Origin and Dissemination of Almond

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I. INTRODUCTION

The almond differs from the other Prunus crops both botanically and horticulturally, and the combinations of these differences have had widespread consequences on its role in human history and the role of humans in its dissemination. Botanically, the consumed part is a nut rather than a fruit, representing a durable propagation source for
expanding plantings as well as a concentrated, desirable, and relatively nonperishable food item, which made it a readily fungible commodity even in ancient times. The wild almonds traded and consumed by early human communities were represented by over 30 species of diverse quality, morphology, and geographic origin. Early dissemination of this genetically diverse commodity followed the trade routes of emerging civilizations from Central Asia westward to the Mediterranean. Almond’s widespread desirability and easy transportability appear to have made it an important commodity in prehistoric trade in Asia, North Africa, and Europe, apparently leading to the establishment of an evolving market standard as well as a new species: the cultivated sweet almond, or “Greek nut,” [*Prunus dulcis* (Mill.) D. A. Webb L, syn. *Prunus amygdalus* Batsch., *Amygdalus communis* L., *Amygdalus dulcis* Mill.] possibly selected by prehistoric societies from an interspecific hybridization. The subsequent, rapid reverse dissemination of these Greek nuts from the early Greek and Persian civilizations eastward into centers of almond’s origin and beyond, including India and China, is an indication of the extent of global commerce at this time. Also disseminated was a rich folklore and associated culinary practices based on almond’s unique horticultural characteristics of very early flowering and associated traits, allowing it to thrive under harsh arid environments yet produce a sweet and symmetrical amygdaloidal-shape kernel. The widespread adoption of the commercially more desirable Greek nut would displace previously utilized almond species, inevitably resulting in a loss of germplasm and trait diversity. The current globalization of trade is promoting even greater uniformity in commerce, leading to further reductions in genetic, ecological, and culinary diversity.

II. CLASSIFICATION

A. Botanical

As with other *Prunus* crops, almond fruit is classed botanically as a drupe with a pubescent exocarp (skin), a fleshy but thin mesocarp (hull) and a distinct hardened endocarp (shell) (Fig. 2.1). In almond, however, the mesocarp undergoes only limited enlargement during development, becoming dry and leathery and dehiscing at maturity. The mature endocarp ranges from hard to soft and papery. The tree, while relatively slow growing, can survive for 100 years or more, reaching heights exceeding 20 m. Almond’s outlier status within the *Prunus*, however, has also confounded its botanical classification. Presently, the most
widely accepted scientific name, *Prunus dulcis* (from Latin *dulcis*, for “sweet”), acknowledges its taxonomic affinities with other *Prunus* based on similar morphology, molecular-genetic relatedness, and reported hybridization with peach, apricot, and some plums. Because it was the first to be proposed in the literature, *Prunus dulcis* has superseded the scientific name *Prunus amygdalus* (*amygdalus* is Latin for “almond”) commonly still found in the European literature. In its Central Asian center of origin and diversity, the taxonomic experts most familiar with almond species in their native ecosystems have preferred to classify them in a separate genus, *Amygdalus communis* (Browicz and Zohary 1996), arguing that their evolution of specialized botanical structures and development patterns in these often extreme environments justify a separate genus.

Conversely, the molecular genetic structure and composition of almond is very similar to peach, suggesting that both belong to the same species (Martínez-Gómez et al. 2007). This view is further supported by absence of any formidable barriers to their hybridization and subsequent gene introgression (Gradziel et al. 2001; Martínez-Gómez et al. 2003). Cultivated almond also readily intercrosses with wild almond relatives (Fig. 2.2), which represent a wide range of morphological and

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**Fig. 2.1.** Nut, flower, shoot, and fruit of cultivated almond, *Prunus dulcis*. 
developmental forms as found throughout western and central Asia (Komorov et al. 1941; Browicz and Zohary 1972; Grasselly, 1976a; Grasselly and Crossa-Reynaud 1980; Denisov 1988; Kester et al. 1991; Browicz 1996). Some of the more than 30 species described by botanists may represent subspecies or ecotypes within a broad collection of genotypes adapted to the wide range of ecological niches in the deserts, steppes, and mountains of central Asia. A classification into five sections was proposed by the German botanist Spach (1843) (Grasselly and Crossa-Raynaud 1980; Kester et al. 1991) (Table 2.1). More recently, Browicz (1974) separated almond species into two subgroups: *Amygdalus* (leaves conduplicate in bud and 20 to 30 or more stamens) and *Dodecandra* (leaves convolvulate in bud and fewer than 17 stamens). The most northeasterly group located in western China and Mongolia includes *P. mongolica, P. pedunulata,* and *P. tangutica* (*P. dehiscens*), the latter probably in Section *Chamaeamygdalus*. The remainder occupies a more or less contiguous area in west-entral Asia (Fig. 2.3). Those with the

![Fig. 2.2. Leaf and nut morphology of parent species (top) and hybrids with cultivated almond *P. dulcis* (bottom). Leaf and nut typical of cultivated almond at right.](image-url)
most northern range include species in Section Chamaamygdalus and extend from the Balkan Peninsula to the Altai Mountains. The most southern and xerophytic groups includes species in the Spartiodes Section, which developed leafless, slender shoots, and the Lyciodes (Dodecandra) Section, which are very dwarfed and thorny. A third section (Euamygdalus) resembles cultivated almonds and includes many species extending from central Asia to southern Jordan and parts of Europe.

The cultivated almond as well as most almond species express gametophytic self-incompatibility, although self-compatibility is present in some P. bucharica and P. webbii populations. Gametophytic incompatibility prevents self-fertilization (Socias i Company 1992), favors cross-pollination (Weinbaum et al. 1985), and maintains genetic variability within seedling populations (Socias i Company and Felipe 1992). This

Table 2.1. Botanical relationship of Prunus species in subgenus Amygdalus.

<table>
<thead>
<tr>
<th>Almond Group</th>
<th>Section Euamygdalus Spach</th>
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<tbody>
<tr>
<td></td>
<td><em>Prunus dulcis</em> (Miller) D.A.Webb</td>
</tr>
<tr>
<td></td>
<td><em>P. bucharica</em> Korshinsky</td>
</tr>
<tr>
<td></td>
<td><em>P. communis</em> (L) Archangeli</td>
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<tr>
<td></td>
<td><em>P. fenzliania</em> Fritsch</td>
</tr>
<tr>
<td></td>
<td><em>P. kuramica</em> Korchinsky</td>
</tr>
<tr>
<td></td>
<td><em>P. orientalis</em> (Mill.), syn. <em>P. argentea</em> (Lam)</td>
</tr>
<tr>
<td></td>
<td><em>P. kotschyi</em> [Boissier and Hohenm. (Nab,) and Rehd.]</td>
</tr>
<tr>
<td></td>
<td><em>P. korschinskii</em> Hand-Mazz.</td>
</tr>
<tr>
<td></td>
<td><em>P. webbii</em> (Spach) Vieh.</td>
</tr>
<tr>
<td></td>
<td><em>P. zabulica</em> Serafinov</td>
</tr>
<tr>
<td>Section Spartioides Spach</td>
<td><em>P. scoparia</em> Spach</td>
</tr>
<tr>
<td></td>
<td><em>P. spartioides</em> Spach</td>
</tr>
<tr>
<td></td>
<td><em>P. arabica</em> Olivier</td>
</tr>
<tr>
<td></td>
<td><em>P. glauca</em> Browicz</td>
</tr>
<tr>
<td>Section Lycioides Spach</td>
<td><em>P. spinosissima</em> Franchet</td>
</tr>
<tr>
<td></td>
<td><em>P. turcomanica</em> Lincz.</td>
</tr>
<tr>
<td>Section Chamamygdalus Spach</td>
<td><em>P. nana</em> (Stock)</td>
</tr>
<tr>
<td></td>
<td><em>P. ledebouriana</em> Schle.</td>
</tr>
<tr>
<td></td>
<td><em>P. petunnikowi</em> Lits.</td>
</tr>
<tr>
<td></td>
<td><em>P. tangutica</em> Batal.(syn. <em>P. dehiscens</em>) Koehne</td>
</tr>
<tr>
<td>Peach Group</td>
<td><em>P. persica</em> (L.) Batsch.</td>
</tr>
<tr>
<td></td>
<td><em>P. mira</em> Koehne</td>
</tr>
<tr>
<td></td>
<td><em>P. davidiana</em> (Carriere) Fransch.</td>
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</table>
trait would have contributed to almond’s extensive genetic diversity, which insured wide adaptation and wide distribution of these species in the wild. The chromosome number of Prunus dulcis (P. amygdalus), P. fenzliana, P. nana (P. tenella), P. bucharica, P. kotschyi, P. scoparia, and peach (P. persica) is $2n=16$ (Darlington and Ammal 1945; Grassely 1977), which is the same as many other Prunus.

The taxonomic closeness of almond with peach (Fig. 2.4) led Watkins (1979) to suggest that both originated from the same primitive species but evolved separately following the mountain upheavals of the Central Asian massif approximately 10 million years ago. Thus peach evolved in the East, spread over several regions of China, in a more humid and uniform climate and at lower elevations, whereas almond evolved in the West, in arid steppes, deserts, and mountainous regions, under severe and erratic conditions. The often highly variable nature of these environments may have encouraged almond’s evolution toward self-incompatibility as it would enforce outbreeding and so promote greater genetic diversity to cope with changing environments.
The fruit of different almond species and cultivars vary in size, shape, pubescence, shape and retention of the pistil remnants and suture line, all of which can be useful in identification. The pattern by which “splitting” occurs in the hull also differs and can be described by specific classes. Wood (1925) showed four basic types: (1) ventral split, opening on one side; (2) ventral and dorsal split; (3) four-way split; and (4) dorsal split. The thickness and weight of the mature hull may also differ significantly. Some hulls are thin and dry and constitute only a small
portion of the entire fruit. Others are thick and fleshy and provide a relatively large proportion of the final weight. In California, hulls of cultivated almond are used for livestock feed, and the food value is better with larger hulls (Aguilar et al. 1984).

Shell hardness is the most important characteristic of the endocarp and is associated with the total amount of lignin deposited during nut development. Shelling proportion (dry weight of kernel/weight of in-shell nut) is used to obtain a quantitative measure of shell hardness and is utilized in commercial activities to calculate final yield of kernels from whole nuts. Shelling percentage has an exponential relationship to hardness but is subject to considerable variation due to nongenetic factors. Markings on the outer shell are unique and identify specific species as well as cultivars. Within *Prunus dulcis*, the markings or openings (pores) tend to be mostly circular, though sometimes elongated and sometimes a mixture of both. Among species, pores may be large or small, many or few. Other species have smooth and thin shells (as in *P. bucharica*) or are distinctly grooved (scribed) as in *P. kuramica* (Fig. 2.2). The shell consists of an outer and an inner layer separated by channels through which vascular tissues develop (Fig. 2.1). As the hull dehisces and separates from the nut, the outer layer may remain attached to the hull and separate from the inner shell layer. The latter type is associated with high shelling percentages but often poor seal.

Kernel size is established during the first growth phase of nut development in the spring and is completed by late spring. There is a strong environmental and seasonal component on size, including crop load, vigor of tree, soil moisture, and environment. Crop density has a strong inverse relationship to average size. Kernel mass is determined during the last accumulative phase of almond nut growth and increases continuously until maturity (Labavitch 1978).

