Genetic Resources of Almond Species in the Former USSR

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Abstract. *Prunus dulcis* (Mill.) D.A. Webb. is grown as an economically valuable crop in a number of countries worldwide, but large-scale cultivation has been primarily restricted to semiarid and arid regions with mild, temperate climates. Considering the species' wide native range and inherent genetic, morphologic, and phenologic diversity, almond remains quite underused in areas outside those currently in cultivation. The area comprising the former USSR represents an extremely large and diverse region and is a center of genetic diversity for *P. dulcis* and related species. Much of this region, which is the center of origin and/or diversity of many important crops, has been inaccessible to the Western world for centuries, and much of the scientific literature produced there has not been widely disseminated in the English language. Since the breakup of the USSR, this region has become increasingly open and opportunities for reciprocal germplasm collection, exchange, and scientific collaborations are growing. To bring increased attention to the valuable *P. dulcis* genetic resources endemic to this region, and to promote better use, management, and preservation of these important resources, the wild distribution of almond and closely related species, and extensive germplasm holdings of institutions across the former USSR, are herein described. Recent and ongoing collection and breeding activities in the U.S. Intermountain West are also discussed.

Taxonomy. The cultivated almond [*Prunus dulcis* (Mill.) D.A. Webb.; syn. *Amygdalus communis* L., *Amygdalus dulcis* Mill.; *Prunus amygdalus* Batsch.] has a long and complex history, both taxonomically and geographically. The species belongs to subgenus *Amygdalus* (L.) Focke of the genus *Prunus* L. in the Rosaceae family (Yazbek, 2010; Yazbek and Oh, 2013). The genus *Prunus* is itself taxonomically complex, and over the centuries, botanists have developed various circumscriptions. These

classifications have ranged from splitting *Prunus* sensu lato (s.l.) into many segregate genera, including *Amygdalus* L., *Armeniaca* Scop., *Cerasus* Mill., *Emplectocladus* Torr., *Laurocerasus* Duhamel, *Maddenia* Hook.f. & Thomson, *Padus* Mill., *Persica* Mill., *Prunus* L. sensu stricto (s.str.), and *Pygeum* Gaertn., to considering it a large, single genus with many subgenera (De Candolle, 1825; Focke, 1894; Hutchinson, 1964; Koehne, 1893; Linchevskii and Fedorov, 1941; Takhtajan,

1997; Yü et al., 1986). Rehder (1940) divided the genus into five subgenera: *Amygdalus* (L.) Focke, *Cerasus* (Mill.) Focke, *Laurocerasus* (Duhamel) Rehder, *Padus* (Mill.) A. Gray, and *Prunophora* Focke (= *Prunus* s.str.), and this treatment has been followed by many taxonomists [see Bortiri et al. (2002), Lee and Wen (2001), and McVaugh (1951) for detailed review regarding taxonomic treatments of *Prunus*].

Subgenus *Amygdalus* includes 24 to 40 species depending on the treatment and is composed of deciduous shrubs or small trees (Gradziel, 2010; Yazbek, 2010). These species are native to the Old World with a particular diversity of species in southwestern and central Asia. Spach (1843), who classified *Amygdalus* as a separate genus, divided the group into five sections. Browicz and Zohary (1996) and Denisov (1988) also retained *Amygdalus* as a separate genus, and both presented a complex system of taxonomy with four and five sections, respectively. Alternatively, a simplified classification with two sections has been proposed: section *Persica*, the peach-type species, and section *Amygdalus*, the almond-type species (Browicz and Zohary, 1996; Yazbek and Oh, 2013; Zhukovsky, 1971). The taxonomy of the species within subgenus *Amygdalus* is complicated by the fact that many of the species have the capability to hybridize. This has led to confusion about species delineations and whether many of the described species should be categorized as subspecies or ecotypes (Gradziel, 2010). Based on phylogenetic analyses, Yazbek and Oh (2013) removed a number of species from *Prunus* subg. *Amygdalus*. Two of the species, *P. tenella* Batsch. and *P. petunnikowii* Litv., have been traditionally placed in *Prunus* subg. *Amygdalus* sect. *Chamaeamygdalus* Spach but were determined to fall outside the monophyletic clade representing species normally considered to be in *Prunus* subg. *Amygdalus*.

This review focuses on the 16 species traditionally placed in *Prunus* subg. *Amygdalus* that are found in the area comprising the former USSR (Abdurasulov, 1990; Dzhangaliev et al., 2003; Rubtsov, 1971; Zhukovsky, 1971). The distribution and significant traits of *P. dulcis* and closely related species are presented (Table 1) and extensive germplasm holdings of institutions across the former USSR are described. It is the aim of this review to highlight the great genetic diversity that is available and to bring increased attention to the valuable genetic resources that are unique to this region. To promote better use, management, and preservation of these important resources, dissemination of this information is critical. Recent and ongoing collection and breeding activities are also discussed. By accessing and using these resources, it may be possible to expand the range of almond cultivation in the future and find genetic material for the improvement of important traits such as disease resistance, cold and drought tolerance, and desirable nut characteristics.

Global almond production. Almond was the fourth most abundantly produced nut crop

worldwide in 2012 and 2011, the years with the most recent global statistics (FAOSTAT, 2014). In 2012, there were 1.935 million MT of in-shell nuts produced, which was down from 1.964 million MT in 2011 (FAOSTAT, 2014). According to FAOSTAT (2014), almond production in the United States was 720,000 MT in 2012 and 731,236 MT in 2011, which accounted for $\approx 37\%$ of the world supply in both years. The other top almond-producing countries in 2012 were Spain, Australia, Iran, Morocco, and Italy (FAOSTAT, 2014; Table 2). Although important wild germplasm and institutional germplasm collections can be found in countries of the former USSR, they do not have a significant almond industry in terms of global production (Table 2).

The percentage of global production attributed to the United States is markedly different in data presented by the U.S. Department of Agriculture, who stated that for the 2011–12 marketing year, the United States was responsible for nearly 85% of the global production of shelled almonds (USDA-FAS, 2013). This difference may be the result of reporting in-shell vs. shelled production and variation of kernel percentage between soft shell and hard shell-type cultivars. Typically, 60% to 70% of the weight of in-shell ‘Nonpareil’ almonds (a paper-shell cultivar) will be kernel and only 30% to 40% will be shell. The soft-shelled cultivars, Nonpareil and Carmel, account for the majority of cultivated area in California. Hard-shell almonds, commonly produced in Spain and elsewhere, may have 25% kernel and 75% shell (Rosengarten, 2004).

Almond cultivation in the United States is primarily located in California’s Central Valley with the majority of production (63%) occurring in Kern, Fresno, Merced, and Stanislaus Counties (CDFA, 2013). As of 2010, the ‘Nonpareil’ variety accounted for the largest total cultivated area, covering $\approx 111,767$ ha (37%) of the 299,188 ha in California planted with almonds. The other most commonly grown varieties are ‘Carmel’ (34,104 ha), ‘Butte’ (35,433 ha), ‘Monterey’ (33,380 ha), and ‘Padre’ (22,558 ha). The

2012 value of production of all California almond tonnage was reported to be over \$4.1 billion (USDA-NASS, 2013). Because over 60% of the California almond acreage is composed of only four cultivars, and because almond is such an economically significant crop, it is important to consider the germplasm necessary to support breeding efforts and the development of high-performance cultivars.

