seedlings of 'Annette,' 'Flame,' 'Redskin,' 'Super Spur,' 'Texas Super Berry,' 'Toledo Giant,' 'Turnage #57' and 'Warpaint' in a multiyear, replicated trial in Louisiana. There were no significant differences in trunk caliper, fruit number/tree, fruit weight/tree, fruit size, or yield efficiency detected among rootstocks (Graham et al. 2005). Trials using other hawthorn species for rootstocks in Louisiana has been limited predominantly to observational tests of *C. arnoldiana*, *C. azarolus* L., *C. brachyacantha* Sarg. & Engelm., *C. coccinoides* Ashe, *C. columbiana, C. crus-galli* L., *C. cuneata* Siebold., *C. douglasii* Lindl., *C. laevigata* (Poir) DC., *C. marshallii* Eggl., *C. mollis* Scheele, *C. phaenopyrum* (L.f.) Med., *C. punctata* Jacq., *C. uniflora* Munchh. and *C. viridis* L. Species deemed unacceptable and rogued from the test are *C. crus-galli* L., *C. laevigata* (Poir) DC., *C. marshallii* Eggl., *C. monogyna* Jacq., and *C. phaenopyrum* (L.f.) Med. (Craft 2003, Personal communication). In Mississippi, *C. marshallii* Eggl. is considered an excellent rootstock for *C. opaca* (McDaniel 1980). In Georgia, *C. flava* Aiton can be used, but due to its slow growth rate, the mayhaw scions may overgrow the rootstock. Mayhaw seedlings are currently the best choice as a rootstock in damp soils (Payne et al. 1990).

4.5 Breeding History

Improvement of native mayhaws began in the 1970s by selection of superior clones from native seedling stands. Most commercially important cultivars being grown in current orchards have originated in this manner. While selection in native stands for potential cultivars is not as efficient as controlled hybridization, it is still the most common method of introducing new cultivars. However, this practice has led to some confusion in the industry, since more than one person can collect scion wood from the same native tree and introduce it to the industry under different cultivar names.

Following selection from native stands, growers began screening seedlings derived from superior clones in several states. Progress is slowly being made for improved disease resistance and fruit quality. Controlled hybridization for mayhaw improvement was initiated in the late twentieth century (Craft et al. 1996). Initial breeding objectives included (1) late blooming clones, (2) improved fruit size, skin toughness, and flesh firmness, (3) increased fruit quantity per cluster, (4) reduced fruit shattering before maturity, and (5) improved cold hardiness of flowers. Currently, three cultivars developed by controlled hybridization have been released to the public. They are 'Red Majesty' ('Cajun' × 'Texas Star'), 'Abundance' ('Cajun' × 'Texas Star') and 'Double GG' ('Texas Star' × 'Royal Star'). All three of the cultivars have dark red skin, red flesh, bloom late, and are shatter resistant. Unfortunately, all are susceptible to fire blight (Craft Personal communication).

Current mayhaw cultivars are still deficient in many horticultural characteristics and many of the previous goals have not changed. Improvements that would benefit growth of the industry include (1) late blooming selections that reach peak flowering after danger from late frost is past, (2) shatter resistance, (3) high antioxidant levels, (4) uniformity of ripening within a plant for mechanical harvesting, and (5) resistance to fire blight for expansion of the industry.

Little breeding work has been done to improve mayhaw rootstocks. Present trends in the mayhaw industry toward intensive culture with high-density plantings and mechanical harvesting indicate that greater demands will be made for improved mayhaw rootstocks than ever before. To be adapted to the intensive system of culture, mayhaw rootstocks should have certain properties, including broad adaptability to varying climates and soils, resistance to major diseases and pests, good anchorage, compatibility with scion cultivars, dwarfing ability, and the capacity to induce precocious fruiting. No rootstock cultivars are available that possess all of the characters just mentioned, although the genetic resources exist in *Crataegus* to make the required improvements possible. Dwarfing germplasm may be found within *Crataegus*, but it requires a careful search of the available sources and the use of effective test procedures.

4.6 Breeding Methods and Techniques

Mayhaw flowers are produced slightly before or at the same time as the leaves. They are born in 2–5 flowered glabrous corymbs on short pedicels, usually on spurs, but also on terminal or lateral buds of previous season's growth. The flower consists of five white petals, a calyx of five sepals, 20 stamens, and a pistil divided into five styles. Hawthorn fruits are known as pomes, although the seeds and their bony endocarps are termed pyrenes, or nutlets (Vines 1977; Craft et al. 1996).

Flowers of the seed parent are emasculated at the balloon stage. Removal of the petal and stamens prevents self-pollination, exposes the stigmas, and minimizes insect visitation and possible contamination with unknown pollen. Collected pollen of the desired male parent is applied to the stigmatic surface using a brush, pencil eraser, or fingertip. Following pollination, clusters can be bagged to reduce possible pollen contamination and to reduce insect and bird deprivation.

Crossed fruits are harvested at maturity, and the fruits can be macerated to separate the seeds from the fleshy pericarp. The macerated pericarp material can be removed by water flotation; and if seeds are to be stored, they must be dried thoroughly and stored at 5°C. Stored seeds must be stratified at 5°C for 10–16 weeks prior to sowing. Unlike most fall ripening hawthorns, freshly collected mayhaw fruit can be fermented for up to 8 days and planted. Such treatment has resulted in over a 90% seed germination rate (Baker 1991).

Following seed germination, the evaluation procedure is similar to other pome and stone fruits. The seedlings are planted in nursery rows for initial selection, followed by testing as grafted trees at normal orchard spacing in a single location. The final step is to test the grafted selection at normal orchard spacing at multiple locations.

4.7 Integration of New Biotechnologies in Breeding Programs

The vision of orchardists and breeders and their skills of observation have served the mayhaw industry well. Improvements in biotechnology may help overcome some of the limitations of conventional breeding. Development of the technique of marker-assisted selection in other pome fruit, such as apple and pear, may provide an avenue for transferring the technology to mayhaw scion and rootstock breeding. Of course, this technique relies on sufficient markers being identified in mayhaw

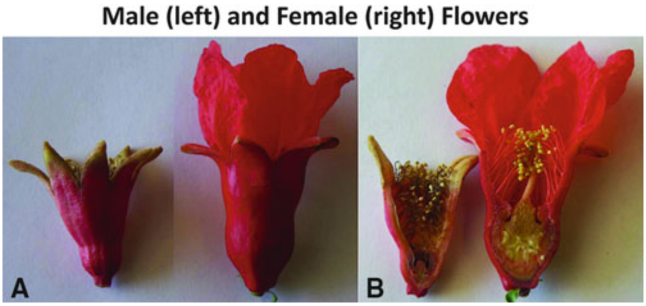

Fig. 4.4 Pomegranate flowers, male (l) and hermaphroditic (r) in (**A**) full and (**B**) cross-section. Photo credit: Jeff Moersfelder, USDA ARS

that are linked to important characteristics. Currently, complex characteristics influenced by many genes such as yield, flavor, enhanced color, and texture cannot be targeted by biotechnology. At present only traditional breeding can effectively manipulate polygenic traits which will ultimately lead to superior cultivar development and release.

5 Pomegranate

5.1 Botany

Pomegranate (*Punica granatum* L.) is subtropical and although naturally grows as a multitrunked small tree or large shrub (3–6 m at maturity), it can be trained to form a single trunk. Plants are typically deciduous, though evergreen types are noted (Singh et al. 2006). Branches are often spiny, with small, narrow, oblong leaves and short stems, and aggressive sprouts often develop from the crown area and the roots (Morton 1987). Flowers occur as single blossoms or in clusters of up to five and are usually borne subterminally on short lateral branches older than 1 year (El-Kassas et al. 1998), but some genotypes flower on spurs. Flowers are heterostylous: larger long-styled perfect flowers set more fruit than short-style types, which are often functionally male. Flowers are typically red to red-orange (Fig. 4.4) and funnel shaped and are self-pollinated or cross-pollinated by insects (Morton 1987). Double and variegated flowers are found in some ornamental selections. Period of bloom may be very prolonged, but most flowering in the Central Valley of California occurs from mid-May to early June.

The fruit is berry-like and has a prominent calyx which is maintained to maturity and contributes to the fruits' distinctive shape as observed in the cultivar 'Wonderful,' (Fig. 4.5) which is an industry standard. The leathery rind includes a pericarp, comprising a cuticle layer and fibrous mat, and the mesocarp which is the inner fruit wall and is further elaborated into membranes dividing a number of locules.

Fig. 4.5 Pomegranate 'Wonderful' fruit. Photo credit: Malli Aradhya, USDA ARS National Clonal Germplasm Repository, Davis, California

The juicy arils are the edible portion of the fruit, are attached to the mesocarp, and are derived from epidermal cells. In different cultivars, arils range from deep red to virtually colorless, seed softness varies greatly based on content of schlerenchyma tissue, and acidity varies from 0.2 to 3% of the expressed juice. At maturity, soluble solids are quite high (15–20%) and differing levels of acid result in fruits which range from sweet to sweet/tart to very tart indeed.

