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Pomegranate: Botany, Horticulture, Breeding

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I. INTRODUCTION

Pomegranate (*Punica granatum* L., Punicaceae) is an ancient, beloved plant and fruit. The name ''*pomegranate*'' follows the Latin name of the fruit *Malum granatum,* which means ''grainy apple.'' The generic name *Punica* refers to Pheonicia (Carthage) as a result of mistaken assumption regarding its origin. The pomegranate and its usage are deeply embedded in human history, and utilization is found in many ancient human cultures as food and as a medical remedy. Despite this fact, pomegranate culture has always been restricted and generally considered as a minor crop. The pomegranate tree requires a long, hot and dry season in order to produce good yield of high-quality fruit.

Pomegranates are native to central Asia, but since the pomegranate tree is highly adaptive to a wide range of climates and soil conditions, it is grown in many different geographical regions including the Mediterranean basin, Asia, and California. Recent scientific findings corroborate traditional usage of the pomegranate as a medical remedy and indicate that pomegranate tissues of the fruit, flowers, bark, and leaves contain bioactive phytochemicals that are antimicrobial, reduce blood pressure, and act against serious diseases such as diabetes and cancer. These findings have led to a higher awareness of the public to the benefits of the pomegranate fruit, particularly in the western world, and consequently to a prominent increase in the consumption of its fruit and juice. The development of industrial methods to separate the arils from the fruit and improvement of growing techniques resulted in an impressive enlargement of the extent of pomegranate orchards. New orchards are now planted in the traditional growing regions as well as in the southern hemisphere in South America, South Africa, and Australia.

II. TAXONOMY AND MORPHOLOGY

A. Botanical Classification

Punicaceae contains only two species, *Punica granatum* L. and *P. protopunica* Balf. f. 1882. *Punica protopunica* is endemic to the Socotra Island (Yemen) and is the only congeneric relative of *P. granatum* species currently is cultivated (Zukovski 1950; Levin and Sokolova 1979; Guarino et al. 1990; Mars 2000; Levin 2006). Based on xylem anatomy, *P. protopunica* has been suggested as the ancestral of the genus (Shilkina 1973). The $n = x$ chromosome number is 8 (Yasui 1936; Darlington and Janaki Ammal 1945; Raman et al. 1971; Sheidai and Noormohammadi 2005) or 9 (Darlington and Janaki Ammal 1945).

B. Vegetative Growth

Pomegranate is a shrub that naturally tends to develop multiple trunks and has a bushy appearance. When domesticated, it is grown as a small tree that grows up to 5 m. Under natural conditions, it can sometimes grow up to more than 7 m; at the other extreme, in severe natural environment, one can find creeping bush varieties (Levin 2006). In addition, there are dwarf cultivars that do not exceed 1.5 m (Levin 1985, 2006; Liu 2003).

Most of the pomegranate varieties are deciduous trees. However, there are several evergreen pomegranates in India. Singh et al. (2006) reported deciduous Indian varieties and identified 16 genotypes that behaved as evergreen in Rajasthan India. Sharma and Dhilom (2002) evaluated 30 evergreen cultivars in Punjab India. There are clearly prominent differences among pomegranate varieties with respect to leaf shed. Some evergreen cultivars shed their leaves in higher elevations and colder climates (Nalawadi et al. 1973) and should be regarded as conditionally deciduous.

The young branches from the vegetative growth of the recent year are numerous and thin. The color of the bark of young branches depends on the variety. In some, bark color varies from pink to purple, while in others it is light green with pink-purple spots or stripes. Upon maturation, the pink color of the branch starts to disappear, and in the second year, the bark will become light gray that darkens as the tree matures (Goor and Liberman 1956). The bark of the old tree tends to split, and in certain cases it is detached from the trunk. The wood color is light yellow. Young branches sometimes have thorns at their tips that are visible already in the axils in the young bloom. The young branches are polygonal (quadrangular). As the branches mature, they become round. Young leaves tend to have a reddish color that turns green when the leaf matures. In varieties with young pink-purple bark, this color appears also on the sheath and the petiole, on the lower part of the central vein, and in the leaf margins.

Leaves have an oblanceolate shape with an obtuse apex and an acuminate base. Mature leaves are green, entire, smooth, and hairless with short petioles. They usually have a special glossy appearance (particularly at the upper part of the leaf) and contain idioblasts with secretory substances that have not yet been identified (Fahan 1976). The leaves are exstipulate, opposed and pairs alternately crossing at right angles. Some varieties have 3 leaves per node arranged at 120 degrees and even 4 leaves per node on the same tree (2 opposed leaves per node) (Moreno 2005).

C. The Flower

Flowering occurs about 1 month after bud break on newly developed branches of the same year, mostly on spurs or short branches. Flowers can appear solitary, pairs, or clusters. In most cases, the solitary flowers will appear on spurs along the branches while the clusters are terminal. In the northern hemisphere, flowering occurs in April-May. However, flowering may continue until end of summer, particularly in young trees. Such flowers are fertile, but the fruit will not properly mature because the trees enter the cooler season and the dormancy period in Mediterranean climatic conditions. Flowering and the consequent fruit set last about 1 month. During this period, there are three waves of flowering (Ben-Arie et al. 1984; Shulman et al. 1984; El Sese 1988; Assaf et al. 1991b; Hussein et al. 1994; Mars 2000). In evergreen cultivars in southern India, flowering season was observed in three periods: June, October, and March (Nalwadi et al. 1973) or throughout the year (Hayes 1957).

In the early balloon stage, the flower resembles a small pear with a greenish color on its basal part and reddish color on its apex or entirely dark red. As the flower matures, it develops an orange-red to deep red sepal color, which varies among different varieties. The petals are orange-red or pink and rarely white (Feng et al. 1998; Wang 2003; Levin 2006; Beam Home 2007). Several pomegranate cultivars from India, Russia, China, and Turkmenistan were reported as ornamental pomegranates that are ''double flowered'' (Iskenderova 1980, 1988; Feng et al. 1998; Wang 2003; Levin 2006). These cultivars have an unusually high petal number and petal color. Some of these cultivars are fertile and produce edible fruit while others are infertile. Nalawadi et al. (1973) defined 10 stages for flower development. According to these authors, the time required for completion of flower bud development in Indian cultivars is between 20 and 27 days (Nalawadi 1973; Josan 1979a). We found a good correlation between the color of the sepals and the final color of the fruit skin. Usually cultivars with deep-red fruit skin will have a darker-red flower.

Pomegranate flowers develop into one of two types of flowers normally produced by pomegranates: hermaphrodite flowers (''vase shape'') (Plate 2.1A) and male flowers (''bell shape'') (Plate 2.1B). Both types have several hundred stamens. The bell-shape flower has a poorly developed or no pistil and atrophied ovaries containing few ovules and is infertile. Therefore, the bell shape flower is referred as a male flower and will drop without fruit set. The vase-shape flower is fertile with a normal ovary capable of developing fruit. The stigma of the hermaphrodite is at the anthers height or emerging above them. This position allows for self-pollination as well as pollination by insects. The factor that determines the fruit set capacity is the number of vase-shape flowers. Therefore, cultivars with higher vase-shape to bell-shape ratio will have a higher fruit yield potential. The percentage of the vase-shape flowers among the Israeli cultivars is 43% to 66% (Assaf et al. 1991b). Other studies in India indicate 53% to 80% ratios for Indian local cultivars (Nalawadi et al. 1973). An intermediate third type of a flower has been described that has short style and a developed ovary which is sometimes fertile (Goor and Liberman 1956; Nalawadi et al. 1973; Assaf et al. 1991b).

The sepals, 5 to 8 fused in their base, form a red fleshy vase shape. The sepals will not drop with fruit set but will stay as an integral part of the fruit as it matures, generating a fruit crowned with a prominent calyx. The flower has 5 to 8 petals. Their number usually equals the number of sepals. The petals, which alternate with the sepals, are separated and have a pink-orange to orange-red color depending on the variety. The petals are obovate, very delicate, and slightly wrinkled. The multiple long stamens are inserted into the calyx walls in a circle and frequently number more than 300 per flower. They have an orange-red filament and yellow bilocular anthers that remain attached to the prominent calyx. Nectaries are located between the stamens and the ovary base (Fahan 1976). The carpels vary in number but are usually eight superimposed in two whorls. They form a syncarpic ovary and are arranged in two layers. Josan et al. (1979b) studied anthesis and receptivity of stigma. These authors report that the time taken by the flowers to complete anthesis was 3 to 5 hours. The stigma attained

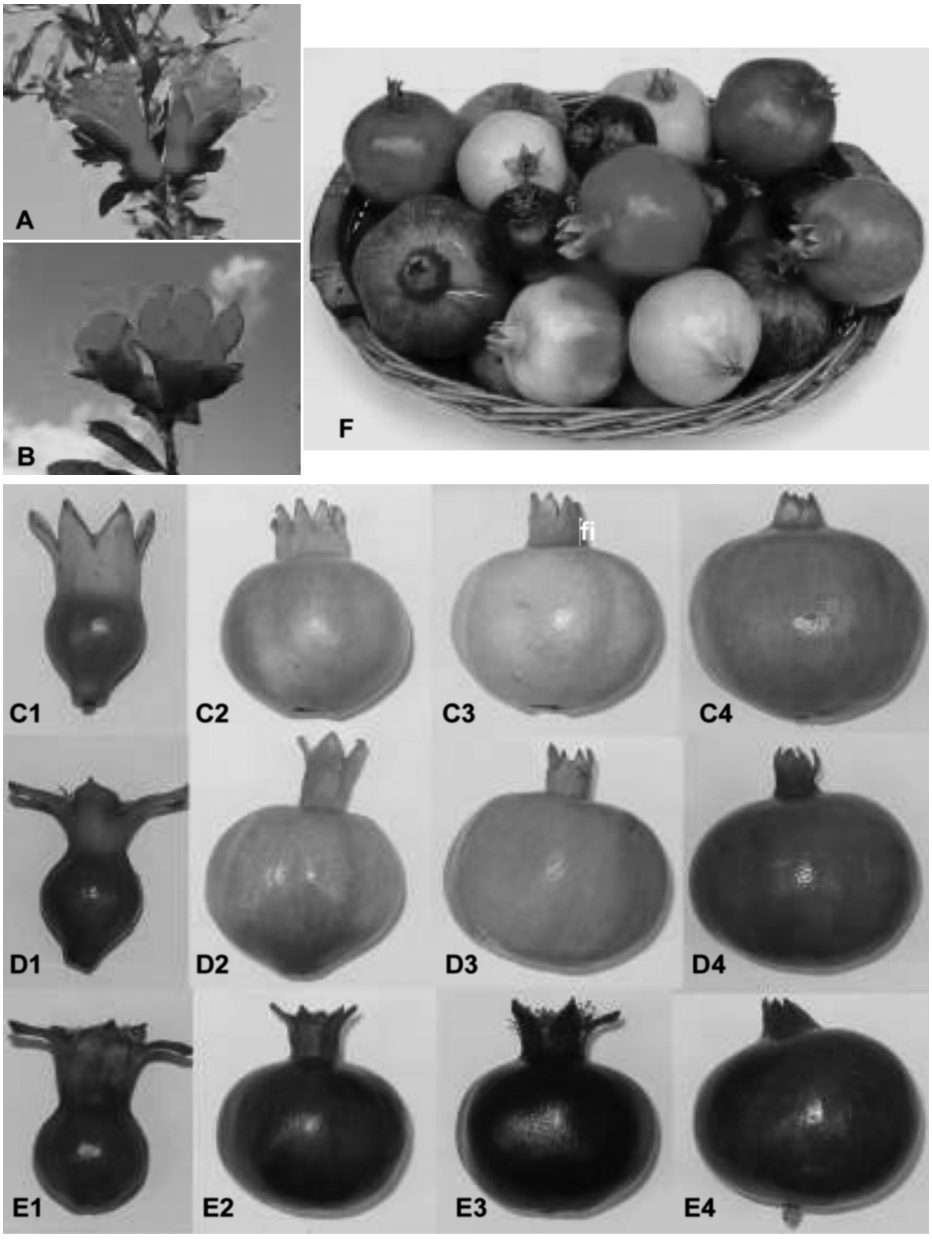

Plate 2.1. Pomegranate cultivars diversity and fruit development. A. Vase-shape flower; B. Bell-shape flower; C–E. Different stages of fruit color development in three cultivars: C. ‘C13’, D. ‘P.G.116-17’, E. ‘P.G.127-28’, 1. May, 2. June, 3. August, 4. October (Nadler-Hassar et al. unpublished); F. Fruit diversity of pomegranate cultivars grown in Israel. (See insert for color representation of this plate).

receptivity one day before anthesis and remained in receptive condition up to the second day after anthesis.

The pomegranate is both self-pollinated and cross-pollinated by insects, mainly bees. Wind pollination is reported to occur but infrequently (Morton 1987). Emasculation and bagging studies on Indian, Turkmen, Israeli, and Tunisian pomegranate cultivars indicate that pomegranate flowers can self-pollinate and produce normal fruit (Nalawadi et al. 1973; Karale et al. 1993; Mars 2000; Levin 2006; Holland et al. unpubl.). It was noted, however, that the degree of fruit set by self-pollination varies among different pomegranate cultivars (Levin 1978; Kumar et al. 2004). In hermaphrodite flowers, 6% to 20% of pollen may be infertile; in male flowers, 14% to 28% are infertile. The size and fertility of the pollen vary with the cultivar and season (Morton 1987).

D. The Fruit

The fruit develops from the ovary and is a fleshy berry. The nearly round fruit is crowned by the prominent calyx. The apex of this crown is almost closed to widely opened, depending on the variety and on the stage of ripening. The fruit is connected to the tree with a short stalk.

Following fruit set, the color of the sepals' skin in the developing fruit changes continuously from the prominent orange-red to green. In later stages of fruit maturation, the color will change again until it reaches its final characteristic color as the fruit ripens. The external color ranges from yellow, green, or pink overlain with pink to deep red or indigo to fully red, pink or deep purple cover, depending on the variety and stage of ripening (Plate 2.1 C1–C4, D1–D4, E1–E4). There are some exceptional cultivars, such as the black pomegranate which acquires its black skin very early and remains black until ripening time (Plate 2.1 E1–E4). The skin (leathery exocarp) thickness varies among pomegranate cultivars.

The multi-ovule chambers (locules) are separated by membranous walls (septum) and fleshy mesocarp. The chambers are organized in a nonsymmetrical way. Usually the lower part of the fruit contains 2 to 3 chambers while its upper part has 6 to 9 chambers. The chambers are filled with many seeds (arils). The arils contain a juicy edible layer that develops entirely from outer epidermal cells of the seed, which elongate to a very large extent in a radial direction (Fahan 1976). The sap of these cells develops a turgor pressure that preserves the characteristic external shape of these cells. The color of the edible juicy layer can vary from white to deep red, depending on the variety. Levin (2006) reports that occasionally metaxenia is observed such that there are several seeds of different color within an individual pomegranate. The arils vary in size and the seeds vary in hardness among different varieties. Varieties known as seedless actually contain seeds that are soft.