Distribution and Cultivation of Almond in the Former USSR

The domestication of almond began in central and south Asia during the third millennium B.C. (Spiegel-Roy, 1986). Vavilov (1931, 1951) classified central Asia as a center of origin for almond as a result of the diversity of almond-related species that occur in the region. As a result of this long association with humans, determining the extent of the natural distribution of *P. dulcis* has been complicated (Zohary and Hopf, 2000). Consequently, researchers delineate the boundaries of naturally occurring almond populations in different ways and disagree as to whether some populations growing spontaneously are truly wild populations, feral populations, or remnants of historical orchards (Yazbek, 2010).

It has been stated that truly wild populations of the species can be found in two separate areas of central Asia (Chernobay and Yarov, 2012; Pakhomova, 1961; Richter, 1972; Zhukovsky, 1971). The first area consists of places on the western side of the Tian Shan mountain system including the Chirchik, Pskem, and Ugam River basins in northeast Uzbekistan and on the slopes of the Chatkal and Gissar ranges in Uzbekistan and Tajikistan (Abdurasulov, 1990; Chernobay and Yarov, 2012; Fedorov, 1957; Kalmykov, 1973; Kasatkin, 1931; Kichunov, 1931). The actual “wildness” of these populations has been contested because of patterns in distribution, the presence of morphological traits associated with domestication (sweet-seeded and paper-shelled), the uniform age of many older trees, and a lack of young trees and seedlings (Browicz and Zohary, 1996; Ladizinsky, 1999). The second area reported to have wild almond trees is in the western Kopet Dag region of Turkmenistan. In this area the species is found within the Ay-dere, Por-dere, and Sumbar Gorges at altitudes of 500 to 1200 (1500) m (Fedorov, 1957; Kalmykov, 1968; Kasatkin, 1931; Kenjebaev et al., 2005; Kichunov, 1931; Richter, 1985; Shalit, 1951; Zhukovsky, 1971). The total land area of wild almond in central Asia in late 1950s was reported to be more than 23,000 ha (Fedorov, 1957). Yarov (1979) and Fedorov (1957) suggested that the ancient areas of wild almond include the western Kopet Dag region (Turkmenistan), the western Tian Shan, Afghanistan, northern Iran, Transcaucasia, Asia Minor, and North Africa. Browicz and Zohary (1996) presented distribution maps representing their treatment of the species, which included three subspecies of *A. communis* (= *P. dulcis*): *A. communis*

L. subsp. communis, *A. communis* L. subsp. *spontanea* (Korsh.) Browicz & D. Zohary, and *A. communis* L. subsp. *microphylla* (Post) Browicz & D. Zohary.

Much of central Asia, the Caucasus, and southern Russia is mountainous, and over 94% of the territories of Tajikistan and Kyrgyzstan are montane or alpine (Akimaliev et al., 2013; Djuraev and Pulatov, 1988). As a result of this topography, the cultivation of nut species on hillsides is necessary and relatively large almond orchards are located in the foothill and mountain areas, where terracing is a commonly used agricultural technique. Expanding human populations in these regions puts a premium on any non-sloping lands, and planting on hillsides allows for better cold air (frost) drainage, particularly during flowering (Fig. 1). Almonds are often grown in home backyards and harvested from wild-growing trees as well. In the southern regions of the former USSR, almonds have been in cultivation for a very long time. This can be observed in the etymology of the name Kanibadam (formerly Kend-i-bodom), a very old city in the Ferghana Valley region of Tajikistan, which translates to “city of almonds” (Bakhteev, 1970).

In central Asia, almond is currently cultivated in Uzbekistan, Tajikistan, and Turkmenistan as well as in some parts of Kyrgyzstan (Osh and Jalal-Abad Provinces). In Uzbekistan, a significant portion of almonds is grown in Tashkent, Surkhandarya, and Samarkand Provinces and in the Ferghana Valley, which spans adjacent regions of Uzbekistan, Tajikistan, and Kyrgyzstan. The total land area of almonds in Uzbekistan is more than 2500 ha with ≈ 1000 ha being cultivated (Mirzaev et al., 2004). The FAO estimated that 2012 almond production (area harvested) in Uzbekistan was 6400 ha (FAOSTAT, 2014). In Tajikistan, 90% of all cultivated almond area is concentrated in the northern part of the country in the Ferghana Valley (Gaivoronskaya et al., 1965). The most favorable regions for the cultivation of almonds are the Khodjent, Kanibodom, Isfara, Ura-Tyube, Shaartuz, Javanese, Kulyab, and Panj Districts (Richter, 1972). In Turkmenistan, small stands of cultivated almonds can be found in the oases of foothills with the best regions for development of commercial-scale almond plantations being in Kizil Atrek and Kara-Kala. In Kyrgyzstan, almonds are primarily cultivated in the southern region of Osh. In the Transcaucasian Republics, almond culture arose during the Persian Empire in the Derbent region (of the Russian Federation), adjacent to the Araks River regions of Armenia and Georgia (Richter, 1972). The seeds of cultivated almonds were discovered in excavations of archaeological sites, near the village of Khanlar in Azerbaijan, and were dated to the first stage of the Bronze Age ≈ 2000 B.C. (Gummel, 1940).

In the former USSR, almond cultivation has apparent advantages when compared with other fruit crops. Almond trees generally require a lower amount of irrigation and fertilization during the growth and harvest periods because the root system can penetrate

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Table 1. Species, synonyms, distributions, and relevant characteristics of almond species found within the former USSR.