Most pomegranate genotypes root extremely easily and are seldom grafted. Orchards are sometimes established by direct planting of unrooted cuttings (Blumenfeld et al. 2000). Pomegranate is especially well adapted to hot summer/cool winter Mediterranean climates, but can be grown in the humid tropics or subtropics, and is injured by temperatures below −11°C (Morton 1987). Dry summer climates are most conducive to commercial production. While extremely drought-tolerant, pomegranate crops better with regular moisture. Pomegranate has high salinity resistance and is adapted to a wide variety of soils (Melgarejo 2003).

5.2 *Origin and Domestication*

Pomegranate is one of only two species in its genus, *Punica*, which is the sole genus in the Punicaceae (ITIS 2006). This fruit was likely dispersed by humans in

Fig. 4.6 Center of origin for Pomegranate (*Punica granatum* L.). Prepared by Ed Stover, USDA ARS

prehistoric times and interpretation of the original native range varies among authors, but Iran and the surrounding area (Mars 2000) are widely accepted (Fig. 4.6), while others extend the region of origin more broadly (Morton 1987). In general, wild pomegranate fruits have thicker rinds, extremely high acidity, and smaller arils compared to cultivated types (Bist et al. 1994; Kher 1999). Human use of pomegranate has a long history, with cultivation projected as early as 3000 BCE (Stover and Mercure 2007). Pomegranates are important in the symbolism and literature of many middle-eastern cultures. It is one of the symbols of the love goddess Aphrodite (Encyclopedia Britannica 2006), is central to the Greek myth of Persephone, and is mentioned three times in the Qur'an and 23 times in the Hebrew Bible (Janick 2007).

5.3 Production and Use

Pomegranate is widely grown in many countries where it is well-adapted, but no global production estimates are available. India produces pomegranate on more than 100,000 ha and it is considered one of the most important fruits of tropical and subtropical areas of that country (Indian Council of Agricultural Research 2005). In Iran, 600,000 tons of pomegranate are produced annually on 65,000 ha, and 30% is exported (Mehrnews 2006). Turkish production in 1997 was 56,000 tons (Gozlekci and Kaynak 2000). Spain is the largest Western European producer with ~3,000 ha in 1997 and expectation of continued growth (Costa and Melgarejo 2000). Production is also growing in the USA, with 5,600 ha of commercial pomegranate (mostly in the San Joaquin Valley) in 2006, largely dominated by the cultivar 'Wonderful' (Kotkin 2006).

US production of pomegranate has expanded as a result of reported health benefits from consuming the fruit and its juice. Antioxidant content of pomegranate juice is among the highest of any foods (Guo et al. 2003), and it is reported that these polyphenol compounds may lower risk of heart disease (Aviram et al. 2004) and slow cancer progress (Adams et al. 2006). Pomegranate also has a range of wonderful flavors, ranging from mild watermelon or strawberry-like flavors in low-acid types to bright cherry and cranberry-like flavors in sweet/tart cultivars. California commercial orchards are reportedly expected to produce mature yields of up to 33 tons/ha (Karp 2006). With reported health benefits, high juice yields, modest pest pressures, and relatively undemanding handling of fruit for processing, pomegranate juice production should continue to grow in commercial importance.

The pomegranate fruit is not climacteric (Kader et al. 1984), has a storage life equaling the apple, and ships very well (Morton 1987). However, greatly increased consumption of fresh pomegranates may be unlikely, as many consumers are daunted by peeling the fruit and extracting the arils. The greatest fresh fruit potential appears to be in minimally processed arils (Sepulveda et al. 2000), for eating as snacks and use as a garnish.

5.4 Breeding Potential

There are innumerable pomegranate cultivars, and germplasm collections have been established in many countries. More than 1,000 accessions were assembled in the Turkmenistan Experimental Station of Plant Genetic Resources (Levin 1995). Collections of 200–300 accessions are maintained in Azerbaijan, The Ukraine, Uzbekistan, and Tajikistan. Local cultivars have been conserved in many Mediterranean and Middle Eastern countries (Spain, Morocco, Tunisia, Greece, Turkey, Egypt) (Mars 1996). India has three collections containing at least 30 accessions each (Gulick and Van Sloten 1984). There are diverse genotypes (238 reported cultivars) within China (Feng et al. 2006). The US National Clonal Germplasm Repository (NCGR), in Davis, Calif., has almost 200 pomegranate accessions, including many obtained from the Turkmenistan collection. Included in the NCGR are many soft-seeded types, sometimes called 'seedless.' The NCGR policy is to distribute plant material, free of charge, to research interests around the world (see our Web site http://www.ars-grin.gov/dav/).

Most pomegranate cultivars likely arose through selection among chance seedlings through millennia of cultivation. Recently, directed plant improvement efforts have been employed in several countries. India, China, and Israel appear to have the most developed and sustained pomegranate breeding programs (Feng et al. 2006; Jalikop et al. 2006). The characteristics of greatest interest have been similar in most programs: bigger fruit, larger arils, greater juice yield/thinner skins, attractive fruit and aril color, soft seeds, altered time of maturity, good soluble solids and acid levels, less fruit splitting, and sometimes resistance to diseases. In China, 50 cultivars are reportedly being grown from these directed programs and selection of sports (Feng et al. 2006). There is one report of a Chinese cultivar yielding 90% juice (Zhu et al. 2004). 'Mridula' and 'Bhagwa,' two important cultivars exported from India, are products of controlled crossing and selection. Pomegranate cultivars have also been released from breeding programs in the USA. There appears to be a considerable potential for further development of improved pomegranate cultivars, perhaps including selection for higher levels of health-promoting compounds.

6 Fig

6.1 Botany

Cultivated fig (*Ficus carica* L.) trees are deciduous, spreading in habit, and fast-growing. Where freezing or other damage does not disrupt tree structure, figs grow into single-trunked trees with little training. They also root easily and so are seldom grafted.

The fig is a composite 'fruit' called a 'syconium' (reviewed in Condit 1947), comprising a shell of receptacle tissue enclosing hundreds of individual fruits, which are drupelets developing from the female flowers lining the receptacle wall. The syconium has a small opening (called the ostiole or eye) at the distal end. The mature edible fig fruit has a thin skin which may be somewhat tough, a pale interior rind, and a sweet gelatinous pulp comprising the individual ripe drupelets. The seeds (achenes) within the drupelets range from virtually nonexistent to subtly crunchy.

The fig has a distinctive pollination biology which is important in commercial production. It is gynodioecious, with both male and female flowers produced in wild figs and cultivated caprifigs (which are grown to provide pollen), while fruiting cultivars produce only functionally female flowers, though aborted hermaphroditic flowers surround the ostiole (Beck and Lord 1988). The female flowers in edible figs are long-styled and produce a much more succulent drupelet than do the female flowers in the short-styled monoecious wild-type figs. Figs are distinguished by their cropping/ pollination characteristics. The type called 'common figs' are edible figs requiring no pollination to set a commercial crop. The other two types of edible fig require pollination to set the main crop of figs on current season's growth: Smyrna types (e.g. 'Calimyrna') and San Pedro types (e.g. 'King'). The San Pedro types are distinguished by also setting a crop, but without the need for pollination, on previous season growth.

The wasp (*Blastophaga psenes* L.), which has coevolved with the fig (Kjellberg et al. 1987), carries the fig pollen. The protogynous nature of the wild-fig/caprifig is a critical aspect of the wasp–fig coevolution. Female flowers are receptive 6–8 weeks before anthers mature in the same syconium (Condit 1932): this permits wasps to enter, pollinate, and oviposit in syconia which will have mature pollen during the emergence of the next wasp generation. The wasp larvae cannot mature in edible figs, so the life cycle is completed solely within caprifigs.

6.2 Origin and Domestication

The species in the genus *Ficus* ranges in number from 600 to more than 1,900, according to different taxonomists, with most found in the tropics or subtropics and just a few producing palatable fruits (reviewed in Condit 1955). Edible figs reportedly became established across the Mediterranean region around 6,000 years ago (Ferguson et al. 1990). Archeological evidence from the Jordan Valley suggests it is one of the earliest plants domesticated, 11,000 years ago, much earlier than wheat, barley and legumes (Kislev et al. 2006). Storey (1975) proposes that the long-styled pistils and succulent fruitlet of the edible fig resulted from a single mutation in the wild fig, and this trait was key to domestication. The edible fig is well adapted to high temperatures and drought and is commonly planted in home gardens throughout regions with Mediterranean climates. Commercial plantings range in scale from small production for local markets to large mechanized farm operations. Even though most of world's figs are eaten fresh, their short market-life restricts them to largely local consumption. By contrast, high sugar content and stability make dried figs easily transportable, and therefore most fig exports are as dried fruit.

6.3 Production and Uses

Worldwide, over one million MT of figs are harvested annually from 427,000 ha (FAO 2006). The largest fig producer is Turkey with ~26% of the world's figs, and producer price is listed as $892 per ton (for dried product) for 2005 (FAO 2007). Turkey, Egypt, Iran, Greece, Algeria, and Morocco are the top six global producers and account for ~70% of world annual production. Data from 2005 indicate that the USA ranked eighth with 4% of global fig production. Commercial fig production is reported in fourteen US states. However, 98% of the US crop is produced in California, on 5,100 ha, with yields per ha three times the global average. Almost all California production is in the San Joaquin Valley, with ideal conditions for both fig production and the drying of figs under ambient conditions.