Native almond species predominantly have bitter kernels because of high levels of the glucoside amygdalin, which hydrolyzes to benzaldehyde and cyanide when exposed to the enzyme emulsin (Conn 1980; Sánchez-Pérez 2008). Both substrate and enzyme are present in the seed and come together when the cells are injured. This trait has adaptive value in the wild by discouraging seed predation by birds and rodents but would discourage human consumption since the cyanide would first have to be processed out using heating, grinding, or leaching practices similar to those used by hunter-gatherer societies to detoxify certain wild roots and legumes (Alexander-Essers 1994). Plants producing sweet almond kernels have appeared from mutations and subsequent seedling segregation within various almond species, including *Prunus bucharica*, as well as other *Prunus*, such as peach and apricot (*Prunus*...
The early-flowering habit of almond also made it very susceptible to spring frost in more temperate growing regions and limited its plantings to more moderate, almost subtropical climates. In addition, a general susceptibility of the almond foliage to fungal diseases limited tree survival to those regions free from appreciable summer rainfall. Excessive moisture in the root zone is also deleterious (Kester and Grasselly 1987) and can result in tree losses due to “crown rot,” or asphyxia.
Consequently, the range of almond production has been limited to areas with relatively mild winters. Fall freezing is a hazard because almonds tend to respond to warm temperature and accessible moisture even in late fall by growing and delaying the normal acquisition of hardiness. During the winter when trees are fully dormant, cambium and buds reportedly can withstand temperatures of $-2^\circ C$ (Grasselly and Crossa-Renaud 1980). Flower buds may be injured by temperatures of $-15$ to $-20^\circ C$, particularly in late winter after the normal rest period has been fulfilled (Cociu 1985; Ristevski 1992).

III. WILD BADAM

The kernels of a geographically wide range of Asian almond species represented a nutritious, compact, and relatively nonperishable food source that is also appetizing even when eaten in quantity or over a period of time. These qualities combined with its presence throughout the range of early plant domestication by humans ensured that it was among the first tree crops to be domesticated, probably during the third millennium BCE (Spiegel-Roy 1976).

The natural range of the various almond species from northwestern China to the northern Indus Valley in the East, to Mesopotamia and southern Europe in the West (Fig. 2.2), overlapped areas important in the transition of humans from hunter-gatherers to more permanent settlements. These cradles of civilization were also inherently cradles of plant domestication, which undoubtedly involved selection within the numerous wild almonds. The edible kernels of wild almonds and related species were thus important food staples from ancient times. Stone tools used for the apparent cracking of almond shells supports the harvesting of wild almonds in northern Israel by our human ancestors as early as 780,000 years ago (Goren-Inbar et al. 2002; Martinoli and Jacomet 2004; Weiss et al. 2004). Around 11,000 BCE, almonds, pistachios, and lentils were being utilized at Franchthi cave in southern Greece, indicating that the farming of legumes and nuts preceded that of grain in Greece and possibly the rest of Asia Minor (Hansen and Renfrew 1978; Farrand 1999). In addition to wild almond, kernels of wild apricots, plums, and possibly peaches, also present in various western and Central Asian ecosystems, would have been consumed regardless of fruit quality, as they are to this day. The term badam, which when used alone refers to almond in a wide range of Asian languages (Turkish, Persian, Arabic [either badam or loz], Urdu, Hindi, Punjabi, Telugu Kashmiri, Kannada, Marathi, Gujarati, Tamil, and Chinese [either
badam, bwa-dam or xíng rén—the latter also referring to apricot seed]) can also refer to the edible kernels of other Prunus; for example, tao’ze badam refers to peach kernel in western China and khasta badam to apricot kernel (sometimes called “poor man’s almond”) in India. Thus, in the absence of well-preserved endocarp remnants for species identification, it can be difficult to know which Prunus species was present in archaeological reports. Other distinguishing characteristics of almond species, however, are the symmetrical amygdaloidal (from amygdala, or ἀμυγδάλη) kernel shape (versus the more ovate peach and apricot kernel) and a flowering time among the earliest of all temperate trees and in which the flowers emerge well before the leaves. This explosion of life toward the end of an otherwise barren winter apparently captured the imagination of ancient observers as it does now, contributing to a rich and varied folklore.

Almonds are mentioned in the earliest Sumerian culinary texts in a list of banquet menu items (Rosengarten 1984). Biblical references to the almond show it was common in Palestine (where it can bloom as early as January) by at least 1700 BCE (Goor and Nurock 1968; Janick 2007). A reference to almonds in the book of Genesis 43:11 documents its high value: “their father Israel said unto them, if it must be so now, do this; take the best foods in the land in your vessels, and carry down to the man a present, a little balm, and a little honey, spices, and myrrh, nuts and almonds.” The man in this case was the governor of Egypt, from whom the Israelites were soliciting food aid in their time of famine, suggesting that almonds were also valued in Egypt but possibly not grown there. The Hebrew name for almond is שׁהַקֶד or shaqed, which has its roots in an ancient Semitic term, as seen in the Akkadian sˇiqdu and Ugaritic thaqid as well as in old Ethiopic language. Shaqed may also be translated as “watchful,” symbolizing God’s watchfulness over his people; as in Jeremiah 1:11–12, “And the word of the Lord came to me, saying ‘Jeremiah, what do you see?’ And I said, ‘I see an almond branch.’ Then the Lord said to me, ‘You have seen well, for I am watching over my word to perform it.’” An early biblical reference, Numbers 17: 8, describes how the staffs of the 12 princes of Israel were placed into the Tabernacle after the Exodus. Only the staff of Aaron of the house of Levy, which was almond, flowered (Fig. 2.5). This was interpreted as a sign of divine favor to Aaron, of God’s watchfulness over him and his descendants (Rosengarten 1984). According to tradition, the staff of Aaron bore sweet kernels on one side and bitter kernels on the other, symbolizing sustenance if the Israelites followed the Lord but bitterness if they were to forsake of the Lord. (Although an almond staff could flower if cut just prior to bloom and even continue to flower for many days if placed in
water, the cut branch would soon collapse well before fruit development.) The almond blossom also supplied a symbolic model for the menorah or ark that stood in the Holy Temple: “Three cups, shaped like almond blossoms, were on one branch, with a knob and a flower; and three cups, shaped like almond blossoms, were on the other... on the candlestick itself were four cups, shaped like almond blossoms, with its knobs and flowers” (Exodus 25:33–34; 37:19–20). That the golden candlesticks for the Tabernacle should have almond-shape bowls may explain why ornamental pieces of crystals attached to candlesticks sometimes are still called almonds. Interestingly, in areas of Pakistan, western China, and India, the prayer cap, or topi, is often adorned with paisleylike patterns said to represent almond blossoms (Fig. 2.6). In Arabia and other Muslim areas, almond’s early flowering on leafless branches is seen as a symbol of hope (Rosengarten 1984). The early-flowering habit of almond appears also to have made it symbolic for watchfulness or insight in ancient Greek mythology (Fig. 2.7). The symbolism derived from the Mycenaean Bronze Age (ca. 1200 BCE) myth of Phyllis of Thrace who grieved so much when her lover Demophon did not return from Troy that the gods transformed her into an almond tree, thereafter called Phylla by the Greeks. Upon Demophon’s return, he embraced the tree, which burst into blossom. A more ominous interpretation of almond bloom (perhaps alluding to the rather sudden whitening of a man’s hair as he approaches old age and death), is given in Ecclesiastes 12:5: “when men are afraid of heights and of dangers in the
Fig. 2.6. A prayer cap, or topi, adorned on top with paisley-like patterns said to represent single almond blossoms.

Fig. 2.7. Greek vase from 450 BCE showing the Oracle at Delphi holding almond branch in right hand. Source: www.talariaenterprises.com.
streets; when the almond tree blossoms and the grasshopper drags himself along and desire no longer is stirred. Then man goes to his eternal home and mourners go about the streets.” A similarly ominous significance appeared to be held by the Bronze Age Phrygian culture of Anatolia, in present-day Turkey, whose rites of worship to their main goddess Cybele were so savage that they were eventually banned. According to legend, the almond tree sprang from the blood of Cybele and played prominent roles in the creation of lesser gods. Besides symbolizing Cybele for her devotees, the almond was also regarded as the Father of Everything, according to Rawlinson (1917).

The symbolic importance of almond in these early cultures may have referred to its dramatic, life-reaffirming early bloom or to the amygdaloidal kernel shape. The almond shape symbolized the female genitalia in the East, while in Europe it often represented the womb. In early Christian art, Christ is sometimes shown surrounded by almonds or an almond-shape mandorla (from the Italian mandorlo, for “almond”) representing the womb (Fig. 2.8). In other parts of Europe, particularly central Italy, the almond symbolized the Virgin Mary. Consequently, almond nuts often have been associated with fertility. Romans showered newlyweds with almonds as a fertility charm. An old Romanian contraceptive measure was to carry roasted almonds on the person, perhaps because the roasting counteracted the nuts’ traditional powers on fertility. It is still a modern European custom to give female guests at weddings a bag of five sugared almonds representing children, happiness, romance, good health, and fortune (Fig. 2.9). In Greece, almond cookies remain a popular wedding food. In Britain, their traditional Mothering Sunday Simnel cake is covered with almond paste in a possible reference to motherhood. The traditional almond paste and royal icing of British wedding cakes symbolizes the intermingled sweetness and bittersweetness of the couple’s new life together. Even in ancient China, almond’s amygdaloidal shape was considered a symbol of female beauty as well as enduring sadness (perhaps because the symmetrical amygdalus or mandorla is the product of overlapping circles or because it refers to the inevitable bitterness present in the occasional bitter kernels).

In the wild, almond species usually produce cyanogenic and bitter seed; however, individual trees producing sweet and edible nuts have been reported in native populations of many almond and related species (Vavilov 1930; Denisov 1988; Werner and Crellar, 1997). Although relatively rare, these individuals can be readily identified by consumption of their seed by native rodents and birds. Human gatherers from early times to present would mark such trees for recurrent annual
harvest, as has been documented in present-day hunter-gatherer groups in Asia and Africa (Alexander-Essers 1994). The mutation for sweet kernel is expressed in all seed of the parent tree and, unlike most other cyanogenic plants, including apricot and peach, is dominant in almond (Werner and Crellar 1997; Dicenta et al. 2007; Negri et al. 2008). Consequently, not only will all seed in a selected tree have sweet kernels, but the majority of seedlings derived from those seeds will also have sweet kernels. Domestication of sweet kernel genotypes would have been advanced by the propagation of these selected individuals, either through the germination and growth of harvested seed or by relatively simple propagation techniques, such as rooted cuttings developed during these prehistoric times, or through the weeding out of bitter almonds within a wild grove and the promotion of greater growth of the selected sweet types (Zohary and Spiegel-Roy 1975). In addition, birds of
Fig. 2.9. A bomboniere, or Italian party favor, containing five symbolic almonds. Note the almond flower design in this example.

certain species, such as the western scrub-jay, *Aphelocoma californica*, will systematically bury or cache single sweet almond seeds at several thousand distinct sites for later retrieval and consumption (Pravosudova et al. 2006). It is not unusual for many of these seeds to germinate and, if the site is appropriate, to grow into productive trees.