There is no correlation between the outer skin color of the rind and the color of the arils. These colors could be very different or similar, depending on the variety. The external outer skin color does not indicate the extent of ripening degree of the fruit or its readiness for consumption because it can attain its final color long before the arils are fully ripened. The fruit ripens 5 to 8 months after fruit set, depending on the variety. The most pronounced difference in ripening time among cultivars is not derived from the differences in flowering dates but rather from the time required to ripening from anthesis.

E. Juvenility and Age of Fruiting

The pomegranate has a relatively short juvenile period compared to other fruit trees, such as citrus, members of the Rosaceae, and nuts. When grown from seeds, a small proportion of pomegranate seedlings will develop flowers in their first year of growth (Terakami et al. 2007; Holland et al. unpubl.). In their second year, these plants will bear fruits (Fig. 2.1a,b). Most seedlings will flower and bear fruit in their second or third year. The fruit color characteristics of juvenile plants will stay similar to those of mature pomegranate trees, although the first-year fruits are usually smaller. The ability to flower and to bear fruit in very young seedlings was also noted in 'Nana', a dwarf type (Terakami et al. 2007). It is noteworthy, however, that there is a physiological difference between young plants established from seeds (juvenile) and young plants established from cuttings of mature plants. Among perennial plants, the time required for seedlings to flower is not necessarily identical to the time required for young plants established from cuttings of mature plants. In pomegranates, these two physiologically different periods last for a similar duration, while in other species, the time length required for flowering could vary dramatically. In citrus, for example, the juvenile period for seedlings may extend up to 5 to 7 years while trees prepared by grafting of mature cuttings will set fruit in about 3 years.

III. ORIGIN AND GENETIC RESOURCES

A. Origin and Cultivating Regions

Wild pomegranates are growing today in central Asia from Iran and Turkmenistan to northern India. Pomegranate is considered as native

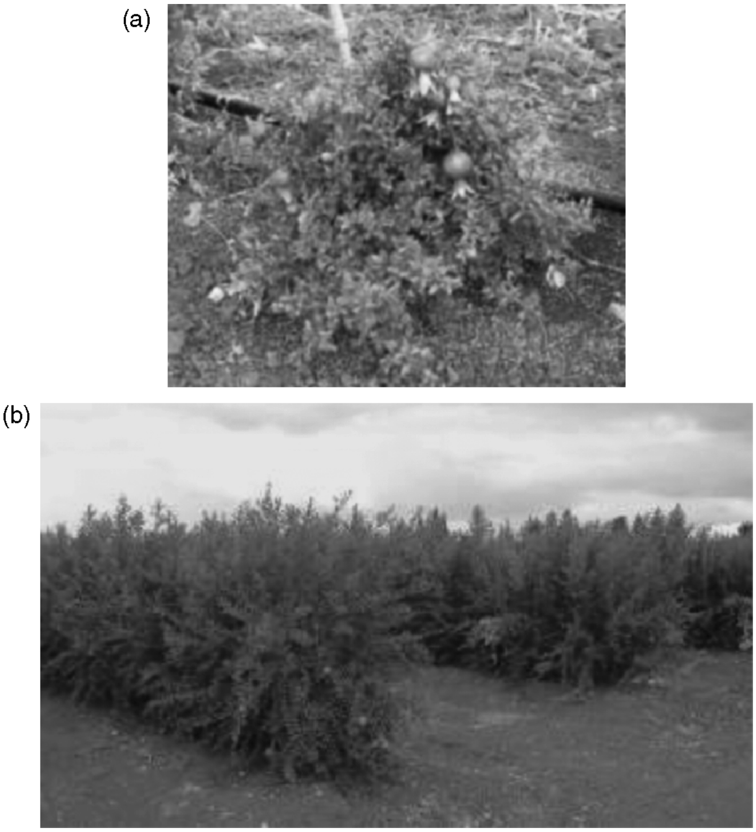

Fig. 2.1. (a) Six-month-old seedling of 'Nana' var. bearing fruits; (b) Fruit-bearing F1 population in their second year.

to these regions. N.I. Vavilov stated that the pomegranate origin is in the Near East. A.P. de Candolle determined Iran and its surrounding as its origin (Goor and Liberman 1956). Goor and Liberman (1956) defined southwest Asia as the pomegranate origin. Culture of pomegranate began in prehistoric times. It is estimated that pomegranate domestication began somewhere in the Neolithic era (Levin 2006; Still 2006). Pomegranates are thought to have been domesticated initially in the Transcaucasian-Caspian region and northern Turkey (Zohary and Spiegel-Roy 1975; Harlan 1992). Evidence for using pomegranates in the Middle East is dated at over 5,000 years ago. Pomegranate artifacts and relics dating to 3000 BCE and on were found in Egypt, Israel Armenia, and Mesopotamia (Goor and Liberman 1956; Still 2006; Stepanyan 2007). Carbonized fragments of pomegranate rinds dating from early Bronze Age were found in Jericho and Arad, Israel (Still 2006), in Nimrod, Lebanon (Still 2006), in Egypt (Still 2006), and in

Armenia (Stepanyan 2007). Pomegranates were introduced throughout the Mediterranean region to the rest of Asia to North Africa and to Europe. They traveled to the Indian peninsula from Iran about the first century CE and were reported growing in Indonesia in 1416. The Greeks and the successor empires distributed the pomegranate all over Europe. Spanish sailors brought pomegranates to the New World, and Spanish Jesuit missionaries introduced pomegranates into Mexico and California in the 1700s (Goor and Liberman 1956; Morton 1987). The ability of pomegranate trees to adjust to variable climatic conditions is reflected in the wide distribution of the wild form throughout Eurasia to the Himalayas (Levin 2006).

The optimal climatically growth conditions for pomegranate exist in Mediterranean-like climates. These include high exposure to sunlight; mild winters with minimal temperatures not lower than −12°C; and dry hot summers without rain during the last stages of the fruit development (Levin 2006). Under such conditions, the fruit will develop to its best size and optimal color and sugar accumulation without the danger of splitting. Pomegranate is cultivated today throughout the world in subtropical and tropical areas in many different microclimatic zones. Commercial orchards of pomegranate trees are now grown in the Mediterranean basin (North Africa, Egypt, Israel, Syria, Lebanon, Turkey, Greece, Cyprus, Italy, France, Spain, Portugal) and in Asia (Iran, Iraq, India, China, Afghanistan, Bangladesh, Myanmar, Vietnam, Thailand; and in the former Soviet republics: Kazakhstan, Turkmenistan, Tajikistan, Kirgizstan, Armenia, and Georgia). In the New World, pomegranates are grown in the United States and Chile. New orchards are now established in South Africa, Australia, Argentine, and Brazil.

B. Collections and Germplasm

Pomegranate collections of wild and domesticated accessions were reported to be in Asia, Europe, North Africa, and North America. Still (2006) based on data of Frison and Servinsky (1995) lists the sites and numbers of pomegranate accessions in Albania, Cyprus, Italy, Spain, France, Germany, Hungary, Israel, Portugal, Russia, Tunisia, Turkey, Turkmenistan, Ukraine, the United States and Uzbekistan. Mars (2000) adds India, Morocco, Greece, Egypt, and Tajikistan. The larger collections are in Garrygala, Turkmenistan, and St. Petersburg, Russia (Still 2006). Four important centers not mentioned in these lists include the Iranian collection in Tehran, Saveh, Yazd, and Markazi (Fadavi et al. 2006; Zamani et al. 2007) and China's collection. The reported pomegranate germplasm collections are listed in Table 2.1. The accessions

Table 2.1. Pomegranates germplasm collections in the world.

Country	Location	No. accessions	Reference
Azerbaijan	Unknown	200–300	Levin 1995
China	Different provinces	238	Feng et al. 2006
China	Yunnan	At least 25	Yang et al. 2007
India	3 collections (unknown locations)	At least 30 each	Mars 2000
India	National Bureau of Plant Genetic Resources Regional Station, Phagli, Shimla	90	Rana et al. 2007
Iran	Agricultural research stations of Saveh (Markazi province) and Yazd (Yazd province)	More than 100	Fadavi et al. 2006
Iran	Yazd	About 760	Zamani et al. 2007
Israel	Newe Ya'ar Research Center, Agricultural Research Organization, Yizre'el Valley	67	Bar-Ya'akov et al. 2003, 2007
Russia	N.I. Vavilov Research Institute of Plant Industry, St. Petersburg	800	Frison and Serwinski 1995
Tajikistan	Unknown	200–300	Levin 1995
Thailand	5 locations in Chiang Mai, 1 in Bangkok	29	Thongtham 1986
Turkmenistan	Turkmenian Experimental Station of Plant Genetic Resources, Garrygala	1,117	Levin 2006
Tunisia	2 collections, 1 in Gabes, South Tunisia	63	Mars and Marrakchi 1999
Turkey	Alata Horticultural Research Institute, Erdemli	More than 70	Onur 1983; Onur and Kaska 1985
Turkey	Plant Genetic Resources Department, Agean Agricultural Research Institute, Izmir	158	Frison and Serwinski 1995
Turkey	Cukurova Universiy, Adana	33	Ozguven et al. 1997; Ozguven and Yilmaz 2000
Ukraine	Unknown	200–300	Levin 1995
Ukraine	Nikita Botanical Gardens, Yalta, Crimea	370	Yezhov et al. 2005
U.S.A.	U.S. National Clonal Germplasm Repository, Davis, CA	Almost 200	Stover 2007; USDA 2007
Uzbekistan	Unknown	200–300	Levin 1995
Uzbekistan	Schroeder Uzbek Research Institute of Fruit Growing, Viticulture, and Wine Production, Tashkent, Glavpochta	Unknown	Zaurov et al. 2004

include pomegranate trees that are classified wild, semiwild, or cultivated. In this review, cultivars are defined as cultivated pomegranates that have been selected and have a name. Varieties are all other pomegranates types for which there is no information concerning their cultivation.

The origin of pomegranate is considered by some authors to be in Central Asia, parts of which are in Iranian territory. The Iranian collection is of special interest since it is expected to contain some of the more diverse pomegranate varieties. Talebi Baddaf et al. (2003) reported low variability among Iranian genotypes using random amplification of polymorphic DNA (RAPD). However, RAPD analysis of 24 Iranian cultivars reported by Zamani et al. (2007) indicated a high level of polymorphism among genotypes.

The Indian collection is also interesting since wild pomegranates were reported to be grown on the slopes of the Himalayas and because most of the evergreen pomegranate cultivars reported today originate from India (Singh et al. 2006). Thus, it is expected that pomegranate germplasm from India might include highly genetically diverse pomegranate varieties. Previous reports indicate at least three Indian collections of pomegranate germplasm (Gulick and Van Sloten 1984; Mars 2000). A survey of wild pomegranates from western Himalaya was recently reported by Rana et al. (2007). They report on a highly diverse collection of 90 accessions that is being conserved and characterized in the National Bureau of Plant Genetic Resources Regional Station field gene bank.

In China, there are several reports of diverse germplasm resources (Feng et al. 2006; Yang et al. 2007). Of 238 cultivars grown in different provinces, 50 are recently bred (Feng et al. 2006). One of these collections is in Yunnan (Yang et al. 2007). RAPD analysis of 25 pomegranate accessions showed that their genetic background is complex and difficult to classify. The RAPD data disagreed with the traditional taxonomy based on flavor, petal color, and skin and aril color.

The collection from Garrygala, Turkmenistan, is of special interest since it contains specimens collected from a geographical region that is a part of the central Asian region considered as the origin of pomegranate. This collection contains wild material (Levin 1981) as well as pomegranate cultivars collected from cultivated regions. The high morphological diversity among its specimens includes dwarf and decorative specimens and accessions varieties that differ in shape, color, resistance to splitting, date of ripening, taste, juice content, and seed size (Levin 1994). The collection in Garrygala contains also specimens from Transcaucasia and foreign countries such as Spain, the United States, Iran, Tajikistan, and India. Levin (1995) reports the establishments of 200 to 300 accessions for collection in each country in Azerbaijan, Ukraine, Tajikistan, and Uzbekistan. Mirzaev et al. (2004) report on the Uzbek pomegranate collection located in the Schroeder Uzbek Research Institute of Fruit Growing, Viticulture, and Wine Production in Tashkent. Yezhov et al. (2005) report on a collection of 370 accessions in the Nikita Botanical Gardens in the Ukraine established by Nina K. Arendt. This collection includes accessions from central Asia, Transcaucasia, Iran, Afghanistan, Spain, Italy, and the United States.

Despite the high diversity expected from central Asian pomegranate varieties, amplified fragment length polymorphism (AFLP) analysis of 65 pomegranate accessions representing the central and west Asia regions as well as Russia and the United States suggested a narrow variation and lack of significant genetic divergence (Aradhya et al. 2006). Consequently Yilmaz et al. (2006) have also found narrow genetic base in pomegranate genotypes selected from different regions of Turkey using RAPD analysis.

In Turkey, a collection of more than 180 accessions was established in Alata Horticultural Research Institute. This collection contains genotypes from the Mediterranean, Aegean, South Eastern, and Bitlis Turkish regions. Onur (1983) and Onur and Kaska (1985) report on 72 cultivars. Ozguven et al. (1977 Ozguven and Yilmaz 2000) report on 33 cultivars in Cukurova University Adana, and Frison and Serwinski (1995) report on 158 pomegranate accessions in Izmir.

Wild pomegranate survey and morphological analysis on populations from the southeast regions of Armenia was reported by Stepanyan (2007). However, it is unclear whether a live collection was established.

In Tunisia, Mars and Marrakchi (1999) reported the establishment of two collections containing 63 accessions that represent 20 local landraces collected from different growing regions in Tunisia. The Tunisian collection was reported as highly divergent (Mars and Marrakchi 1999; Mars 2000). Genetic analyses of Tunisian cultivars report high polymorphism using RAPD and AFLP analyses (Hasnaoui et al. 2006; Jbir et al. 2006).

A collection of 29 cultivars was established in Thailand (Thongtham 1986). Only five specimens of this collection are from Thailand; the rest are from India, the United States, Israel, Russia, Iran, Spain, and Italy.

The Israeli collection of pomegranate in Newe Ya'ar Research Center contains 67 accessions. Most of the specimens in the collection are from Israel, including semiwild accessions, and the rest are introduced from the United States, Spain, China, India, and Turkey. All of these accessions are grown today in a single plot in Newe Ya'ar Research Center to validate their morphological characteristics excluding the effects of microclimatic conditions. All of the accessions in the Israeli collection were analyzed for their phenological and morphological characteristics (Assaf et al. 1991a; Bar-Ya'akov et al. 2003; Bar-Ya'akov et al. 2006). Some of the data are documented in the Israel Gene Bank for Agricultural Crops in the Agricultural Research Organization in Bet Dagan (http://igb.agri.gov.il/). The Israeli germplasm collection was analyzed for its content of antioxidant constituents. A comparative study among different specimens of the collection was reported on the levels of ellagic acid, punicalagin, punicalin, and galagic acid, the major contributors to antioxidant activity (Tzulker et al. 2007). The chemical analysis was followed by a genetic analysis based on inter-small sequence repeats (ISSR) technique in order to characterize the 36 genotypes of the collection. Although it was possible to demonstrate a substantial amount of polymorphism among the Israeli genotypes, additional techniques such as SSR and AFLP should be developed for pomegranates to significantly advance the study of pomegranate divergence and evolutionary relationships. As pointed out by Still (2006), much more sophisticated and elaborate research in pomegranate genomics will be required to reliably assess evolutionary relationships among different pomegranate accessions and relate genetic markers to morphological characteristics. It is highly probable that there is considerable redundancy among accessions.