Species	Synonyms (not exhaustive)	Distribution within former USSR and relevant traits
<i>Prunus bucharica</i> (Korsh.) Hand-Mazz	<i>Amygdalus bucharica</i> Korsh. <i>Prunus bucharica</i> (Korsh.) B. Fedtsch.	In the Pamir-Alai mountain system: primarily in Tajikistan (south slopes of Gissar and Peter the First Ranges and the south part of the Republic, (Zapryagaeva, 1941, 1964, 1976). The western Tian Shan Mountain system: the Kurama Range (Uzbekistan and Kyrgyzstan). The Kugitang Mountains of Turkmenistan. Occurs at altitudes of 800 to 2600 m (Mirzaev, 1982; Zhukovsky, 1971). The kernels of this species are bitter, but in Tajikistan, there are sweet forms (Zapryagaeva, 1976). The shell (endocarp) is soft. This is very drought-tolerant and has higher winter-hardiness of buds and shoots. A species that is used as a rootstock in almond, peach, and apricot cultivation.
<i>Prunus dulcis</i> (Mill.) D.A. Webb	<i>Amygdalus communis</i> L., <i>Amygdalus dulcis</i> P. Mill., <i>Prunus amygdalus</i> Batsch, <i>Prunus communis</i> (L.) Arcang.	Found growing wild in central Asia, Iran, Turkey, and North Africa (Bakhteev, 1970; Fedorov, 1957; Kasatkina, 1931; Richter, 1985; Zapryagaeva, 1964; Zhukovsky, 1971). Naturalized in south Armenia (Mirmanov, 1935; Zhukovsky, 1971). The kernels can be sweet (used in cultivation) or bitter (in wild populations). Endocarp can be soft or hard. Almost all cultivated material belong to this species.
<i>Prunus fenzliana</i> (Fritsch) Lipsky	<i>Amygdalus divaricata</i> Fenzl ex Fritsch; <i>Amygdalus fenzliana</i> Fritsch	Armenia and the Nakhchivan Autonomous Republic (within Azerbaijan). On slopes up to 1500 m (Aleksanyan, 2012; Zhukovsky, 1971). The fruits occur individually, are sessile, round in shape. It is a cold-resistant species.
<i>Prunus georgica</i>	<i>Amygdalus georgica</i> Desf.; some consider <i>P. georgica</i> a synonym of <i>P. tenella</i> Batsch	Endemic to the Republic of Georgia. Found on hillsides and mountain slopes (Fedorov, 1942; Vermishyan, 1951; Zhukovsky, 1971)
<i>Prunus ledebouriana</i> (Schlecht.) Y.Y. Yao	<i>Amygdalus ledebouriana</i> Schlecht.; some consider <i>P. ledebouriana</i> a synonym of <i>P. tenella</i> Batsch	Endemic to the Tarbagatay Range and the Altai Mountains of Kazakhstan (Dzhangaliev et al., 2003; Zhukovsky, 1971). The kernels contain up to 4% amygdalin and 54% fatty oil. It produces high-yielding crops every year. This species is very similar in appearance to <i>P. tenella</i> but is generally larger in terms of tree size as well as size of leaves and fruits.
<i>Prunus nairica</i>	<i>Amygdalus nairica</i> Fed. and	Endemic to Armenia where it is only found in the Meghri region. Grows at an altitude of 800 to 1500 m (Aleksanyan, 2012; Zhukovsky, 1971). Flowers are solitary and the fruit are nearly round or ovate and flattened. Very drought-tolerant.
<i>Prunus pedunculata</i> (Pall.) Maxim.	<i>Amygdalus pedunculata</i> Pall.; <i>Amygdalus pilosa</i> Turcz.; <i>P. pilosa</i> (Turcz.) Maxim.; <i>Amygdalus petunnikowii</i> Litv.	Found in East Siberia and Mongolia (Zhukovsky, 1971). The flowers open slightly earlier than the leaves. The tube of the calyx is different from other almond species. It is a very cold-hardy species, is very high-yielding, and easily crosses with other almonds.
<i>Prunus petunnikowii</i> (Litv.) Rehder		Endemic species found in the Western Tian Shan Mountain system, the southern Kara-Tau Mountain Range in Kazakhstan, and is widely distributed in Bostandik, Parkent, and Akhangaran area of Uzbekistan. Found at altitudes of 1200 to 2000 m (Dzhangaliev et al., 2003; Mirzaev, 1982; Zhukovsky, 1971). The kernels of this species are bitter, containing 3% to 4% amygdalin and 58% fatty oil (Zhukovsky, 1971). According to a study by Denisov (1990), this species is the most cold-hardy of the central Asian almonds.
<i>Prunus pseudopersica</i>	<i>Amygdalus pseudopersica</i> (Tamamsch.) Fed. and Takht.; <i>Amygdalus urartu</i> Tamamsch. subsp. <i>pseudopersica</i>	Endemic to Armenia. Found on slopes up to 1500 m high with <i>P. fenzliana</i> (Zhukovsky, 1971). The stones are round, very small (1 cm or less), and usually purple in color.
<i>Prunus scoparia</i> (Spach) C.K.Schneid.	<i>Amygdalus scoparia</i> Spach	Southwest Kopet Dag region of Turkmenistan, as well as in Iran. Found at altitudes of ≈ 350 to 700 m (Shalit, 1951; Zhukovsky, 1971). Stones dehiscence freely when ripe. The kernel can be up to 50% of the stone (by weight) and is usually bitter with over 50% oil content (Denisov, 1976; Shalit, 1951). Some populations bloom very late and are early-ripening, resistant to drought, diseases, and insects in comparison with <i>P. dulcis</i> (Mizgireva, 1973)
<i>Prunus spinosissima</i> (Bunge) Franch.	<i>Amygdalus spinosissima</i> Bunge	Across southern central Asia from the Kopet Dag region of Turkmenistan to the Western Tian Shan including the Talas Alatau Range as well as Pamir-Alai (Kuraminsky, Mongoltau, Zeravshamsky, and Turkestansky Ranges), nearly to the Kyzyl-Kum desert. Found in Crimea (Ukraine) as well. Generally occurs at altitudes of 400 to 1500 m (Abdurasulov, 1990; Dzhangaliev et al., 2003; Rubtsov, 1971; Zhukovsky, 1971). The kernel can be 40% to 48% of the drupe (by weight) and is usually bitter with 60% to 62% oil. This species is regarded as being very drought- and frost-tolerant and has both the longest dormancy and latest flowering time.
<i>Prunus tenella</i> Batsch	<i>Amygdalus nana</i> L.	Widely distributed in temperate Eurasia, growing on hillsides and in ravines. Can be found outside of the Ukraine from the steppe zone of Russia to the Altai. Occurring in Kazakhstan in Tobol-Ishim, Kokshetay, Mugodzhari, Torgai, and the Altai foothills (Dzhangaliev et al., 2003; Rubtsov, 1971; Zhukovsky, 1971). Fruits 1 to 2 cm long and 1.2 to 1.8 cm wide. The kernels are bitter, contains 4.5% amygdalin. It is a very cold-hardy species.
<i>Prunus turcomanica</i> (Linez.) Kitam	<i>A. turcomanica</i> Linez.; <i>A. spinosissima</i> subsp. <i>turcomanica</i> (Linez.) Browicz	Found growing on the Badkiz and Kopet Dag mountains, Turkmenistan (Shalit, 1951; Zhukovsky, 1971). Stones drop freely when mature. There are forms with sweet kernels and the kernel can be 50% of the drupe (by weight). It is extremely drought-tolerant and can be cultivated and used as a rootstock for <i>P. dulcis</i> and peach.
<i>Prunus ulmifolia</i> Franch.	<i>Aflautunia ulmifolia</i> (Franch.) Vassilez.; <i>Amygdalus ulmifolia</i> (Franch.) Popov; Louiseania ulmifolia (Franch.) Pachom.; <i>P. baldschuanica</i> Regel; some consider <i>P. ulmifolia</i> a synonym of <i>P. triloba</i> Lindl.	Endemic to central Asia (Goloskokov, 1954). Can be found in the western Tian Shan and Pamir-Alai Mountain systems. Found at altitudes of 1500 to 2500 m in Tajikistan, Uzbekistan, and Kyrgyzstan (Zhukovsky, 1971). Fruits are nearly round, covered with short hairs, and pale red. When ripe, the mesocarp does not open, although all fruits drop from the tree. It readily hybridizes with other <i>Prunus</i> species.

(Continued on next page)

Table 1. (Continued) Species, synonyms, distributions, and relevant characteristics of almond species found within the former USSR.