Toxins in bitter seeds can be removed through various basic processing methods. Bitter almonds possess the almond’s nutritional quality and long storage life as well as a natural protection against undesired feeding by mammals, birds, and insects. Nutritionally, almond represents a compact, readily stored, and high-energy food (Table 2.2). Both the edible, immature fruit and the mature kernel contain the amino acid linolenic acid, which is essential but not naturally synthesized in humans. Recent studies have also indicated that moderate consumption of almond kernels can suppress hunger. An exceptional postharvest stability of almond kernels of over 2 years, when stored dry and in shell, would further contribute to almonds value as an easily transportable, high-quality food source in early human transmigrations and commerce. The same traits would also facilitate the establishment of widely dispersed almond stands through the accidental or deliberate planting of seed.
Table 2.2. Nutrient composition of the almond kernel per 100 g fresh weight of edible portion.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Energy</td>
<td>578 kcal</td>
</tr>
<tr>
<td>Protein</td>
<td>21.26 g</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>19.74 g</td>
</tr>
<tr>
<td>Fiber, total dietary</td>
<td>11.8 g</td>
</tr>
<tr>
<td>Glucose</td>
<td>4.54 g</td>
</tr>
<tr>
<td>Starch</td>
<td>0.73 g</td>
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<tr>
<td>Calcium</td>
<td>248 mg</td>
</tr>
<tr>
<td>Magnesium</td>
<td>275 mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>474 mg</td>
</tr>
<tr>
<td>Potassium</td>
<td>728 mg</td>
</tr>
<tr>
<td>Sodium</td>
<td>1 mg</td>
</tr>
<tr>
<td>Folate, total</td>
<td>29 mcg</td>
</tr>
<tr>
<td>Vitamin E</td>
<td>25.87 mg</td>
</tr>
<tr>
<td>Saturated fatty acids</td>
<td>3.88 g</td>
</tr>
<tr>
<td>Monounsaturated fatty acids</td>
<td>32.16 g</td>
</tr>
<tr>
<td>Polyunsaturated fatty acid</td>
<td>12.21 g</td>
</tr>
</tbody>
</table>

Source: Adapted from Socias i Company et al. 2007.

IV. CULTIVATED GREEK NUT

Although the kernel of native almond and even apricot and peach species continue to be harvested today much as they were in antiquity, evolving market factors, particularly during the great flourishing of trade associated with the Achaemenian Dynasty of Persia (559–334 BCE), resulted in a market standard that appears to have become widely known in ancient times as the Greek nut and in more modern times as the cultivated sweet almond. Several hypotheses have been advanced concerning its origin. Russian scientists Kovalev and Kostina (1935) suggested that the cultivated almond emerged by selection from within the species listed initially as *Amygdalus communis* L., whose range may have extended across Iran and eastern Turkey into Syria, Lebanon, and Jordan (Browitz 1974). Two natural sweet-kerneled *A. communis* populations have been reported on the slopes of the Kopet Dagh Mountains in central Asia between present-day Iran and Tadjikistan and on the slopes of the Tian Shan Mountains between Uzbekistan and western China (Vavilov 1930; Denisov 1988) (Fig. 2.3). This species was reported to be adapted to mild winter and dry hot summer conditions by traits of low chilling, early bloom, rapid early shoot growth, deep penetrating root systems, and high tolerance to summer heat and drought. Its phenotypic range closely resembles that of present-day cultivated almonds.
Another hypothesis originated by Evreinoff (1958) is that the cultivated almond arose by hybridization among *P. fenzliana* and possibly *P. bucharica, P. kuramica*, and other species. This view, which has recently been supported by molecular analysis (Zeinalabedini et al. 2009), holds that the cultivated almond originated through human intervention and is not a natural species. Grassely (1976b) reported that *P. kuramica*, whose range includes Afghanistan and northern Pakistan, somewhat resembles cultivated almonds and coexists with it in many farming areas. *P. kuramica* grows on the more xerophytic sites, *P. dulcis* being a mesophytic species. Different almond species, particularly those of the same section, cross readily, and considerable natural hybridization between cultivated almond and nearby wild species takes place (Grassely 1976; Denisov 1988). Introgressive hybridization and exchange of genes thus can take place whenever ranges overlap. Many of the more than 30 named almond species may not be true species but products of such interspecific hybridization events. The previously described Kopet Dagh and Tian Shan sweet-kerneled populations are proposed to be more recent feral populations of cultivated almonds or their natural hybrids (Browicz and Zohary 1996). *Amygdalus communis* thus represents feral populations of *P. dulcis* (*A. dulcis*) rather than a native species. Furthermore, as almond cultivation expanded, new hybridizations/introggression would have occurred, as with the wild species *P. webbii* (Spach) Vierh. (Godini 1977; Socias i Company 2002) and cultivated almond populations found along the northern shore of the Mediterranean sea from Greece and the Balkans to Spain and Portugal. Godini (2000) showed that *P. webbii* from the Italian region of Puglia was self-compatible and that it probably contributed this trait to local cultivated almond landraces since many almond orchards were made up of seedling plantings during prehistoric times to the present. Molecular analysis recently has shown this proposed interspecific introgression of self-compatibility from wild *P. webbii* to cultivated *P. dulcis* to be correct (Cortal et al. 2002; Martínez-Gómez et al. 2007). Zohary and Hopf (1993) proposed that the area of initial domestication was the eastern part of the Mediterranean basin. However, the wild populations and species found in the eastern Mediterranean appear genetically more distant from the cultivated almond than the wild populations and species of the Caucasus and Zagros mountains of eastern Asia Minor and Persia (Sorkheh et al. 2007). Both regions, however, were then part of the Achaemenian Dynasty of Persia (559–334 BCE), which actively encouraged both commercial and cultural exchange among its diverse regions (Fig. 2.10). The Achaemenian kings,
including both Cyrus the Great (ca. 600–530 BCE) and Darius the Great (ca. 549–486 BCE), took a special interest in plant collection and cultivation. The Spartan mercenary Lysander, who joined the Achaemenian Persian king Cyrus the Younger in 401 BCE, reported to Xenophon of Athens how the Persian kings excelled not only in war but also in creating protected gardens, or *pairidaeza*, of plants, especially fruit-bearing trees, collected during their foreign expeditions. Xenophon (who was a supporter and chronicler of Socrates) went on to write, in his *Oeconomicus* (Economics [399 BCE]) “The Great King ... in all the districts he resides and visits ... takes great care that there are ‘paradies’ (from Greek form *paradeisos*) as they call them, full of all the beautiful things the soil will produce” (Eduljee 2009). One of the earliest pairidaeza may have been the mythical Hanging Gardens of Babylon, purportedly built by King Nebuchadnezzar (605–562 BCE) to placate his homesick Median wife, Amytis, by copying the lush gardens from her childhood home on the slopes of the Zagros Mountains. Several wild almonds are common species in the Zagros Mountains, suggesting their possible inclusion in the Hanging Gardens. One of these species, *P. fenzliana*, from which cultivated almond was probably derived, also may have been present at an even earlier *paradeisos*; recent archaeological research has identified an area within the native habitat of *P. fenzliana* in the Caucasus Mountains as a possible site of the mythical Garden of Eden (Eduljee 2009).
V. OLD WORLD DISSEMINATION

It is known that the introduction of cultivated almond in the eastern Mediterranean area took place by the second millennium BCE, because cultivated almond remains have been found in the tomb of Tutankhamen, who was buried in 1323 BCE (Zohary and Hopf 1993). Almond cultivation appears to have existed in Greece long before the creation of the Greek myths to explain its incorporation into them (Graves 1955), and there is evidence of extensive almond trade in the eastern Mediterranean in the fourth century BCE (Cerdá, 1973) and possibly much earlier (Hansen and Renfrew 1978; Farrand 1999). The wide dissemination of modern almond and its cultivation has been separated into four phases: Asiatic, Mediterranean, Californian, and Southern Hemisphere (Kester et al. 1991). Often concurrent with the spread of cultivated almond is a dissemination of a surprisingly similar folklore, including medical and culinary uses, suggesting that the spread was through well established and interconnected trade routes (Albala 2009).

A. Asiatic Stage

The Asiatic stage included the initial domestication and the subsequent spread throughout central and southwestern Asia. The Greek naturalist Theophrastus described almond, which he called *amugdalai* in his treatise on the history of plants about 300 BCE. During the early Roman expansion, Marcus Porcius Cato (ca. 236–149 BCE) referred to almond as the “Greek nut,” suggesting its dissemination via Greece. Pliny (23–79), in his *Natural History*, also listed almond as *prima omnium*, or “first of all.” Within a few hundred years, the range of known almond cultivation includes the regions now known as Turkey (Ayfer 1975; Dokuzogus 1975), Iran (Grigorian 1976), Syria (Thompson 1983), Israel (Spiegel-Roy 1976), and east to the Xinjiang Province of China (Gustaffson et al. 1988), northern Pakistan (Thompson et al. 1989), and northwest India (Singh and Uppal 1977; Singh et al. 1977). In Kashgar, in Xinjiang Province, cultivated almonds were reported to originate from Central Asia across the Tian Shan Mountains to the west (Gustaffson et al. 1988). Kashgar is on the old Silk Road connecting China to India and the West, as were most other sites of eventual domestication. The extent and sophistication of this prehistoric trade was recently documented with the discovery of the wreck of the *Kyrnenia*, dating from around 350 BCE, in which both vessel and cargo remain remarkable intact (Fig. 2.11). In addition to cultivated almonds, the ship was carrying amphorae of wine and olive oil, grain millstones, coins, and iron blooms.
Using presumed and sometimes known origins for this cargo, the vessel’s probable trading route was deduced, showing that an advanced commerce had already been well established by this time (Albala 2009). Such archaeological finds, as well as parallels in the associated folklore, support a central role of prehistoric Greco-Persian culture and commerce in advancing the cultivation, utilization, and dissemination of the modern almond. As a traded commodity, the range of almond extended to the edge of the known world (Fig. 2.3).

In far eastern China, the almond initially was described in the ancient text *Yu yan tsa tsu* as a flat peach from Persia. “The meat is bitter and acrid, and cannot be chewed; the interior of the kernel, however, is sweet, and is highly prized in the Western Regions and all other countries” (Albala 2009). The Persian name for almonds, *badam*, or in Old Persian, *vadam*, became the Old Chinese *p’o-tam* or *bwa-dam*. It also entered Tibetan as *ba-dam*. A later document, *Pen ts’ap kan mu* by Li Si-sen,
identifies the origin of almonds as the land of the Mohammedans and states that they occur everywhere west of Gansu, the province bordering Xinjiang (literally, “New Frontier”). Because the more temperate and humid climate of eastern China limits almond cultivation, it was imported, especially in the T’ang Dynasty (618–907), a period of rich cultural exchange between East and West. Fragments of Chinese pharmacopoeias survive, including seventh-century works by Meng Shen, which mention almonds and a number of western foods grown in imperial gardens (Simoons 1991). Later, the Hsin Tang shu (new T’ang history) describes plants grown in Western Asia, including almonds, grapes, and figs from Persia (Albala 2009). In the 16th century, Li Shizhen in his Bencao Gangmu (a classification of materia medica) reports: “It comes from the lands of Hui people and is now in all the lands of the west. ... The tree is like an apricot but its leaves are smaller; the fruit is pointed and small, the flesh thin. Its kernel is like a plumstone, the skin is thin and the almond is sweet and nice. It is eaten for tea, its taste is similar to that of the hazelnut. The people in the west consider it a local specialty” (Métailié 2001).