The U.S. National Clonal Germplasm Repository in Davis, California, has almost 200 pomegranate accessions. The collection includes accessions from all over the world including Turkmenistan, Russia, Iran, and Japan (Stover 2007; USDA 2007)

A significant proportion of the accessions is comprised of pomegranate cultivars introduced from foreign countries. It is expected that in many cases, the true origin of the cultivars is obscured. Clearly the Davis, California, collection, the Garrygala, Turkmenistan, collection, the Newe Ya'ar, Israel, collection, and most probably other collections contain specimens that originated from other countries. Levin indicated that selected accessions from his collection were distributed to the United States and Israel (Mars 2000; Levin 2006; Stover 2007). The Thai collection and the Indian collection also were reported to contain accessions from other countries. In the local collection in Israel, for example, one can find accessions that have the same name but are actually different varieties (homonyms), and likely there are instances where identical cultivars are called by different names (synonyms). Efforts toward eliminating redundancy within the collections of each country and between countries will help to assess the divergence among pomegranate accessions. In this respect, the evolvement of landraces of introduced foreign accessions in the new hosting country should be considered.

IV. HORTICULTURE

A. Cultivars

Interesting pomegranate cultivars were reported from several locations all over the world, including Europe (Spain, France, Italy, Greece, and Cyprus), Asia (Turkey, Turkmenistan, Kirgizstan, Azerbaijan, Iran, India, China, Russia, Israel), and North Africa (Morocco, Tunisia, Egypt). The botanical differences between wild pomegranates and cultivated pomegranates are not obvious except for *P. protopunica*.

Pomegranate cultivars were spread throughout different regions and continents, and it is probable that some of the pomegranate cultivars acquired different names in different countries and are in fact the same basic genotypes. On several occasions, a clue to the origin of the cultivar is embedded within its name. For example, the cultivars 'Kaboul' or 'Kandahary' in the Indian collections hint to their possible origin from from the Afghan cities of Kabul and Qandahar. Similarly in the collection from Turkmenistan, one can find names such as 'Afghansky', 'Washingtonsky', 'Iran 29-3', and 'Kalifornijsky' (Levin 1996). The name of pomegranate in Chinese is ''An Shi Liu'', which means ''the fruit of Kabul'', reflecting its origin in Afghanistan (Fazzioli and Fazzioli 1990). Despite the difficulty in assessing the authenticity of cultivars and their distinguishing characteristics, some cultivars are clearly distinguished. Different cultures favor different fruit characteristics, and cultivar selection reflects these differences. For example, in India, most people dislike acidic fruit, and nonacidic cultivars have been selected. In Israel, most people originating from western European countries prefer sweet-sour cultivars, such as 'Wonderful'. Israelis originating from Middle East countries usually prefer nonacidic cultivars with very soft seeds, such as 'Malisi'. Thus, part of the variability in pomegranate cultivars in the world is a reflection of the different tastes and priorities in each country. Most of the cultivars known today are selections from an unknown origin, mostly chance seedlings or mutations collected from places where there are no records documenting their origin. However, some cultivars are the result of deliberate crosses. Such cultivars were reported particularly from India (Keskar et al. 1993; Samadia and Pareek 2006), China (Zhao et al. 2006; Yang et al. 2007), and to a smaller extent Israel (Holland et al. 2006; Bar-Ya'akov et al. 2007). In these countries, active breeding programs were reported, and are described in Section V.

1. India. Some of the better-known Indian cultivars ('Ganesh', 'Mridula', 'Bhagwa') share common characteristics. These include sweet flavor low-acid, small to medium fruit size, and thin rind. Unlike pomegranate cultivars from other countries, quite a significant proportion of Indian cultivars originate from active breeding programs.

'Ganesh' is perhaps the best-known Indian cultivar (Purohit 1986; Sonawane and Desai 1989; Aulakh 2004; Singh 2004). This evergreen cultivar has very soft seeds. The arils are red and the taste is low-acid and sweet. The highest yield of marketable fruits is in January, but cropping could be achieved in October, March-April, May-June, June-August, or July-September (Sonawane and Desai 1989). The skin color of 'Ganesh' is green to orange-yellow, depending on the season, and the fruit size is small. However, fruit thinning can enhance the fruit size significantly and fruit above 350 g is achievable. The yield and juice content of 'Ganesh' is good (Aulakh 2004; Singh 2004), but depend on whether the trees are grown under intensive agricultural conditions or under inadequate agricultural treatment. The yellow-green color of 'Ganesh', its tendency to split, and its relatively lower quality are reasons why it is not used a great deal as an export cultivar. 'Ganesh' was extensively used in India for breeding and crosses with other cultivars, such as 'Kabul' (large fruit, yellow red skin, sweet, hard seeds); 'Jyoti' and 'Bedana' (medium-size fruit, brownish skin, sweet, soft seeds) (Nageswari et al. 1999); 'Nana' and 'Kabul Yellow' (Jalikop 2003; Jalikop et al. 2005).

Two Indian cultivars, 'Mridula' ('Arkta') and 'Bhagwa' ('Kesar') (Vasantha Kumar 2006), are most extensively used for export, particularly to Europe. These cultivars have an appealing red skin and aril color and are soft seeded. Their taste is low-acid, sweet with a relatively small size (200 to 300 g). The rind is relatively thin, which is a weakness, because they are amenable to physical damage. 'Bhagwa' is more prone to physical damage. 'Mridula', 'Bhagwa' and 'Ganesh' are evergreen cultivars. They are exported to Europe usually in January–February.

The enormous area of the Indian peninsula and its very divergent climatic zones clearly require cultivars that are adapted to each of the regions. Additional Indian cultivars include ‘Alandi’, ‘Muskat’ (Wavhal and Choudari 1985; Purohit 1986), ‘Jalore’, ‘Jodhpur Red’, ‘Dholka’ (large fruit, yellow red skin, sweet, hard seeds, evergreen), ‘Bassein’, ‘Malta’, ‘Kandhari’ (large fruit, deep red skin, pink-blood red arils, subacid, hard seeds) (Singh 2004), ‘Guleshah’, ‘Molus’, ‘Sharin’, ‘Anar’ (Aulakh 2004), ‘Jylothi’, ‘Bedana’, ‘Bosco’ (Nageswari et al. 1999), ‘Srinagar Special’ (Misra et al. 1983), ‘Chawla’, ‘Nabha’, and ‘Achikdana’ (Kumar and Khosla 2006).

2. Iran. About 760 genotypes, specimens, and cultivars were reported in the Yazd pomegranate collection (Behzadi Shahrbabaki 1997; Zamani et al. 2007). Since these specimens were brought from many provinces, synonyms or obvious similarities in appearance were observed among these specimens (Zamani et al. 2007). Zamani et al. (2007) list 24 Iranian genotypes. Varasteh et al. (2006) listed five commercially important Iranian cultivars and discussed their fruit characteristics and their potential for further breeding. ‘Malas-e-Saveh’, ‘Rabab-e-Neyriz’, ‘Malas-e-Yazdi’, ‘Sishe Kape-Ferdos’, and ‘Naderi-e-Budrood’ were considered valuable (Varasteh et al. 2006). These cultivars are late ripening, medium to large size with thick red rind and red arils. In addition, several other late Iranian cultivars were noted: ‘Ardesstani Mahvalat’, ‘Bajestani Gonabad’, ‘Ghojagh Ghoni’, ‘Khazr Bardaskn’, ‘Malas Yazd’, ‘Galou Barik’, ‘Bajestan’, ‘Zagh’, ‘Shavar Daneh Ghermez’, ‘Sefid’, ‘Togh Gardan’, and ‘Esfahani Daneh Ghermez’ (Varasteh et al. 2006; Iran Agro Food 2007). ‘Alack’ is an early Iranian cultivar that ripens in late August to early September and is used for export. The season for this cultivar lasts until 15 September (Van der Wiel 2007a). Zamani et al. (2007) report on ‘Alak Shirin’ (sweet) and ‘Alak Torsh’ (sour); both are red, small sized, with hard seeds. ‘Maykhosh’ is a late export cultivar that can be picked until the end of December (Van der Wiel 2007a).

3. China. Chinese cultivars are characterized by a very large variability and sometimes unusual features, such as spur-type growth habit, double flowers, and white flowers. Chinese cultivars vary from small to very large. Taste could be sour or sweet. Some of the Chinese cultivars are very early, beginning in early August, and some are late, ending the season in November. Evergreen cultivars are also known (Dong 1997). Most Chinese cultivars are either selections from unknown origin or seedlings of known cultivars.

'87-Qing 7' is an early-bearing, productive spur-type cultivar that is one of the very few published reports of a mutation in pomegranate (Liu et al. 1997). Aside from its commercial importance, '87-Qing 7' and its parent 'Qingpitian' might be of special help for gene mapping and functional gene analysis. 'Duanzhihong', selected from a local orchard, is another spur-type cultivar from Xingcheng (Liu 2003). This cultivar has a compact bush; it ripens in the end of August: Fruit size is above 340 g on average with bright red skin color; arils are pinkish red.

Feng et al. (1998) evaluated 30 Chinese cultivars and identified four superior cultivars: 'Dabaitian' (sweet, white skin, white flowers), 'Heyinruanzi' (sweet-sour, green skin, red flowers), 'Tongpi' (sweet-sour, green skin, red flowers), and 'Bopi' (sweet-sour, red skin, red flowers). The 'Teipitian' cultivar was reported to be popular with a very large fruit that can reach more than 1.5 kg; skin is yellow-green and the arils are bright red (Dong and Yang 1994). Two cultivars ('Linxuan 8' and 'Lintong 14') are from the Lintong area in China: 'Linxuan 8' ripens in September and has soft seeds; 'Lintong 14' matures toward October (Sun et al. 2004). 'Taishan Dahong', an early cultivar, is a seedling of an unknown origin from the southern foothills of Tai Mountain, Shaanxi (Sun et al. 2004). One of the common pomegranate cultivars from Sichuan province is 'Qingpiruanzi' (Diao 2004), which matures in mid- to late August and has large fruit, soft seeds, and pink arils. Other cultivars with commercial importance were reported from Longyang district in Baoshan municipality (Zhou 2005). Three promising cultivars ('Baishuijing', 'Chuanshiilu', and 'Hongshuijing') were selected. Other cultivars from Hui Li County in the Sichuan province are 'Ping Di' and 'Jian Di'; both have green skin and soft seeds (Sichuan Hui Li Pomegranates Association 2007). 'Yushiliu 1', 'Yushiliu 2', and 'Yushiliu 3' are red-skinned and highly adapted to sandy alkaline soils (Feng et al. 2000). From these samples, it is apparent that in China, cultivars were mostly chosen based on size, juice content, seed softness, and time of ripening. Pink color of skin and arils was not a reason for disqualification. Chinese cultivars with unusual number of petals (''double flower'') and petal color were considered suitable cultivars for ornamental purposes. The color of these cultivars varies from red-pink to pink-white, and some are fertile and produce edible fruit. Examples of double-flowered selections with good eating quality include 'Honghuachongbai' and 'Baihuachongbai' (Feng et al. 1998). The double-flowered 'Mudanhua' has peonylike flowers and was noted for its long flowering season, from early May to late October (Wang 2003).

4. Turkmenistan and Tajikistan. The Turkmen collection in Garrygala is of special interest due to its size, variability, and geographical location. Levin (1996) provided a detailed report on the various qualities and characteristics of the Turkmen pomegranate fruit. The Turkmen varieties were categorized by size, taste, skin color, aril color, seed softness, productivity, tendency to split and to diseases, storage capabilities, sugar content, juice content, and time of ripening. Cultivars combining early ripening, good flavor, and chemical com-position were noted (Levin and Levina 1986). Kzyl Anar' and 'Achik-Dona' from the Garrygala collection were also tested in Tajikistan together with 'Bashkalinski', 'Desertnyi', 'Shainakskii', and 'Podarok' (Ivanova 1982). 'Kzyl Anar' has relatively small fruits (200 to 250 g), hard seeds, and red or dark-cherry arils. 'Acik-Dona' has a medium-size (Ivanova 1982) to large-size (Levin 1996) fruits with hard seeds and pale crimson to red arils, along with high yield. Published records of commercial Turkmen cultivars in Turkmenistan or in any other countries appear to be lacking. Some of the Turkmen cultivars were sent to Israel and to the United States (Mars 2000; Levin 2006; Stover 2007).

5. Turkey. Few reports on Turkish cultivars were published. Among the known Turkish cultivars are 'Cekirdksiz', 'Ernar', 'Fellahyemez', 'Hatay', 'Hicaznar', 'Izmir 1', 'Izmir 1264', 'Izmir 1265', 'Janarnar', 'Katrbas', 'Lefan', 'Mayhos II', 'Mayhos IV', 'Silifke Asisi', and 'Yufka Kabuk' (Ozguven and Yilmaz 2000; Ozguven et al. 2006). There are several selections of 'Hicaznar', 'Izmir', and 'Silifke' differentiated by numbers. 'Hicaznar' is a red cultivar that is considered a high producer. The fruit has a sweet-sour taste and hard seeds and is somewhat similar to 'Wonderful'. 'Lefan' is a selection from Hatay with yellow skin, large arils, a sweet-sour flavor, and very hard seeds. 'Janarnar' has red skin, red arils, sweet-sour flavor, and hard seeds. 'Izmir 26' has a sweet flavor. It appears that most of the Turkish cultivars are sweet-sour, and the preferred color is red.

6. Israel. Israeli pomegranate varieties are unexpectedly diverse compared to the small size of the country (Plate 2.1F). More than 50 pomegranate accessions were found in Israel. These accesssions are very divergent in their fruit external and internal appearance, growth habit, ripening time, taste, and seed softness. The outside skin color of the Israeli cultivars varies from deep purple to yellow-pink, or green. and eight are grown commercially. All the Israeli accessions were given identity numbers in recognition that synonyms and homonyms were likely among the names when collected. Based on comparisons in a single orchard in Newe Ya'ar certain pomegranate cultivars are very different from one another but have the same name (e.g., 'Hershkovich') while others that are identical got different names (e.g., 'Wonderful'). These cultivars were identified as valuable for commercial growth: 'P.G.116-17', 'Wonderful' ('P.G.100-1' and 'P.G.101-2'), 'P.G.128-29' ('Akko'), 'Shani-Yonay', 'Rosh Hapered', 'P.G.127-28' ('Black'), 'P.G.118-19' ('Hershkovich'), and 'Malisi' ('P.G.106-7') (Plate 2.2 A–G).