Most Western European and US fig production relies on common figs which do not require pollination. However, generally the major world fig producers, and many California orchards (of 'Calimyrna' fig), focus on production of Smyrna-types which do require pollination. Separate orchards of caprifig trees are maintained to control pollen flow. For edible figs requiring pollination, mature caprifig fruits are typically supplied three times in California fig production, at regular intervals in

May–June. Ideally each fig is entered by only one wasp, since fruit splitting can result from excessive pollination and the entry of multiple wasps increases the risk of introducing microorganisms which cause internal defects.

Mature tree height varies by cultivar and typically ranges from 3 to 10 m. Since most fruit is on current season's growth, fig trees can be pruned aggressively and remain productive. Orchards for fresh figs are typically pruned low for ease of harvest. Some growers now produce figs on small plants trellised and pruned like grapevines.

Worldwide, fig production is small compared to major commodities such as apples, bananas, and citrus fruits. However, at a third to half the global production of familiar crops such as apricot and sweet cherry, the fig may have transcended the threshold for being considered a minor crop. Most commercial efforts have focused on dried fig production, and most growth potential for fig appears to revolve around greater consumer access to top-quality fresh figs.

In Mediterranean and Middle-Eastern countries, most consumers already enjoy fresh figs. The interest in commercial fresh fig production in California has increased with consumer demand for diverse premium produce. Total California production of processed fig was fairly constant from 2000 to 2005, but fresh fig production doubled in this period, so that in 2005, fresh figs represented more than 9% of California commercial production (NASS 2006). Consumer prices for fresh figs are quite high and are similar to those for raspberries and blackberries. It seems likely that successfully marketing fresh figs provides greater grower profits than does dried fig production.

The greatest limitation to expansion of fresh fig sales is the very short shelf life of fresh figs. Currently a useable life of 3–10 days from harvest to sale is typical. Advances in postharvest handling and/or development of varieties with better shelf-life are sorely needed. Fresh fig quality is greatest at tree ripeness, when the pedicel begins to sag, but such figs are very soft, sensitive to damage (Chessa 1997) and have very short market life. Therefore, harvest at early ripeness (good color) is essential for current fresh-fig commercial sale.

Leading commercial fig cultivars in the USA have mostly been grown for drying and feature mild honey, melon, or mild berry-like flavors with little balancing acidity. Visitors to the US fig genebank are often delighted by the bright fruity flavors, reminiscent of berries or citrus, of some fig varieties which are not yet grown commercially. The potential for broader fig appreciation may be demonstrated by a quote from the prophet Mohammed indicating, "If I could wish a fruit brought to paradise it would certainly be the fig" (Condit 1947).

6.4 Breeding Potential

The National Clonal Germplasm Repository (NCGR) in Davis, California houses the US collections of most of the Mediterranean-adapted fruit and nut crops. The NCGR fig collection currently includes: 78 named fruiting cultivars, 44 regional

Fig. 4.7 Fruits of Brown Turkey fig. Photo credits: Louise Ferguson, University of California, Davis

selections from diverse areas of the world, 40 advanced selections from plant breeders (mainly from the UC Riverside breeding program), 28 caprifigs, and a small number of species and hybrids. The named cultivars in the NCGR collection represent a fair cross-section of figs from major old-world growing areas and represent the largest collection in North America. It is our policy to distribute plant material, free of charge, to research interests around the world (see our Web site http://www.ars-grin.gov/dav/). Other large international collections include the Conservatoire Botanique National Méditerranéen in Porquerolles, France and the Instituto Valenciano de Investigaciones Agrarias, in Spain. Turkey and many other countries have invaluable collections of local cultivars.

Domestication and early human selection for edible figs from among chance seedlings contributed many of the fig types grown today in gardens and commercial orchards (Fig. 4.7). Few important fig cultivars arose through a planned breeding program. A sustained fig improvement program was maintained by the University of California at Riverside from 1928 to 1980s, by Ira Condit and William Storey. The focus of this effort was development of drying figs with ‘Calimyrna’-like quality without the need for pollination and with a small ostiole (reviewed in Storey 1975). Doyle et al. (2003) of the University of California at Davis recently released the ‘Sierra’ fig for drying and the ‘Sequoia’ fig, which is expected to find a place in fresh fig production. Louisiana State University has released four new fig cultivars in the last 6 years, continuing their efforts to identify material well adapted to the humid southeatern USA (O’Rourke et al. 2005; Johnson et al. 2010a, b, c). Other efforts are ongoing in the USA and in other countries.

Existing commercial fig cultivars vary markedly in post harvest qualities (Stover et al. 2006), suggesting that breeding efforts to enhance and pyramid desirable traits should provide improved varieties. Dark figs generally show less marking as they pass through steps necessary for marketing, so a focus on highly pigmented varieties may prove desirable.

There are significant opportunities to develop cultivars with enhanced production of fruit for fresh sales both early and late in the production season. Brebas are the first figs of the season, setting on wood from the previous year, and typically maturing in June in the Central Valley of California (vs. August through October for main crop fruit). Brebas tend to be larger than main crop figs, are relatively scarce on the market and tend to get a high price as fresh fruit. The cultivar 'King' is especially noteworthy for producing a high proportion of brebas (with only modest quality) and may prove a useful parent for enhancing breba production. Some varieties tend to be much later than others, with continued production well into November and sometimes December in our collection, and may serve as parents in an effort to enhance late season production.

7 Blue Honeysuckle

7.1 Botany

Blue honeysuckle, honeyberry or haskap (Thompson 2006), *Lonicera caerulea* L., is in the family Caprifoliaceae, section Isika Rehd., subsection Caeruleae Rehd. It is a polymorphic, circumpolar species, with several ecogeographic forms, designated subspecies or sometimes, separate species. Plants are deciduous shrubs, to 2 m or more in height. Leaves are simple, opposite, oval to elongate, 3–5 cm in length. At each node, there are 3 buds, one above the other. Normally the most advanced, lower buds on previous year's growth, develop into one, or rarely 2, shoots the current year, whereas the uppermost buds remain dormant until a few years later, when vigorous shoots may emerge from older wood lower down in the shrub. Pairs of flowers are borne at the lowest one to 4 nodes of current year's shoots. Compared to ornamental *Lonicera* species, flowers are small, about 2 cm long, tubular with flared lobes, pale yellow to cream-colored. Each flower consists of two tubular corollas atop what appears to be a single ovary, but that actually consists of two ovaries surrounded by fleshy bracts. Plants are essentially self-incompatible and require bees for cross-pollination. Because blooming occurs rather early in spring when temperatures are unfavorable for honey bees, bumble bees are the principal pollinators. Also, blue orchard bees (*Osmia* sp.) are used in Japanese plantings. Fruits are dark blue to purple berries, with varying amounts of a white waxy covering, or bloom. Shapes are variable ranging from oval to long and thin. Size ranges from 0.3 g to rarely over 2.0 g. Flavors are unique and vary considerably; from a pleasant mild taste, more sprightly tart-sweet, mildly tart, very tart to slightly or very bitter. There is a maximum of 20, but usually fewer, very small seeds in a fruit.

Climatic adaptation varies with the subspecies. In Russia, cultivars developed from *L. c.* subsp. *kamtschatica*, native to NE Russia, are more successful in NW and

NE regions, whereas cultivars developed from *L. c.* subsp. *edulis* or *L. c.* subsp *boczkarnikovae*, native to SE Russia and Central Siberia perform well in those regions. Russian cultivars are extremely cold-hardy in long severe winters (to −50°C), but are not successful in moderate climates with fluctuating winter temperatures (Plekhanova et al. 1993). Following completion of very short chilling requirements by October–November, plants lose their hardiness when temperatures rise to +5 to 10°C. Then as cold weather resumes, there occurs varying degrees of freeze damage, depending upon the temperature severity. The Japanese *L. c.* subsp. *emphyllocalyx*, native to Hokkaido and northern Honshu, appears to be more adapted to moderate climates. Plants bloom a few weeks later than Russian types. Winter cold hardiness is not known but is under test in Saskatchewan. Over a 6-year period, plants have performed very well in western Oregon and northern Idaho (Thompson and Barney 2007). In spite of very early blooming, spring frosts are not a hazard: Russians claim that flowers are hardy to −7°C. For optimum performance, all forms of blue honeysuckle require good soil moisture conditions and moderately warm summer temperatures. Plants are relatively free of serious pests and diseases and tolerant of a wide range of soil types.

7.2 Origin and Domestication

Historically, blue honeysuckle berries were harvested from wild plants by local people in regions where edible forms exist, primarily in Russia and in Hokkaido, Japan. Folklore in both regions has long attributed high nutritional and medicinal values to these berries, a fact supported by recent phytochemical analyses (Chaovanalakit et al. 2004; Plekhanova et al. 1993; Tanaka and Tanaka 1998). Domestication of this crop occurred only in the twentieth century. Minor efforts to develop this crop in Russia date back to 1913–1915 but not until the 1950–1960s was a serious research program initiated (Plekhanova 2000). Extensive germplasm explorations were conducted by the Vavilov Institute for Plant Industry in Leningrad (now St. Petersburg), and plants were distributed to the Lisavenko Research Institute for Horticulture in Siberia at Barnaul and several other research stations in the USSR for evaluations. From these studies, over 200 cultivars have been named and distributed to farmers and gardeners.