In India, where almonds can be cultivated in the more Mediterranean climates of the northern provinces of Jammu and Himachal Pradesh, descriptions of almond and its often medical and culinary uses appeared during the same period and also suggest a Greco-Persian origin (Peregrine and Melvin 2003). Almonds in Hindi are called badam, which comes from the Sanskrit vatama, in turn from Persian badam or old Persian vadam. As early as the third century BCE (around the time of voyages of the Kyrnenia), the classic Indian medical texts Caraka Samhitā and Susruta Samhitā characterized sweet almond (vātāma or bādāma) as heavy, hot in potency, unctuous, sweet, strength promoting, alleviator of Vata (wind/spirit/air), nourishing, aphrodisiac, and aggravator of Kapha (phlegm) as well as Pitta (bile). Although the Caraka Samhitā and Susruta Samhitā, ancient Indian Ayurvedic texts on internal medicine, are an early source of medical understanding believed to be independent of ancient Greece, Albala (2009) has recently pointed out the strong similarities between medical (and culinary) uses of almond as initially described in Greece with subsequent uses in Persia and its trading partners, including India and China. He proposes the apparent Greek origin of much of the traditional folklore associated with cultivated almond is evidence for a Greek origin or major role in the dissemination of the cultivated form of almond (P. dulcis).

The ancient Greek physician Hippocrates (ca. 460–370 BCE), considered the father of western medicine, founded the humoral, or Unani, doctrine
of medicine. Unani medicine is based on the concepts of the four humors: phlegm (balgham), blood (dam), yellow bile (safra'), and black bile (sauda'). (The word “Unani” refers to Ionian Greek, meaning the Greek-populated west coast of Asia Minor, in what is now Turkey. Thus the term “Greek” during this period of history refers not only to the Greek islands but much of the eastern Mediterranean, which was then also strongly networked with Persian culture [Fig. 2.10].) Hippocrates was among the first to record the medical uses of almonds. He reports: “Almonds are burning but nutritious; burning because they are oily, and nutritious because they are fleshy” (Jones 1967). In the Greek system of humoral physiology, this means that almonds would have been categorized as a hot and dry food, one that stimulates choler or energy in the body. Diocles of Carystus, a follower of Hippocrates, adds: “almonds are nourishing and good for the bowels, and are moreover, calorific because they contain some of the properties of millet. The green are less unwholesome than the dry, the soaked than the unsoaked, the roasted than the raw” (Bottero 2004). Soaking almonds would activate seed digestive enzymes and facilitate removal of the bitter brown seedcoat. Roasting makes them more easily digested. Although green almonds would have been unknown outside their area of cultivation, soaking or blanching was a common practice in both Indian and Chinese medicine (Achaya 1998). Medical philosophies differed, but the goal appears to be the same for each: to reduce their tendency to heat the body (Albala, 2009). Because of its classification as a hot food, which scavenges the body’s passages, almond was recommended by Hippocrates and his followers to relieve coughs, for weight gain, and as an aphrodisiac (Albala 2009). The Persian Al-Qanun fil-tibb (canon of Avicenna) (980–1037) became the standard medical text in medieval Europe and was the primary means of Greek humoral medicine reaching Arabia and Asia, particularly in India (where the canon is still the principal authority for Unani medicine) (Achaya 1998; Bottero 2004). Almond’s medical values were described in a manner very consistent with the earlier view of Hippocrates: “Almonds are more slowly digested and thus less likely to convert to choler,” and “sweet almonds comfort coughs and spitting of blood... they open clogs of the liver and spleen on account of their bitterness. They even open clogs occurring in the extremities of the veins and if eaten fresh with the peel, clean humidity in the stomach” (Albala 2009).

The Yin-Shan Cheng-Yao dietary by Szu-Hui, of the Chinese Mongol era, dating from 25 AD, also describe almonds in a similar fashion: “Almonds control coughing and bring down ch’i. They disperse impeded pressing of the chest and abdomen” (Buell et al. 2000). The Greco-Persian view of health as a balance of humors thus finds its
parallel in the Chinese idea of ch’I, or the balancing yin and yang forces, which can also be described as cold and hot. In the Indian Ayurvedic medical system, almonds, in addition to the previously listed attributes of cough relief and aphrodisiac, are also classified as a hot food. In Ayurvedic medicine, as in Greek medicine, health consists of a balance of elemental forces, or doshas (which are not exactly humors but energy principles that regulate physiological functions). Almonds are said to enhance the kapha dosha, which maintains the structural integrity of the body, but they also suppress an excess of the vata dosha, which is the principle of movement and transportation in the body. Thus, low weight gain in a thin overactive body in which nourishment dissipates quickly can be treated with a regimen including almonds (Albala 2009). In the associated Rasayana approach to health and longevity, almonds provide vital energy, or ojas, a belief comparable to the Chinese concept of ch’i and the Greek concept of pneuma (Albala 2009).

Almond kernels, in addition to being a high-quality food source, are also source of high-quality oil. The oil, which can constitute more than 50% of the kernel by weight, is primarily composed of oleic acid (approximately 65%) and linoleic acid (approximately 30%), which results in good flavor and nutritional value as well as stability in storage (Abdallah et al. 1998). These qualities encouraged its use as a base for various ointments in both ancient and modern cultures. The most extensive use of almonds in Ayurveda is in the form of oil, used for various skin ailments and to warm the body in massage and other therapies. Almond oil is used in various vata disorders, chronic constipation, dry cough, semen disorders, leucorrhoea, and dysmenorrhoea. It is a good aphrodisiac, galactogogue, and health tonic (Albala 2009). In addition to the similar medicinal uses of almond in disparate Asian cultures, there were also a number of culinary dishes that appear to have a Greco-Persian origin. An ancient Baghdad cookbook, the Kitab al-Tabikh, records a number of sweet almond recipes, among which are lauzinaj, faludhaj, and samal wa-aqras (Bottero 2004; Albala 2009). (The Arabic word for almond is lauz or loz, whose occasional reference in the Old Testament documents its use in antiquity). The lauzinaj recipe begins with finely pounded sugar and pounded almonds, kneaded together with rosewater. This is essentially marzipan, and it also comes with various flavorings, such as camphor or musk (Albala 2009). These are ancestors of a number of dishes of India, such as badam barfi, halwa, and similar almond sweets found throughout central Asia and as far as China. The term “lozenge” is also derived from the Arabic lauz, perhaps in reference to its almond shape (Albala 2009).
B. Mediterranean Stage

The westward dissemination of cultivated almond into the Mediterranean had two stages. Almonds were first brought into the Peloponnesian peninsula and Greek isles (Stylianides 1976), becoming well established by 300 to 400 BCE (Fig. 2.3). Gradually almonds were introduced to all adapted areas of the Mediterranean, including Italy, southern France, Spain, Portugal, North Africa, and the Madeira Islands. These introductions may have come from the early ocean trading Phoenicians of Asia Minor (Egea and Garcia 1975) and/or from the Greeks while establishing colonies in Sicily, Europe, and North Africa, and from other merchant groups as extensive trade routes were well established by this time. Cultivation typically was limited to within 50 miles of the Mediterranean coast, extending onto the slopes of river valleys and the interior plateau of Spain. Further introductions came from about 500 to 600 with the conquest of North Africa by the Arabs; they brought almonds into Tunisia (Jaquani 1976) and Morocco (Laghezali 1985) and then into Spain and Portugal (Egea and Garcia 1975). One of the ancient Silk Road caravan routes also crossed north-central Africa, through Timbuktu into Morocco, thus representing an even earlier route of possible dissemination to North Africa and western Europe (Evreinoff 1952, 1958). Remnants of such pre-Arabic introductions may exist today in the diverse germplasm only now being documented in the geographically isolated Atlas Mountains in Morocco and Tunisia (Laghezali 1985; Lansari et al. 1994).

Archaeological studies at the site of the Mount Vesuvius eruption, which occurred in the year 79, indicate that almond was a common food of the Campenians of southern Italy by the first century, although almonds appear to be well known much earlier in Rome’s history, as they were described by Marcus Porcius Cato as the “Greek nut” as early as 200 BCE. In Latin, almond was called *amandola*, derived from the Greek ἀμυγδάλη (amingdala) (*cf.* amygdala). The Latin *amandola* appears to be the root for the term used for almond in Italian (*mandorla*), German (*mandel*), Swedish (*mandel*), Russian (*mindal*), Croatian (*mandula*), French (*amande*), Spanish (*almendra*), and Portuguese (*amendoa*). Interestingly, in the etymologically more isolated Romani language, almond is *migdala* and so probably derived from the Greek. It has been widely postulated that the “*al*” prefix, as in the Spanish *almendra*, and English *almond*, resulted from its fusion of the Arabic article “*al*” with the Latin *amandola* (and dropping the initial “a,” as done with the Italian *mandorla*), which represents an etymological and cultural legacy of the 800-year control of Spain by the Arabic-speaking Moors.
There is no doubt that Roman knowledge of almond was strongly influenced by the Greeks. Pliny the Elder (23–79), the ancient Roman nobleman and historian, reiterated earlier Greek ideas that almonds act as a diuretic and emmenagogue. They provoke sleep and sharpen the appetite and are also useful against headache and fever, the latter presumably from their purging qualities to drive out the fever rather than to counteract or cool it (Albala 2009). Galen of Pergamum (129–200), a highly influential Greek physician serving several Roman emperors, believed that although bitter almonds were not very astringent, they cleansed and attenuated and thus purged, and “act towards the expectoration of moist matter from the lungs and chest. The very bitter cut through thick and viscous matter. But they are also oily, so not as useful for purging the stomach, and bitter almonds unlike the sweet afford little nourishment for the body” (Grant 2000).

Rosengarten (1984) describes an almond-based cold cream used by fashionable French women in the 17th century. This ‘Ninon de Lenclos’ ointment contained 4 ounces (112 g) of almond oil, 3 ounces of hog’s lard (104 g), and 1 ounce (28 g) of spermaceti (a waxy component of sperm whale oil). These ingredients were melted, lemon juice was added, the mixture was stirred until cool and then scented with rose water. Almond oil continues to be an important oil base for cosmetics and other pharmaceuticals to the present. Additional medicinal uses of almond ointment included the treatment of pattern baldness and as a soothing ointment for burns. A continuing practice in parts of Asia is the application of almond oil to the heads of babies, as it is believed to promote their subsequent intelligence. Salves containing concentrations of oleic and related fatty acids may also help control of head lice (Socias i Company et al. 2007), which might further explain the application of almond oil to the scalps of children.

While bitter almonds and almond oil were used primarily as medicine, sweet almonds and oil of bitter almond (an alcohol-based extract of bitter almond essence, primarily benzaldehyde) were used as both food and medicine. Both also found culinary uses. One of the oldest surviving Roman cookbooks, Apicius (fourth or fifth century CE), describes a dish called apothermum, which is boiled wheat with pine nuts and almonds that have been soaked, skinned, and whitened with silver chalk (creta argentaria) to which is added raisins and raisin wine, with pepper over the top (Bottero 2004). As pointed out by Albala (2009), this recipe bears a striking resemblance to a rice dish in Persian cookery. In turn it has found its way to India and China and ultimately to England and the West as rice pudding. A similar soup made with ground almond, rice, and sugar was used for sore throats in the Ch’ing court in China (1644–1911).
In modern China, a popular dish to combat colds and sore throats is made with apricot kernels powdered and mixed with rice congee (Simoons 1991). A traditional Christmas dessert in Sweden and parts of northern Germany is cinnamon-flavored rice pudding into which a single almond has been hidden; the one who finds the almond will have good fortune for a year.