Species	Synonyms (not exhaustive)	Distribution within former USSR and relevant traits
<i>Prunus urartu</i>	<i>Amygdalus urartu</i> Tamamsch.	Occurring in Armenia, in the Gami, Geghard, and Gokht River Gorges. Predominantly in the southern slopes of the Gami River Gorge, on the slopes of Mount Aragats in Vedensky Canyon, Azizbayov District, and in Nakhchivan. Found primarily in dry and rocky environments (Zhukovsky, 1971). The fruits are typically solitary, but sometimes in pairs. This species is drought-tolerant.
<i>Prunus × vavilovii</i> (Popov) A.E. Murray	<i>Amygdalus vavilovii</i> Popov	In the western Tian Shan (the basins of Chirchik, Chatkal, Kok Su, Ugam Rivers, Uzbekistan) and in the Pamir Alai, Tajikistan. Found at altitudes of 1600 to 1900 m (Abdurasulov, 1990; Zapyrugaeva, 1976). Determined to be a naturally occurring hybrid of <i>P. dulcis</i> × <i>P. turcomanica</i> . The pink flowers are large, up to 3.5 to 4 cm in diameter and almost sessile. The fruits are usually 2.5 to 3 cm long, although larger have been found (up to 3.8 cm), and 1.5 to 1.8 cm wide (2.5 cm have been reported). Kernels are sweet or sometimes bitter.

Table 2. Top 10 almond-producing countries and production in countries of the former USSR for 2012 and 2011 (FAOSTAT, 2014).

Country	Production (tonnes) ^z	
	2012	2011
United States	720,000	731,236
Spain	215,100	211,717
Australia	142,680	150,506
Iran	100,000	92,491
Morocco	99,067	96,231
Italy	89,865	104,790
Syria	86,271	130,296
Turkey	75,055	69,838
Tunisia	70,000	61,000
Afghanistan	62,000	60,611
Uzbekistan	20,000	19,313
Tajikistan	3,500	3,433
Kyrgyzstan	1,700	1,609
Turkmenistan	1,200	1,073
Georgia	900	858
Republic of Moldova	600	600
Azerbaijan	565	559
Kazakhstan	100	89
Ukraine	10	10
Russia	Not reported	Not reported

^zAlmonds, with shell.

to a depth of more than 6 m (Richter, 1972). Almond harvests in the former USSR, as a whole, have been steadily increasing over the last few decades, mostly as a result of increased cultivation, whereas past production was heavily reliant on wild collection. In the early 1960s, the USSR had ≈700,000 cultivated almond trees, including ≈200,000 in central Asian countries [48% in Tajikistan, 42% in Uzbekistan, 6% in Turkmenistan, and 3% in Kyrgyzstan (Gaivoronskaya et al., 1965)]. In 1970, the total number of cultivated almond trees was over 1.2 million (Richter, 1972). By 1985, total almond cultivation in the USSR stayed consistent at ≈1.2 million trees (Epikhina, 2007).

The amount of trees in each region of the former USSR varies considerably. The Ukraine has ≈264,000, including ≈262,000 in Crimea and ≈2,000 trees in the Nikolaev Province. The Republic of Georgia has nearly ≈33,000 almond trees, whereas Moldova has ≈15,000. Armenia has 8000 trees in the Megrinsky, Idjevsky, Oktomberyansky, Ashtarasky, and Mikoyanovsky regions. In Azerbaijan ≈5000 trees are growing in the Nakhichevan and Nagorniy Karabakh regions. Southern Russia has ≈8000 almond trees, including 3500 in Dagestan, 2500 in the Krasnodar region, and 2000 in Kabardino-Balkaria (Statistical Department of USSR, 1984). Since 1985, especially after the collapse of the USSR, the cultivated area and yield of almonds and other crops have begun to decline (Lugovskoy and Bolatova, 2005; Ryndin et al., 2009; Ulyanovskaya et al., 2011).

Prunus dulcis populations found in the former USSR are generally adapted to the soil and climatic conditions of semiarid zones. Seasonal conditions in these areas typically consist of short winters and long hot summers, and as a result, the period of winter dormancy for almond is very short (Richter, 1972). However, flowering time depends on the location and phenological

traits of specific cultivars. For example, on the Absheron peninsula (Azerbaijan), flowering has been observed as early as December and January in some years (Fedorov, 1957). In the Kulyab (Tajikistan), long-term observations have shown that flowering of early-blooming cultivars typically began around 14 Feb., whereas late-blooming cultivars began 10 Mar., and in Ura-Tube, early- and late-blooming cultivars began flowering 9 and 19 Apr., respectively (Gaivoronskaya et al., 1965). In Dagestan (southern Russia), almond blossoms in the second half of April to early May, and in the same period, flowering occurs at a latitude of Kiev (Fedorov, 1957). With a long spring, the flowering period may last up to 15 to 20 d (usually 8 to 14 d) and by the end of flowering, there are young leaves and shoots. (Fedorov, 1957; Mirzaev et al., 1983). In California, almond blossoming starts at the end of January and ends in mid-March, depending on the cultivars and the year (Gradziel et al., 2007; Kester and Asay, 1975).

During winter dormancy, almond trees (under normal management) have been observed to tolerate freezing temperatures ≈−24 to −29 °C in Uzbekistan, Turkmenistan, and Tajikistan and even up to −30 to −34 °C in Armenia and the Ukraine without damage (Abdurasulov, 1990; Fedorov, 1957; Mirzaev, 1982). In some cases, reduced hardiness of almond plants has been attributed to conditions such as drought stress earlier in the season, depletion of energy stores from very large harvests, poor agricultural management, and damage by pests and diseases (Elmanov, 1959; Elmanov et al., 1964). The almond is considered a drought-resistant species (Fedorov, 1957; Torrecillas et al., 1996; Yadollahi et al., 2011). Some cultivars can be grown without irrigation, even on poor soils, but typically with reduction in yields (Table 3; Bakhteev, 1970; Pakhomova, 1961). In general, almond trees can also tolerate very low levels of relative humidity (down to 10%), and excessive moisture has been shown to be detrimental to almond trees (Denisov, 1971; Richter, 1972). Early-blooming almond cultivars will generally tolerate early fall frosts and will sustain less damage to freezing temperatures below −15 to −20 °C in November and December. Late-flowering plants are more sensitive to early fall frosts, but in the second half of winter, they are harder against spring frosts and may begin the growing season with less damage (Richter, 1985).

Almonds in the former USSR have traditionally been propagated by seed, grafting, or sometimes through propagation of suckers. Seedling trees produce fruit in 3 to 4 years, whereas grafts will produce in 2 to 3 years. Maximum fruit yields come after 12 to 15 years, although these yields will tend to slowly decrease after 40 to 45 years. Maximum bearing age for almond is usually 120 to 130 years (Fedorov, 1957).