Traditionally, three types of pomegranate cultivars were grown in Israel, 'Rosh Hapered' 'Malisi', and 'Red Lufani' ('Shara'bi'). The first two cultivars have pink arils and their taste is sweet without any sourness. 'Rosh Hapered' has a large fruit, large arils, hard seeds, and pink skin. This cultivar is traditionally used in the Jewish holidays since it ripens at the end of August and in the past was considered one of the main early cultivars for export. 'Malisi' has soft seeds, light pink arils, and yellow-pink to green skin. 'Malisi' is grown only in small plots and is not used for export. 'Red Lufani' is a synonym of 'Wonderful'.

The main cultivar that is grown today is 'P.G.101-2' ('Wonderful'). This cultivar was reported to be imported from the United States about 100 years ago (Goor and Liberman 1956). This large-size pomegranate ripens in the beginning of October. It is a sweet-sour pomegranate with red arils and skin when fully ripened. There are many 'Wonderful' selections in Israel. Seven were characterized in the Newe Ya'ar collection. The landraces vary in their time of ripening, their external color, the timing of skin color appearance during fruit development, and the degree of seed hardness. Among the 'Wonderful' landraces, 'Kamel' is the most colorful cultivar (Plate 2.2G). This cultivar has a full red skin color that develops much earlier than regular 'Wonderful'. It is very productive cultivar and produces high-quality fruits. As the export market increased and demand for early red cultivar strengthened, two additional early red cultivars were introduced to commercial cultivation: 'Akko' and 'Shani-Yonay' (Holland et al. 2007). Both are soft-seeded cultivars with sweet/sourless taste and red skin color. Their appealing look and good taste makes them the leading early Israeli export cultivars. 'Akko' differs from 'Shani-Yonay' in growth habit and shape of fruit and tree. Both cultivars produce small-medium fruit of average size of 300 to 400 g. Two cultivars 'P.G.116-17' and 'P.G.118-19' ('Hershkovich') ripen between the late 'Wonderful' and the early cultivars. 'P.G.116-17' is today the best export cultivar. It has a large fruit, large red arils, and an appealing red skin. An additional Israeli cultivar just recently introduced to commercial growth is the black 'P.G.127-28'. This cultivar has a deep purple-black skin with red

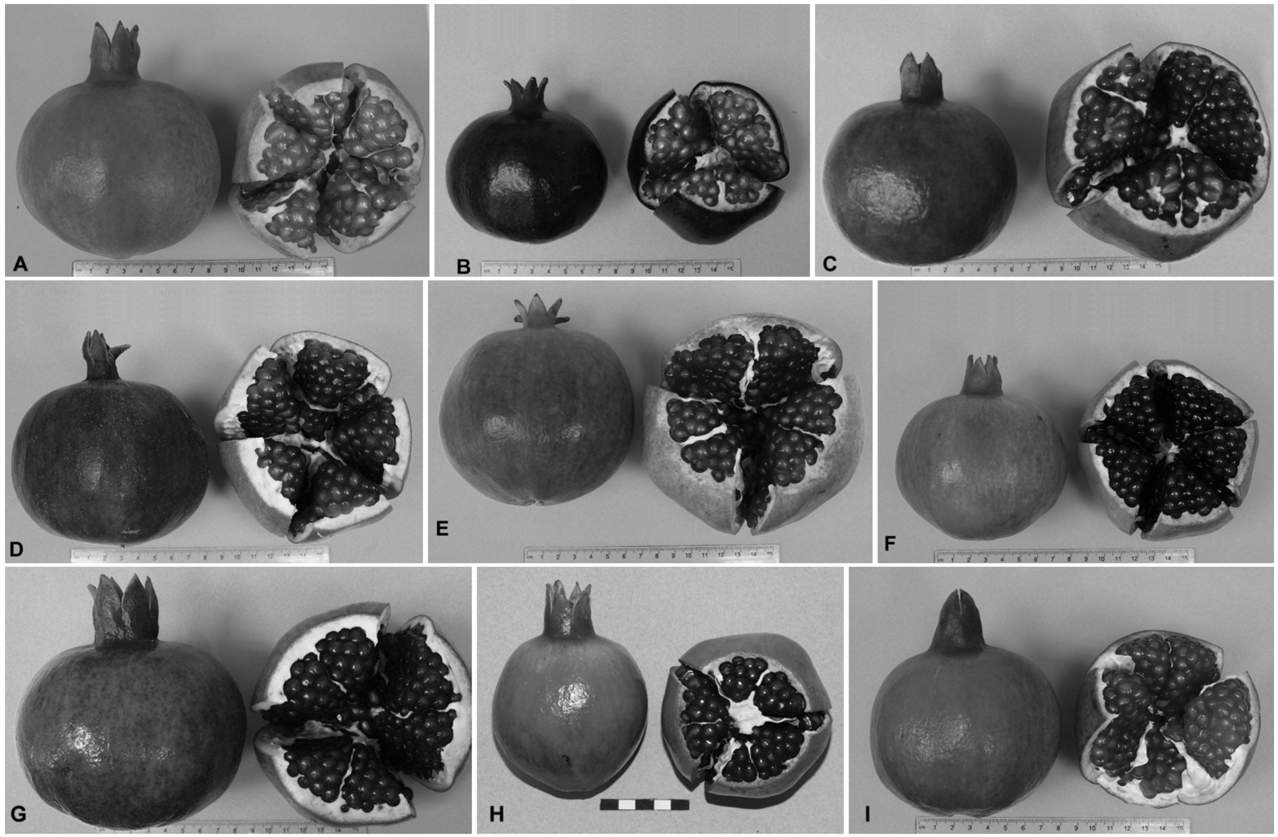

Plate 2.2. Pomegranate cultivars. A. 'Rosh Hapered'; B. 'P.G.127-28'; C. 'P.G.116-17'; D. 'P.G.118-19' ('Hershkovich'); E. 'Wonderful'; F. 'Shani-Yonay'; G. 'Kamel'; H. 'P.G.128-29' ('Akko'); I. 'Emek'. (See insert for color representation of this plate.)

soft-seeded arils. It produces a small fruit that matures in November in Newe Ya'ar conditions and is the latest ripening cultivar tested. The unusual skin color, the very late ripening time, and the soft red arils make 'P.G.127-28' an appealing late cultivar.

7. Spain. At least 40 Spanish cultivars were reported in the literature. Melgarejo divides these cultivars into three groups: sweet, sweet-sour, and sour (Melgarejo et al. 2000). Some of the common commercial cultivars include 'Mollar de Elche' and its selections 'ME1' ('Mollar de Elche No. 1'), 'ME5', 'ME6', 'ME14', 'ME15', 'ME16', and 'ME17', 'Agria de albatera', 'Agria de Blanca', 'Agridulce de Ojos' ('ADO'), 'Albar de Bianca' ('BA'), 'Borde de Albatera' ('BA') and its selection 'BA1', 'Borde de Blanka' ('BB'), 'Casta del Reino de Ojos' ('CRO') and its selection 'CRO1', 'Mollar de Albatera' ('MA') and its selection 'MA4', 'Mollar de Orihuela' ('MO') and its selection 'MO6', 'Pinon Duro de Ojos' ('PDO'), 'Pinon Tierno Agridulce de Ojos' and its selections 'PTO1' ('Pinon Tierno de Ojos No. 1'), 'PTO2' and 'PTO7', 'San Felipe de Bianca' ('SFB'), and 'Valencian No. 1' ('VA1') (Melgarejo et al. 1995, 2000 Hernandez et al. 2000; Legua et al. 2000a, 2000b; Martinez et al. 2006). Some Spanish cultivars like 'Mollar de Elche', 'Borde de Albatera', 'Pinon Tierno de Ojos', 'Casta del Reino de Ojos', and others have several selections or clones, which are actually landraces. A different number associated with the cultivar name indicates the different landraces within each cultivar (Melgarejo et al. 1995, 2000; Hernandez 2000; Legua et al. 2000a, 2000b).

The best-known Spanish cultivar is the landrace 'Mollar de Elche', which produces sweet fruit with soft seeds. The outside color is pink-red and the arils are red. 'Mollar de Elche' ripens in October-November. Martinez et al. (2000) indicate that 'ME14' and 'ME15' have the highest yield. Another sweet cultivar is 'Valencian'. 'Agridulce de Ojos' and 'Pinon Tierno de Ojos' are sweet-sour (Melgarejo et al. 2000), and 'Agria de Albatera', 'Agria de Blanca' (Melgarejo et al. 1995), 'Borde de Albatera', and 'Borde de Blanca' are sour (Melgarejo et al. 2000). 'PTO2' and 'CRO1' have shown a high juice content (Martinez et al. 2006).

Many of the Spanish cultivars have been subjected to detailed studies of their sugar and organic acid content (Legua et al. 2000; Melgarejo et al. 2000), oil content of their seeds, and fatty acid composition of the oil seed (Melgarejo et al. 1995; Hernandez et al. 2000). It was found that citric acid and malic acid were the predominant organic acids (Melgarejo et al. 2000). The predominant fatty acid in the oil seed was polyunsaturated (n-3) linolenic acid followed by oleic acid (Melgarejo et al. 1995).

Under the conditions of Newe Ya'ar, Israel, the Spanish cultivars 'ME17', ME20', 'VA1', and 'PTO1' were found to have a pink-yellow skin color and light-pink aril color. Overall, the colors of the Spanish cultivars in Israel were poor and unattractive compared to their colors in Spain. 'ME' selections ripen at the beginning of October in Israel. It appears that the examined Spanish cultivars are sensitive to their environmental conditions with respect to color intensity.

8. United States. Pomegranates in the New World probably were imported by travelers from Europe. There is a relatively limited number of pomegranate cultivars in the United States 'Wonderful', the most important cultivar, originated in Florida and was discovered in Porterville, California, about 1896 (LaRue 1980). This cultivar is the most widely planted commercial pomegranate cultivar in California. The fruit is a large with red arils, sweet-sour taste, and semihard seeds, and it ships well. The external appearance of the fruit is very appealing with red glossy color. The several Israeli landraces of 'Wonderful' are either 'Wonderful' seedlings (most likely) or sports. It is unclear whether the American 'Wonderful' is genetically distinguishable from any of the Israeli 'Wonderful' landraces. The American 'Wonderful' fruit is much harder and less prone to mechanical aril extraction than the Israeli landraces, but these differences could reflect variations in growth condi-tions. 'Wonderful' is also grown in western Europe and Chile (Stover and Mercure 2007).

'Early Wonderful' is a sport of 'Wonderful' found in California (Stover and Mercure 2007). It ripens about two weeks before 'Wonderful' and acquires a red skin color much earlier than the original one (California Rare Fruit Growers Inc. 1997). The quality of the juice is inferior to the original 'Wonderful'. Another commercial cultivar is 'Early Foothill', an early cultivar with red skin and aril color. It is much smaller than 'Wonderful' and its fruit quality is not as good. A cultivar grown in the United States to a much lesser extent is 'Granada', a 'Wonderful' sport (Stover and Mercure 2007). This early-maturing cultivar ripens in mid-August. The quality of the fruit and juice is not considered as good and its commercial value is limited. 'Ruby Red' is a cultivar with similar size and ripening time as 'Wonderful' but stores less well than 'Wonderful'. Other cultivars grown to a limited extent are 'Balegal', 'Cloud', 'Fleshman', 'Crab', 'Francis', 'Green Globe', 'Home', 'King', 'Phoenicia', 'Sweet', and 'Utah Sweet' (California Rare Fruit Growers 1997). Several ornamental pomegranate cultivars, such as 'California Sunset', are being sold in the United States. At least two originated in Japan. These include the ''double-flower'' cultivars: 'Nochi Shibori' and 'Toyosho', according to the Davis depository list (USDA 2007).

9. Georgia. Several cultivars were reported in Georgia, including 'Pirosmani', 'Gruzinskii No. 1', 'Gruzinskii No. 2', 'Vedzisur'i, 'Lyaliya', 'Tengo', 'Imeretis Sauketeso', 'Bukistsikhe', 'Khorsha', 'Zugdidi', 'Erketuli', 'Forma No. 1', 'Forma No. 15', 'Forma No. 70', 'Shirvani', 'Apsheronskii Krasnyi', 'Burachnyi', 'Rubin', 'Frantsis' 'Sulunar', 'Kyrmyz Kabukh', 'Shiranar', Shakhanar', and 'Gyuleisha Krasnaya' (Trapaidze and Abuladze 1989; Alkhazov and Chakvetadze 1991; Vesadze and Trapaidze 2005). These cultivars were noted for their resistance to splitting: 'Apsheronskii Krasnyi', 'Burachnyi', 'Frantsis', 'Kyrmyz Kabukh', 'Lyaliya', 'Pirosmani', 'Rubin', 'Shirvani', and 'Verdzsuri' (Trapaidze and Abuladze 1989; Vesadze and Trapaidze 2005). The highest juice content was found in 'Sulunar', 'Pirosmani', 'Vedzisuri', and 'Imeretis Sauketeso' (Vesadze and Trapaidze 2005).

10. Tunisia. Almost all the pomegranate fruits produced in Tunisia are consumed locally, and the cultivars grown in traditional orchards are not of the best quality. Just a few local cultivars are planted in new orchards (Mars and Marrakchi 1999). Among the Tunisian cultivars one can find 'Gabsi' (the main cultivar, sweet); 'Tounsi' (sweet, late ripening); 'Zehri' (sweet, ripens end of August or beginning of September); 'Chefli' (sweet, poor skin color, big nice arils); 'Mezzi', 'Jebali', 'Garoussi' (sweet-sour, green skin); 'Garoussi'; 'Kalaii' (sweet, poor skin color, big nice arils); 'Zaghouani'; 'Andalousi' (sweet); and 'Bellahi' (Mars and Marrakchi 1999; F. Abed Elhadi pers. commun.)

11. Egypt. Four Egyptian cultivars were documented in the literature: 'Arabi', 'Manfaloty', 'Nab ElGamal', and 'Wardy' (Abu-Taleb et al. 1998; Saeed 2005). 'Manfaloty' was more sensitive to salt stress while 'Nab ElGamal' was the best with respect to loss of chlorophyll in response to elevated salt concentration in the irrigation water (Saeed 2005). 'Manfaloty' (or 'Manfaloot') has large, juicy dark-red arils and ripens from the end of August or the beginning of September (Van der Wiel 2000b). Apart from these cultivars, 'Granada' is used in Egypt as an early cultivar. It is unclear whether the Egyptian 'Granada' is identical to the American 'Granada', although its early ripening season suggests that they are similar (Van der Wiel 2000b).

12. Saudi Arabia and Iraq. Very little information is available on pomegranates from Saudi Arabia and Iraq. 'Ahmar' (red), 'Aswad' (black), and 'Halwa' (sweet) were reported as important in Iraq and 'Mangulati' in Saudi Arabia (Morton 1987).

13. Vietnam. 'Vietnamese' is an evergreen cultivar from Vietnam. It has orange flowers, bright red skin color, and small and juicy arils (Jene's Tropical Fruit 2006).