A renaissance in European cuisine that involved spices as well as almond and other foods from Asia appears to have occurred from the 10th through the 13th centuries following the spread of Islam. Evidence for even earlier almond plantings in France can be found in the charter granted by King Chilperic II (716) and in an edict of Charlemagne in 812 (Rosengarten 1984). An inventory of the household goods of the Queen of France in 1372 listed only 20 pounds of sugar but included 500 pounds of almonds. Almonds appear to have been relatively inexpensive and generally available to the emerging middle class even in areas such as England, where the climate would make a local production more difficult. Rosengarten (1984) estimates an average price of approximately 2 to 3 pence per pound between the years 1259 and 1400. The almond trade appeared substantial by the 14th century with Venice becoming an important center of commerce. To capitalize on this extensive commerce, the Knights Templar levied tithes on almonds, honey, and sesame seed in 1441.

The Arab conquest of North Africa and Spain introduced Middle Eastern cuisine, which included almond and sugar-based confections similar to the previously described marzipan as well as more staple fare such as harisa, a popular dish of 10th-century Baghdad, which consisted of meat and vegetables served with a sauce thickened with powdered almonds (Rosengarten 1984). Similarly, almond milk, which could be used as a milk substitute for direct consumption or in cooking, was made by soaking in water pulverized almonds from which the outer seed coat had first been removed. Almond milk became a more frequent ingredient in Mediterranean cuisine than in the Middle East. For example, the grand medieval European dish blancmanger was typically chicken stewed in almond milk. The comparable and popular Persian dish isfidhabaj (white stew) used almond milk in some recipes though many recipes contained no reference to almonds at all. Religious and medical views have played roles in the emergence of almond in European cuisine. For example, almond milk could be conveniently substituted for dairy milk, whose consumption was forbidden on Fridays by the Roman Catholic Church.

In addition, physicians from the 12th to the 16th century continued the belief that the nature of the food consumed was a critical component of
health. Echoing ancient Greek beliefs, foods such as almonds, chicken, and rice were viewed as moderately warm and moist in their characteristics and so compatible with the healthy human body. The prevailing view among the upper class was that such moderate foods were more ideally suited for consumption and had the added value of moderating foods perceived as being too hot (ginger), too cold (many vegetables), too dry (turnip), and too wet (watermelon) (Albala 2009). Even more extensive culinary uses of almond were eventually brought to Europe by the returning Crusaders, many of whom had developed a preference for the more exotic Middle Eastern cuisine compared to the blander European diet of the time. As an example, a recipe from the *Forme of Cury*, dating back to 1390 (http://homecooking.about.com/od/foodhistory/a/almond-history.htm), uses ground almonds in a gravy for oysters that is still fashionable.

A rich folklore, including extensive medical and culinary uses of almond, also can also be found in Spain, particularly southern Iberia, which was under Moorish control the longest. The origin of this folklore is often uncertain, though during the Dark Ages, the Muslim Arab kingdoms were the main repository and disseminator of the earlier Greek and Roman knowledge. Paella, the national dish of Spain, or at least the Valencia region, has its equivalent in the Persian dish of *dan-pukhtak* also known as *biryani*, with almonds often being included in both (Albala 2009).

A bit of mythology often credited to Aristotle (but probably not disseminated by the abstinent Arab Muslims) was this proposal of Roman author Pliny the Elder: “It is said that if five bitter almonds are taken by a person before sitting down to drink, he will be proof against inebriation.” Plutarch (ca. 42 BCE–37 CE) likewise says that Drusus, brother of Tiberius, who was a prodigious drinker, used almonds this way. The logic here is that the almond, due to its bitterness and diuretic properties, speeds the alcohol through the system before it has a chance to send vapors up to the head (which was believed to cause inebriation). The *Herbal* of John Gerard (1597) states that “five or six (almonds) being taken fasting do keepe a man from being drunke” and may have become the forerunner of the cocktail nut of today (Rosengarten 1984). Purported protection from inebriation may have also contributed to the previously cited popularity of almonds in weddings. In traditional Greek weddings, slightly bitter sugar-coated almonds called *koufeta* are placed in little bags in odd numbers and served on a silver tray. Odd numbers are indivisible, symbolizing how the newlyweds will share everything and remain undivided. Tradition holds that if an unmarried woman puts the almonds under her pillow, she will dream of her future husband.
Five (often sugar-coated or “Jordan”) almonds signifying five wishes (health, wealth, happiness, fertility, and longevity) are common in traditional Italian weddings and other special occasions. These almonds decorate each place setting as favors, tucked into pretty boxes or tulle bags called bomboniere that are often personalized with the couple’s names and date (Fig. 2.9). A different and new type of favor is the favor cake or Torta Bomboniera, which is made using little boxes forming one or more tier of a cake. Inside each box are the sugared almonds and a card printed with the data of ceremony. Sugar-coated almonds are also traditional in Middle Eastern weddings and are considered by some to be aphrodisiacs.

In southern Europe, almonds also symbolized good luck as well as long life and happiness. The heartening capability of a dormant almond shoot in winter to quickly flower when cut and brought into warmer temperatures is frequently alluded to in European art and literature from medieval times to the present (Figs. 2.12, 2.13, 2.14). In the legend of Tannhauser, made famous by Richard Wagner’s 1845 opera, the knight was informed by the pope that he was as likely to have his sins forgiven as the pope’s staff was likely to bloom (Rosengarten 1984). The staff, which was made of almond, did indeed bloom but, tragically, Tannhauser died.

Fig. 2.12. Lithographic reproduction of an almond twig from the 1517 Herbal by Johanes Niger. Source: D. Avanzato and I. Vasssallo 2006.
before his pardon arrived. The almond’s seemingly magical flowering ability also may have contributed to the preference for a wand made from almond wood by professional magicians during the Middle Ages as well as the use of almonds in Tuscany for making dowsing rods for the divination of underground water or other hidden items of value (reminiscent of the almond branch of the Oracle at Delphi (Fig. 2.7)).

Almond was also well suited for cultivation in the Mediterranean climate with its traditional low-input moderate-return dry-land cropping systems. Easy propagation by seed, rapid development of the tree, and adaptation to marginal soil, summer drought and heat, combined with its food value made the almond well adapted to the subsistence form of agriculture predominating in early Mediterranean culture. High root tolerance to drought but high susceptibility to excessive soil moisture placed almonds in a mixed culture system with olives, carob, and other drought-tolerant crops. Almonds were usually found on well-drained slopes at higher elevations of valleys to escape shoot damage from frosts and root damage from excessive soil water. A traditional culture system evolved that minimized inputs of labor, fertilizers, and use of supplementary water. Some trees producing bitter nuts were tolerated in local seedling orchards since bitter seed were mixed in

Fig. 2.13. *Almond Blossom* by Vincent Van Gogh (1853–1890) for his newborn nephew as a symbol of a budding life.
small quantities with sweet kernel to produce the distinctive amaretto flavor. Because sweetness is the dominant trait, genes for bitterness may still be present in sweet-kernel trees, allowing the occasional recombination of bitter seedling trees. The Italian naturalist Scribonius Largus documented this distinction in the first century CE by naming bitter almonds *Amygdali amari*. Bitter forms of the cultivated almond sometimes are classified as *Prunus dulcis* (Mill.) D. A. Webb var. amara (DC.) Buchheim (Fig. 2.15). Bitter almonds are also commercially cultivated for their oil, which is used to extract benzaldehyde for the amaretto essence, known to bakers and chefs as almond extract or oil of bitter almond but known to many consumers as the cherry flavor in cherry colas, drinks, and confectionaries. The presence of excessive trees producing bitter or otherwise undesirable seeds in segregating seedling populations would be an incentive to use the undesired bitter trees as
rootstocks for topworking with scions from the more desirable trees. Grafting was widely used in antiquity and is mentioned in writings of Hippocrates, Theophrastus, Cato, Varro, Columella, and Pliny. Two thousand years of continuous almond culture in the Mediterranean basin concentrated production to specific regions where well-defined seedling ecotypes and local cultivars evolved (Grasselly 1972, 1976b; Grasselly and Crossa-Raynaud 1980). These highly selected regional

Fig. 2.15. Bitter almond (*Amygdalus communis* L. var. *amara* (syn. *P. dulcis* var. *amara*) from 1926 *Textbook of Pharmacognosy* by T.C. Denston showing similar morphologies to cultivated sweet almond despite distinct botanical classification.
cultivars and landraces represent a rich genetic, horticultural, and culinary diversity (Tables 2.3 and 2.4). Dryland, seedling orchards remained the major almond culture system in the Mediterranean region for centuries, persisting to recent times in such areas as Sicily, Sardinia, Majorca, the Madeira Islands, Greece, Turkey, and Morocco.

By the middle of the 19th century, cultivars of specific Mediterranean countries were recognized by nurseries by name (Fig. 2.16) and were introduced into California as early as 1843. By the turn of the 20th century, most of the almond countries of the Mediterranean region and the United States had identified “local cultivars” that were seedling selections which, while representing the germplasm of the region, were often of unknown origin. Italy became a major almond-growing area, and many cultivars have been described in Puglia (Fanelli 1939; Grasselly and Crossa-Raynaud 1980), Sicily (Bianca 1872; Spina 1958), and Sardinia (Milella 1959; Agabbio et al. 1984; Chessa and Pala 1985). Puglian cultivars were predominantly late blooming, had hard shells with a kernel/nut ratio of 25% to 30%, with high percentages of double kernels. Sicilian cultivars tended to be early blooming, very hard shells, and more or less round in shape. Several Italian cultivars were also self-compatible.

Spain has a long history of almond culture with almonds being grown in most provinces (Felipe 1976; Gardner and Lee 1979). Principal concentrations are in coastal provinces (Tarragona, Valencia) along the Mediterranean coast (Murcia) and the Ebro valley (Lerida), although the range extends to the southeastern border with Portugal and into the interior (Murua et al. 1993). ‘Marcona’ and ‘Desmayo Largueta’, both of unknown origin, have been the most widely grown cultivars. Both have very hard shells, are highly productive, and have well-recognized eating and cooking qualities such that they are marketed by name. Many other named cultivars of local origin (Vargas 1975; Felipe 1984; Garcia et al. 1985, 1988) have evolved from localized ecological niches that occur in different valleys extending inland from the Mediterranean coast.

France is an old almond-growing country with areas in the southern Rhone valley and the surrounding foothills (Grasselly and Crossa-Raynaud 1980). Cultivars originating in Provence and the foothills of the Alps tend to be late blooming. Cultivars associated with the Languedoc region nearer the center of the Rhone valley (‘Ai’, ‘Princesse’, ‘Languedoc’, ‘Pistache’, ‘Ardechoise’, ‘Fournat de Brezenaud’, ‘Rabasse’) show a range of tree and nut characteristics from hard to soft shelled and large to small kernels.