Currently, blue honeysuckle plants are widely grown in Russia, mainly in gardens, but also in some commercial plantings. No production statistics are available. As the first fruit of the season, and because of the widely acknowledged healthful attributes, this berry is very popular in Russia. No doubt, due to the isolation of Russia from the rest of the world during the period of its domestication, this crop was virtually unknown elsewhere. In recent years, with open exchange of information and plant materials, there has been increasing interest in northern European countries. Also, a small industry, based on introduced Russian cultivars and wild-gathered berries, is developing in Jilin province in N.E. China (Huo et al. 2005). In North America, a few Russian cultivars (sold as ‘honeyberries’) were introduced several years ago and are available in many nurseries but, as yet, these are mainly on trial in home gardens. As expected, when planted in the moderate climatic regions in most of the USA, plants have failed to perform satisfactorily. In the past decade, a research program at the University of Saskatchewan in Canada has stimulated considerable enthusiasm for this new crop. A few selections have been made and a haskap grower's organization established for promotion of this berry that performs well in the severe climate of the northern prairie region (http://www.haskap.ca).

Domestication of the Japanese ssp. *L. c.* subsp. *emphyllocalyx* occurred even more recently. Beginning in the late 1960s and 1970s both the Hokkaido Prefectural Agriculture Experiment Station and a Farmers Coop in Chitose began to make selections from the nearby wild populations in the Yufutsu Plains near Tomakomai city. This region was famous for the abundance of fruiting shrubs from which people had long collected wild berries. Selections were evaluated for several years and the best few distributed to farmers, including one named cultivar, 'Yufutsu' (Tanaka et al. 1994). Small scale commercial production began in the 1970s and increased to 195 ha by 1991. During this initial enthusiasm for haskap (the Ainu word used by the Japanese for this berry) a large array of high quality, high priced processed products were developed and have become popular as gift items. However, due to the high cost of labor, and the lack of mechanical harvesting, by 2005 the area under production had decreased to 85 ha with an estimated 200 tons of berries, an insufficient amount to satisfy the demand that had been created (Lefol 2007).

7.3 Production and Uses

With its unique flavors and high nutritional values this tart/sweet berry (Fig. 4.8) should receive good acceptance by consumers, especially as processed products. Haskap berries are expected to fill a niche market in specialty food stores where they will attract health-conscious customers and those who seek organically grown products. Thus far, because of the lack of significant pests or diseases, haskap appears to be a good candidate for organic growers. As it is the earliest fruit to mature, these plants make a good complement to other berries with similar culture (e.g. blueberries) by spreading the harvest season. When cultivars are developed with milder taste (i.e., higher sugar–acid ratios), and fruits firm enough for prolonged storage, there is also potential for the fresh market. In addition to commercial production, this berry is an excellent plant for the home gardener because of its easy care.

The two major restraints to production in the USA are unfamiliarity with this berry and dearth of well-tested cultivars to recommend to growers. The first step to develop a successful new crop is the selection of superior cultivars. This requires breeding programs. As funding for horticultural research is usually driven by grower and processor demands, without these pressures funds are very difficult to obtain. In order to promote this new berry crop, plants must be available in nurseries and growers must provide berries for processors and consumers. For commercial

Fig. 4.8 Russian blue honesuckle *Lonicera caerulea* 'Morena.' Photo credit: Kim Hummer USDA ARS

production, it is essential that cultivars be suitable for mechanical harvesting. Although it appears feasible, this aspect has not been tested, as yet, but is under consideration for future research.

7.4 Breeding Potential

Within the relatively limited germplasm available in the USA, there is a wide range of variability in all traits so there is good potential to select cultivars that satisfy needs of both commercial production and the home garden or small U-pick farms. The potential of available diversity has not yet been fully exploited. However, additional germplasm from Japan is desirable to increase the range of diversity available for future breeding. In North America, there are two main sources of germplasm. In the USA, the USDA/ARS National Clonal Germplasm Repository in Corvallis, Oregon, has a small collection of Russian cultivars (Hummer 2006). In 2000, at this same location, and with collaboration with the University of Idaho, Sandpoint REC, in Sandpoint, ID, Oregon State University initiated the first, and only, genetic improvement program in the USA. This small breeding program, using primarily the Japanese *L. c.* subsp. *emphyllocalyx*, has several selections under trial. In Canada, the University of Saskatchewan has a much larger collection of Russian cultivars, as well as some Japanese germplasm on trial. In this region, where the climate is similar to that of Siberia, Russian cultivars and hybrids are doing very well. Over the past decade, there has been an active breeding program which has already released a few cultivars, ‘Tundra’ and ‘Borealis,’ and there is much enthusiasm among farmers to grow this crop. University scientists have been in discussions with Japanese processors concerning a possible export market (Lefol 2007). At the Vavilov Institute of Plant Industry (VIR) in St. Petersburg Russia, there has been a blue honeysuckle research program for several decades. There, exists the largest collection of blue honeysuckle germplasm in the world, 500 accessions as of 2000 (Plekhanova 2000). There are several other selection programs in Russia; e.g. at the Siberian Horticulture Institute in Barnaul and in VIR, Vladivostok. Recently, in Japan, a breeding program was initiated at Hokkaido University (Takada et al. 2003).

8 Elderberry

8.1 Botany

The genus *Sambucus*, which includes the edible elderberry (Fig. 4.9a, b), is presently classified as a member of the family *Adoxaceae* (Donoghue et al. 2003), though long considered a member of the *Caprifoliaceae*. This small family of five genera and approximately 200 species is distributed in northern and southern hemispheres and is primarily temperate and tropical montane in distribution (Stevens 2007). The genus *Sambucus* includes 9–20 species with nearly worldwide distribution. Three closely related species, *S. canadensis* L., *S. nigra* L., and *S. cerulea* Raf. are of commercial interest for fruit, blossoms, and other plant parts. The relationship of these three species is of some discussion; Bolli (1994) classified all three as subspecies of *S. nigra*. Others classify them as distinct species (Yatskievych 2006), noting differences among the species in leaf form, number of rhizomes formed, berry characteristics, and anthocyanin profiles. The American elderberry, *S. canadensis*, is native to eastern North America from Nova Scotia to Manitoba and south to Florida, Texas, the Caribbean islands, and Mexico. The European or black elderberry, *S. nigra*, is native to Europe, northwest Africa, and western Asia. The blue elderberry, *S. cerulea*, is native to western North America from British Columbia to California and east to Montana and Utah. At present, most commercial interest is centered on the American and European elderberries.

The plant is a medium to large shrub or small tree with spreading roots. American elderberry suckers freely from the root system; European elderberry is less prone to

Fig. 4.9 Elderberry (**a**) flower and (**b**) fruit. Photo credits: Patrick Byers, University of Missouri

suckering. The leaves are opposite, pinnate, and 5–30 cm long, with 5–9 leaflets (usually five leaflets in *S. nigra* and seven leaflets in *S. canadensis*) with serrated margins. The bark is gray to yellowish brown, often appearing roughened or warty. The flowers (Fig. 4.9a) are borne in dense cymes, usually terminal on the branches. Individual blossoms are white to pink, usually 3–5 mm in diameter. The fruits

(Fig. 4.9b) are rounded berry-like drupes, 4–7 mm in diameter, that are orange-red to bluish black at maturity. The plants are hardy and long-lived.

The elderberry is an adaptable plant, as might be inferred from its broad range. The native range of *S. nigra* stretches from Norway (63°N) to the Mediterranean basin (Atkinson and Atkinson 2002). *S. canadensis* is found from eastern Canada (45°N) to subtropical areas of the North American Gulf Coast, Mexico, and the Caribbean Islands. The plant is tolerant to a range of soil types and exposures, but is typically found in moist, well-drained soils in full sun.

8.2 Origin and Domestication

Bolli (1994) proposes a center of diversity for *Sambucus* in central Asia, with the parent type established perhaps as long ago as the Oligocene. Dispersal of the genus possibly took two routes—west to Europe, North America, South America, and northern Asia; and east to southeast Asia and Australia. A second center of diversity is North America (Eriksson and Donoghue 1997). The genus at present is widely distributed; several species have circumboreal ranges. Natural dispersal was likely assisted by birds and other animals. Humans were also important in dispersal as elderberry is naturalized throughout much of the temperate and subtropical regions where humans live (Ritter and McKee 1964).

Although elderberry was widely utilized in traditional medicine and as a food source in the New and the Old World, records of cultivation are scanty and most fruits were probably harvested from the wild. Commercial production of elderberry began in the late nineteenth century.

8.3 Production and Uses

Commercial production of European elderberry is well established. While actual production figures are difficult to obtain, sizeable plantings are found in Austria, Hungary, Denmark, Poland, Switzerland, and Italy (Charlebois 2007; Kaack Personal communication; Lee and Finn 2007). The 2006 Austrian crop was estimated at 7,400 tons (Statistik Austria 2008). A considerable amount of the European elderberry crop is harvested from the wild (Kaack Personal communication). Commercial production of American elderberry is much less, with sizeable plantings reported only from Oregon (Lee and Finn 2007) and Missouri. While commercial scale plantings are increasing, much of the American elderberry crop is also harvested from the wild. Historically, 2,000–2,500 tons of wild fruits were harvested annually in the 1960s in Pennsylvania, Ohio, and New York (Darrow 1975).

