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Pomegranate

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INTRODUCTION

The pomegranate (*Punica granatum* L.) is one of the ancient yet more sought after fruit. The pomegranate, contrary to previous records citing that the pomegranate was considered native to the region of Iran and/or northern India (Morton, 1987), probably originated in northern Turkey, based on the fact that in the vicinity of the late-14th-century BCE Uluburun shipwreck near Kas, Turkey, pomegranate remains were found (Ward, 2003). The pomegranate spread from Anatolia to Persia, Israel, India, China, Greece, Egypt, Tunisia, Spain, Indonesia, Mexico, South America, and, more recently, the United States.

The pomegranate plant is a fruit-bearing, small tree that is highly branched but can grow up to 10 m tall and survive in extreme conditions (Stover and Mercure, 2007). The leaves have short stems and leathery surfaces; the flowers are flashy, from white to red in color (Stover and Mercure, 2007).

Pomegranate fruit, more or less round in shape, 6.25–12.5 cm in diameter, has a course, leathery rind with a pink to deep red or indigo to fully red color (Morton, 1987; Holland et al., 2009). Pomegranate has some unusual varieties, for example, the black pomegranate (Holland et al., 2009). Seed plus exterior tissues make up the arils that are transparent sacs full of flavorful, fleshy, juicy, pink, red or whitish pulp and separated by membranous walls and white tissue (Morton, 1987). Each aril usually contains only one seed that is white or red, soft or hard, representing approximately 52% of the weight of the whole fruit, as shown in Figure 27.1 (Morton, 1987). Skin color of the rind does not necessarily match the color of the aril, indicating no correlation between the color of fruit skin and aril (Holland et al., 2009). Arils, the edible part of the fruit, contain around 80–85% juice and 15–20% seed and are mostly consumed fresh. The number of arils per fruit varies but may be as high as 1,300 per fruit (Al-Maiman and Ahmad, 2002; Levin, 2006).

Consumption trends

The demand for pomegranate fruit and its by-products is rising exponentially, especially in the Western world, owing to the growing awareness of the health-promoting benefits of pomegranate. Because of this trend, Iran and India are becoming leaders of the pomegranate market, followed by China and Turkey (Borgese and Massini, 2007). The trend for either cultivation or consumption is increasing in many pomegranate-cultivating countries. These countries opt to process fruit to juice and juice concentrate, exporting the concentrate to the entire world since numerous different juices, products, and functional beverages are formulated using juice concentrate (Borgese and Massini, 2007).

Significance in human health

Pomegranate fruit is highly appreciated for beneficial health effects in the form of decreasing cardiovascular and other chronic diseases due to its high contents of organic acids, vitamins, polysaccharides, essential minerals, and most importantly, antioxidants (Al-Maiman and Ahmad, 2002; Longtin, 2003). The high antioxidant nature of pomegranate fruit has played a major role in its increased consumption across developed countries, especially in the form of juice and other processed products.

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Figure 27.1. Pomegranate fruit and arils of different types. For color detail, please see color plate section.

Recent clinical studies have postulated that pomegranate has several beneficial health effects, including antioxidant (Gil et al., 2000; Singh et al., 2002), antiviral (Zhang et al., 1995), antibacterial (Prashanth et al., 2001), and wound-healing effects (Murthy et al., 2002). Moreover, pomegranate has been used to treat infectious (Holetz et al., 2002), cardiovascular (Aviram et al., 2002) and oral diseases (Vasconcelos et al., 2003), breast cancer (Mehta and Lansky, 2004), prostate cancer (Lansky et al., 2005), skin tumorigenesis (Hora et al., 2003; Afaq et al., 2005), and colon carcinogenesis (Kohno et al., 2004; Sharma et al., 2010).

PRODUCTION, VARIETIES, AND HARVEST

Major producing countries

Pomegranates are grown on all continents with the exception of Antarctica. However, this plant is commercially cultivated in the Mediterranean basin (North Africa, Egypt, Israel, Palestine, Syria, Lebanon, Turkey, Greece, Cyprus, Italy, France, Spain, and Portugal), Asia (Iran, Iraq, India, China, Afghanistan, Bangladesh, Myanmar, Vietnam, Thailand, Malaysia, Kazakhstan, Turkmenistan, Tajikistan, Kirgizstan, Armenia, and Georgia), the Americas (United States, Chile, Argentina, and Brazil), South Africa, and Australia (Holland et al., 2009).