14. Morocco. About 17 pomegranates clones and cultivars were reported by Oukabli et al. (2004) from Meknes, including 'Gjeigi', 'Dwarf ever Green', 'Grenade Jaune', 'Gordo de Javita', 'Djeibali', and 'Onuk Hmam'.

15. Sicily, Italy. Six Sicilian pomegranate selections were reported by Barone et al. (2001): 'Dente di Cavallo', 'Neirana', 'Profeta', 'Racalmuto', 'Ragana', and 'Selinunte'. The local accessions were considered less attractive than the Spanish cultivars.

B. Irrigation

Although pomegranates enjoy heat and thrive in arid and semiarid areas, they need regular irrigation throughout the dry season to reach optimal yield and fruit quality (Sulochanamma et al. 2005; Levin 2006; Holland et al. unpubl.). The pomegranate fruit requires heat for its development. Sulochanamma et al. (2005) found that drip irrigation had positive effects on pomegranate growth parameters such as tree height, stem diameter, and plant spread. Positive effect was also noted on fruit yield and fruit weight (Prasad et al. 2003; Shailendra and Narendra 2005; Sulochanamma et al. 2005). In most growing areas where commercial growth of pomegranates is practiced, some sort of irrigation is required. In Israel, irrigation usually starts in late April and lasts throughout the summer, productinq yields of 25 to 45 t/ha. Similar data are reported from California. Drip irrigation is used most commonly in these orchards, although some growers prefer sprinklers (which cause difficulties in weed control). Most of the large commercial orchards in Israel, India, and the United States utilize drip irrigation methods. In experiments done in India and Iran, drip irrigation saved up to 66% of water compared to surface irrigation (Behnia 1999; Chopade et al. 2001).

The total amount of water for pomegranate irrigation in Israel for the entire season is 5,000 to 6,000 m^3/ha, depending on the type of soil and the weather conditions. Daily irrigation is practiced during the irrigation season. The amount of daily irrigation is calculated as percentage of daily water loss measured by evaporation from Class A evaporation pan. The percentage of water compensation varies according to field conditions. Computerized irrigation yields better results and allows for better control of water quantities and time intervals between successive water applications. Computerized irrigation is of special importance when fertilization and other treatments are applied through the water. There are few reports on the effect of irrigation levels and the time and interval of water application on yield and quality of pomegranate fruit.

Control of irrigation timing and seasonal application are important not only for better growth and yield of the pomegranate trees but also are used to control time of ripening. For example, in India, timing of irrigation is used to control and optimize the yielding season of evergreen pomegranates (Sunawane and Desai 1989). By applying different irrigation regimes, it was possible to direct the desirable time of fruit yield in Indian pomegranates.

In view of the global warming phenomenon and the increasing water shortage experienced in many arid and semiarid regions that are the most suitable regions for pomegranate growth, water availability and irrigation are of major considerations in pomegranate culture. Therefore, many more efforts will be required to develop optimal and effective irrigation methods that are suitable for pomegranate growth. One direction toward this goal is the development of a computer program for calculating pomegranate drip irrigation. This program calculates the irrigation and fertilizer requirements (Gimenez et al. 2000).

One of the most important issues concerning pomegranate irrigation is the ability to use alternative water sources, particularly recycled water and saline water. Usage of recycled water is strongly connected to salinity since quite often salinity increases in recycled water (Raviv et al. 1998). Pomegranates are amenable to irrigation with saline water. In Israel, several desert orchards in the Negev Highlands and in the southern Arava are irrigated with saline water. The level of salinity in the water of these orchards ranges between 2.5 to 4.0 dS/m. Under these conditions in Israel, Israeli and Turkmen cultivars grew to produce normal yield and fruit qualities without apparent damages on the trees. Production using saline waters requires constant irrigation to leach the salt and prevent the detrimental effects of increased salinity. One of the side effects of such practice is higher vegetative growth, which should be controlled in trees that grow too fast. Pomegranate trees were irrigated with 4,000 and 6,000 parts per million (ppm) saline water. Under these conditions, the saline water negatively affected various vegetative growth factors. Differences among different cultivars were observed, and application of Paclobutrazol was reported to reduce salinity damage (Saeed 2005). Salinity tolerance among 10 commercial Iranian cultivars in pots was reported by Tabatabaei and Sarkhosh (2006). In this experiment, the authors indicate pronounced differences to irrigation with saline water among pomegranate cultivars.

The mechanisms responsible for pomegranate tolerance to saline water are not yet fully understood. However, it is well documented that pomegranate tissues accumulated sodium, chlorine, and potassium in response to irrigation with saline water and that the concentration of these ions was increased with increased concentrations of salt in the irrigation water (Doring and Ludders 1987; Naeini et al. 2004, 2006). These authors indicated tolerance to saline water up to concentration levels of 40 mM NaCl in the water. Above this concentration, growth parameters such as the length of the main stem, length and number of internodes, and the area of leaf surface were severely affected (Naeini et al. 2006). The data just mentioned suggests that the pomegranate tolerance to salinity is due to resistance of its tissues to higher levels of salt rather than ability to prevent penetration of ions into its tissues.

Recycled water is now relatively abundant in several regions in Israel. Some pomegranate orchards are irrigated with recycled water after secondary or tertiary treatment. It appears that pomegranate trees respond well to irrigation with recycled water. Positive response to irrigation with recycled water was also reported by Levin (2006) in pomegranate orchards in Turkmenistan. As high-quality water becomes less available and more expensive, it is expected that recycled water will become a common irrigating practice in arid areas.

C. Fertilization

The available data on pomegranate fertilization is very limited. Most of the reported fertilization experiments were conducted in India and few in Turkey and Iran. A common practice in Israel is to supply fertilizers via the irrigation system (Blumenfeld et al. 2000). When surface irrigation combined with fertilizers was compared to drip irrigation with solid soluble fertilizers, the drip irrigation proved to be the better treatment (Firake and Kumbhar 2002).

In Israel, the recommended quantity for nitrogen is 200 kg/ha and for potassium (potassium oxide) is 300 kg/ha (Kosto et al. 2007). About 60 kg/ha of phosphorus (phosphorus pentoxide) is recommended.

Nitrogen is applied with the beginning of growth through the entire irrigation period up until two weeks before harvest. However, additional nitrogen fertilization is supplied after harvest in early-ripening cultivars. Excessive or late applications of nitrogen may delay fruit maturity and color development (LaRue 1980). Potassium is applied throughout the irrigation season. Phosphorus is applied as phosphoric acid or in complete fertilizer mixtures. When phosphoric acid is used, applications are in two phases, the first at the beginning of the season and the second at the end. The last application is also used to clean the irrigation system. When a complete fertilizer mixture is used, it is applied throughout the nitrogen fertilization season (Kosto et al. 2007).

Foliar application of potassium chloride and potassium sulfate for maintaining optimal levels of potassium were reported by Muthumanickam and Balakrishnamoorthy (1999). Microelements, such as zinc, iron, and manganese, applied on leaves have resulted in increased yield and juice content (Balakrishnan et al. 1996).

A crucial step toward more educated application of fertilizers is to determine the standard levels of macro- and microelements in pomegranate leaves of important commercial cultivars. In Israel, such data are not yet available; however, a survey of four different orchards resulted in these values: 1.99% N, 0.22% P, 1.07% K, 2.97% Ca, 0.25% Mg, 0.02% Na, 0.76% Cl, 23 ppm B, 75 ppm Fe, 33% Mn, 11 ppm Cu (F. Abed Elhadi, pers. commun.).

Prasad and Mali (2003) have shown that the ratio of aril weight to total fruit weight is linearly correlated with the rates of supplied nitrogen while total soluble solids (TSS) were not affected. The dependence of yield, fruit weight, aril number, aril volume, pH, acidity, and TSS on nitrogen, manganese, and potassium were studied by Panahi and Amiri (2006) in Iran. It was shown that potassium application increased fruit weight, significantly increasing the yield.

D. Tree and Orchard Design

Unlike most other fruit trees, use of rootstocks with pomegranates is not a common practice. Pomegranates are very easy to root from cuttings, and this is the major method for pomegranate propagation. Orchard establishment can be done by directly planting the cuttings in the soil or by planting potted nursery trees. The latter method sometimes is preferred because it assures a better uniformity and establishing success of the trees.

Pomegranates are bushy plants that tend to produce multiple suckers which sprout from the stem either underground or aboveground. The traditional way of growing pomegranates is the multiple trunk method. In this practice, the tree is allowed to develop 3 to 5 main trunks that sprout from the ground level. The branches are trained to grow as an open vase (Blumenfeld et al. 2000). The height of the tree is typically maintained below 4 m. This method helps maintain productive branches through many years and helps to cope with pathogens inflicted by stem borers, such as *Euzophera* sp. When a branch is lost, a shoot is trained as a replacement branch. The disadvantage of multiple trunks is that it complicates many cultivation practices such as pruning, spraying, removal of unwanted growth, and fruit harvesting. The plants tend to produce many new branches in their interior, and the bushy new growth is amenable to aphid attacks. With the development of effective chemicals against stem borers, today it is possible to rely on the single-stem method, which has several variations.

The most common practice today in modern orchards in Israel is to train a single trunk up to about 30 cm. The trunk is than split to 3 or 4 main branches, and the tree is trained as a vase shape to a height of 3.5 to 4 m. Properly irrigated and fertigated orchards trained in this way often produce more than 30 tonnes per hectare on the average.

One of the main problems in pomegranate production is the tendancy for young branches to bend from fruit weight in the first years of production, distrupting tree structure and causing ground-contact of fruit. For this reason, it is a common practice to tie up branches or to shorten the main branches by pruning. Frequently it is necessary to support the branches, particularly when there is a heavy load of fruit on the young branches.

Light is a very important factor in pomegranate bearing and fruit quality. Therefore, summer pruning is required to remove suckers and new branches that appear continuously on the exposed trunks. Winter pruning is used mostly when there is a need to induce new growth, eliminate broken or intrusive branches, and/or control the tree height.

In California, pomegranate trees are frequently pruned in the first years of growth to strengthen the main trunk and leading branches. The branches growing from the main trunk are maintained relatively short, and the tree is topped by machine to keep control of its height. This method requires intensive labor, and sometimes the trees are overexposed to sunlight, which may cause fruit sunburn.

To provide optimal light for fruit development, pomegranate trees are planted with wide spacing (typically 6×4 m) despite relatively small tree size. Some growers plant denser orchards (6×2 m) to obtain higher yields in early years with removal of alternate trees in later years.

E. Plant Protection

Pomegranates are prone to various pests and plant diseases that include insects, fungi, and bacteria. Primary pests and diseases vary between the different geographical regions. While some pests are a big problem in one place, they are unharmful or absent from other regions. However, some pests and diseases are common to most of the pomegranate-growing regions. The list of the main pomegranate pests is provided in Table 2.2.

Among the main insects that attack the pomegranate stems and trunk are the bark beetle Island pinhole borer or shothole borer *Xyleborus perforans* Wollaston 1857 (Coleoptera: Scolytidae), the stem borer moth *Euzophera sp.* (Lepidoptera: Pyralidae) (Blumenfeld et al. 2000; Jagginavar and Nalik 2005), and the tea shothole borer *Euwallacea* (*Xyleborus*) *fornicatus* Eichhoff 1868 (Coleoptera: Scolytidae) (Mote and Tambe 1990). Effective insecticides for the management of these insects were reported (Mote and Tambe 1990; Blumenfeld et al. 2000; Jagginavar and Nalik 2005). The bark-eating caterpillar *Indarbela quadrinotata* Walker 1856 (Lepidoptera: Cossidae) is known as pomegranate pest in India (Shevale 1991). Leopard moth *Zeuzera pyrina* Linnaeus 1761 (Lepidoptera: Cossidae) was reported as pome-granate trunk borer in Spain (Juan et al. 2000), Turkey (Ozturk et al. 2005), and Israel (Goor and Liberman 1956). In China, *Zeuzera coffeae* Nietner 1861 (Lepidoptera: Cossidae) was reported as an important pomegranate pest (Ma and Bai 2004).

Aphids are serious and widespread pests in pomegranate orchards. Young pomegranate leaves are highly susceptible to aphid attacks. Aphids *Aphis punicae* Passerini 1863 (Aphididae: Homoptera) (Blumenfeld et al. 2000) and the cotton aphid *Aphis gossypii* Glover 1877 (Hemiptera: Aphididea) (Juan et al. 2000; Carroll et al. 2006) tend to attack the leaves in early spring and secrete honeydew, which attracts ants and sooty mold (a charcoal-black fungus of several genera) that appears as a black cover on the surface of the infected leaves, branches, and fruits. The fungus is not pathogenic but can cause major damage, particularly to young trees. The ash whitefly *Siphoninus phillyreae* Haliday 1835 (Hemiptera: Aleyrodidae) was reported to be a pest on pomegranate leaves in several countries, including Turkey (Ozturk et al. 2005), Egypt (Mesbah 2003), Venezuela (Arnal and Ramos 2000), India (Shevale and Kaulgud 1998), and California (Carroll et al. 2006).

Some scales were reported as pomegranate pests. Among them are Japanese wax scale *Ceroplastes japonicus* Green (Hemiptera: Coccidae)

Table 2.2. Pest list of pomegranate and their distribution in pomegranate-growing regions.

Pest target	Pest scientific name	Order: family	Common name	Known distribution	Reference for damage
Branches and trunk	*Xyleborus perforans* Wollaston 1857	Coleoptera: Scolytidae	Bark beetle, island pinhole borer, or shothole borer	India, Portugal, USA	Jagginavar and Nalik 2005
	Euzophera sp.	Lepidoptera: Pyralidae	Pomegranate stem borer moth	Israel	Blumenfeld et al. 2000
	Euwallacea (*Xyleborus*) *fornicatus* Eichhoff 1868	Coleoptera: Scolytidae	Tea shothole borer	From Japan south to New Guinea and west to India, U.S.A.	Mote and Tambe 1990
	Indarbela quadrinotata Walker 1856	Lepidoptera: Cossidae	Bark-eating caterpillar	India	Shevale 1991
	Zeuzera pyrina Linnaeus 1761	Lepidoptera: Cossidae	Leopard moth	Southern Europe, Mediterranean, Southeast Asia, Central Asia, USA	Goor and Liberman 1956; Juan et al. 2000; Ozturk et al. 2005
	Zeuzera coffeae Nietner 1861	Lepidoptera: Cossidae	None	Southeast Asia, Australia	Ma and Bai 2004
Branches	*Ceroplastes japonicus* Green	Hemiptera: Coccidae	Japanese wax scale	Southern Europe, central Asia, China	Ma and Bai 2003
	Parasaissetia nigra Nietner 1861	Hemiptera: Coccidae	Nigra scale	Worldwide	Jadhav and Ajri 1992; Shevale and Kaulgud 1998
	Saissetia oleae Olivier 1791	Hemiptera: Coccidae	Black scale	Worldwide	Goor and Liberman 1956; Juan et al. 2000; Carroll et al. 2006

(*Continued*)

Table 2.2. (*Continued*).