The elderberry, though considered a minor fruit crop, is of increasing interest worldwide (Charlebois et al. 2010). The ripe fruit is processed into jelly, juice, and juice blends, wines and other alcoholic beverages, a heat stable colorant, and flavoring for a wide range of products. The blossoms are eaten fresh in various preparations, dried for teas, and used to flavor wines and other products such as enhanced waters and candies. Considerable interest worldwide is focused on elderberry as a nutraceutical (Charlebois 2007). A wide range of health benefits are claimed for elderberry as the ripe fruits are rich in anthocyanins and other substances with antioxidant properties (Lee and Finn 2007). The blossoms and other plant parts also have appreciable amounts of antioxidants (Thomas et al. 2008).

While superior wild plants of both species were likely propagated and cultivated from ancient times, organized efforts to improve the elderberry are recent (Way 1957, 1981). Many of these early wild selections are still currently grown, including the American elderberry cultivars 'Adams 1' and 'Adams 2' and several European elderberry cultivars (Kaack Personal communication). Efforts to select superior wild plants continue at present (Byers and Thomas 2005). Organized breeding efforts included programs at the New York Agricultural Experiment Station; the Kentville, Nova Scotia experiment Station; the Research Center for Horticulture in Arslev, Denmark; and several private breeding efforts.

8.4 Breeding Potential

As might be expected with a genus of worldwide distribution, a considerable amount of variability is present within and among *Sambucus* species. Two basic chromosome karyotypes are recognized in *Sambucus*, $2n=38$ (*Sambucus cerulea* (including synonyms *S. glauca* Nutt. and *S. mexicana* Auct.), *S. racemosa* L., *S. racemosa* f. *stenophylla* (Nakai) H. Hara (syn. *S. sieboldiana* var. *miqueli* [Nakai] H. Hara), *S. racemosa* subsp. *kamtschatica* (E. L. Wolf) Hultén (syn. *S. kamschatca* E.L. Wolf), *S. racemosa* subsp. *sibirica* (syn. *S. siberica* Nakai), *S. racemosa* subsp. *sieboldiana* (Miq.) H. Hara (syn. *S. sieboldiana* [Miq.] Blume ex Graebn), *S. racemosa* var. *arborescens* (Torr. & A. Gray) A. Gray (syn. *S. callicarpa* Greene), and *S. racemosa* var. *melanocarpa* (A. Gray) McMinn) and $2n=36$ (*Sambucus canadensis* var. *laciniata* A. Gray (syn. *Sambucus simpsonii* Rehder, *S. williamsii* Hance), *S. canadensis, S. nigra, and S. ebulis L.*) (Ourecky 1970). Interestingly, *S. racemosa* is reported to have three karyotypes, $2n=36$, 38, and 42 (Chia 1975). The following interspecific hybridizations among *Sambucus* species are reported: *S. canadensis* × *S. cerulea* (Slate 1955), *S. canadensis* × *S. pubens* Michx. (*S. racemosa* subsp. *pubens* (Michx.) House) (Eaton et al. 1959), *S. nigra* × *S. racemosa* (Koncalova et al. 1983), *S. nigra* × *S. ebulis* (Koncalova et al. 1983), *S. canadensis* × *S. nigra* (Chia 1975), and *S. cerulea* × *S. nigra* (Chia 1975).

In a discussion of *S. canadensis* and *S. nigra*, Lee and Finn (2007) note that variability in several traits of interest is present and should allow for selection of superior progeny through traditional breeding. From personal observation, considerable variability is present in wild populations of these species, and selection can often be made for traits of interest among wild plants. *Sambucus canadensis*, for example, is a likely source for large individual fruit clusters and profuse annual suckering from the root system as well as a potential source for acylated anthocyanins (Lee and Finn 2007). Other species may also offer traits of interest to plant breeders, including *S. cerulea* for its large and attractive berries with a heavy layer of surface bloom and *S. pubens* for its early ripening (Eaton et al. 1959).

Over 100 years have passed since the description of one of the first American elderberry cultivars, ‘Brainerd’ in 1890 (Bailey 1906). Ritter and McKee (1964) describe the development of improved elderberry cultivars. Most early cultivars were selected from the wild, such as the cultivars ‘Adams 1’ and ‘Adams 2’ selected by William W. Adams in New York in 1926 and released by the New York Agricultural Experiment Station. ‘Ezyoff,’ of unknown parentage, was introduced by Samuel H. Graham of Ithaca, New York, in 1938. More recent breeding efforts at the Agriculture and Agri-Foods Canada (Kentville, Nova Scotia) experiment station have resulted in ‘Nova,’ ‘Scotia,’ ‘Kent,’ and ‘Victoria,’ all released in 1960, as well as the release of an older selection, ‘Johns,’ in 1954. The more recent Nova Scotia releases are all seedlings of either ‘Adams 1’ or ‘Adams 2.’ ‘York’ (1964), is a cross of ‘Ezyoff’ and ‘Adams 2’ and was developed by the New York Agricultural Experiment Station. The University of Missouri/Missouri State University development program has recently released two cultivars, ‘Bob Gordon’ and ‘Wyldewood,’ both wild selections (Byers et al. 2010, Byers and Thomas 2011). Although the origins of many European elderberry cultivars are unclear, many undoubtedly are selections from the wild, such as ‘Korsor’ (Denmark), ‘Allesø’ (Denmark), and ‘Mammoth’ (Germany). ‘Haschberg’ was developed in an Austrian breeding program. Recent breeding efforts at the Research Center for Horticulture in Arslev, Denmark, have produced a series of cultivars particularly suited for juice production, including ‘Samyl,’ ‘Samidan,’ ‘Sampo,’ and ‘Samdal’ (Kaack 1989). Little improvement is reported for *S. cerulea*; Luther Burbank released the cultivar ‘Superb’ in 1921.

Breeding objectives for elderberry include large berry size, firmer berry texture, large berry cluster size, small seeds, self fruitfulness, increased productivity (number and size of cymes and berry size), vigorous and strong canes, uniformity of ripening within and among clusters, attractive color (glossy, dark), better fruit and juice quality, increased nutraceutical content, resistance to shattering, resistance to diseases, immunity or tolerance to virus diseases, wider adaptation, and pendulous fruit clusters less prone to bird damage (Darrow 1975; Kaack et al. 2008; Lee and Finn 2007). The Danish breeding program is seeking plants that are low growing with strong upright shoots from the root or lower part of the bush, characteristics that improve harvest efficiency (Kaack 1989). The University of Missouri/Missouri State University development program, in addition to the characteristics mentioned above, is seeking plants with tolerance to leaf diseases and a species of eriophyoid mite that causes a significant economic impact.

9 Gojiberry or Wolfberry

9.1 Botany

The genus *Lycium* L., family *Solanaceae*, was named in 1753, by Carl Linnaeus. He likely chose this name from the ancient southern Anatolian region of Lycia, or from the Latin, lychnus, meaning ‘light’ or ‘lamp,’ possibly due to the fruit shape and color. His species *L. barbarum* L., Latin for ‘foreign’ or ‘from the outside,’ may refer to the ancient country of Barbary, formerly part of northern Africa (Gross et al. 2006). Stuartevant’s list of edible plants of the world included *L. europaeum* L. a native of Asian minor (Hedrick 1919) that escaped through Europe.

The genus includes more than 100 species of deciduous or evergreen woody shrubs, native to tropical or warm temperature parts of mainland East and Southeast Asia, Asia Minor, Europe, South Africa, and North America (Hitchcock 1932; Bailey L. H. Hortorium 1976).

Common names for *Lycium* include box thorn, matrimony vine, bocksdorn, Duke of Argyll’s tea tree, gojiberry, and wolfberry. Several species of *Lycium* are now being sold as gojiberry or wolfberry. The names Tibetan goji and Himalayan goji are names applied by the health food promoters for a nomenclatural marketing advantage, though commercial cultivation of the crop does not occur in those regions.

The plant is an erect or clambering, woody perennial shrub. Some species have spines, others do not. The plant, left unattended, can grow to 6 m. Leaves are alternate, often clustered, small, commonly narrow, entire, and are usually grayish-green without stipules. Flowers (Fig. 4.10) are perfect and solitary or clustered in leaf axils. Corolla is funnel form and different species are greenish, whitish, or purplish. Fruits ripen orange to scarlet (Fig. 4.10), sometimes yellow or black, e.g., *L. ruthenicum* Murr.

Some species are considered noxious weeds because of their tendency to sucker (Bailey L. H. Hortorium 1976; GRIN 2009) and because of their potential spread by birds. Like other genera in the Solanaceae, the vegetative plant parts are poisonous (FDA 2009), though the berries are edible.

9.2 Cultivation

Gojiberry plants prefer full sun but can tolerate some shade. Soils in Ningxia are alkaline (pH 7–8), but plants do well in a wide pH range. Soils can be heavy clay loams, but a higher sand ratio in the loam is best. *Lycium* does not grow well in wet soil. Much of the acreage in the Yinchuan is on flat areas in the Yellow River Valley, and plantings are successful on the surrounding hills. Ningxia has a continental climate with severe winters, but damage from winter cold or spring freezes seldom occurs. The plants are hardy to −23°C (−10°F) (Gross et al. 2006). The optimum

Fig. 4.10 *Lycium barbarum* L. flower and fruit. Photo credits: Kim Hummer USDA ARS

fruit quality (chemical content) occurs under hot dry summer conditions, while cooler or cloudy weather diminishes fruit quality. Ripe fruit also tends to crack in rain at maturity.