Uses of *Prunus dulcis* in the Former USSR

The almond is highly regarded for its excellent taste, high commercial quality,

Fig. 1. Almond grown on terraced land in Kyrgyzstan (Kolmo, Institute of Walnut and Fruit Culture).

and portability of its nuts. The composition of the almond kernel is 40% to 80% fat, consisting of 80% to 90% non-drying oil (glycerides of oleic acid), 20% to 25% proteins, vitamins B₁ and B₂, and a variety of enzymes collectively known as emulsin. The seeds of bitter almonds contain 2% to 8% of the cyanogenic glycoside amygdalin (Khalmatov et al., 1984; Rybakov and Ostroukhova, 1972), whereas sweet almonds generally have much lower amygdalin content. For example, CAN cultivars had amygdalin contents ranging from 0.33% to 0.84% (Gradziel, 2009). Some cultivars of sweet almonds have been found to lack amygdalin (Tsukervanik, 1948). Analysis of 890 kernels from 16 sweet almond cultivars demonstrated that 8.5% of seeds contained amygdalin, 19.5% contained in very low quantity, and 72% did not contain any traces of amygdalin (Richter, 1972). According to studies conducted at the Nikita Botanical Garden (NBG), 100 g of sweet almond kernels contain 805 mg% potassium, 385.7 mg% calcium, 201 mg% magnesium, 25.3 mg% sodium, 228 mg% sulfur, 451 mg% phosphorus, and 4 mg% iron as well as 75 mg% B₁, 600 mg% B₂, 75 mg% vitamin A, B₆, pantothenic and folic acids, and biotin (Chernobay and Yarov, 2012; Gapchenko, 1930–31; Pavlenko, 1940; Tserevitinov, 1949).

In the former USSR, ≈92% of almonds produced are used in unprocessed foods and for the production of high-quality confectionery products with the remainder being used in the medical (6%) and perfume industries (2%) (Richter, 1972). In Tajikistan, wild almonds are harvested for preparation of a special national food called “cadu-bodom” or “umochi-bodom.” To this end, almonds are ground whole, including the shells, and the resulting mass is mixed with water. After removing the solid particles and evaporating some of the liquid to obtain a thicker consistency, it is then boiled with pumpkin and rice. This is one of the most popular national foods of Tajiks (Zapryagaeva, 1964). In Armenia, unripe almond fruits with undeveloped shells are used to make jams or are marinated in

a way similar to olives. The almond shells are used for the production of special gas-adsorbing charcoal as well as for flavoring and coloring of brandy. The gum that appears on the almond trees is also used in the textile industry to make dyes (Vermishyan, 1951). In central Asia different parts of the almond tree are used in traditional folk medicine as well (Khalmatov et al., 1984; Nuraliev, 1989).

Breeding Work and Germplasm Collections

The majority of almond-breeding efforts in the former USSR was conducted at the Schroeder Research Institute (Uzbekistan) and at the Nikita Botanical Garden (Ukraine). The Bostandik branch of the Schroeder Research Institute of Horticulture, Viticulture and Winemaking, located in Tashkent Province of Uzbekistan, holds a large collection of *Prunus* germplasm. This station maintains plantings of the best local selections as well as many related species. In addition to maintaining germplasm holdings, a significant breeding program has developed cultivars such as Ranniy, Pervenets, Bostanlikskiy pozdny, and Ugamskiy, which are widely cultivated throughout central Asia. Some of the cultivars developed at the Schroeder Institute are described in Table 3. The breeder S.S. Kalmykov undertook work at the Mountain Branch of Bostandik of Schroeder Institute (Tashkent Province) with a program focused on selecting desirable material from locally occurring trees found growing in the Bostandik region. Simultaneously, work was done on developing frost-resistant and late-blooming cultivars to promote almond culture in new areas with more severe climatic conditions. Interspecific hybrids were developed using the related species *P. bucharica*, *P. georgica*, *P. ledebouriana*, and *P. petunniakowii*, and intersubgeneric crosses were conducted with *Prunus persica* (peach) and *Prunus domestica* (plums).

The Bostandik District (Tashkent Province) is located between 41° and 42° N

latitude and has a large area of wild-growing almond trees. The region is protected from cold northeasterly winds by the high mountain ranges of the western Tian Shan and is open to the west. The area has a mild climate with a high level of precipitation (over 1000 mm per year occurring primarily in the fall, winter, and early spring) and winter minimum temperatures that rarely fall below –20 °C. Because of its mild climate, the Bostandik District is a highly suitable area for almond culture. The almond trees, adapted to the climate of this area, bloom relatively late and are very rarely affected by late spring frosts. In addition to the holdings of the Schroeder Institute Bostandik station, almond trees can be found growing wild in the Bostandik area in thickets on mountain slopes and in cultivated orchards as well. Almond trees cultivated in these orchards are produced solely by seed, and as a result, there is great diversity in the fruit characteristics and quality. For example, the average nut weight varies from 0.61 to 4.03 g with the kernel content ranging from 12% to 80%. The thickness of the shell varies from paper-like to stony and the kernels range from sweet to very bitter with a high amygdalin content (Abdurasulov, 1990). As of 2006, the Schroeder Institute station had a living collection of 54 unique almond cultivars (Djavacynce, 2006). That station also maintains over 350 different intercultural and interspecies hybrids. This collection of hybrids was started by S.S. Kalmykov in the 1930s. He used many of these hybrids to create late-blooming cultivars by crossing the common almond with *P. spinosissima*, a much later flowering species, and other late-blooming species, including some peach species and almonds from the Nikita Botanical Garden. To improve cold-hardiness and drought tolerance, he crossed *P. dulcis* with *P. bucharica*, *P. spinosissima*, *P. petunniakowii*, and others. To improve yields, two of the most productive cultivars, Kolhozniy and Krasiviy, were crossed with a wide diversity of other accessions. Other hybrids of note are crosses between common almonds and peaches (Abdurasulov, 1990). Accessions of other almond species, including *P. dulcis*, *P. bucharica*, *P. scoparia*, and *P. spinosissima*, are also held in the collections of the Uzbek Research Institute of Plant Industry (Mavlyanova et al., 2005).

Prunus dulcis was introduced to the Ukraine and the Crimean region in the sixth century by the Greeks (Richter, 1972). For many centuries, its spread was limited to the coastal regions of the Crimean peninsula, a region with a mild, Mediterranean-like climate. Some of the earliest attempts to select the best forms of almonds growing in the coastal zones of the Crimea were made by members of NBG as early as 1814–40 (Yarov and Chernobay, 2001). These collections were made from trees cultivated by local people as well as seeds imported from other southern Europe countries. Practically all almond plants from these regions were early-blooming and, as a result, early March

frosts frequently damaged flower buds and ovaries (Denisov, 1968). Fundamental work with almonds at the NBG was begun by A. Richter in 1930, who subsequently devoted his career to the study and breeding of almonds (Isachkin and Vorobev, 2001; Mirzaev et al., 1983; Richter, 1938, 1972, 1985; Yezhov et al., 2005). He conducted numerous expeditions to study and collect almonds grown in the southern parts of the former USSR. The first collection of almonds in the Ukraine was organized in the 1920s at the NBG, and the best cultivars developed by the NBG produced high-quality almonds that flower late in season and produce consistently large annual crops (Yadrov and Popok, 1994–99; Yezhov et al., 2005). Currently, the collection holds six species and more than 1100 cultivars, selections, and unique forms developed at the NBG and collected from Uzbekistan, Tajikistan, Armenia, the United States, Italy, France, Spain, Hungary, Bulgaria, Greece, and Iran. Also included are

several new cultivars created at the Gardens through the use of gamma radiation and chemically induced mutagenesis (Chernobay et al., 2005). The main breeding objectives are developing improved late-flowering cultivars with a stable period of flower bud dormancy, high productivity, and more than 40% kernel with a small percentage of double kernels (Yezhov et al., 2005). Some characteristics of almond cultivars developed at NBG are presented in Figure 3 and Table 4.