Few statistics related to pomegranate production, area, or sales are available. India (more than 100,000 ha) is the largest producer, followed by Iran (more than 65,000 ha), Turkey (almost 10,000 ha), Tunisia, and Spain (3,000 ha) (Stover and Mercure, 2007). India reported annual production of 1,200,000 tons, followed by Iran (700,000 tons), Turkey (300,000 tons), the United States (100,000 tons), Spain (60,000 tons), Tunisia (30,000 tons), and Israel (20,000 tons). According to the University of California Cooperative Extension, California produced approximately 17,000 tons of pomegranate fruit on about 6,639 ha in 2009.

Varieties

The *Punica* genus contains only two species, first of which is better known as the pomegranate (*Punica granatum* L.), and second of which is the Socotra or Yemen pomegranate (*Punica protopunica* Balf. f. 1882), native to island of Socotra, not edible, and not commercially available, though it is cultivated (Levin, 2006). Many variety names are distinctive to the region where they are grown, and genetic origins of these varieties are mostly undecided. Therefore numerous varieties and hundreds of types exist across many countries. Cultivars are often categorized as sweet, sweet/sour, and sour; early-, mid-, or late-season; juice and table fruit; and soft- or hard-seeded. Hard-seeded fruit possesses poor eating quality; soft-seeded fruit has good eating quality; therefore soft-seeded cultivars are preferred for table fruit and hard-seeded fruit is better for processing. Furthermore, the desired pomegranate taste varies and is country or region specific; for example, in North Africa, nearly all the commercialized cultivars are sweet types, while in many other countries, the sour cultivars have been commercialized (Al-Kahtani, 1992). The cultivars documented in the literature, by country, are listed in Table 27.1; a brief description follows.

Table 27.1. Pomegranate cultivars of the selected countries.