Portugal has two principal areas of production, the Algarve region in the south and the Alto Duoro in the north. Each region has cultivars
Table 2.3. Characteristics of important new almond cultivars from selected breeding programs.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPAIN</strong></td>
<td></td>
</tr>
<tr>
<td>CITA of Aragón (Zaragoza)</td>
<td>'Genco' OP, SC, mid-blooming, hard shell, large kernel, medium ripening</td>
</tr>
<tr>
<td>Blanquerna</td>
<td></td>
</tr>
<tr>
<td>Cambra</td>
<td>'Ferragnès' × 'Tuono', SC, late blooming, hard shell, medium ripening</td>
</tr>
<tr>
<td>Felisia</td>
<td>'Titan' × 'Tuono', SC, very late blooming, medium-hard shell, small kernel, very low alternance</td>
</tr>
<tr>
<td>Belona</td>
<td>'Blanquerna' × 'Belle d’Aurons', SC, late blooming, hard shell, large kernel with an outstanding composition, medium ripening</td>
</tr>
<tr>
<td>Soleta</td>
<td>'Blanquerna' × 'Belle d’Aurons', SC, late blooming, large kernel with an outstanding performance when roasted, medium–late ripening</td>
</tr>
<tr>
<td>Mardía</td>
<td>'Felisia' × 'Bertina', SC, extremely late blooming, disease tolerant, early–medium ripening</td>
</tr>
<tr>
<td><strong>CEBAS - CSIC (Murcia)</strong></td>
<td></td>
</tr>
<tr>
<td>Antoñeta</td>
<td>'Ferragnès' × 'Tuono', SC, late blooming, hard shell, high vigor, spreading with dense, very early ripening</td>
</tr>
<tr>
<td>Marta</td>
<td>'Ferragnès' × 'Tuono', SC, hard shell, high vigor, upright, late ripening, early ripening</td>
</tr>
<tr>
<td>Penta</td>
<td>S5133 × 'Lauranne', SC, extremely late blooming, hard shell, intermediate vigor and branching, early ripening</td>
</tr>
<tr>
<td>Tardona</td>
<td>S5133 × R1000, SC, extremely late blooming, hard shell, small kernel, intermediate vigor with dense branching, medium ripening</td>
</tr>
<tr>
<td><strong>IRTA - Mas de Bover (Reus)</strong></td>
<td></td>
</tr>
<tr>
<td>Constantí</td>
<td>('Ferragnès' × 'Ferraduel') OP, SC, late blooming, mid ripening, vigorous, mid branching</td>
</tr>
<tr>
<td>Marinada</td>
<td>'Lauranne' × 'Glorieta', SC, very late blooming, mid-ripening, mid-vigor, mid-branching</td>
</tr>
<tr>
<td>Tarraco</td>
<td>('Ferralise' × 'Tuono') × 'Anxaneta', SI, very late blooming, mid-ripening, mid-vigor, large kernel, mid-branching</td>
</tr>
<tr>
<td>Vairo</td>
<td>('Primorskij' × 'Cristomorto') × 'Lauranne', SC, late blooming, early ripening, high vigor, mid-branching</td>
</tr>
<tr>
<td><strong>FRANCE</strong></td>
<td></td>
</tr>
<tr>
<td>INRA (Avignon)</td>
<td></td>
</tr>
<tr>
<td>Lauranne</td>
<td>'Ferragnès' × 'Tuono', SC, medium-hard shell, medium vigor, late ripening, some double kernels</td>
</tr>
<tr>
<td>Steliette</td>
<td>'Ferragnès' × 'Tuono', SC, semi-hard shell, medium vigor, late ripening, some double kernels</td>
</tr>
<tr>
<td>Mandaline</td>
<td>'Ferralise' × 'Tuono', SC, late blooming, medium ripening, hard shell, medium to upright growth</td>
</tr>
<tr>
<td><strong>ISRAEL</strong></td>
<td></td>
</tr>
<tr>
<td>Shefa</td>
<td>'Tuono' × local cross, SI, vigorous, early blooming, highly adapted to Israeli conditions, soft shell, large kernel, early ripening</td>
</tr>
</tbody>
</table>
specific to the region (Grasselly and Crossa-Raynaud 1980). Similar situations exist in other traditional almond-growing countries, such as Tunisia, Greece, and Canary Islands.

The traditional almond production system of the Mediterranean and Asian regions, however, began to fail in the 1940s, and the French almond industry essentially went out of production by the 1950s (Grasselly and Crossa-Raynaud 1980). By the 1970s, production could not keep pace with the world demand for almond products because the most productive land was used for high-value crops such as peach and grape. Italy, historically the leading almond producer of the world, experienced a sharp decline in production (Federation Italiani 1973; Godini 1977; Bacarella 1993) and began to import almonds (Bacarella et al. 1991). Spain expanded its area and production but the scarcity of productive irrigated land has made production increases relatively modest (Abdelwahed and Albisu 1993; Murua 1993; Murua et al. 1993). In addition, supplemental honeybee pollination is not widely practiced (Felipe and Socias y Company 1992; Godini 1977b; Godini et al. 1992), significantly reducing final yield potential. Declines in production relative to other higher-value tree crops also took place in

---

Table 2.3. (Continued).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UNITED STATES</strong></td>
<td></td>
</tr>
<tr>
<td>University of California (Davis)</td>
<td></td>
</tr>
<tr>
<td>Avalon</td>
<td>Probably ‘Nonpareil’ OP, SI, medium kernel, early blooming, paper shell, harvest approx. 8 days after ‘Nonpareil’</td>
</tr>
<tr>
<td>Morley</td>
<td>‘Mission’ × late-blooming almond seedling, SI, late blooming, medium kernel, semi-soft shell</td>
</tr>
<tr>
<td>Savanna</td>
<td>‘Nonpareil’ × late-blooming almond seedling, SI, late blooming (2 weeks after ‘Nonpareil’), large kernel, semi-soft shell, harvest 14 days after ‘Nonpareil’</td>
</tr>
<tr>
<td>Winters</td>
<td>‘3-1’ (‘Peerless’ × ‘Harpereil’) × ‘6-27’ (‘Nonpareil’ × ‘Jordanollo’), SI, early blooming, large Carmel-type kernel, paper shell, good bloom overlap with early ‘Nonpareil’ bloom, harvest 3 weeks after ‘Nonpareil’</td>
</tr>
</tbody>
</table>

the Asiatic regions of cultivation, where in many areas almonds continue
to be grown under conditions similar to those used thousands of years
ago. The genetic, horticultural, and culinary diversity that initially made
these selections highly adapted to their production regions proved
inconsistent with the new kernel ideotype of an increasingly global and
so increasingly standardized market.

Similarly, attempts to extend the range of cultivated almond into
continental areas, such as Yugoslavia (Ristevski 1992), southern Russia
(Richter 1972), Romania (Cociu 1985), Bulgaria (Serafimov 1975, 1976),
and Hungary, have met with only partial success. This has been due to
almond’s susceptibility to winter cold and spring frosts as well as flower
and foliar disease, which is exacerbated by summer rains in these regions.

Table 2.4. Characteristics of the new rootstocks for almond from selected breeding
programs.

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPAIN</strong></td>
<td></td>
</tr>
<tr>
<td>CITA de Aragón (Zaragoza)</td>
<td></td>
</tr>
<tr>
<td>Felinem</td>
<td>‘Garfi’ almond × ‘Nemared’ peach, red leaves, easy propagation, nematode resistant, good vigor, adapted to replanting and to poor and calcareous soils</td>
</tr>
<tr>
<td>Garnem</td>
<td>‘Garfi’ almond × ‘Nemared’ peach, red leaves, easy propagation, nematode resistant, good vigor, adapted to replanting and to poor and calcareous soils</td>
</tr>
<tr>
<td>Monegro</td>
<td>‘Garfi’ almond × ‘Nemared’ peach, red leaves, easy propagation, nematode resistant, good vigor, adapted to replanting and to poor and calcareous soils</td>
</tr>
<tr>
<td><strong>EE Aula Dei - CSIC (Zaragoza)</strong></td>
<td></td>
</tr>
<tr>
<td>Adafuel</td>
<td>Natural hybrid selection (probably ‘Marcona’ seedling), easy propagation, very vigorous, adapted to calcareous soils</td>
</tr>
<tr>
<td>Adarcias</td>
<td>Natural hybrid selection, easy propagation, low vigor, adapted to calcareous soils</td>
</tr>
<tr>
<td><strong>ITALY</strong></td>
<td></td>
</tr>
<tr>
<td>University of Pisa</td>
<td></td>
</tr>
<tr>
<td>Sirio</td>
<td>‘INRA GF 557’ OP, low vigor, poor vegetative propagation, good root system</td>
</tr>
<tr>
<td><strong>UNITED STATES</strong></td>
<td></td>
</tr>
<tr>
<td>California</td>
<td></td>
</tr>
<tr>
<td>Atlas</td>
<td>Interspecific cross to Prunus blireiana, vigorous, upright</td>
</tr>
<tr>
<td>Hansen 536</td>
<td>Almond × peach hybrid, vigorous, deep rooting, resistant to drought</td>
</tr>
<tr>
<td>Nickels</td>
<td>Almond × peach hybrid, vigorous, deep rooting, resistant to drought, soil fungi</td>
</tr>
<tr>
<td>Marianna M40</td>
<td>P. cerasifera × P. munsoniana, improved anchorage, fewer suckers</td>
</tr>
<tr>
<td>Viking</td>
<td>Interspecies cross to P. blireiana, vigorous, upright, tolerant wet soils</td>
</tr>
</tbody>
</table>
VI. NEW WORLD DISSEMINATION

Almond dissemination to the New World followed early colonization by European and Asian settlers, eventually resulting in commercial plantings in North and South America, Australia, and South Africa. Successful cultivation typically occurred only after a series of failures as early settlers, not recognizing the degree of almond’s vulnerability to winter cold, spring frosts, and summer rains, tested different growing regions and germplasm until suitable combinations were found. Almond’s introduction into California, which began as an extension of the Mediterranean culture utilizing a limited range of European germplasm (Wood 1925) is representative of the New World stage from 1850 to the present. California production, however, inevitably broke from the “traditional” methods of almond growing utilized in the rest of the world. Key adaptations included: (1) selection of specific vegetatively propagated cultivars and rootstocks to maximize production; (2) standardization of markets based on cultivar; (3) selection and optimization of growing sites; and (4) development of new cultural and management techniques, including increased mechanization, agrochemical inputs, and supplemental pollination. The impact of these changes has been to maximize yield and to promote modern industrial and marketing techniques (Kester et al. 1991; Micke 1994). Commercial cultivars introduced to California from the Languedoc area of southern France from 1850 to 1900 included ‘Princess’, ‘Languedoc’, ‘Gros Tendre’, ‘Sultana’,

Fig. 2.16. Illustrations representing different heirloom almond varieties from the Genoa region of Italy.
and others that ultimately provided the germplasm from which the California almond industry evolved (Wood 1925). Originally these were grown primarily in solid plantings and considered to be “shy-bearing” (because almond is self-sterile and needs pollenizers), “nonadapted,” and “susceptible to frost and disease” (Chappelow 1893; Dargitz 1910; Wickson 1910). The eventual combination of highly adapted and rootstocks and multiple interplanted cultivars, the use of honeybee hives to maximize cross-pollination at flowering (Thorp and Roper 1994), favorable soil and climate, and abundant water and effective management has resulted in the highest productivity in the world and the domination of world markets (Kester et al. 1991; Micke 1994). Yields per hectare continues to show upward trends with yield as high as 4,500 kg/ha not unusual.