9.3 Origin and Domestication

Lycium barbarum L. is native to eight autonomous regions and provinces of China (GRIN 2009) (Table 4.1). The largest gojiberry producing area is Ningxia Hui, a small autonomous region on the northwestern loess-soil highlands of China, which used to be part of Gansu Province. The Chinese characters 寧夏枸杞, 'Ningxia wolfberry,' refer to the plant of *L. barbarum*.

A closely related species, Chinese wolfberry, *Lycium chinense* P. Mill., native to Mongolia, China, Japan, Korea, Taiwan, and Thailand is also cultivated (GRIN 2009) (Table 4.1). While *L. barbarum* tends to have more large-sized fruit per plant than does *L. chinese*, both species are labeled and sold as gojiberry or wolfberry. The name 'goji' probably was derived from the Chinese, 枸杞, gǒuqǐ, with the character for 'gǒu' being related to a character for dog or wolf (Dharmananda 2007).

9.4 Production and Uses

An early description of the use of *Lycium* is in, the *Shennong Bencao Jing*, the Divine Farmer's Materia Medica Classic, one of the ten premodern classics of

Table 4.1 Selected *Lycium* species, common name: gojiberry or wolfberry[a]

Species	Native range	Comments
L. barbarum L. (Syn. = *L. halmifolium* P. Mill)	Gansu, Hebei, Nei Monggol, Ningxia, Qinghai, Shanxi, Sichuan, and Xinjiang, China	Erect plant with spreading branches, reaches 6 m without size control; fruit orange to red
L. chinense P. Mill	China—Anhui, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Nei Monggol, Ningxia, Qinghai, Shaanxi, Shanxi, Sichuan, Xinjiang, Yunnan, and Zhejiang Japan—Hokkaido, Honshu, Kyushu, Ryukyu Islands, and Shikoku Mongolia, Korea, Taiwan, Thailand	Prostrate rambler, can grow on itself to 2 m (WPSM p. 694–696); fruit orange to red
L. ruthenicum Murr.	Afghanistan; Iran; Iraq; Turkey; Armenia; Azerbaijan; Kazakhstan; Kyrgyzstan; Tajikistan; Turkmenistan; Uzbekistan; Mongolia; China—Gansu, Nei Monggol, Ningxia, Qinghai, Shaanxi, Xinjiang, Xizang; Pakistan; Russian Federation (European part)	Black-fruited species. The small, sweet, and flavorless berry is eaten in India. Common name: Russian box thorn

[a]Taxonomic and distribution information adapted from (GRIN 2009)

Chinese herbal medicine (Gross et al. 2006). Traditional use of gojiberry in tonics was limited until the end of the Ming Dynasty when production was encouraged (1368–1644) (Dharmananda 2007). Gojiberry species are widely scattered throughout China, and wild plants in fence rows and nonfarmed areas have been picked for family use or sold for about 800 years.

Gojiberry cultivation in Ningxia was promoted beginning in 1987 by government-backed company projects. Since 2005, the production and sales of these products have skyrocketed, because nutritionists have described the berry as an 'exotic superfood' for the polysaccharide, vitamin, and carotenoid content (Dharmananda 2007). Now gojiberries are processed for juice and juice combination drinks, dried in tea, and as nutraceutical supplements. Dried fruits can be eaten directly and used in confectionary goods or in bakery products (Fig. 4.11).

Most of the gojiberries of world commerce are produced in Ningxia Hui Autonomous Region, China. Their products include juice and juice concentrate, dried fruit, goji seed oil, and powdered goji (Dharmananda 2007). Juice types are formulated for marketing in different countries. The Chinese producers expect that the demand for juices will grow most rapidly in the next several years (E. Hanson Personal communication). The berries are sold as dried fruit (Fig. 4.11) to be used in bakery and confectionary products, and the seed oil and powdered gojiberry are prepared for nutritional supplements.

Fig. 4.11 Some gojiberries (*Lycium barbarum* L.) products available for purchase in the USA. *Upper left proceeding clockwise*: natural carbonated juice, packaged tea, dried fruit combination, chocolate covered dried gojiberries, goji cookie bar, dried gojiberries. Photo credits: Kim Hummer, USDA ARS

Commercial plantings have increased recently due to the availability of improved cultivars and the increased demand for health products. The new plantings are composed of clonally propagated improved genotypes, not seedlings.

In 2004, the China Daily (2004) reported that 86 MT (95 tons) of gojiberry were produced worth US$120 million. In 2008, Ningxia Hui grew gojiberries on 72,843 ha (180,000 acres) while about 101,171 ha (250,000 acres) total were grown in China. The maximum yield is about 7,845 kg/ha (7,000 lb/acre) from elite genotypes, while the yield from seedlings is lower (E. Hanson Personal communication). These figures would indicate almost a 10-fold increase for 2008 over the China Daily's report for the 2004 crop.

Individual growers manage between 0.08 and 0.8 ha (0.2–2 acres). They sell their fruit to brokers, who then sell to processors or distributors. Growers can also sell at specialty markets. In 2008, grower prices were about $1.00/kg ($0.45/lb) fresh or $6.61/kg ($3.00/lb) of dried fruit (E. Hanson Personal communication).

One Chinese processor exports to ten countries and their top three customers are in the USA. In 2007, sales for this exporter were $4 million. Between 80 and 90% of their product is from Ninxia Province (E. Hanson Personal communication).

In Ningxia, the plants are grown with 1.5 m between rows and about 1 m between plants. Full production is reached by year 3 or 4. Row middles are cultivated to control suckers. The plants are pruned by removing nonfruitful shoots in

May and June. Dormant pruning is not practiced in China (E. Hanson Personal communication).

Plants can be propagated by softwood cuttings in June or with semi-hardwood cuttings in July to August. These 5–10 cm long cuttings are taken with a heel, i.e., with a piece of the previous year wood, and placed into individual pots in a frame (Sheat 1957). Alternatively, cuttings of mature wood of the current season's growth can be collected in autumn to late winter and placed in a cold frame for rooting. Thirdly suckers can be divided from mother plants in late winter. This technique is very easy because the suckers can be planted out directly into their permanent positions.

In China, plant nutritional requirements are met with manure applied in the spring. Too much fertility results in excess vegetation, shading, and reduced fruit quality. Foliar nutrient sprays are also routinely applied. Plantings are irrigated by surface flooding. Soils are allowed to dry considerably between irrigations. Excess irrigation reduces fruit quality. Growers generally treat plantings with fungicides or insecticides 2–3 times per year.

Plants are pruned in several systems. In the first system, the plants are allowed to grow into a large bush. Pruning is performed annually to encourage more fruit and flowers. If left alone, the bushes will overgrow themselves, causing shading. Pruning is done to prevent overlapping growth. The second method is to shape plants into a small tree. Commercial growers use this technique to allow for easy picking. Finally, the plants can also be trellised to promote a vining growth habit. Growing gojiberry in tropical areas where the plants receive no chilling hours is under research (E. Hanson Personal communication).

9.5 Seeds

Seeds can be extracted from fruits by pressing the pulp through a screen and floating out the fruit flesh (Rudolf and Busing 2002). On a larger scale berries may be fermented, mashed, and run through screens. The seeds can be dried and stored at 5°C. Germination of *L. barbarum* can be hastened and improved by stratification in moist sand for 60–120 days at 5°C. After stratification, the seeds can be germinated at diurnally alternating temperatures of 30 to 20°C. The seeds of *L. barbarum* have about 20 seed per fruit and about 573,000 seed per kg. The seeds of *L. chinense* are larger having about 377,000 seed per kg (Rudolf and Busing 2002).

For nursery practice, the seeds can be sown in the fall as soon as the fruits ripen or can be stratified in the spring and then covered with soil. Two-year-old seedlings are transplanted (Rudolf and Busing 2002).

Most gojiberry genotypes appear to be self-fruitful; cross-pollination is not required for commercial production. Plants are harvested from late June until October, on 5–7 day intervals (E. Hanson Personal communication). Given that the annual yield is 7,845 kg/ha (7,000 lb/acre) and plantings are picked 16 times, less than 560 kg/ha (500 lb/acre) is harvested in each picking.

Mechanical harvesting is not performed, although investigations in China are beginning to address this need since labor is a limitation where large plantings have been established in remote areas. The mechanization will not be simple to develop. A combination of breeding and cultural approaches is needed. One primary issue is the reduction of the fruit ripening period. Shoots of the present genotypes grow continuously and may simultaneously contain flowers, green fruit, and ripe fruit. Machinery that damages shoots will reduce later harvests. The ripe fruit do not readily dehisce when a branch is mechanically shaken unlike blueberries or cherries.

Many traditional medicinal uses of gojiberry have been described in Chinese folk medicine. The berries have been used in tonics to lower cholesterol or blood pressure, to treat kidney disease, to improve vision and eye disease, and to increase longevity. Some Chinese tonic soups combine gojiberries with chicken or pork, vegetables, and other herbs such as wild yam and licorice root. The berries are boiled to make an herbal tea (Facciola 1990), often along with chrysanthemum (*Chrysanthemum* L.) flowers and/or red jujubes (*Zyziphyus jujube* Mill.).