In Turkmenistan, almond breeding work was begun by P.N. Bogushevsky in the early 1930s at the VIR Experimental Station, Kara-Kala. He collected from more than 500 wild specimens that exhibited significant variation and from these he selected six cultivars: Karakalinsky 30, Karakalinsky 35, Aiderinsky 98, Aiderinsky 147, Aiderinsky 149, and Aiderinsky 158. All of the cultivars were characterized by high kernel and oil content from 44.1% to 63.1% and from 49.9% to 58.1%, respectively. His work

was later continued by O.F. Mizgireva. She made crosses among the cultivars Princess, Prekker, Hatch, and IXL with Aiderinsky 98, Aiderinsky 147, Aiderinsky 149, and Aiderinsky 158. As a result, five new cultivars were developed: Turkemsky Otlchiy, BumadzniiPestriy, Rozovatiy, VIR 4 (late-blooming), and Turkemsky Belyi. All of the new cultivars possessed high kernel and oil content from 51% to 73% and from 52% to 60.4%, respectively (Mizgireva, 1973). From 1989 to 1992, 140 different almond cultivars and forms were studied at the VIR Experiment Station (now part of the Academy of Sciences of Turkmenistan). A number of cultivars were identified as being later blooming (starting during the end of March and flowering for a duration of 14 to 27 d): Vinosliviy, Konditerskiy, Yaltinsky, Sostskiy, Krimskiy, Sudakskiy, and Nikitskiy. Interestingly, early- and intermediate-flowering cultivars such as Burbank Seedling, Ne Plus Ultra, and Nonpareil were also observed to flower later

Table 3. Almond cultivars developed at The Schroeder Institute widely used in and recommended for ventral Asia and other countries of the former USSR (Abdurasulov, 1990, 2010; Mirzaev et al., 1983).

Cultivar	Bearing age	Bloom time	Yield (kg/tree)	Fruit characteristics						Other characteristics
				Avg size unshelled (mm)	Avg wt (g)	Kernel (%)	Fat content (%)	Shell hardness	Ripening date	
Bostandiskiy pozdnosvetushiy (<i>P. dulcis</i> × <i>P. persica</i>)	4	3 to 15 April	12–15 ^z 4 ^y	29 × 19 × 16	2.41	47.5	59.6	Standard	9 to 19 Sept.	Low susceptibility to diseases and pests; resistant to spring frosts
Krasiviy	3–4	Late March to early April	12–14 (–24) ^z 2.5 ^y	31 × 18 × 15	2.17	47.5	59.26	Standard	Late August to early September	Drought-, frost-, and pest-resistant
Pervenets	3–4	Late March to early April	7 ^z 3 ^y	36 × 19 × 12	2.41	47.7	59.6	Soft	Early September	Disease-resistant
Ranniy (<i>P. dulcis</i> × <i>P. bucharica</i>)	3–4	Late March to early April	8–12 (–18) ^z 6 ^y	32 × 16 × 11	2.15	43.9	58.5	Soft	Late July to early August	Very drought- and cold-resistant; disease-resistant
Sablevidniy	3–4	4 to 19 April	5.5 (–12) ^z 4 ^y	48 × 25 × 22	2.9	58.9	59.9	Soft	End of September	High-quality nuts; resistant to spring frosts
Ugamskiy	3–4	5 to 8 April	17 ^z 3 ^y	37 × 23 × 16	2.7	42.86	63.0	Standard	17–30 Aug.	Resistant to drought and spring frosts

^zIrrigated fields.

^yUnirrigated fields.

Table 4. Almond cultivars developed at the Nikita Botanical Gardens, Yalta, Ukraine, that are widely grown in Ukraine and other countries of the former USSR (Richter, 1972; Yadrov and Popok, 1994–1999).

Cultivar	Bearing age	Bloom time ^z	Yield ^y (kg/tree)	Fruit characteristics					Ripening time	Other characteristics
				Avg size unshelled (mm)	Avg wt (g)	Kernel (%)	Fat content (%)	Shell hardness		
Desertniy	3	1 to 20 Apr.	7.8	35 × 23 × 16.5	2.8	49.4	52.2	Soft	September	Resistant to spring frost
Geliodor	4	1 to 20 Apr.	5.5	24.6 × 14.7 × 6.2	2.6–3.2	60.0	51.4	Soft	August	Resistant to frost
Mangup	5	1 to 20 Apr.	5.5	25.8 × 14.3 × 8.1	2.5–3.0	42.0	55.2	Standard	September	Resistant to frost
Milas	3–4	20 to 30 Apr.	5.0	25.3 × 14.4 × 8.0	2.8–3.2	56.0	54.3	Soft	Mid-August	Very low occurrence of multiple embryos per seed
Nikitsky 2240	3–4	1 to 20 Apr.	5.0	28.5 × 13 × 8.3	3.0	48.5	57.5	Soft	September	Flower buds resistant to frost
Primorsky	3	20 to 30 Apr.	9.2	29.0 × 14.4 × 8.3	2.7–3.2	50.0	52.0	Soft	Late September to early October	Flower buds resistant to frost
Stepnoy	4	1 to 20 Apr.	5.0	26.7 × 14.0 × 8.3	2.4–3.1	56.0	55.1	Soft	August	Drought-tolerant; poor resistance to frost

^zFor reference, at the Nikita Botanical Garden, the cultivars Ne Plus Ultra (early-flowering) and Nonpareil (intermediate) have been recorded as flowering between 6 Mar. to 11 Apr. and 25 Mar. to 8 Apr., respectively (Abdurasulov, 1990; Gulcan, 1985).

^yUnirrigated fields.

in the subtropical environments of Turkmenistan and the Crimean Peninsula (Avdeeva et al., 2004; Richter, 1972). Over a span of 15 years, 'Ne Plus Ultra' was observed to flower from 16 Mar. to 11 Apr. and 'Nonpareil' from 25 Mar. to 18 Apr. at the Nikita Botanical Garden (Richter, 1972). The mild winter in these areas may have extended the time necessary to meet these cultivars' chilling requirements, ultimately delaying their flowering time (Covert, 2011). 'Princess' was observed to be mid- to late-blooming, and the early-blooming cultivars were found to be Aiderinsky 15, Aiderinsky 435, Diflet, and Zavetnyi, among others. The Mizgireva hybrids exhibited mostly midtype blooming (Avdeeva et al., 2004).

In Kyrgyzstan, almond breeding work was begun by A.F. Zarubin in 1936. His work was later continued by A.A. Bulichev and S. Bolotov, who organized research and test plots at several higher elevation sites, including Ak-terek (1747 m), Dendropark (769 m), Kara-Bulak (900 m), Kolmo (1100 m, Figs. 1 and 2), Kur-maidan (1300 m), and Zhardar (1200 m). In 1976, they created a collection selected from the NBG and the Schroeder Institute. After 20 years of evaluations, they identified the seven best cultivars for the Kyrgyz and Ferghana regions: Desertniy, Nikitskiy 2240, Pozdnyy, Gvardiyskiy, Yaltinskiy, Pervenets, and Bostandikskiy. Now, the living sweet almond collection includes 22 cultivars from the Schroeder Research Institute and the NBG (Kenjebaev et al., 2005).