Pest target	Pest scientific name	Order: family	Common name	Known distribution	Reference for damage
Branches	*Coccus pseudo-magnoliarum* Kuwana 1914	Hemiptera: Coccidae	Citricola scale	Southern Europe, Near East, Caucasus, Australia, USA	Carroll et al. 2006
	Ceroplastes sinensis Del Guercio 1900	Hemiptera: Coccidae	Chinese wax scale	Southern Europe, Mediterranean, Near East, Australia, South America, USA, South Africa	Juan et al. 2000
	Eriococcus lagerstroemiae Kuwana 1907	Hemiptera: Coccidae	Crapemyrtle scale	India, China	Zhao et al. 1998
Leaves and branches	*Planococcus citri* Risso	Homoptera: Pseudococcidae	Citrus mealybug	Worldwide	Blumenfeld et al. 2000; Juan et al. 2000; Mani and Krishnamoorthy 2000; Ozturk et al. 2005
Leaves	*Aphis punicae* Passerini 1863	Aphididae: Homoptera	None	Southern Europe, Mediterranean, Near East, Central Asia, Southeast Asia	Blumenfeld et al. 2000
	Aphis gossypii Glover 1877	Hemiptera: Aphididae	Cotton aphid	Southern Europe, East Mediterranean, Southeast Asia, Australia, South America, USA, South Africa	Juan et al. 2000; Carroll et al. 2006

	Siphoninus phillyreae Haliday 1835	Hemiptera: Aleyrodidae	Ash whitefly	Worldwide	Shevale and Kaulgud 1998; Arnal and Ramos 2000; Mesbah 2003; Ozturk et al. 2005; Carroll et al. 2006
	Creatonotos gangis Linnaeus 1763	Lepidoptera: Arctiidae	Moth	Southeast Asia, Australia	Raghunath and Butani 1977
Fruit	*Virachola livia* Klug 1834	Lepidoptera: Lycaenidae	None	North Africa, East Mediterranean	Goor and Liberman 1956; Awadallah et al. 1971; Wisam and Mazen 2000
	Deudorix epijarbas Moore 1858	Lepidoptera: Lycaenidae	Cornelians	India, Sri Lanka, Burma, Australia	Zaka-ur-Rab 1980; Divender and Dubey 2005
	Virachola isocrates Fabricius 1793 or *Deudorix isocrates* Fabricius 1793	Lepidoptera: Lycaenidae	Common Guava Blue	India	Morton 1987; Shevale and Kaulgud 1998; Karuppuchamy et al. 2001
	Helicoverpa armigera Hübner 1805	Lepidoptera: Noctuidae	Cotton Bollworm moth	Worldwide	Teggelli et al. 2002
	Cryptoblabes gnidiella Milliére	Lepidoptera: Phycitidae	Honeydew moth	South Europe, North Africa, Southwest Asia, Central and South America, USA	Blumenfeld et al. 2000; Juan et al. 2000
	Apomyelois ceratoniae Zeller 1839 (or *Actomeylois ceratoniae*)	Pyralidae: Phycitinae	Carob moth (or the date moth)	Europe, Near East, USA	Moawad 1979; Mirkarimi 2000; Ozturk et al. 2005; Carroll et al. 2006

(*Continued*)

Table 2.2. (*Continued*).

Pest target	Pest scientific name	Order: family	Common name	Known distribution	Reference for damage
Fruit	*Platynota stultana* Walsingham 1884	Lepidoptera: Tortricidae	Omnivorous leafroller moth	USA	LaRue 1980; Carroll et al. 2006
	Lobesia botrana Denis & Schiffermüller	Lepidoptera: Tortricidae	Grapevine moth	South Europe, former USSR, Near East, North Africa.	Vasil'eva and Sekerskaya 1986
	Ceratitis capitata Wiedemann 1824	Tephritidae: Dacinae	Mediterranean fruit fly	Worldwide	Juan et al. 2000; Ozturk et al. 2005
	Pseudococcus maritimus Erhorn	Homoptera: Pseudococcidae	Grape mealybug	Mediterranean basin, Central Asia, Southeast Asia, South America, USA, South Africa	Carroll et al. 2006
	Pseudococcus comstocki Kuwana	Homoptera: Pseudococcidae	Comstock mealybug	Asia, Australia, USA	Carroll et al. 2006
	Drosicha quadricaudata Green 1922	Homoptera: Margarodidae	Mealy bug	India, Sri Lanka	Rawat et al. 1989
	Scirtothrips dorsalis Hood 1919	Thysanoptera: Thripidae	Chilli thrips	Southeast Asia, Australia, USA	Bagle 1993; Shevale and Kaulgud 1998
	Brevipalpus lewisi McGregor 1949	Prostigmata: Tenuipalpidae	Citrus flat mite	South Europe, Near East, North Africa, Southeast Asia, Australia, USA	Carroll et al. 2006

Leaves	*Tenuipalpus punicae* Pritchard & Baker 1958	Prostigmata: Tenuipalpidae	Mite	Near East, South Europe, Southeast Asia	Khosroshahi 1984; Juan et al. 2000
	Tenuipalpus granati Sayed 1946	Prostigmata: Tenuipalpidae	Mite	Most of the world	Blumenfeld et al. 2000
	Tenuipalpus (*Brevipalpus*) *yousefi* Nassar & Ghai 1982	Prostigmata: Tenuipalpidae	Red mite	India	Ram and Singal 1990
	Eutetranychus orientalis Klein 1936	Acarina: Tetranychidae	Oriental red mite	South Europe, Asia, Africa, Australia, USA	Kumawat and Singh 2002
Roots	*Meloidogyne incognita* Kofoid White 1919 Chitwood 1949 and *Meloidogyne javanica* Treub 1885 Chitwood 1949	Tylenchida: Heteroderidae	Root knot nematode	Worldwide	LaRue 1980; Verme 1985; Siddiqui and Khan 1986; Juan et al. 2000; Shelke and Darekar 2001

in Sichuan, China (Ma and Bai 2003); nigra scale *Parasaissetia nigra* Nietner 1861 (Hemiptera: Coccidae) in Maharashtra, India (Jadhav and Ajri 1992; Shevale and Kaulgud 1998); black scale *Saissetia oleae* Olivier 1791 (Hemiptera: Coccidae) in Spain, California, and Israel (Goor and Liberman 1956; Juan et al. 2000; Carroll et al. 2006); citricola scale *Coccus pseudomagnoliarum* Kuwana 1914 (Hemiptera: Coccidae) in California (Carroll et al. 2006); and Chinese wax scale *Ceroplastes sinensis* Del Guercio 1900 (Hemiptera: Coccidae) (Juan et al. 2000) and crapemyrtle scale *Eriococcus lagerstroemiae* Kuwana 1907 (Hemiptera: Coccidae) in Shandong, China (Zhao et al. 1998).

The larvae of the moth *Creatonotos gangis* Linnaeus 1763 (Lepidoptera: Arctiidae), which is found in southeast Asia and Australia, was found feeding on pomegranate leaves. This pest caused extensive defoliation of the trees (Raghunath and Butani 1977).

Insect pests of the fruit can cause major problems in those regions where the insects exist. One of these pests is the pomegranate butterfly *Virachola livia* Klug 1834 (Lepidoptera: Lycaenidae), which penetrates the fruit in early stages of fruit development and causes arils rot (Goor and Liberman 1956; Awadallah et al. 1971; Wisam and Mazen 2000). The pomegranate fruit borers Cornelians *Deudorix epijarbas* Moore 1858 (Lepidoptera: Lycaenidae) (Zaka-ur-Rab 1980; Divender and Dubey 2005) and the common guava blue *Virachola isocrates* Fabricius 1793 (or *Deudorix isocrates* Fabricius 1793) (Lepidoptera: Lycaenidae) (Morton 1987; Shevale and Kaulgud 1998; Karuppuchamy et al. 2001) are important pomegranate pests in east Asia, especially in the Indian peninsula. The butterfly lays eggs on flower buds and the calyx of developing fruits, and in a few days the caterpillars enter the fruit by way of the calyx. These fruit borers may cause loss of an entire crop unless the flowers are sprayed (Morton 1987). The cotton bollworm moth *Helicoverpa armigera* Hübner 1805 (Lepidoptera: Noctuidae) was also reported as fruit borer in India (Teggelli et al. 2002). The honeydew moth *Cryptoblabes gnidiella* Milliére (Lepidoptera: Phycitidae) causes crown rot toward ripening and storage (Blumenfeld et al. 2000; Juan et al. 2000). The carob moth *Apomyelois ceratoniae* Zeller 1839 (Pyralidae: Phycitinae) (or the date moth *Actomeylois ceratoniae*) is known to damage pomegranate fruits in many countries: California (Carroll et al. 2006), Saudi Arabia (Moawad 1979), Iran (Mirkarimi 2000), and Turkey (Ozturk et al. 2005). The omnivorous leafroller moth *Platynota stultana* Walsingham 1884 (Lepidoptera: Tortricidae) causes fruit damage in California where two fruits touch or a leaf touches the fruit, but the effect is usually minor (LaRue 1980; Carroll et al. 2006). The grapevine moth *Lobesia botrana* Denis & Schiffermüller

(Lepidoptera: Tortricidae) attaks pomegranate trees in Crimea, Ukraine (Vasil'eva and Sekerskaya 1986).

Recently increased damages in Israeli pomegranate orchards were reported to be inflicted by the Mediterranean fruit fly *Ceratitis capitata* Wiedemann 1824 (Tephritidae: Dacinae) (I. Kosto, pers. commun.). It is thought that the recent damages were caused by a secondary attack of the fly after the initial fruit penetration by *V. livia. C. capitata* was reported as pomegranate pest in Spain and in Turkey (Juan et al. 2000; Ozturk et al. 2005).

Citrus mealybug *Planococcus citri* Risso (Homoptera: Pseudococcidae) (Blumenfeld et al. 2000; Juan et al. 2000; Mani and Krishnamoorthy 2000; Ozturk et al. 2005), grape mealybug *Pseudococcus maritimus* Erhorn (Homoptera: Pseudococcidae), and Comstock mealybug *Pseudococcus comstocki* Kuwana (Homoptera: Pseudococcidae) (Carroll et al. 2006) might cause damage by settling between two fruits or inside the crown. Rot can occur where the mealybugs secrete honeydew. The mealy bug *Drosicha quadricaudata* Green 1922 (Homoptera: Margarodidae) was recorded on wild pomegranate in Himachal Pradesh, India (Rawat et al. 1989).

Thrips can cause damage to fruit and tree. Reports from India indicate such damages by the thrips *Scirtothrips dorsalis* Hood 1919 (Thysanoptera: Thripidae) (Bagle 1993; Shevale and Kaulgud 1998). Proper pest management can easily solve thrips damages.

Mites can attack pomegranate leaves, especially the *Tenuipalpus punicae* Pritchard & Baker 1958 (Prostigmata: Tenuipalpidae) and *Tenuipalpus granati* Sayed 1946 (Prostigmata: Tenuipalpidae). Severe damage might result in defoliation (Khosroshahi 1984; Blumenfeld et al. 2000; Juan et al. 2000). The citrus flat mite *Brevipalpus lewisi* McGregor 1949 (Prostigmata: Tenuipalpidae) causes ''alligator skin'' damage to pomegranate rind in California, which makes the fruit nonmarketable (Carroll et al. 2006). The red mite *Tenuipalpus (Brevipalpus) yousefi* Nassar & Ghai 1982 (Prostigmata: Tenuipalpidae) was recorded in India (Ram and Singal 1990). The oriental red mite *Eutetranychus orientalis* Klein 1936 (Acarina: Tetranychidae) heavily infests pomegranate in Rajasthan, India (Kumawat and Singh 2002).

Reports from Spain, California, India, and Libya mentioned nematodes as a problem, especially in sandy soils. The main pests are the root knot nematode *Meloidogyne incognita* Kofoid and White 1919 Chitwood 1949 and *Meloidogyne javanica* Treub 1885 Chitwood 1949 (LaRue 1980; Verme 1985; Siddiqui and Khan 1986; Juan et al. 2000; Shelke and Darekar 2001).

Fungi and bacteria are responsible for several serious pomegranate diseases. The list of pomegranate diseases is given in Table 2.3.

Table 2.3. Diseases list of pomegranate and their distribution in pomegranate-growing regions.

Scientific Name	Fungus or bacterium	Damage	Regions reported	Reference for damage
Ceratocystis fimbriata Ellis and Halsted	Fungus	Wilt	India, China	Somasekhara and Wali 2000; Huang et al. 2003
Zythia versoniana Sacc. Sacc. 1884	Fungus	Canker	China	Morton 1987; Tang et al. 1998
Phomopsis sp.	Fungus	Dry rot	Not specified	Morton 1987
Fusarium solani	Fungus	Dry root rot	India	Kore and Mitkar 1993
Coniella granati Hebert & Clayton 1963 Sutton 1969	Fungus	Dry rot	India, Greece	Sharma 1998, Tziros and Tzavella-Klonari 2007
Dematophora nectarix Hartig	Fungus	White root rot	Israel	Sztejnberg and Madar 1979
Pleuroplaconema sp.	Fungus	Twig dieback	Not specified	Morton 1987
Ceuthospora phyllosticta C. Massalongo	Fungus	Twig dieback	Not specified	Morton 1987
Xanthomonas axonopodis pv. *punicae*	Bacteria	Leaf black spot	India	Upasana and Verma 2002; Vijai and Indu 2005
Pseudocercosporella granati Rawla Deighton 1976	Fungus	Leaf spot	India	Mahla and Ashok 1989
Discosia punicae Shreem. & M. Reddy	Fungus	Leaf spot	India	Shreemali and Reddy 1971
Cercospora sp.	Fungus	Fruit spot	India	Morton 1987; Reddy et al. 2005

Colletotrichum gloeosporioides	Fungus	Fruit spot	India	Jamadar et al. 2000; Reddy et al. 2005
Sphaceloma punicae	Fungus	Scab	China	Morton 1987; Zheng et al. 2004
Alternaria alternate Fr. Keissl. 1912	Fungus	Leaf spot	India	Raghuwashi et al. 2005
Aspergillus niger Tiegh. 1867	Fungus	Leaf spot	India	Raghuwashi et al. 2005
Setosphaeria rostrata K.J. Leonard 1976	Fungus	Leaf spot	India	Raghuwashi et al. 2005
Alternaria alternate Fr. Keissl. 1912	Fungus	Fruit rot	Greece, Spain, USA	LaRue 1980; Juan et al. 2000; Tziros et al. 2007
Coniella granati Sacc. Petr. & Syd.	Fungus	Fruit rot	Turkey	Yildiz and Karaca 1973
Phytophthora sp.	Fungus	Fruit rot	India, Spain	More et al. 1989; Juan et al. 2000; Sushma and Sharma 2006
Glomerella cingulata	Fungus	Fruit rot	India	Singh and Chohan 1972

Relatively high incidence of pomegranate wilt caused by the fungus *Ceratocystis fimbriata* Ellis and Halsted was reported in Karnataka and Maharashtra provinces in India (Somasekhara and Wali 2000) and in Yunnan, China (Huang et al. 2003). The initial disease symptoms were yellowing and wilting of the leaves on a single branch. Severely affected plants show brown discoloration of roots and stems (Somasekhara and Wali 2000). Pomegranate canker caused by *Zythia versoniana* Sacc. Sacc. 1884, which attacks the fruit, branches, and trunk, was reported in China (Tang et al. 1998). Morton reports this fungus as causing pomegranate disease as well (Morton 1987). Antifungal treatment with carbendazin was reported to be effective against the disease. Dry rot may be caused by *Phomopsis* sp. (Morton 1987), *Fusarium solani* (dry root rot) (Kore and Mitkar 1993), or *Coniella granati* Hebert & Clayton 1963 Sutton 1969 (Sharma 1998, Tziros and Tzavella-Klonari 2007). *Dematophora nectarix* Hartig is the causal agent of white root rot in pomegranate in Israel (Sztejnberg and Madar 1979). Twig dieback may be caused by either *Pleuroplaconema* sp. or *Ceuthospora phyllosticta* C. Massalongo (Morton 1987).