Fresh fruits may be squeezed for juice which is then concentrated for beverages. About 2 kg fruit is needed to produce 1 kg juice. A combination of grape and gojiberry fruit is used to produce wine. At least one Chinese company produces gojiberry beer or ale. Since the early twenty-first century, an instant coffee product containing gojiberry extract has been produced in China.

Alternatively, the fruits are dried to about 15% of the fresh weight. The fruits can be dried with or without sulfur. The fruits are dried in the sun for 7 days, or in driers. Driers are quicker and produce a better quality product. Dried gojiberries are eaten as a snack. Their taste has an accent of tomato and seems similar in flavor to that of dates, dried cranberries, or raisins, though drier, more pungent, less sweet, and with an herbal scent. Some people describe the fruit as having a sweet, licorice-like flavor. The fruits can be added to soups and braised dishes or used to prepare a liqueur (Facciola 1990).

Young goji shoots and leaves are also grown commercially in China as a leaf vegetable; however, FDA, lists the leaves and stems of some *Lycium* species as poisonous to humans and livestock (FDA 2009).

Gojiberry plants are used for land conservation plantings. The plants have an extensive root system and can stabilize sandy river banks. In Europe and Asia, these plants are grown as informal hedges (Hedrick 1919; Rehder 1940) succeeding in desert, subtropical, and maritime exposures.

Lycium fruit is known for its carbohydrate and carotenoid content (Gross et al. 2006). The carotene pigments of *Lycium* fruit include beta-carotene, zeaxanthin, lutein, lycopene, cryptozanthin, and xanthophyll (Gross et al. 2006; Dharmananda 2007). The fruit also contains protein, fiber, minerals (calcium, phosphorus, potassium, iron, zinc, and selenium), and vitamins (C, riboflavin, nicotinic acid, and thiamine) (Gross et al. 2006).

Some fruit marketers promote sugars from goji as having supermedicinal or healthful qualities, but cure-all and extreme longevity claims are undocumented and are under scrutiny from governments in Europe, Canada, and the USA.

9.6 Breeding Potential

The Ningxia Research Center of Wolfberry Engineering Technology in Yinchuan, Ningxia Hui Autonomous Region, China, has a goji breeding program. The Center is the only Chinese national institute devoted to goji (E. Hanson Personal communication).

The objectives of the research institute are

1. Breeding goji to increase yields, fruit size and to improve the quality.
2. Improve the planting technology and culture to increase yield.
3. Improve the postharvest /processing of the fruit.

The Center has 21 full-time staff, several buildings, a goji museum, and several thousand acres of farm land for collections. The land or 'base' is a nationalized farm. It is mostly planted to goji for fruit production, but some wine grape (*Vitis vinifera* L) vineyards are also planted. Proceeds from fruit sales help support the Center functions.

Scientists are performing chemical analyses of the goji fruit in Yinchuan including the measurement of antioxidant activity. The Chinese consider *L. barbarum* to have the highest quality fruit for health, and that Ningxia provides the best climate for optimal health promoting compounds of the fruit.

Lycium species hybridize readily. The Center has developed four cultivars, which contain material from 1 to 3 different species:

1. Ninxia #1. This type comprises 80% of the acreage in Ningxia Province and is grown in other regions as well. It is believed to have the highest antioxidant content. This cultivar is marketed as 'Crimson Star™' in the USA.
2. Ninxia #2. No information given.
3. Ninxia #3. This cultivar is being propagated for distribution now. It is a large-fruited type that is well suited for drying. They hope this fruit will be shipped throughout China.
4. Ninxia #4. This is a unique cultivar developed for production of edible shoots. The tips of the young succulent shoots are cut and eaten steamed or in dishes. The shoots also have high antioxidant content. The taste seems similar to that of steamed spinach.

Gojiberry, like many better known small fruit and berry shrubs and trees, produce nutritious, tasty fruits. The plant has potential for cultivation in environments equivalent to its native environment in China.

Small fruit producers in the northern tier of states and Canada may wish to diversify their present plantings and grow some acres of this crop. Growers should be cautious to guard against escapes of this plant because it has the potential to become a noxious weed. Cultivars should be planted in preference to seedlings and are now available in some American plant nurseries. Additional research needs to be done to improve mechanical harvesting technology and develop cultivars for mechanical harvesting. This would be necessary for any potential North American crop to be competitive with present Chinese production.

10 ‘Ōhelo Berry

10.1 Botany

The ‘ōhelo and closely related species are members of section *Myrtillus* of the genus *Vaccinium* L., family Ericaceae. The genus comprises not only the economically important crops such as the blueberry, cranberry, and lingonberry but also more than 400 berry-producing species distributed the South Pacific, Southeast Asia, and around the world (Vander Kloet 1993).

On Hawai’i, native *Vaccinium* species were called ‘ōhelo’ or ‘ōhelo ‘ai’ by the indigenous people (Table 4.2). The true ‘ōhelo refers to a low growing plant species, *V. reticulatum*, which is distributed in open forests at medium to high elevation on Hawa’i and Maui (Degener 1984). This species is rhizomatous and rarely grows taller than 0.6 m although some plants may reach 1.0 m. A second low-growing shrub, *V. dentatum* Smith, is less common but is also endemic. A high-bush species, ‘ōhelo kau la’au, *V. calycinium* Smith, which can attain a height of 5.0 m (Wagner et al. 2005), and an intermediate form *V.* ×*pahalae* Skottsberg, are also present (Degener 1984).

Vaccinium reticulatum (Fig. 4.12a, b) thrives on the less weathered lava flows and beds of volcanic ash and cinders (Degener 1984). ‘Ōhelo, a member of the pioneer plant community, is most common on disturbed sites at elevations from 600 to 3,700 m. It is frequently found on Maui and the Island of Hawai’i but only occasionally found on Kaua’i, O’ahu, and Moloka’i (Wagner et al. 1990; Herring 2008).

The ‘ōhelo is common on Kilauea, Hawa’i, on high slopes of Haleakala, Maui, and near the Koolau Gap, Maui. The plant has coriaceous, orbicular, green leaves that overlap when viewed from the stem apex. The leaf attachment and branching structure provide a noteworthy texture to the plant from an ornamental landscape perspective. In optimal Hawai’ian conditions, the plant can have simultaneous flowering and fruiting. Peak flowering season is from April to September and, because the berries take 50–60 days to ripen, mature berries are available from June through November. One plant can produce two crops of fruit in 1 year (Vander Kloet 1993). The flowers, one per pedicel, are epigynous, brilliant red, narrow convolvulate, and cluster near branch apices. Wagner et al. (1990) describes the fruits as being red, reddish purple, bluish purple, dull black, yellow, orange yellow, yellowish green, or pink (Fig. 4.12a, b). The skins of lighter colored berries can have red speckles.

Table 4.2 Distribution of ‘ōhelo species in Hawaii

Vaccinium species	Distribution
V. calycinum Small	Kaua’i, O’ahu, Moloka’i, Lana’i, Maui, Hawai’i
V. dentatum Small	Kaua’i, O’ahu, Moloka’i, Lana’i, Maui, Hawai’i
V. reticulatum Small	Kaua’i, O’ahu, Moloka’i, Maui, Hawai’i
V. ×*pahalae* Skottsberg	O’ahu, Hawai’i

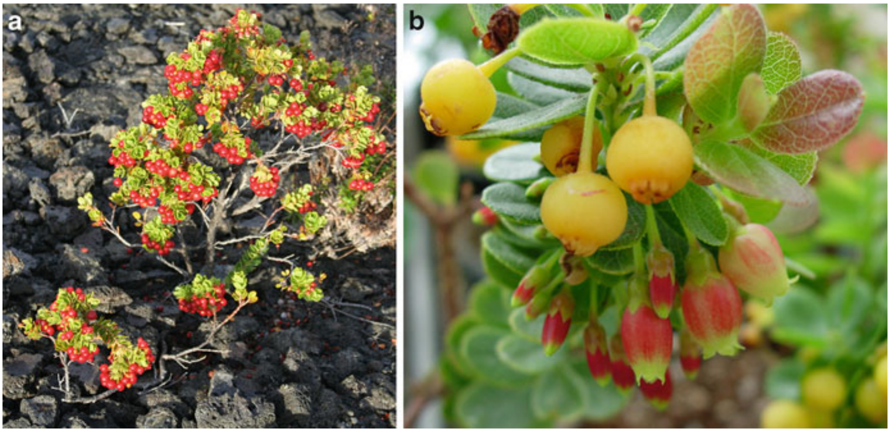

Fig. 4.12 (**a**, **b**) ‘Ōhelo (*Vaccinium reticulatum* Sm.) (**a**) with red fruit growing out of lava rock on the Big Island, Hawaii (**b**) yellow fruited form. Photo credits: Kim Hummer, USDA ARS

The berries range from 0.6 to almost 1.2 cm (1/4 to almost 1/2 in.) in diameter and contain numerous (70 to over 100) small, brown seeds. The flowers of *V. reticulatum* are self fertile. However, self pollination results in fewer seeds per berry than does cross-pollination (Herring 2008).

Typical fruits are globose, with a flattened top and bottom. The fruit can be covered with a waxy bloom. The ‘ōhelo berry is one of the few endemic, edible fruits in Hawai’i, and is an important food for the native and endangered nēnē goose (*Branta hylobadistes* Storrs L. Olson & Helen F. James).