Country	Cultivars
China	Dahangpao, 87-Qing 7, Teipitian, Duan, Duanzhihong, Dabaitian, Heyinruanzi, Tongpi, Bopi, Linxuan 8, Lintong 14, Taishan Dahong, Qingpiruanzi, Baishuijing, Chuanshiilu, Hongshuijing, Ping Di, Jian Di, Yushiliu 1, Yushiliu 2, Honghuachongbai, Mudanhua, Baihuachongbai (Liu et al., 1997; Sun et al., 2004; Zhang et al., 2008; Holland et al., 2009)
Egypt	Arabi, Manfoloty, Nab El Gamal, Wardy, Banati, Hegazy, Baladi, Yellow, Black, Granada (Mansour, 1995; Saeed, 2005; Yilmaz, 2007)
Georgia	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, Gyuleisha Krasnaya Apsheronskii Krasnyi, Burachnyi (Vasadze and Trapaidze, 2005)
India	Ganesh, Bhagwa, Arakta Ruby, Mridula, Bhagwa, Bedana, Kandari Hansi, Khandari Kabuli, Alandi, Dholka, Kabul, Muscat Red, Paper Shell, Poona, Spanish Ruby, Vellodu, Muscat White, Achikdana, Anar SM Ali, G-137, Jalore, P-75-K-3, P-23, P-26, Jalero, Jodhpur Red, Bassein, Malta, Guleashah, Molus, Sharin, Jylothi, Bedana, Bosco, Srinagar Special, Chawla, Nabha (Kulkarni and Aradhya, 2005; Yilmaz, 2007; Holland et al., 2009)
Iran	Malas-e Yazdi, Malas-e Saveh, Males-e Torsh, Rabeb-e Neyriz, Sishe Kape-Ferdos, Naderi-e Budrood, Bajastani Gonabad, Ghojagh Ghoni, Khazr Bardaskn, Galou Barik, Bajestan, Zagh, Shavar Daneh Ghermez, Sefid, Togh Gardan,Esfahani Daneh, Ghermez, Sefeede Robi Avale Brojen, Toghe Gardan, Zaghe Yazdy, Mesrie Torshe Kazeron, Ardestany Torshe Semnan, Khoram Dizin Torshe Gorgan, Gorch Shahvare Yazdy, Post Syahe Yazdy, Vahshi Kane Tehran, Torshe Mamooly Lasjar, Jangaly Post Ghermeze Rodbare Torsh, Malase Porbarij, Estahban, Alake Torsh, Malase Torsh, Pust Sefeede Shirin, Malase Shirin, Tabestani, Shirin Hastehe Bafgh, Post Sorkhe Ravar, Post Sefeede Torsh, Maykhosh (Rahemi and Mirdehghan 2004; Varasteh et al., 2006; Aarabi et al., 2008; Holland et al., 2009; Khoshroo et al., 2009)
Israel	Wonderful, P.G.116–17, P.G.100–1, P.G.101–2, P.G.128–29 (Akko), Shani-Yonay, Rosh Hapered, P.G.127–28 (Black), P.G.118–19 (Hershkovich), Malisi (P.G.127–28), Red Lufani (Shara'bi), Akko, Shani-Yonay (Holland et al., 2009)
Italy	Dente di Cavallo Tipica, Dente di Cavallo Coccio, Dente di Cavallo Tardiva, Dente di Cavallo Coccio Duro, Neirana, Profeta, Racalmuto, agana, Selinunte, Primosole (Barone et al., 2001; Yilmaz, 2007; D'Aquino et al., 2010)
Morocco	Gjeigi, Dwarf Ever Green, Grenade Jaune, Grenade Rouge, Gordo de Javita, Djeibali, Djeibi, Onuk Hmam, Zheri, Sefri (Oukabli et al., 2004; Yilmaz, 2007)
Spain	Mollar, Assaria, Tendral, Mollar de Elche, ME1, (Mollar de Elche No. 1), ME5, ME6, ME14, ME15, ME16, ME17, Agria de Albatera, Agridulce de Ojos (ADO), Albar de Bianca (BA), Borde de Albatera (BA), BA1, Borde de Blanka (BB), Casta del Reino de Ojos (CRO), CRO1, Mollar de Albatera (MA), MA4, Mollar de Orihuela (MO), MO6, Pinon Duro de Ojos (PDO), Pinon Tierno Agridulce de Ojos, PTO1 (Pinon Tierno de Ojos No. 1), PTO2, PTO7, San Felipe de Bianca (SFB), Valencian No. 1 (VA1) (Melgarejo et al., 2000; Miguel et al., 2006; Mirdehghan et al., 2006; Holland et al., 2009)
Tunisia	Gabsi, Tounsi, Zehri, Chefli, Mezzi, Jebali, Garoussi, Kalaii, Zaghouani, Andalousi, Bellahi (Mars and Marrakchi, 1999)
Turkey	Hicaznar, Silifke Asisi, Yufka Kabuk, Cekirdeksiz II, Cekirdeksiz III, Mayhos II, Asın Nar, Eksi Kirmizi, Beynar II, Cekirdeksiz IV, Fellahyemez I, Tatlı Mayhos, Mayhos IV, Cekirdeksiz VI, Cevlik, Lefan, Gliksiz, Mayhos VI, Mayhos VII, Katırbası, Mayhos VIII, Eksi Nar, Izmir 1, Izmir 2, Izmir 8, Izmir 10, Izmir 12, Izmir 15, Izmir 16, Izmir 23, Izmir 26, Izmir 29, Izmir 1261, Izmir 1264, Izmir 1265, Izmir 1267, Izmir 1445, Izmir 1453, Izmir 1465, Izmir 1479, Izmir 1483, Izmir 1499, Izmir 1513, Batem Nar 1, Batem Nar 2, Batem Nar 3, Batem Nar 4, Dikenli Incekabuk, Eksi, Kan, Katirbasi, Serife, Tatli, Fellahyemez (Yilmaz, 2007; Ozgen et al., 2008)
Turkmenistan	Kzyl Anar, Achik-Dona, Bashkalinski, Desertnyi, Shainakskii, Podarak (Levin, 2006; Holland et al., 2009)
USA	Wonderful, Early Foothill, Granada, Ruby Red, Balegal, Cloud, Fleshman, Crab, Francis, Green Globe, Home, King, Phoenicia, Sweet, Utah Sweet, Ambrosia, Eversweet, Red Silk (CRFG, 1987; Holland et al., 2009)

Afghanistan

Pomegranate has the second place in the country's total fruit production and occupies 7% of the total fruit cultivation area. The varieties are usually small and produced for the local markets. A few cultivars have been cited so far as follows: 'Black Kandahar,' 'Kabul,' 'Red Kandahar,' and 'White Kandahar' (Yilmaz, 2007).