In Armenia, the main region of almond production is the Ararat valley and the northeast regions of the country. In Armenia, local varieties of almonds are cultivated nearly exclusively. Propagation for orchards is conducted by sowing seeds, which has led to diverse and variable plantings, which differ in morphological and phenological characteristics. In the late 1940s to the early 1950s Armenia obtained numerous late-blooming Crimean cultivars from the NBG. This included the cultivars Primorskiy, Desertniy, Nikitskiy Pozdnosvetuschiy, Nikitskiy 2240, Nikitskiy 62, Rryaniy, and others (Sadikhov, 1949). An almond breeding program was also developed at the Vohchaberdskoy Experiment Station in Armenia. The most notable Armenian cultivars developed at this station are: Vohchaberdsky 4, Vohchaberdsky 5, Vohchaberdsky 9, Vohchaberdsky 27, Vohchaberdsky 48, Noragukhi, Aigestani, Getari, and Kyazgi Bodam (Vermishyan, 1951; Yaroshenko and Grigoryan, 1941). Later, after field trials consisting of 45 cultivars and hybrids, seven cultivars were identified as being the most suitable cultivars for Armenian production: Yaltinskiy, Nikitskiy 62, Ranni, Primorskiy, Desertniy, Krimskiy, and Nonpareil (Beketovskiy and Mkrchyan, 1971).

In Georgia, almonds are cultivated in the eastern part of the country. From 1946 to 1950, a frost tolerance study focusing on almond wood showed that local accessions,

Fig. 2. Blooming almond trees in Kyrgyzstan (Kolmo, Institute of Nut and Fruit Culture).

particularly from the Saburtalo Nushi area, had significantly greater frost tolerance when compared with cultivars originating in other regions. These local accessions survived winter temperatures of -30.5°C , whereas all other cultivars perished. After extensive field trials including many almond cultivars from NBG, the following cultivars were recommended for commercial use in that region: Bumazhnoskorlupniy, Yaltinskiy, Nikitskiy 62, Drake, and Reams (Nijaradze et al., 1973).

The North-Caucasus Zonal Research Institute of Horticulture and Viticulture is located in Dagestan (North Caucasus region of southern Russia). This Institute is a major center for scientific research and breeding in the Southern Federal District of Russia. Other public research institutions in this area are the Anapa Zonal Experimental Station of Viticulture and Winemaking (Anapa) and Stavropol Experimental Station of Horticulture (Georgievsk city, Stavropol Krai). Research stations are also found in the Abinsk and Temryuksky Districts of Krasnodar Krai and in Rostov Province and Abkhazia, and research experiment stations include "Centralnoe" (Krasnodar), the K.A. Timiryazev research station (Ust-Labinsky District), and "Anapa" (Anapa). Scientists introduced and extensively planted cultivars developed at the NBG, including: Aleynik, Alushtinskiy, Viktoriya, Geliodor, Mangup, Nizjniy, Nikitskiy 10, Nikitskiy 62, Pryanni, Sevastopolskiy, Leninobadskiy from Tajikistan, and Turkmenkiy urozainiy from Turkmenistan (Isachkin and Vorobev, 2001).

Scientific work with almond in the Republic of Moldova was organized in the late 1940s at the Agricultural Experiment Station near Kishinev. They began with a small collection of ≈ 200 almond trees. This collection included the following cultivars: Nikita 1, Stewart, Princess 2077, Ne Plus Ultra, Languedoc, Drake, Nonpareil, and California (Khranov, 1950). Later, in the 1970s at the Scientific Research Institute of Fruits, numerous cultivars were identified as suitable or developed after field trials and extensive breeding work: Viktoriya, Moldavsky

standartoskorlupniy, Moldavsky bumajnoskorlupniy, Moldavsky tverdoskoplupniy, Moldavsky beliy, Pervenets Hramova, VK-17, VK-15, VK-9, 51-617, IV-4-3, IV-4-8, JXL, Nonpareil, Desertniy, Sovetskiy, and Nikitskiy Pozdnosvetuschiy (Khranov and Zhuravel, 1980).

Genetic Diversity of *Prunus dulcis*

Numerous studies have been conducted to assess the genetic diversity held in different almond collections around the world. These analyses have used a variety of molecular techniques including the analysis of allozymes and amplified fragment length polymorphism, random amplified polymorphic DNA, simple sequence repeat, and intersimple sequence repeat markers (Sorkheh et al., 2007, 2009). Many of these studies have shown that there is significant variation and heterozygosity among cultivars of different geographical origins. This genetic diversity may be attributed to the fact that almonds, along with many other species in the Rosaceae, exhibit gametophytic self-incompatibility and as such are obligate outcrossers (Abdurasulov, 1990; Gradziel and Martínez-Gómez, 2013; Kester, 1969). Self-incompatibility of this species has been attributed to the gametophytic expression of a multiple allelic S locus, which codes for ribonucleases expressed in the style and for F-box proteins expressed in the pollen. The occurrence of self-fertility in almond has been reported in several cultivars of *P. dulcis* and in the species *P. webbii* (Bošćević et al., 2007; Crossa-Raynaud and Grasselly, 1985; Dicenta and García, 1993; López et al., 2006; Ushijima et al., 2003). No wide-scale genetic analyses have been conducted to assess the genetic diversity held in the major almond germplasm collections of the former USSR. It must be noted that Lansari et al. (1994) found that as a result of the use of common parents (possibly 'Nonpareil', 'Languedoc', and 'Princess'), some major cultivars developed by U.S., Soviet, and Israeli breeding programs actually have a significant degree of common genetic ancestry. They stated that extensive use of

Fig. 3. Almond cultivars developed at the Nikita Botanical Gardens in Yalta, Ukraine.

a few select parents for breeding programs may lead to an eventual reduction of fitness from inbreeding depression. The extensive germplasm found in collections and growing wild in the former Soviet countries may be a rich source for increasing genetic diversity and obtaining desirable traits.

Worldwide, a relatively limited number of accessions is currently held in the main almond germplasm collections (Gradziel and Martínez-Gómez, 2013). Within the past few decades, there has been some integration of almond germplasm from former Soviet countries into the USDA National Plant Germplasm System. This material varies in terms of state of horticultural development, including seed collected from wild-growing trees and clonal material of cultivars. The countries from which the most collections have been made are Armenia (11 accessions of cultivars), Azerbaijan (32 accessions), Georgia (41 accessions), Kyrgyzstan (17 accessions), Turkmenistan (26 accessions), Ukraine (seven accessions), and Uzbekistan (seven accessions). These accessions represent but a small fraction of the diversity found in the former USSR, and there is still an

extensive pool of useful material to draw from (USDA, ARS, National Genetic Resources Program, 2014).