Vaccinium dentatum is a decumbent, sprawling or weakly rhizomatous shrub. Its leaves are elliptic to narrowly elliptic, in contrast with the ovate to obovate leaves of *V. reticulatum*. The leaves are persistent have serrate margins and are usually glabrous at maturity. The berries are bright to scarlet red, 8–10 mm in diameter, round, and slightly smaller in diameter than those of *V. reticulatum*.

The plant form of *V. calycinum* is an understory shrub, somewhat reminiscent in of the flame azalea [*Rhododendron calendulaceum* (Michx.) Torr.] of North Carolina, with a notable difference that the fruits are red berries rather than dry capsules. The high-bush ‘ōhelo is distinguished from the low-growing ‘ōhelo by its height and leaf morphology. It grows in the open rain forest east of Kilauea and below the Koolau Gap of Haleakala Crater on Maui (Degener 1984). The leaves are deciduous, relatively thin, and lanceolate with serrate margins. The flowers are greenish, and the fruits are red, globose and can be bitter. The fruits are borne singly and occur basal to the flush of newest growth (Wagner et al. 2005).

Vaccinium × *pahalae* is native to the Sulphur Bank near the Tree Fern Forest near Kilauea (Degener 1984). The plants of this species are slender but have hard, leathery, recurved leaves with serrated margins. The berries are elongated. Further study using molecular markers is needed to determine the relationship of the ‘ōhelo species and to the others in section *Myrtillus*.

10.2 Origin and Domestication

ʻŌhelo (*V. reticulatum* Smith) is a small, native Hawai'ian shrub (Fig. 4.12a, b) commonly found in disturbed, open sites at 640–3,700 m elevation on several islands in the Hawai'ian archipelago. The plant has been significant to native Hawai'ian legends and lore. Local people collect berries of this plant for individual uses. Concerns of the impact of this wild collection on delicate environments might be reduced if ʻōhelo was cultivated and marketed to meet the demand for the fruit.

Some Hawai'ian myths (Beckwith 1940) describe gods who have lived on earth and take the form of a plant at their death. From the body of Kaohelo, sister of Pélé, the Hawai'ian volcano goddess, grew the ʻōhelo bushes which are abundant on Hawai'ian volcanic mountainsides: "the flesh became the creeping vine (*V. reticulatum*) and the bones became the bush plant (*V. calycinum*)."

The ʻōhelo plant was especially sacred to the worshipers of Pélé. Old Hawai'ian law, or kapu, required that upon arriving near the Kilauea crater, a branch bearing ʻōhelo berries, be broken and half of the branch was thrown toward the center of the active volcano while the visitor said, "Pélé here are thy ʻōhelo. I offer some to thee; some I also eat." Only after performing this ritual could the berries be eaten freely without incurring Pélé's wrath. The kapu were officially abolished after 1818, though many people continued the old customs.

In December, 1824, Princess Kapiolani, a devout Christian, set out to break the ʻōhelo kapu. She and her followers walked more than 100 miles over rugged lava flows. Though she was entreated not to, Kapiolani descended to a ledge near the Kilauea volcano and ate ʻōhelo berries without first making the required offering. She defied the old Hawai'ian way and demonstrated to her people the foundation of her new faith. She read passages from the bible and sang a hymn. This was a courageous act considering the reverence and fear with which her contemporaries regarded Pélé. This event was immortalized by the British poet, Alfred, Lord Tennyson (1892) in a poem entitled 'Kapiolani.'

Another association of ʻōhelo is stated in proverb 2044 (Pukui 1983).

"Mai hahaki ʻoe I ka ʻohelo o punia I ka ua noe." [Do not pluck the ʻōhelo berries lest we be surrounded by rain and fog.] This is a warning not to do bad things.

10.3 Production and Use

Because of the old Hawaiian traditions and laws, little domestication and even less breeding of ʻōhelo has occurred until the past several years. This plant has the potential for agricultural development and several research and improvement projects have been initiated (Zee et al. 2008). Potential uses include

- Ornamental outdoor landscape plant for cooler climates (best 10–20°C)
- Colorful red and green potted plant for the holiday season
- Berry for fresh eating

- Processed berries for jams, jellies, and the baking industry
- Processed berries for the candy industry
- Dried fruits
- Value added products into chocolates, sauces, or liquors
- Infusion of the leaves for tea
- Extracts or concentrates for the health industry

Chefs and confectionery trades in Hawaii would appreciate a broader availability of this specialty berry for their products, but production has not been sustainable or reliable thus far. The development of this crop could provide an alternative to sugar cane production, which has greatly reduced acreage, for local Hawaiian agriculture.

The plant can be propagated sexually by seed or asexually via cuttings or tissue culture (Zee et al. 2008). The seeds (100 seeds weigh about 0.1 g) are small (Zee et al. 2008). Open pollinated seeds can be harvested from healthy ‘ōhelo plants. Berries are placed in a blender with 3–4 cups of water and blended at medium speed. The viable seed sink to the bottom and the nonviable seed can be decanted off. The cleaned seeds are air-dried on paper towels for 2 days at ambient temperature. ‘Ōhelo seeds are very small, 100 seeds weigh about 0.1 g. Fresh seeds have a high germination rate. Seeds stored at 4°C lose viability after a year (Zee et al. 2008).

Seeds can be germinated in a 1:1:1 mixture of peat, vermiculite and perlite in a greenhouse at 60–80% shade. Seedlings germinate about 40–45 days after sowing. Seedlings younger than 3 months were sensitive to over watering and drying. After 4 months, the seedlings should be transplanted to a 1:1:2 media mixture after 4 months. After establishment, the ‘ōhelo seedlings were very hardy to drought.

Four-month-old ‘ōhelo seedlings can be transplanted to 5-cm pots containing 1:1:2 peat, vermiculite, and perlite, side-dressed with 14–14–14 slow-release fertilizer. Foliar fertilizer every 2 weeks also improves seedling health. Seedlings can be tipped pruned at transplanting to encourage multiple branching with the goal to form a compact crown of reddish new growth for market. At 10 months old, the seedlings can be transplanted into 4 liter containers containing the 1:1:2 medium for foliage plant production. Six to ten month old plants can be field planted for fruit production.

Stem cuttings should be harvested from healthy, upright woody branches (Zee et al. 2008). The cutting should consist of a 2-in.-long internode below a whorl of intact leaves. Rooting is stimulated by dipping the basal end of the cutting into a low concentration of a powdered auxin formulation. The stem is then stuck into a 2×2-cm moistened rooting cube. The cuttings should be kept under 60% shade and protected from drying, wind, and heat. Overhead mist or a humidity tent is required. Most of the cuttings should root within 3 months.

Tissue culture procedures have been described (Zee et al. 2008). Explants are placed in sterile solutions and placed on a base medium modified from Lloyd and McCown (1980). Initiation medium containing zeatin (Reed and Abdelnour-Esquivel 1991) and growth/multiplication and rooting media follow. A maintenance medium can be used for medium-term (5-year) storage of the plantlets under refrigerated conditions.

Several disease symptoms have been observed on cultivated highbush blueberries, *V. corymbosum*, growing at the Mealiani Agricultural Research Station in Waimea, Hawai'i (Hummer and Zee 2007; Keith et al. 2008). The main disease pressure that may limit 'ōhelo berry production and ornamental qualities in Hawaii was determined to be powdery mildew (Keith Personal communication). Diseases of *Vaccinium* include *Lasiodiplodia* (an anamorph of *Botryosphaeria*) causing wilting and reddening of the leaves; *Botrytis*, brown lesions and tip dieback; *Phytophthora*, reddening of leaves, discoloration of roots and stems, *Pestalotiopsis*, leafspot; *Fusarium* wilt disease; and foliar rust caused by *Pucciniastrum vaccinii* (Bristow and Stretch 1995).

The Mediterranean fruit fly (*Ceratitis capitata* Wiedemann), oriental fruit fly (*Bactrocera* dorsalis Hendel), melon fly (*B. cucurbitae* Coquillett) and Malaysian fruit fly (*B. latifrons* Hendel) are major pests of fruits and vegetables in Hawai'i. Control measures for these flies should be implemented during the cultivation of *Vaccinium* for fruit (Hummer and Zee 2007). 'Ōhelo berry is a marginal host for *B. dorsalis* and apparently a nonhost for *C. capitata*, *B. cucurbitae*, and *B. latifrons* (Follett and Zee 2011).

While the native 'ōhelo berries are a staple for native and endangered nēnē goose, cultivated berries could be a favorite food of large birds on the islands. The most effective way to exclude birds is to enclose the plants under bird or smaller screened netting on a metal pipe frame.

10.4 Potential Breeding

'Ōhelo species are neither endangered nor threatened (Wagner et al. 2005). The US Department of Agriculture, Agricultural Research Service, National Clonal Germplasm Repository in Corvallis Oregon holds the national *Vaccinium* genebank for the USA. Limited samples of wild and cultivated *V. reticulatum* and wild *V. calycinum* are preserved at this genebank. Additional representatives of *V. dentatum* and *V.* ×*pahalae* are sought. Species are represented by seedlots and selected genotypes are maintained clonally. Selections from wild material have been named. Initial breeding for this crop in Hawaii has shown that from several hundred seedlings from seeds extracted from wild-collected fruits, a few seedlings had an impressive yield per plant while others had high quality in ornamental characteristics (Zee et al. 2008).

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