Leaf spot diseases are caused by the infection of fungi or bacteria and, if not treated, they can cause leaf blight and defoliation. Bacterial black spot disease caused by *Xanthomonas axonopodis* pv. punicae (Upasana and Verma 2002; Vijai and Indu 2005). *Pseudocercosporella granati* Rawla Deighton 1976 (Mahla and Ashok 1989) and *Discosia punicae* Shreem. & M. Reddy (Shreemali and Reddy 1971) cause fungus leaf spot.

Fruit spot disease is caused by *Cercospora* sp. (Morton 1987; Reddy et al. 2005) or *Colletotrichum gloeosporioides* (Jamadar et al. 2000; Reddy et al. 2005). *Sphaceloma punicae* scab was identified in China (Zheng et al. 2004) and also mentioned by Morton (1987). Some other patho-gens were mentioned in India as fruit and leaf spot associated diseases: *Alternaria alternate* Fr. Keissl. 1912, *Aspergillus niger* Tiegh. 1867 and *Setosphaeria rostrata* K.J. Leonard 1976 (Raghuwashi et al. 2005).

Fruit rot diseases are the result of several fungi infections: among them *Alternaria alternata* Fr. Keissl. 1912 (LaRue 1980; Juan et al. 2000; Tziros et al. 2007), *Coniella granati* Sacc. Petr. & Syd. (Yildiz and Karaca 1973), *Phytophthora* sp. (More et al. 1989; Juan et al. 2000; Sushma and Sharma 2006) and *Glomerella cingulata* (Singh and Chohan 1972).

F. Weed Control

Pomegranates are grown primarily in arid regions and require regular irrigation. Irrigation also encourages weed growth that competes with trees for water and soil nutrients. In addition, weeds can host a wide array of damaging pomegranate pests and might disturb efficient pest control. Weed control in pomegranates is particularly important in younger trees. Later on, as the trees mature, the shade will inhibit the weeds, and the intensity of weed management procedures is reduced. Weed control should be modified according to weed composition in the specific orchard.

Several herbicides are used to control weeds in pomegranate orchards. Goal® (Oxyfluorfen) and simazine (triazine) are used as preemergence weed killers. Both are used to control a wide spectrum of annual broadleaf weeds and grasses. Postemergance, Roundup (Glyphosate) is used as a nonselective herbicide to control grasses and weeds while 2,4-dichlorophenoxyacetic acid (2,4-D) derivatives (phenoxy herbicides) are used to control broad leaf weeds. The combination of both postemergent materials is used when needed (Blumenfeld et al. 2000). Extensive use of these herbicides may result in tree damage; therefore, care should be taken when using them. Bucsbaum et al. (1982) reported phytotoxicity when herbicides were applied to pomegranate grown in pots but not when applied to five-year-old pomegranates grown in the orchard. These authors found that the best weed control was obtained with simazine, oryzalin (sulfonamide herbicide, a selective preemergence herbicide used for control of annual grasses and broadleaf weeds) and terbutryne (s-triazine herbicide, a selective herbicide used for control of annual grasses and broadleaf weeds) (Bucsbaum et al. 1982). Usage of glyphosate to control *Cuscuta monogyna* L., which heavily infested pomegranate trees in Iran, was reported by Saied et al. (2003). Lack of experience growing pomegranate in many areas and small area in cultivation limit both registration and recommendations for herbicide applications to pomegranate orchards. The availability of efficient herbicides is currently relatively limited, and work should be done to broaden the spectrum of certified chemicals for use in pomegranate orchards.

A common practice today in modern pomegranate orchards in Israel is to use polythene mulches. Such mulches conserve soil moisture, reducing water consumption by 20% to 25% (Aulakh and Sur 1999; Ravid et al. 2004), and significantly reduce weed population by 20% to 26% compared to controls (Aulakh and Sur 1999; Ravid et al. 2004).

G. Fruit Physiological Disorders

Fruit splitting and sunburn may affect pomegranate fruits and sometimes cause significant commercial damage. Fruit splitting actually may be regarded as the last stage of normal pomegranate fruit developmental process where the fruit is spreading its seeds. Most known pomegranate cultivars will eventually split when they over-ripen. Some cultivars, such as the Israeli cultivars 'P.G.131-32', and 'P.G.118-19' and some cultivars from the pomegranate collection in Saveh (Tabatabaei and Sarkhosh 2006), tend to split in much earlier stages of fruit development or in higher frequencies than others. 'Shirvan', 'Burachni', and 'Asperonskii Krasnyi' were found to be resistant to splitting (Trapaidze and Abuladze 1989), suggesting that at least some aspects of fruit splitting in pomegranates are genetically controlled independently from environmental conditions. This assumption is also corroborated by Hepaksoy et al. (2000). The extent of fruit splitting is significantly reduced by regular irrigation, particularly by drip irrigation (Prasad et al. 2003). It is known that rainfall on mature pomegranate fruits following the end of the dry season can induce rapid fruit splitting. Therefore, splitting is a problem in regions where the fruit maturation overlaps a rainy season. There are indications from Israel and from Turkey that shading may induce fruit splitting, most probably by changing the water balance due to lower radiation (Yazici and Kaynak 2006; Y. Shahak pers. commun.). A few reports indicate that spraying with gibberelic acid (GA_3) at 150 ppm or with benzyl adenine (BA) at 40 ppm could significantly reduce fruit splitting (Sepahi 1986; Mohamed 2004; Yilmaz and Ozguven 2006). Other studies indicate that application of boron may reduce fruit split (Singh et al. 2003; Shiekh and Rao 2006). The cause for sunburn is the combined action of high solar radiation, low humidity, and high temperatures. Yazici and Kaynak (2006) indicated that solar radiation between 220 J/cm^2 to 324 J/cm^2 as highly correlated with fruit surface temperatures and that fruit surface temperatures that cause sunburn vary between 41°C and 47.5°C. In Israel, late cultivars such as 'Wonderful' that ripen in autumn and are exposed throughout the summer to strong solar radiation and hot temperatures are much more susceptible to sunburn. Early cultivars such as 'Akko' and 'Shani-Yonay' are less susceptible. It is not yet known whether there are differences among cultivars with respect to sunburn sensitivity and whether skin color is a factor in this respect. Studies conducted by Yazici et al. indicated that 35% shading and application of Kaoline are effective in reducing sunburn on pomegranate fruit (Melgarejo et al. 2004; Yazici and Kaynak 2006). For the 'Hicaznar' cultivar, Kaolin treatment proved to be the best method as it also increased color of the fruits (Yazici and Kaynak 2006).

H. Postharvest

A review on postharvest biology and technology of pomegranate was recently published by Kader (2006). The review summarizes the current knowledge on the pomegranate morphological characteristics, composition and compositional changes during maturation and ripening, quality indices, and postharvest biology. This section will mention some of the major points concerning postharvest biology of the pomegranate fruit in addition to the new postharvest technologies developed and practiced today in Israel.

As the pomegranate fruit matures on the tree, a reduction in the titratable acidity and parallel increase in TSS, pH, and color intensity is observed (Kader 2006). Once the fruit is harvested, it keeps respiring at a relatively low rate. This rate is decreased with time after the harvest. Storage at low temperature can keep respiration rate under 8 ml CO_2 per kg min^{-1}. Due to relatively low respiration rates and low amount of ethylene evolved (0.2 ml per kg min^{-1}), the pomegranate fruit is classified as nonclimacteric. The pomegranate fruit increases its respiration rate and ethylene production immediately after exposure to ethylene. However, the effect of ethylene treatment on respiration rapidly declines. Ethylene treatments did not affect significantly fruit parameters of harvested fruit such as color, TSS, pH or titratable acidity. These data indicate that the pomegranate fruit will not mature postharvest and should be harvested only when fully mature.

The major problems in pomegranate storage are loss of fruit weight, fruit size reduction, skin damages such as husk scald (browning of the skin surface) (Or-Mizrahi and Ben-Arie 1984; Ben-Arie and Or 1986; Defilippi et al. 2006), and development of crown and fruit rot (Adaskaveg and Forster 2003; Tedford et al. 2005).

Gray mold caused by *Botrytis cinerea* Whetzel and rot caused by *Penicillium implicatum* Biourge 1923, *Rhizopus arrhizus* Fischer 1892, and *Alternaria solani* Sorauer 1896 are storage diseases of pomegranate fruit (Kanwar and Thakur 1973; Vyas and Panwar 1976; Morton 1987; Labuda et al. 2004; Palou et al. 2007). In California, *Botrytis cinerea,* which causes postharvest decay, is the primary limiting factor for long-term storage (Adaskaveg and Forster 2003; Tedford et al. 2005). Fenhexamid and fluidioxonil treatments were shown to be very effective in reducing natural incidence of gray mold caused by *B. cinerea*. To prevent development of fungicide resistance in these pests, a combination of sanitation treatments with chlorine and fungicides dip was recommended before cold storage (Adaskaveg and Forster 2003). Palou et al. (2007) indicated synergistic effects between antifungal treatments and controlled atmosphere (CA) of 5 kPa O_2 + 15 kPa CO_2 in 'Wonderful' pomegranates artificially inoculated with *B. cinerea*. A combination of waxing with antifungal treatments was suggested by Sarkale et al. (2003) and by Ghatge et al. (2005) to extend the shelf life and the quality of pomegranate in cold storage and ambient conditions.

Pretreatment of pomegranates with hot water at 45°C was shown to reduce chilling injury and electrolyte and K leakage (Artes et al. 2000; Mirdehghan and Rahemi 2005). Heat treatment was also shown to be effective in maintaining the nutritive and functional properties of pomegranate fruit after a long period of storage (Mirdegahan et al. 2006) and in reducing pomegranate moth damage (Moghadam and Nikkhah 2005).

Pomegranate fruits can be kept well for long time after harvesting. Experimental data showed that fruits could be stored between 0°C and 4.5°C at 85% relative humidity for several months (Mukerjee 1958; Kader et al. 1984; Or-Mizrahi and Ben-Arie 1984). Saxena et al. (1987) found that time of harvest, temperature, and oxygen level significantly affected husk scald. These authors found that delaying harvest reduced the percentage of fruit developing husk scald. Low oxygen and low temperatures inhibited husk scald, probably by inhibiting enzyme-dependent oxidation processes (Or-Mizrahi and Ben-Arie 1984). A combination of low oxygen levels (2%–3%), low temperature (2°–6°C), and late harvest were found optimal to reduce chilling injuries while preserving taste qualities. Low oxygen levels may cause anaerobic respiration, which in turn causes the accumulation of fermentive volatiles (Kader et al. 1984; Or-Mizrahi and Ben-Arie 1984). Therefore, 5% oxygen was suggested as a compromise oxygen level where skin damage is inhibited while fermentive volatiles are not produced (Kader 2006). The effectiveness of CO_2 in inhibiting scald development in addition to its fungicidic effects led Hess-Pierce and Kader (2003) to recommend 5% oxygen + 15% CO_2 as the optimal CA for pomegranate storage at 7°C and 90% to 95% relative humidity (Kader 2006). Ranjbar et al. (2006) demonstrated that polyethylene bag wraps significantly reduced weight loss and improved appearance of the fruit following storage. In Israel, several long storage experiments were conducted by Porat et al. (2005, 2006, 2007). These authors have developed new storage technology (modified atmosphere packaging) that involves the usage of special bags (Xtend®) which have small pores (microperfoation) (Porat et al. 2006; Sachs et al. 2006). These bags result in the development of 5% CO_2 and 12% to 14% O_2 within the bag surrounding the fruit. The Xtend packaging reduces weight loss from 7% to 3.5%, reduces scald from 38% to between 2% and 11%, and reduces crown decay when pomegranate fruit were stored at 6°C for 16 weeks. Using either the Xtend packaging technique just described or CA conditions of 2% $O_2 + 3\%$ CO_2 at 6°C permitted storage of pomegranate fruit for to four to five months with acceptable commercial quality. Antifungal pretreatment of the pomegranate fruit was recommended before storage began. Data on storage experiments that was reported by Hess-priece and Kader (2003) and Porat et al. (2005, 2006) were based on the cultivar 'Wonderful'. As mentioned in the cultivar section, the fruit qualities of the Israeli 'Wonderful' and the American 'Wonderful' are different. It was also demonstrated that different pomegranate cultivars contain different levels of secondary metabolites that have antioxidant activities (Tzulker et al. 2007). These in turn could potentially change the sensitivity of pomegranate fruit to skin damage and pathogen attack. Therefore, care should be taken with respect to storage conditions in each geographical region and for each cultivar. Currently many new cultivars are being introduced to commercial growth in addition to 'Wonderful'. Therefore, special postharvest experiments should be carried separately for each cultivar.

Apart from consumption of pomegranates as fresh fruit, they are also used for other purposes, such as isolated arils, juice, wine, and health-promoting agents. One of the newest developments in pomegranate culture is an efficient commercial method to extract intact arils (Rodov et al. 2005; Shmilovich et al. 2006). Several machines were developed, but the most efficient one is able to produce more than 1 ton of arils a day (Shmilovich et al. 2006). This development requires some new studies in order to prolong the shelf life of the arils and to preserve them either as fresh or frozen product. Such studies are only just beginning. Juice is produced industrially from either crushing whole pomegranate fruit or isolated arils. Some manufacturers preferred the isolated arils because the juice is less bitter and tastes better to many people. The byproduct of the aril and juice industry are the remnants of the fruit skin, membranes, and seeds. The fruit skins and membranes are rich in elagitannins, which have a wide array of health-promoting bioactivities (Seeram et al. 2006a), and their extracts have a commercial value for humans and for animal feed. The seeds are a source of oil that contains a rare combination of unsaturated fatty acids (Seeram et al. 2006b) and sterols. Seeds powder is a common component of some Indian food recipes.