When obtaining plant material from abroad, the introduction of disease causing pathogens is a serious concern. Plum Pox Potyvirus (PPV or Sharka) is a disease that mainly affects *Prunus* species such as apricot, plum, peach, and, to a lesser degree, sweet cherry and sour cherry and is an important factor to consider when conducting germplasm introduction. Almond has also been found to be a host of PPV (APHIS, 2012); however, when compared with apricot, plum, and other *Prunus* species known to be highly susceptible, almond has demonstrated a high level of genetic resistance to infection (Festic, 1978; Gradziel, 2009; Gradziel and Martínez-Gómez, 2013; Rubio et al., 2003). In a study of *Prunus* susceptibility to PPV by aphid transmission, Damsteegt et al. (2007) found that *P. dulcis* 'Butte' and 'Mission' tested positive in 17 of 30 plants yet visual symptoms only were recorded on three of the 30 plants. Although strains of PPV were not definitively determined to occur on almond in the field in the former

USSR, more recent assessments have positively detected PPV on *P. dulcis* in the Krasnodar region of Russia as well as in almonds growing in Hungary (Margina, 1975; Novoselova et al., 1981; Prichodko, 2006; Sheveleva et al., 2012). To date, PPV has not been reported in central Asia with the exception of southeastern Kazakhstan (Spiegel et al., 2004). Now, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan are still free of the PPV virus (Sh. Kozubaev, Ministry of Agriculture and Water Resources of the Republic of Uzbekistan; S. Kydyrmaev N. Ministry of Agriculture of the Kyrgyz Republic; G. Begov Ministry of Agriculture of the Republic of Tajikistan, personal communication).

Almond Germplasm Collection from the Former USSR and Expanding the Range of Almond Cultivation within the United States

The authors of this article conducted extensive collection of central Asian apricot germplasm in 1997–2000. This germplasm, collected from farmers' markets and research institutes, has been grown at the Rutgers

Fig. 4. Forty-nine almond accessions from a 2010 collection trip to Uzbekistan. Photograph by Thomas Molnar.

University Cream Ridge Research Farm (Cream Ridge, NJ) since 1998 and has been observed and tested extensively with no sign of PPV (Zaurov et al., 2013). These developments motivated the authors to conduct additional trips to central Asia to collect almond germplasm. In the fall of 2000, the first collection of almond germplasm was made in Uzbekistan. Before import into the United States, the materials were inspected and given a phytosanitary certificate. After stratification, central Asian seeds were planted at the Rutgers University Adelphia Plant Research Center (Adelphia, NJ). This material was not suited for the humid, hot summers associated with the mid-Atlantic region of the United States and most succumbed to disease because no fungicide spray program was implemented.

From 2010 to 2012, a second round of collections was conducted after a large-scale germplasm collection program was initiated

by researchers at Rutgers University and collaborators at Improving Perennial Plants for Food and Bio-energy, Inc. (IPPFBE) in Thatcher, UT. During several trips to Uzbekistan, Kyrgyzstan, and Tajikistan, author David Zaurov visited several major regions for collection. Bostandik, in the Tashkent Province, is home to the aforementioned branch of the Schroeder Institute. Several almond accessions, primarily *P. dulcis*, but also *P. bucharica* and *P. vavilovii*, were selected from their extensive collection of wild and cultivated almond. Numerous accessions were also collected from the Namangan Province in eastern Uzbekistan bordering Kyrgyzstan. The bulk of the accessions was gathered from the Surkhandarya Province, the southern-most province in Uzbekistan along the Afghanistan border, and were primarily obtained from local farmers. In Tajikistan, the Scientific Research Institute of Forestry was visited to obtain

samples of *P. bucharica*, whereas the rest of the almonds (*P. dulcis*) collected from Tajikistan were gathered from the southern regions. Several almond accessions (mostly *P. dulcis*) were collected from south of Kyrgyzstan, in Osh and Jalal Abad Provinces. A total of 150 seed lots was collected with a huge range of diversity between lots (Fig. 4). Each seed lot consisted of 25 to 40 seeds.

The almond collections were stratified at 35 °F in slightly moist sphagnum peatmoss for 90 to 100 d. The stratified seeds were planted in liners in a greenhouse and subsequently planted at the IPPFBE research farm in Thatcher, UT, where they are currently under evaluation. The research farm is located in the Intermountain West region of the United States and is comprised of semiarid rangeland habitat and associated marginal cropland. Small-scale almond cultivation has been occurring in Utah since the 1950s (Plocher, 1998). Seed lots collected since 2010 have

had germination rates approaching 100% and transplant survival rates of greater than 99%. Some accessions had multiple embryos per seed, whereas most accessions had single embryos. Of the many thousands of seeds that were sown, hundreds of seedlings were selected to plant out for evaluation in Utah. Each year, poorly performing trees were culled or succumbed to adverse environmental conditions including cold spring frosts and low winter temperatures.

As of 2013, 300 trees remain, representing the most cold-hardy trees. The surviving trees have been rated for tree vigor, spring frost damage, and winter cold damage. The precocious nature of some of the 2-year-old central Asian almond trees was observed, but the fruit aborted before maturation. The young trees need 3 or 4 years minimum to become well established in the semiarid rangelands and marginal croplands of the Intermountain West. During the summer of 2013, the central Asian accessions of almonds showed the highest degree of drought tolerance. Over the next 3 years these trees were systematically evaluated for characteristics important to the IPPFBE breeding program such as resistance to spring frosts, winter-hardiness, and resistance to insects and diseases.

Conclusions

Globally, almond is one of the most important nut crops, yet the full horticultural potential of this species has yet to be realized. As the human population grows, high-protein foods, which can be produced on marginal and non-tillable land, will become increasingly necessary. By accessing this extensive genetic diversity, there is the potential for breeding almond cultivars that can be grown in areas and climates outside of those currently in use. In the past 20 years a limited amount of germplasm has been obtained by breeders outside the former USSR, but there is a much greater genetic pool to access. Significant germplasm resources, including wild almond populations, numerous cultivars, and closely related species, are found in the former USSR and these have many unique and useful characteristics. Traits such as high kernel fat content; early or late blooming; extreme cold, drought, and heat tolerance; and overall heterozygosity are valuable assets for genetic improvement programs.

As a result of geopolitical conditions in the 20th century, Soviet countries were largely isolated from the Western world and only recently has the region become increasingly accessible for the exchange of plant germplasm and scientific information. Although access to *P. dulcis* in the former USSR has increased, habitat and regeneration of wild populations is decreasing as a result of anthropogenic activities. Additionally, financial constraints at many of the national and regional research institutions have put extremely important collections in jeopardy. This article aims to disseminate information on these valuable resources to promote increased pres-

ervation, use, and management. Additional introduction, selection, and breeding using almond resources from the former USSR can facilitate the production of improved cultivars and could potentially broaden the area in which reliable commercial production is possible including the U.S. Intermountain West as well as other relatively dry, temperate regions of the world. Based on its adaptation to harsh environmental conditions, *Prunus dulcis*, and related species, from the former USSR may be particularly useful for crop development on degraded, deforested, and marginal land as well as for use in stabilizing soils and preventing erosion. The scientific organizations mentioned in this article look forward to collaboration, cooperation, and the reciprocal exchange of almond species and/or germplasm of other plant species with interested scientists and organizations around the world.

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