China

Chinese cultivars vary from small to very large, from sour to sweet, and from early to late ripening (Holland et al., 2009). 'Teipitian' and '87-Qing 7' cultivars are probably the most popular cultivars in China, followed by Qingpiruanzi (Liu et al., 1997; Sun et al., 2004). Commercial cultivars have been chosen based on size, juice content, seed softness, and time of ripening, while some of the ornamental types have a unique number of petals and petal color (Holland et al., 2009).

Egypt

Pomegranates are grown in upper Egypt, especially in Assuit Governorate, for fresh consumption and juice (Mansour, 1995). About ten Egyptian cultivars, as well as 'Granada' have been documented in the literature (Mansour, 1995; Saeed, 2005)

Georgia

Several cultivars were reported in Georgia, such as 'Kyrmyz Kabukh' and 'Lyaliya,' noted for resistance splitting, and 'Sulunar' and 'Vedzisuri,' cultivars noted for higher juice content (Vasadze and Trapaidze, 2005).

India

Although there are more than 30 cultivars cited, 'Ganesh' is the most well-known cultivar in India. The 'Ganesh' cultivar, evergreen, has soft seeds, red arils, and low acid and sweet taste. 'Mridula' and 'Bhagwa' cultivars are usually produced for export. India is the leader in pomegranate breeding studies (Holland et al., 2009), where some undocumented cutivars may also exist.

Iran

Iran is probably the richest country in terms of genotypes, specimens, and cultivars of pomegranate. 'Malase-Yazdi,' 'Malas-e-Saveh,' 'Males-e Torsh,' 'Rabeb-e-Neyriz,' 'Sishe Kape-Ferdos,' and 'Naderi-e-Budrood' are the main commercial cultivars in Iran (Varasteh et al., 2009). Cultivars in Iran are classified as sweet, rootstock, and ornamental type (Mirdehghan and Rahemi, 2005). 'Alack,' an early-ripening cultivar, and 'Maykhosh,' a late-ripening cultivar, are used for export (Holland et al., 2009).

Israel

More than 50 accessions, with varied internal appearance, growth habit, ripening stage, taste, and seed softness, are found in Israel. Of the eight cultivars that are commercially grown, the leading one is 'Wonderful.' 'Wonderful' is the best export cultivar, followed by 'Akko' and 'Shani-Yonay' (Holland et al., 2009).

Italy

More than ten cultivars were reported, especially from Sicily, by Barone et al. (2001) and (Yilmaz, 2007). The cultivars present are mostly of local origin.

Morocco

About 17 pomegranate accessions have been reported in Morocco (Oukabli et al., 2004).

Spain

Nearly 40 Spanish cultivars have been documented. The cultivars are divided into three groups: sweet, sweet-sour, and sour. There is high variability among cultivars; 'Mollar de Elche' is the leading commercial cultivar, followed by 'Roja,' 'Valenciana' and 'Tendral' (Melgarejo et al., 2000). To improve commercial products, new cultivars are constantly being introduced via breeding studies.

Tunisia

Many types and forms or cultivars of pomegranate exist in Tunisia; however, their names are strictly local, originating from the area of cultivation or from the color of the fruit rind (Mars and Marrakchi, 1999). Interchange of plant material between regions was very frequent (Mars, 1995). Nearly all pomegranates, many of which are of low quality, are consumed locally. Only a few local cultivars, 'Zehri' and 'Gabsi,' are propagated in commercial nurseries and used in the new plantations (Mars and Marrakchi, 1999).

Turkey

Many types and forms grow over diverse areas. The cultivars are usually categorized based on sweetness and seed type: sour, sour-sweet, and sweet; soft-seeded, intermediate, and hard-seeded. 'Fellahyemez,' 'Eksilik,' 'Ernar,' Hicaznar,' 'Katirbasi,' 'Beynar,' and 'Asinar' are the leading commercial cultivars in Turkey. 'Hicaznar,' a red cultivar having a sweet-sour taste and hard seeds, is considered a high producer and somewhat similar to 'Wonderful' cultivar (Yilmaz, 2007).

Turkmenistan

Turkmenistan has a very large collection of pomegranate in Garygala in terms of size, variability, and geographical location (Levin, 2006). The Turkmen varieties are classified by size, flavor, skin color, aril color, seed softness, productivity, tendency to split and to diseases, postharvest performance, sugar content, juice content, and time of ripening (Levin, 2006; Holland et al., 2009). Recently, some of the Turkmen cultivars have been exported to Israel and the United States.