V. BREEDING

Most pomegranate cultivars grown today are the result of human selection from naturally occurring varieties. Until recent years, pomegranates were selected according to the demands of local consumers and not for export. Therefore, the main cultivars found today reflect the local priorities of each country or region. Examples are the traditional Indian and Spanish cultivars that are characterized by their soft seeds and low-acid taste. Increased world demand and economic importance of pomegranate exports should significantly influence pomegranate selection criteria, which will have an increasing role in pomegranate breeding. Traditionally pomegranates were selected on the basis of their juice content, fruit size, colors, yield, and taste. The preferences of skin or aril color and taste were not identical in all countries. Export considerations raise the importance of ripening time, skin and aril color, taste, and health benefits as prioritized by consumers in the end markets. The most intensive breeding projects based on crosses between cultivars and aimed toward pomegranate improvement were reported from India. Breeding of pomegranates in India was done for disease resistance (Jalikop et al. 2005; Jalikop et al. 2006), low acidity and high fruit quality under hot arid environment (Samadia and Pareek 2006); fruit yield (Manivannan and Rengasamy 1999); juice production (Jalikop and Kumar 1998); aril color (Wavhel and Choudhari 1985); fruit weight, flesh color, seed size, and juice content (Karale et al. 1979); TSS (Choudhari and Shirsath 1976); and seed softness (Jalikop and Kumar 1998). Two of the main commercial export cultivars from India, 'Mridula' and 'Bahgwa', are the result of a selection from progenies of a cross between 'Ganesh' and the red 'Gul Shah Red' pomegranate cultivar from Russia (Mahatma Phule Agricultural University 2007). 'Ganesh' itself is an evergreen selection from 'Alandi' (Jalikop 2003) that produces a soft-seeded fruit with poor fruit quality. 'Mridula' and 'Bahgwa' combine the red skin color, seed softness, and evergreen habit of growth from their parents. Since very little is known on the heritability of desirable traits in pomegranates, few experiments were conducted to study the inheritance of some important features, such as acidity, seed hardness, and aril color. From crosses between 'Daru' and 'Ganesh' or 'Daru' and 'Ganesh' progenies, it was found that high acidity was always dominant to low acidity, pink aril color was dominant to white color, and hard-seeded nature was dominant to soft (Jalikop et al. 2005). Recessive markers for yellow foliage color and rosette-forming habit of growth, originated from a mutant of 'Kabul Yellow', were used for breeding and for studying the mode of pollination of pomegranate (Jalikop 2003). 'Daru' was used as a parent in breeding pomegranate cultivars tolerant to bacterial nodal blight (*Xanthomonas campestris* pv. parthenii). These authors indicated that the resistance to bacterial nodal blight is controlled by recessive genes (Jalikop et al. 2005). For many fruit attributes, soft and semisoft seeded pomegranate cultivars share similarities, whereas hard-seeded pomegranates are distinctively different (Jalikop and Kumar 1998). For example, the hard-seeded cultivars as a group had significantly higher fruit weight and volume than semisoft and soft-seeded pomegranates. Soft-seeded pomegranates were recommended by Jalikop and Kumar (1998) as parents for developing high-juice cultivars due to their significantly higher content of juice. Karale and Desai (2000) measured heterosis for fruit characters manifested by the individual hybrids over midparental value. They found that heterosis values were maximal for juice weight and aril weight percentage.

Inheritance of fruit characteristics such as skin and aril color, taste and seed softness was studied using several combinations of crosses between the cultivars 'Fellahyemez', 'Ernar', and 'Hicaznar'. When the sweet-sour 'Hicaznar' was crossed with the sweet cultivar 'Ernar', about 40% of the progenies were sour; when both parents were sweet, about 90% of the progenies were sweet (Ataseven Isik 2006). Breeding for frost resistance was reported from Turkmenistan by Levin (1979). Hybrid seedlings with good frost resistance were achieved following successive crosses (Levin 2006).

In China, several pomegranate cultivars have been obtained by breeding. These include the early-ripening 'Yushiliu 4' (Zhao et al. 2006), the soft-seeded 'Hongmanaozi' (Zhao et al. 2007), good-quality fruit 'Zaoxuan 018' and 'Zaoxuan 027' (Wang et al. 2006) and 'Duo Hong 1', 'Duo Qing 11', and 'Duo Bai 2' (Liang and Cheng 1991).

A breeding project in Israel was initiated in 2002. Breeding objectives are dictated predominantly by the demands of the European markets and exploit the principal advantages of the Israeli cultivars: early ripening, good color, and soft seeds. The project is aimed toward extending the pomegranate season, particularly by producing very early and very late ripening cultivars. In addition, appealing skin and aril color (particularly bright red color) are desirable features. Breeding was initiated by selecting seedlings from open pollination of known cultivars. So far, the cultivar 'Emek' was released from screening these populations (Plate 2.2I). 'Emek' is a very early cultivar that ripens in mid-August. It has a pink-red skin and bright red arils. The seeds are soft and the taste is sweet and low acid. 'Emek' ripens earlier than 'Shani-Yonay' (Holland et al. 2007), and its average weight is higher than 'Shani-Yonay'. Another new Israeli cultivar is 'Kamel', which was selected in Newe Ya'ar. 'Kamel' is essentially a very similar cultivar to 'Wonderful' with respect to fruit quality and tree growth habit. Its most distinguishing trait is the dark-red skin color, which appears about a month earlier than in 'Wonderful'. 'Emek', 'Shani-Yonay', and 'Kamel' were submitted for registration in Israel and abroad. Recently new breeding projects based on deliberate crosses were initiated in Israel. These crosses aim at obtaining very early ripening cultivars that are tolerant to the negative effect of heat on pomegranate anthocyanin content in the skin and the aril. Two populations of crosses between 'Wonderful' and evergreen cultivars from an Indian origin were established. About 400 seedlings for each population were planted (Fig. 2.1b). These populations and their F_2 selfed progenies will also serve to study the inheritance of important traits such as anthocyanin content in the skin and arils of the pomegranate fruit and the inheritance of the evergreen phenotype.

In addition to traditional crosses, other methods used in pomegranate breeding include chemical mutagenesis (Shao et al. 2003; Matuskovic and Micudova 2006), gamma irradiation (Kerkadze 1987), and genetic transformation (Terakami et al. 2007). Pomegranate tetraploids have been produced through colchicine treatment of shoots (Shao et al. 2003). The tetraploid plants that were generated had shorter roots, wider and shorter leaves, and flowers with enlarged diameter as compared to diploid pomegranates. Kerkadze (1987) reported on the generation of cultivar 'Karabakh' by using gamma irradiation. The tetraploid pomegranates produced viable pollen. *Agrobacterium* mediated genetic transformation of pomegranate was recently reported by Terkami et al. (2007). Pomegranate cultivars developed through genetic engineering are not expected in the near future due to severe restrictions on commercial usage of genetically modified plants and because transformation systems have not been developed for commercially important cultivars. However, the development of transformation systems in 'Nana' (Terkami et al. 2007) is expected to be useful as a model system to study genetic manipulation of pomegranate, in identifying important pomegranate genes for future exploitation, and for deciphering the function of genes in pomegranates.

There are very few reports on molecular genetic work done with pomegranate. Only a handful of genes were isolated from *P. granatum* and deposited in Genebank (http://www.ncbi.nlm.nih.gov/Genbank/). Most of the genes deposited are those involved in production of unsaturated fatty acids, genes that encode for parts of ribosomal RNA, the mitochondrial *matR* gene, and the *rbcL* genes encoding for the large subunit of ribulose-1-5-bisphosphate carboxylas. About 10 genes involved in anthocyanin biosynthesis pathways from several cultivars of pomegranates have been isolated (D. Holland et al. unpubl.). A comparative work is now being conducted to study the level of their expression and the structural differences of these genes among pomegranate cultivars that display prominent differences in skin and aril colors. Molecular markers, such as AFLP, RAPD, and ISSR, were reported by several groups. Although Jbir and Zamani concluded that pomegranates are highly polymorphic (Jbir et al. 2006; Zamani et al. 2007), others concluded that the degree of polymorphism in pomegranates was surprisingly low (Talebi Baddaf et al. 2003; Aradhya et al. 2006; Yilmaz et al. 2006). In some of these studies, the apparent phenotypical differences observed among pomegranate cultivars were not reflected in the polymorphism of the molecular markers. Obviously many more markers should be isolated from pomegranates to make them useful for breeding and for evolutionary studies. Work in this direction involves the construction of pomegranate genomic libraries potentially containing microsatellites. Up until now about 26 SSR primer pairs were used for screening pomegranate genotypes (Hasnaoui et al. 2006; Mehranna et al. 2006).

VI. HEALTH BENEFITS

Ancient cultures understood the health-promoting effects of the pomegranate tree. Products from all parts of the pomegranate tree, including the fruit, bark, flowers, roots, and leaves, were used for medical treatments of a wide list of diseases and ailments of humans. A detailed review of modern studies on pomegranate and human health was published in recent book (Seeram et al. 2006a). Modern chemical analysis of bioactive phytochemicals produced by the pomegranate tree is just beginning. Potentially active phytochemicals found in pomegranates include sterol and terpenoids in the seeds, bark, and leaves; alkaloids in the bark and leaves; fatty acids and triglycerides in seed oil; simple gallyol derivatives in the leaves; organic acids in the juice; flavonols in the rind, fruit, bark, and leaves; anthocyanins and anthcyanidins in the juice and rind; and catechin and procyanidins in rind and juice (Seeram et al. 2006b). The level of these compounds in the pomegranate tree may change during the development of the tree, during fruit maturation, under different environmental and cultivation conditions, and between pomegranate cultivars. Tzulker et al. (2007)

showed a large variation among pomegranate cultivars with respect to the level of polyphenols, antioxadative activity, and the corresponding content of phytochemicals, such as elagic acid, galagic acid, punicalin and punicalagin.

Disease targets of pomegranates include coronary heart diseases, cancer (skin, breast, prostate, and colon), inflammation, hyperlipidemia, diabetes, cardiac disorders, hypoxia, ischemia, aging, brain disorders, and AIDS (Shishodia et al. 2006). Modern medical research assessed the bioactivity of pomegranate juice and various pomegranate extracts against the diseases just described and helped to identify some of the molecular mammalian components that are targets for pomegranate phytochemicals. Some of these components include metalloproteinases, vascular endothelial growth factor, lipoygenase, mitogen-activated protein kinase, migration inhibitory factor, c-Jun-N-terminal kinase (JNK), and extracellular signal regulated kinase (ERK1/2) (Shishodia et al. 2006). In fact, most of the pomegranate literature published today focuses on the health benefits of the pomegranate tree. However, little information about the phytochemical constituents responsible for the observed activities or about the bioavailability of the suspected active compounds is provided. Bioavailability is an important issue since some of the main active constituents in pomegranates are rapidly degraded in the body and their physiological levels become negligible.

In vivo experiments with atherosclerotic mice indicated that pomegranate juice consumption has antiatherogenic properties with respect to all three related components of atherosclerosis: plasma lipoproteins, arterial macrophages, and blood platelets (Aviram et al. 2000). Experiments with human patients showed that consumption of pomegranate juice for two weeks decreased angiotensin-convertin enzyme (ACE) activity by 36% and small but significant reduction was found in systolic blood pressure (Aviram and Dornfeld 2001). The importance of pomegranate juice is reflected not only in its high level of antioxidants as compared to other plant sources but also on its wide range of human and animal target components. Antiatherogenic activity was correlated with antioxidant activity and polyphenol content, but very little evidence is available on direct detection of the chemical nature of this activity. A correlation was found between the ability to prevent low-density lipoprotein (LDL) oxidation and the level of antioxidant activity. Antioxidant activity in turn was found to be highly correlated with hydrolysable tannins, particularly punicalagin (Kulkarni et al. 2007; Tzulker et al. 2007). Punicalagin, which is produced in pomegranates, was shown to possess pharmacological attributes including anti-inflammatory, antiproliferative, apoptotic, and antigenotoxic properties (Lin et al. 1999; Chen et al. 2000; Seeram et al. 2005; Adams et al. 2006).

Certain fields of cancer research related to pomegranate products attained phase II clinical trials. In men with rising prostate-specific antigen (PSA) following surgery or radiation for prostate cancer, consumption of pomegranate juice signifantly prolonged PSA doubling time (Pantuck et al. 2006). These results were consistant with corresponding laboratory effects on prostate cancer in vitro as measured by cell proliferation and apoptosis as well as oxidative stress. The authors conclude that the results warrant further studies with placebo-controlled treatments. In this respect, there is evidence that ellagic acid, caffeic acid, luteolin, and punicic acid synergistically inhibit the proliferation and invasion of PC-3 prostate cancer cells across Matrigel^{TM} artificial membranes (Lansky et al. 2005).

Among the oldest known pomegranate health benefits are its activities against infectious diseases (Jayaprakasha et al. 2006). Antibacterial activity of pomegranate extracts was demonstrated against a wide array of bacteria, fungi, and viruses. The active phytochemicals in pomegranates are found to be tannins and alkaloids (Jayaprakasha et al. 2006). Punicalagin was found to have an antimicrobial activity in addition to the other bioactivities already described (Burapadaja and Bunchoo 1995; Machado et al. 2002; Jayaprakasha et al. 2006). Antimicrobial activity was recently attributed to compounds extracted from pomegranate juice that include the anthocyanins pelargonidin-3-galactose, cyanidin-3-glucose, the flavonoids quercetin and myricetin, and gallic acid (Naz et al. 2007).

VII. CONCLUDING REMARKS

Impressive advances in scientific and agricultural work on pomegranates have been achieved in recent years. Research in biology and medicine have discovered some of the molecular sites in mammalian systems at which pomegranate phytochemicals are acting and corroborated some traditional knowledge on pomegranate as an important medical plant. Most of the current published work on pomegranates is on their medical aspects and only a small fraction focused on the physiology and biology of the pomegranate tree. Most of the available clinical data today on pomegranates was obtained by usage of crude extracts, partially purified fractions of tissue extracts, or pomegranate juice. The consumption of fresh fruit and its therapeutic effects require additional studies. Much more analytical chemical work will be required to identify the chemical nature of the active compounds and their mode of action. Relative to other crop plants, the knowledge of the genetics, physiology, and biology of pomegranate trees is poor. Almost no work has been published on pomegranate fruit development, flower development, induction of flowering, root physiology, and stress responses. All of these fields are important for improving pomegranate crops and producing higher yields and healthier fruit. More research effort and more advances have been realized in commercial production methods, postharvest technology, and fruit processing of pomegranate. There is little published molecular work on pomegranates. No databases of expressed sequence tags (ESTs), sequenced genes, or genetic maps were reported. Breeding of pomegranates is done today in few centers, mainly in Iran, India, Turkey, Israel, and China. Most of the breeding projects are based on traditional crosses; few reports exist on the use of more advanced technologies in breeding. A step in this direction is the development of a genetic transformation system in pomegranates, which is essential for gene functional analysis and for exploring the biology of the pomegranate tree. The pomegranate fruit is now sold and recognized almost everywhere in the world, and increased demand requires a concomitant improvement in production and quality. New modern orchards have been planted in the southern hemisphere as well as in the traditional growing areas. The renewed interest in the tree and its products followed by the increase in its commercial importance are expected to increase the amount of research of this interesting and ancient culture.

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