An important initial step toward maximizing output was the (1900 to 1925) selection of four cross-compatible cultivars (‘Nonpareil’, ‘Mission’, ‘Ne Plus Ultra’, and ‘Peerless’) that established the basic industry cultivar pattern in the orchard and the marketplace. Shifts to more productive soil areas, changes in management, and the change to peach rootstocks brought about changes (1925 to 1955) that resulted in a shift from what was initially a subsistence enterprise to a major, dedicated agricultural industry. This change reflected the contributions from many sources, including research and extension from the University of California, Davis, a progressive nursery industry, innovative growers and industry leaders, and government policies that promoted the development of irrigation and marketing. In the period 1955 to 1965, the management patterns and world economic and marketing trends began to change and the industry entered an explosive growth period. Expansion occurred into all areas of the central valleys of California, increasing fivefold in area and tenfold in overall production. As a result, California production came to dominate world production (Fig. 2.17).

Almond cultivars and cultural management methods were introduced to Australia, Chile, and Argentina from California and different Mediterranean areas in the early to mid-19th century. In Australia, chance seedlings from this material resulted in selection of cultivars that have became more or less standard, such as ‘Chellastan’, ‘Johnston’, ‘White Brandis’, ‘Bruce’, and ‘Boxendale’ (Quinn 1928). More recently, the list has been supplemented by new introductions from California. South Africa grows limited almonds following introduction about the turn of the 20th century. The principal cultivars are from California, but a local selection, known as ‘Britz’, was important in establishing the early industry (Davis 1928).
VII. GLOBAL COMMERCE

A. Production

Global commercial production was approximately 772,468 million tonnes (Mt) in 2007–2008. California accounted for approximately 80% with a 2008 production of 627,315 Mt (Fig. 2.17) from 261,076 ha (bearing). Spain, the second leading country, produced approximately 8% of world production but utilizes a cultivated area of over 436,500 ha (Murua et al. 1993). The remaining world production comes from about 20 countries including Australia (3%), Turkey (2%), Greece (2%), Italy (1.5%), Chile (1%), China (0.2%), and India (0.1%) (ABC 2008). Limited almond production for both local and export markets also occur in other areas of the Mediterranean, including Portugal, Morocco, Tunisia, Algeria; areas of the Balkan Peninsula, including Bulgaria, Romania, and Hungary; and central and southwestern Asia, including Syria, Iraq, Israel, Iran, Ukraine, Tajikistan, Uzbekistan, Afghanistan, and Pakistan. Almond growing in much of this area is in a relatively archaic state, although modern production areas exist in Portugal and in some parts of Ukraine and Iran. Despite falling production in most traditional almond producers, global production actually has more than doubled in the last

20 years from a 1998 crop of 354,259.3 Mt. Most of the increase in production has occurred in California, where a fivefold increase in crop area combined with a more than doubling in yields per hectare resulted in an almost tenfold increase in production over the last 30 years. This combination of increased plantings coupled with increased cropping efficiency has made almonds the largest export crop for California (Fig. 2.18) and has resulted in expanded research on production efficiency as well as phytonutrient value and culinary uses of almond (ABC 2008).

B. Consumption

Consistent with its Mediterranean and Asian culinary origins, almond continues to show great versatility with its distinctive culinary heritage, as with marzipan paste (see Fig. 2.19) in addition to its more traditional role as a convenient and nutritious snack nut (Table 2.5). At 0.6 kg, the per capita consumption of almonds in the United States has increased by over 20% over the last four years. Similar increased demand has occurred in traditional European and Asian markets (Fig. 2.20). Expanding markets have increased the food and even industrial utilizations of
almond (such as hand creams) well beyond its traditional use. As in the past, the perceived culinary and medicinal value of almonds remains a driving force for market expansion. Recent medical studies have documented health benefits from almond consumption in a range of areas, including protection from cancer, obesity, and heart disease (see recent review by Socias y Company et al. 2007). The widespread availability and low cost of almonds relative to other nut crops have also encouraged expanded use (Fig. 2.21), either in combination or as replacements for other nuts in confectioneries, cereals, and baked goods. A highly developed international marketing system has emerged to distribute the billion-dollar-per-year almond crop (Alston et al. 1993; ABC 2008). In addition to ensuring product quality and availability, these advanced marketing systems are also important in ensuring food safety, particularly the prevention of product contamination by fungal toxins such as aflatoxin or microbial contamination as with *Salmonella* spp. (IPM 1995). Global market requirements for product consistency, however, have moved beyond food safety and food quality concerns. The increasing sophistication of culinary and food service uses are progressively demanding more standardized kernel type for industrialized handling, as in slicing and slivering (Table 2.5). Even in the making of food products emphasizing the natural amaretto almond flavor, processors often prefer using a more consistently bland cultivar as the basic nut to which they can add either limited bitter nuts or almond extract as needed. In California, ‘Nonpareil’ (Fig. 2.22) has become the cultivar

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**Fig. 2.19.** Almond paste (left), which is commonly called marzipan but known by regional names throughout Europe, Asia, and North Africa, is a confection consisting primarily of sugar and almond meal. The incorporation of bitter almonds, which constitute approximately 5% of the total weight, gives it its distinctive flavor. It is often made into sweets or glazes for cakes, or used as a cake ingredient, as in stollen. In addition, it can be consumed directly, in many regions after being shaped into small figures as a traditional treat for New Year’s Day (right).
most widely planted, partly because it satisfies most of these market needs for consistency combined with a relatively long and elliptical kernel, which further facilitates its processing. Approximately 37% of the current California crop area is planted to ‘Nonpareil’ with an additional 15% planted to do similar market type ‘Carmel’. The remaining cultivars are primarily planted as pollenizers to ensure high fruit set. Thus, the anticipated introduction of self-fruitful ‘Nonpareil’-type cultivars in the next decades would further and probably dramatically

Table 2.5. Commercial almond products and applications.

<table>
<thead>
<tr>
<th>Common products</th>
<th>Benefits</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural almonds, whole and whole &amp; broken</td>
<td>Provides color contrast to lighter foods; adds visual appeal nutritional value and texture; stronger flavor than blanched products</td>
<td>Roasting, flavoring, snack foods; complementary ingredients for confectionery, cake, bread, cookies and cooking, etc.</td>
</tr>
<tr>
<td>Natural or blanched sliced almonds</td>
<td>Increases almond recognition; adds flavor, visual appeal, and nutritional value; provides texture contrast</td>
<td>Cake, bread and cooking garnish; cereal additive ingredients.</td>
</tr>
<tr>
<td>Natural or blanched diced almonds</td>
<td>Adds almond flavor and characteristics, nutritional value, and visual appeal</td>
<td>Cake and confectionery fillings; additive ingredients for cooking</td>
</tr>
<tr>
<td>Blanched almonds, whole &amp; broken</td>
<td>Complementary flavor, high quality, garnishing, visual contrast and nutritional value</td>
<td>Ingredients for mixed dried fruits and nuts retail packing, and blanched manufactured products; cookie and cake garnish</td>
</tr>
<tr>
<td>Blanched slivered almonds</td>
<td>Adds crunchy, complementary flavor, and nutritional value</td>
<td>Ingredients for cake, cookie, bread, snack, and cereals; additive ingredients for cooking</td>
</tr>
<tr>
<td>Natural or blanched almond meal</td>
<td>Adds color, flavor, richness and nutritional value; fat replacement and binding agent</td>
<td>Cake and confectionery fillings; ingredients for fortified breads and cereals</td>
</tr>
<tr>
<td>Roasted almonds</td>
<td>Strengthen flavor and color and nutritional value</td>
<td>Fillings and garnish for dairy products (e.g., ice cream); ingredients for energy and chocolate bars.</td>
</tr>
<tr>
<td>Oil</td>
<td>Stability, low rancidity, high oleic acid content and nutritional value</td>
<td>Base for cosmetics, ointments, skin creams, and other pharmaceuticals</td>
</tr>
<tr>
<td>Hull</td>
<td>High carbohydrates and nutrients, adds flavor</td>
<td>Dairy cattle feed</td>
</tr>
</tbody>
</table>

most widely planted, partly because it satisfies most of these market needs for consistency combined with a relatively long and elliptical kernel, which further facilitates its processing. Approximately 37% of the current California crop area is planted to ‘Nonpareil’ with an additional 15% planted to do similar market type ‘Carmel’. The remaining cultivars are primarily planted as pollenizers to ensure high fruit set. Thus, the anticipated introduction of self-fruitful ‘Nonpareil’-type cultivars in the next decades would further and probably dramatically
Fig. 2.20. California export markets in 2007–2008.

Fig. 2.21. World commercial use of various tree nuts by proportion (2007–2008).
promote greater crop uniformity and compatibility with expanding international markets. These global market pressures toward more uniformity in the almond crop would consequently lead to continued and perhaps accelerated loss of native genetic diversity and thus genetic options against emerging pests and diseases. Considerable losses in germplasm have already been documented in traditional Mediterranean and Asian growing areas as new market-orientated cultivars are brought in to replace the traditional, locally adapted cultivars and landraces established over hundreds to thousands of years.

VIII. EVOLVING REQUISITES FOR COMMERCIAL ALMOND

Recognizing the genetic, environmental, and management deficiencies of the traditional almond industries, most almond-producing countries are pursuing almond research with emphasis on germplasm evaluation and cultivar and rootstock improvement. These activities followed a pattern that included: (1) surveys of local cultivars and seedling populations within the traditional almond growing areas; (2) establishment of

Fig. 2.22. ‘Nonpareil’-type paper shell and uniform, amygdaloidal kernel, which is becoming the market standard in world commerce.
cultivar collections and test planting to evaluate local and introduced almond cultivars; (3) establishment of germplasm collections for maintenance of local and introduced cultivated almond as well as related species; and (4) development of controlled breeding methods to incorporate desirable new traits into locally adapted material and so generate new cultivars and rootstocks to optimize regional performance. Some traits, such as self-fruitfulness and certain disease resistances, were not readily available in cultivated almond and required introgression from related species. Crosses of *Prunus dulcis* with other almond species in Sections *Euamygdalus* and *Spartiodes* are generally easily accomplished (Denisov 1982, 1988, 1989; Kester et al. 1991; Gradziel et al. 2001). Hybridization with Section *Lycioides* is somewhat more difficult and even more so with *Chameamygdalus* and *Leptopus* (Denisov et al. 1983; Denisov 1988; Chepinoga 1990). Crosses with peach (*Prunus persica*) can be made easily, although some types of sterility may occur in the progeny (Ryabov 1969; Kester and Gradziel 1996). Crosses with plum are possible but difficult (Grasselly et al. 1992). Crosses with apricot are very difficult but have been reported (Jones 1968). The extent of new germplasm incorporation, as well as general breeding approach, however, varies by region (Table 2.6).