United States

A small number of cultivars are grown in the United States. ‘Wonderful’ is the major cultivar, which is widely cultivated in California, and possesses a large fruit with red arils, sweet-sour taste, and semi-hard seed (Holland et al., 2009). Other cultivars of much less commercial significance include ‘Ambrosia,’ ‘Eversweet,’ ‘Granada,’ ‘Red Silk,’ and ‘Sweet Pomegranate’ (CRFG, 1997).

Saudi Arabia, Iraq, Palestine, Syria, Cyprus, Portugal, Vietnam, and Australia

Very little information is available from these countries. ‘Ahmar,’ ‘Aswad,’ and ‘Halwa’ cultivars are produced in Iraq (Morton, 1987); ‘Malissi’ and ‘Ras el Baghl’ in Palestine (Morton, 1987); ‘Mangulati’ (Morton, 1987) and ‘Taifi’ (Al-Maiaman and Ahmad, 2002) in Saudi Arabia; ‘Red Loufani,’ ‘Malisi,’ and ‘Ras el Baghl’ in Syria (Yilmaz, 2007); Hicaznar,’ ‘Chocolate,’ ‘Sotirkatice,’ and ‘Ftanofli’ in Cyprus (Yilmaz, 2007); ‘De Javita,’ ‘Mollar de Alcanar,’ ‘Asseria,’ and ‘Mollar de Elche’ in Portugal (Yilmaz, 2007); ‘ Vietnamase’ in Vietnam (Holland et al., 2009); and Wonderful’ in Australia (Weerakkody et al., 2010).

Harvest

Some pomegranate plants grown from seedlings may bear flowers in their first year, and the plants bear fruit in their second year (Holland et al., 2009). Fruits, however, are harvested in the third year, when a tree bears approximately 50–60 fruits, depending on the cultivar. In the fourth and fifth year, the fruit number increases to about 80 to 100, finally reaching up to 120–150 during the sixth year onward (Anon, 2010). Since pomegranates are nonclimacteric fruits, they should be harvested when fully ripe. The calyx at the distal end of the fruit closes and the skin indents slightly when the fruit is ripe (Anon, 2010). While fruit can mature at different stages due to the extended bloom, most fruits are harvested between 135 and 150 days after fruit set, depending on the varieties (Yilmaz, 2007).

Harvest season lasts almost a month, with an interval of 6–7 days, equaling four times per harvest season. In Israel, ‘Wonderful’ is harvested when soluble solids reach 15% (Morton 1987), while in California, titratable acidity is less than 1.85% at harvest, and the color is darker than established reference (Kader, 2006).

Care must be taken when harvesting and handling the fruit since most new varieties have finer and delicate skin that is susceptible to bruising if handled inappropriately. Pomegranates should be harvested by clippers and placed gently into picking bags, then transferred to harvest bins destined for the packinghouse, where pomegranates are separated according to the severity of physical or any other type of defects (Kader, 2006). The mildly defected fruit may be used for processing into juice, and those with very slight or no defects are marketed fresh. For the fresh market, pomegranates are washed, size-graded, and packed in shipping containers after treatment with fungicide or wax (Kader, 2006). A packing application that reduces or prevents bruising and scuffing and allows rapid precooling should be applied (Kader, 2006).

Standards of quality

Fruit quality depends mainly on sugar and acid ratio of the juice along with size and skin color (Kader, 2006). Additionally, a high-quality pomegranate fruit should carry an attractive rind, small or soft seeds in the aril, and be free from sunburn, cracks and splitting, cuts, bruises, and decay. Rind color and smoothness are other external quality criteria; sweet pomegranates have yellowish-green skin, while sour or sour-sweet ones have reddish skin (Pekmezci and Erkan, 2010). Aril color intensity and uniformity are also important internal quality indices (Kader, 2006). Fruit firmness for ‘Mollar de Elche’ should be around 14–16 N at the time of harvest (Mirdehghan et al., 2007a, 2007b).

No US grades exist for pomegranate; fruit are mostly graded according to weight and packed in a single layer with the tops not usually covered by lids.

According to Turkish standards, pomegranates can be categorized into four groups based on size: small (150–200 g, 65–74 mm diameter, 25–34 fruit/5-kg carton), medium (201–300 g, 75–84 mm diameter, 17–25 fruit/5-kg carton), large (301–400 g, 85–94 mm diameter, 13–17 fruit/5-kg carton), and extra large (401–500 g, 94–104 mm diameter, 10–13 fruit/5-kg carton) (Pekmezci and Erkan, 2010).

The Codex Alimentarius Commission (CAC, 2009) describes standards entailing quality aspects related to pomegranate fruit size, safety, and labeling. These standards insist on "supplying high quality and safe products to protect consumer's health and there must be a large framework for standardization of this product which should include all the necessary parameters such as weight, size and proper labeling" (CAC, 2009, p. 3). In addition to typical packaging and labeling, the objectives of the standards are (1) to establish the minimum requirements for pomegranate, which shall comply with, independently from the quality class; (2) to define the categories to classify pomegranates in accordance with the characteristics of the fruit; and (3) to establish tolerance as regards quality and size that may be permitted of pomegranates contained in a package (CAC, 2009).

POSTHARVEST PHYSIOLOGY AND STORAGE TECHNOLOGIES

Postharvest physiology

Pomegranate is a nonclimacteric fruit; therefore, it does not ripen after harvest and must be picked fully ripe. The fruit reaches the fully ripe stage within 4–6 months after flowering, depending on the climatic conditions and variety (Ben-Arie et al., 1984). Maturity indices depend on the cultivars and include fruit skin color, aril color, titratable acidity (TA), and soluble solid content (SSC) (Lee et al., 1974; LaRue, 1980; Ben-Arie et al., 1984). The maximum TA may be 1% for sweet cultivars and 1.5–2% for sweet-sour cultivars. SSC should not be lower than 15% (Kader, 2006).

Pomegranate fruit has a very low respiration rate that usually decreases after harvest storage. The ranges of respiration rates for Indian-grown 'Ganesh' were 445 nmol/kg·sec at 25°C following harvest and about 130 nmol/kg·sec after 11 days at 25°C (Nanda et al., 2001), for Italian-grown 'Primosole' 241 nmol/kg·sec at 20°C following harvest and 20 nmol/kg·sec after 12 weeks at 8°C (D'Aquino et al., 2010), for Spanish-grown 'Mollar de Elche' 462 nmol/g·hr at 2°C following harvest and 595 nmol/g·hr after 60 days at 2°C (Mirdehghan et al., 2007a), and for Californian-grown 'Wonderful' 2–4, 4–8, and 8–18 mL/kg·hr at 5°, 10°, and 15°C, respectively, following harvest (Kader, 2006).

Ethylene production is very low in pomegranate fruit and frequently ignored in the postharvest studies. Ethylene production remained below 0.2 μL/liter at 20°C for the Californian-grown 'Wonderful' and 2.52 pmol/kg·sec at 20°C for the 'Primosole' at following harvest, and after 12 weeks plus 1 day at 20°C about 0.90 pmol/kg.sec (D'Aquino et al., 2010). Ethylene at ≥1 μL/liter stimulated respiration and autocatalytic ethylene in 'Wonderful' cultivar (Ben-Arie et al., 1984). The stimulation, however, caused no changes in fruit quality such as SCC and TA or fruit and juice color.

Postharvest losses: causes and remedies

In the course of postharvest life, pomegranate is susceptible to severe quality losses owing to physiological disorders and enzymatic activity. The disorders increase with duration of storage at 5°C and over (Elyatem and Kader, 1984). The main storage problem is water loss, which may lead to browning in both rind and arils (Mirdehghan et al., 2006). Firmness loss, changes in aril and rind color, and loss of vitamin C and acidity are some additional physiological disorders, which may occur simultaneously, thereby decreasing of acceptability with respect to freshness, juiciness, and taste (Artés et al., 1998; Nanda et al., 2001). Decay is also another major cause of the postharvest losses at the recommended storage conditions of 5°–8°C (Roy and Waskar, 1997).

Sunburn

Exposure of the pomegranate fruit to intense sunlight can result in sunburn, which is visible in the shape of large black spots on the rind, subsequently, resulting in unmarketable fruit. The fact that pomegranates are harvested in late summer or early autumn also contributes to sunburn (Melgarejo et al., 2004). Melgarejo and Martínez (1992) reported that the postharvest losses could run as high as 30% of harvested fruit due to sunburn damage.