A. Mediterranean

Modern cultivar improvement had its start with the beginning of cultivar collections at Bordeaux in 1951 and in 1961 at Nimes under the direction of Dr. Charles Grasselly (1972). A survey of the germplasm potential throughout the Mediterranean region was followed by collecting trips to Iran, the Soviet Union and Afghanistan (Grasselly and Crossa-Raynaud 1980), and 450 accessions from 10 different countries were collected, evaluated and described. This study provided the basis of the concept of local ecotypes in different almond-growing districts (Crossa-Raynaud 1977, 1981), and the collection is the base of an almond Germplasm Repository at Montfavet, France. Controlled crosses begun in 1961 in France produced valuable inheritance data (Grasselly 1972) and resulted in new cultivars and rootstocks. Initial objectives were to combine late bloom, high production, and improved nut and kernel quality. The first releases (Grasselly 1975) from this program, ‘Ferragnes’ and ‘Ferraduel’, were cross-compatible and when planted in combination shifted the blooming date approximately 2 weeks later than prevailing cultivars. This combination quickly became the basis for new orchard plantings in France and the rest of the Mediterranean. These cultivars arose from crossing representatives of two ecotypes,
Table 2.6. Objectives of modern almond improvement programs.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Trait</th>
<th>Objective</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring frosts</td>
<td>Late bloom; blossom resistance</td>
<td>Avoid early and late spring frosts</td>
<td>USA, Ukraine, France, Greece, Spain, Italy, Romania, Turkey, Bulgaria</td>
</tr>
<tr>
<td>Winter freezing</td>
<td>Hardy buds and wood</td>
<td>Avoid loss of dormant flower buds; avoid tree damage</td>
<td>Ukraine, Romania, Bulgaria</td>
</tr>
<tr>
<td>Low winter chilling</td>
<td>Low chilling requirements</td>
<td>Grow in subtropical area</td>
<td>Israel, Tunisia, Australia, Morocco</td>
</tr>
<tr>
<td>Moisture stress</td>
<td>Drought tolerance</td>
<td>Grow with deficient irrigation</td>
<td>Spain, Italy</td>
</tr>
<tr>
<td>Lack of or reduced bee populations</td>
<td>Self-fertility</td>
<td>Eliminate or reduce need for bee pollinizers</td>
<td>France, Greece, Tunisia, Italy, Spain, USA</td>
</tr>
<tr>
<td>Disease and pests</td>
<td>Resistance to fungus and bacterial diseases, and insects</td>
<td>Eliminate or reduce need for chemical sprays</td>
<td>USA, France, Spain, Italy, Turkey</td>
</tr>
<tr>
<td></td>
<td>Virus and viruslike organisms</td>
<td>“Clean” propagation sources</td>
<td>USA, Spain, Italy</td>
</tr>
<tr>
<td>High management costs</td>
<td>Modified tree size, shape, branching, growth habit</td>
<td>Efficient orchard management; adjust orchard density; pruning; shaking</td>
<td>USA, Spain</td>
</tr>
<tr>
<td>Difficult harvest and handling</td>
<td>Optimize time of maturity, ease and completeness of nut removal, hulling</td>
<td>Extend harvest period; efficient and complete harvest</td>
<td>All programs</td>
</tr>
<tr>
<td></td>
<td>Shell character—very hard shell</td>
<td>Kernel protection and storage; prevent worm infestation</td>
<td>Spain, France, Italy</td>
</tr>
<tr>
<td></td>
<td>—semi-soft to soft</td>
<td>Higher shelling percentages</td>
<td>USA, Ukraine, France</td>
</tr>
<tr>
<td></td>
<td>—well sealed</td>
<td>Kernel protection</td>
<td>USA, all programs</td>
</tr>
<tr>
<td>Inconsistent yields</td>
<td>Improve tree: precocity, productivity, regularity of bearing</td>
<td>Early production; high yield, no alternate bearing</td>
<td>All programs</td>
</tr>
<tr>
<td></td>
<td>Nut quality</td>
<td>Increased kernel yield and reduced damage</td>
<td>All programs</td>
</tr>
</tbody>
</table>
‘Cristomorto’, an Italian cultivar from Puglia, which was late blooming due to a high chilling requirement for bloom, and ‘Ai’, a cultivar from France that was late blooming due to a high heat requirement. Later disease resistance from the French cultivars ‘Ardechoise’ and ‘Mandaline’ were incorporated into the program as well as late bloom from ‘Tardy Nonpareil’ (Grasselly 1978; Duval 1999). Almond improvement programs were developed at Zaragoza, Spain, by A. Felipe (Felipe and Socias i Company 1977a, 1985, 1992); at Reus, Spain, by F. Vargas-Garcia (1975a,b), Barraquer and Vargas-Garcia (1975), and Vargas and Romero (1993); and at Murcia, Spain, by Egea and Garcia (1975), Garcia et al. (1988), and Dicenta et al. (1993). Genetic improvement programs were initiated in Tunisia by Jaquani (1976) and El Gharbi (1977) and in 1970 at Rome, Italy, by F. Monastra (Monastra and Fideghelli, 1977; Monastra et al. 1982, 1985). Almond improvement programs were initiated in Greece in 1960 by D. Stylianides (1977).


Turkey began a program of selection among seedling populations for late bloom and frost resistance for interior Turkey (Ayfer 1975) and in southwest Turkey for late bloom, adaptation, and improved quality (Dokuzogus and Gulcan 1973, 1977; Dokuzogus 1975; Gulcan 1977). Crossing programs were begun in 1990 (Gulcan et al. 1992).

Surveys of local germplasm also occurred in Turkey (Dokuzogus 1975; Kuden et al., 1993), Sicily (Barbera et al. 1988), and Sardinia (Agabbio et al. 1984; Chessa and Pala 1985). Evaluations of unique North African germplasm in the local seedling populations were carried out in Morocco (Barbeau and El Baudami 1977; Laghezali 1985; Loussart et al. 1989). These populations are considered to have good potential for germplasm exploration (Lansari et al. 1994). In virtually all of these areas, destruction of many local groves and so loss of traditional germplasm has already occurred.

The Groupe de Recherche et d’Etude Mediterraneen Pour l’Amandier (GREMPA) was formed in 1974. This group organized almond researchers into an informal association whose purposes were to provide a forum to exchange information and plant materials and to coordinate breeding and testing efforts (Crossa-Raynaud 1975; Socias i Company 1998).
B. California

Beginning in the mid-1950s, the major source of new cultivars was the population of almond seedlings found throughout California either along roadsides and near commercial orchards or in orchards from unbudded almond seedling rootstock “escapes.” Since 1957, many selections from this source were patented and introduced by individual growers as commercial cultivars through commercial nurseries (Brooks and Olmo 1997). Most, including ‘Merced’, ‘Price’, ‘Carmel’, and ‘Fritz’, were used to provide cross-pollination to ‘Nonpareil’. Others, such as ‘Thompson’ and ‘Livingston’, were later blooming and were combined with ‘Texas’. A cooperative breeding program initiated in 1923 at Davis, California, between the U.S. Department of Agriculture (USDA) and the University of California was an outgrowth of early pollination and variety evaluation studies (Wood 1938). This program was separated in 1948. The USDA program was continued until 1975. The University of California program has continued and resulted in the release of a number of cultivars and rootstocks (Kester et al. 1996).

C. Eastern Europe and Asia

After California, the second oldest continuous breeding program for almond has been at the Nikitski Botanical Garden at Yalta, Crimea, in the former Soviet Union (now Ukraine) under the direction of A.A. Richter (Richter 1969, 1972) and Yadrov (1993). These began with the research of N. Vavilov (1930) and were based on extensive species and cultivar collections. Other programs have been in progress in the Asiatic republics (Denisov 1988). The primary objectives have been to develop hardiness to winter cold and spring frosts and to investigate the breeding potential of wild almond species.

Hardy, late-blooming cultivars were introduced for commercial production in the southern Soviet Union during the 1950s (Denisov, 1988), into Bulgaria in 1956 (Serafimov 1975, 1976), and later into other Mediterranean countries (Guerriero et al. 1974; Grasselly and Crossa-Raynaud 1980; Garcia et al. 1988; Vargas and Romero 1988). Additional almond cultivars have been introduced by Yadrov in a continuation of this program.

Research has been carried out by other Asiatic republics including Turkmenistan, Tadjististan (Mizgireva 1973), and Uzbekistan (Komarov et al. 1941). This research involves populations of the Kopet Dagh populations of *P. communis* (Denisov 1977a,b; Saporov 1978) and many wild species (Denisov 1982; Eremin and Denisov 1984; Chepinoga 1990).
In Romania, selection of local cultivars has resulted in improved commercial plantings, and a breeding program has introduced new cultivars (Cociu 1981).

The foothill districts of northern India, including the Kashmir, provinces of Jammu and Himachal Pradesh (Uppal 1977a,b; Singh et al. 1977; Singh and Uppal 1977) as well as northeastern Pakistan (Thompson et al. 1990) have historically had many seedling almond orchards. Studies of promising seedlings and introduced almond cultivars have been undertaken (Kumar et al. 1989; Kumar and Uppal 1990).

Several almond species and commercial cultivars exist in the Xinjiang Province of western China (Gustafson et al. 1989) near the ancient cities of Kashgar and Sache on the ancient Silk Route. A program of almond improvement has been carried out by Professor Zhu Jing Lin at the Xinjiang Academy of Forestry since 1970 with the objectives of cold hardiness and dwarfing rootstocks.

IX. CONCLUSIONS

The wide dispersion of almond and its wild relatives in the often severe environments from Central Asia to the Mediterranean was possible largely because of the genetic and associated developmental/physiological diversity promoted by this typically self-sterile yet interspecies fruitful genus. Even today, evidence of species mixing of the traditional Asian badam is evident in many rural bazaars by the presence of shell patterning characteristic of other species (Fig. 2.2). The cultivated Greek nut, which appears to have gained wide prominence in prehistoric Greco-Persian commerce, may well have originated from an interspecies cross with P. fenzliana and owes its existence and eventual commercial ascendancy to human selection. Gene transfer between wild and cultivated almond continued to be important in the early dissemination of this crop, as evidenced in the transfer of self-compatibility from wild P. webbii to the old cultivated landraces in southern Italy. ‘Tuono’, an old Italian cultivar selected from these landraces, is currently the most important source for self-compatibility in Mediterranean and Asian breeding programs (Table 2.3). However, despite its historical wide acceptance throughout the Mediterranean, ‘Tuono’ and many of the regional heirloom cultivars are largely being replaced by new orchards designed to maximize production (Fig. 2.23) of a more globally standardized market quality. Regionally adapted (to both local culture and cultivation) cultivars are also being lost as traditional plantings are converted to other crops or to other consequences of modern
development. Similar “progress” is leading to the loss of native germplasm throughout the Asian and Mediterranean centers of origin and diversity (Ledig 1992). The fragile nature of many of these wild almond ecosystems (e.g., the dependency on a minimum spring snowmelt for summer drought survival) make them particularly vulnerable to a range of environmental perturbations from human enterprises to global warming. Concurrent with and contributing to germplasm loss is the rapid expansion of almond cultivation to satisfy an escalating global demand. The extensive commodity standardization associated with these complex, international markets has been largely achieved by dependence on a few standard cultivar types, as with ‘Nonpareil’/‘Carmel’ type in California (Fig. 2.22), which is also increasingly grown in many international plantings. And with a 2007–2008 California production of over 225,000 Mt, the 5% substandard-size nuts that might normally be considered rejects can effectively compete with markets normally utilizing smaller, lower-value nuts. Even when found to be poorly adapted locally,
these market standards often are used as breeding parents to combine desired market quality with local adaptability (Tables 2.3 and 2.6). For example, virtually all of the other commercially important California cultivars are progeny of ‘Nonpareil’ by ‘Mission’ crosses (Kester et al. 1991, 1996), with the few exceptions being cultivars developed by university programs (Table 2.3). Recent history has demonstrated the dangers of too great a dependence on a limited germplasm, including significant economic losses from disease, pest, and climate change (Tanksley and McCouch 1997). A similar danger also exists in the loss of the extensive medical and culinary legacy of the current diversity of almond germplasm at a time when we are just beginning to understand their unique contributions. Inevitably, the modern marketing folklore that uniformity is good may be found to be myth.

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