For reducing sunburn occurrences, use of special cultivars having more leaf surface or fruits more resistant to sunburn is helpful (Melgarejo et al., 2004). The cultivation practices, such as fertilization and irrigation regimes that increase vegetative development, can also be used for protection of the fruits from direct sunlight (Melgarejo et al., 2004). Shades or screens can reduce sunburn as well. Sunburn damage may be prevented by the use of Kaolin. Melgarejo et al. (2004) observed a decrease in sunburn damage from 21.9% to 9.4% when a concentration of 25–50 kg/1000 l per ha was applied to 'Mollar de Elche' cultivar in Alicante, Spain.

Splitting and cracking

Fruit splitting and cracking, although regarded as the last phase of the pomegranate development process, where seed dispersing occurs, are two main physiological disorders developed on the tree. Both splitting and cracking enable decay microorganisms to enter the fruit, causing further pathological problems. Genetic factors, late harvest, irregular irrigation and precipitation during the ripening stage, sunburn and physical damage on the fruit skin, nutrient deficiencies, large variation in day and night temperatures, dry breeze, and some diseases and pests are the likely causes of the splitting and cracking (Yilmaz, 2007; Holland et al., 2009). The extent of the splitting and cracking may be reduced or prevented by using split/crack-resistant types such as 'Izmir-16' and 'Beynar' in Turkey (Yilmaz, 2007; Holland et al., 2009).

Harvest blemish

For fresh consumption or processing, fruit should be hand-picked and handled very delicately. Even a small bruise or scratch may cause a dark blemish on the rind, resulting in a sharp decline in commercial value.

Weight loss

Weight loss or water loss is the main problem for pomegranate fruit during postharvest life. Among the postharvest treatments tested, chilling temperature regime (<5°C) at high relative humidity (RH) (90–95%), modified atmosphere packing, film wrapping, waxing and controlled atmosphere (CA) storage have been found effective in limiting weight loss.

Chilling injury

Storage at 5°C or below 5°C for even 1 month may initiate chilling injuries in pomegranates, and the degree of the chilling injury symptoms increases with time and temperature decrease under 5°C (Elyatem and Kader, 1984). 'Wonderful' cultivar can be safely stored at 5°C for up to 2 months; however, the minimum safe temperature for longer storage is 7.2°C (Crisosto et al., 2010). Chilling injuries are easily perceivable after transferring fruit to 20°C, causing browning of the rind, surface pitting, husk scald, pale color of the arils, brown discoloration on the white segment, increase in electrolyte leakage, and increase susceptibility to decay organisms (Elyatem and Kader, 1984; Artés et al., 2000; Mirdehghan et al., 2007b).

To alleviate chilling injury symptoms, some postharvest treatments have been examined, and the following applications have been found successful to a variable degree: controlled and modified atmosphere storage (Nerya et al., 2006), thermal application by air or hot water dip (Artés et al., 1998, 2000; Mirdehghan et al., 2007a, 2007b), intermittent film wrapping and coatings (Nanda et al., 2001; D'Aquino et al., 2010), and polyamine application (Mirdehghan et al., 2007a) and salicylic acid treatment (Sayyari et al., 2009). Of these postharvest treatments, the polyamine application seems to be best tool to retard chilling injury symptoms when the fruit is stored at chilling temperatures (Mirdehghan et al., 2007a).

Scald

Scald, a physiological disorder limiting long-term of storage, develops with time, appears first on the stem end, and expands up to 60% of the skin but does not affect the internal tissue. Scald incidence and severity may be related to senescence since pomegranates harvested late showed higher scald degree than those harvested early. Among postharvest applications or treatments tested (such as diphenylamine, 1-MCP or CA), only the controlled atmosphere (5% O_2 + 15% CO_2) seems to be successful to control this disorder (Defilippi et al., 2006).

Internal breakdown

Internal breakdown is another physiological disorder in pomegranates, although the cause has not been explained yet. The symptoms of the disorder include underdeveloped light red-colored arils (Ryall and Pentzer, 1982).

Postharvest pathology

Gray mold (*Botrytis cinerea*) rot, green mold (*Penicillium digitatum*) rot, *Cladosporium* spp., *Aspergillus* spp., and *Alternaria* spp. are the most common postharvest diseases of pomegranate fruit (Roy and Waskar, 1997; Pekmezci and Erkan, 2010). Other fungi or bacteria causing pomegranate fruit decay or damage include *Cercospora* spp., *Penicillium* spp., *Colletotrichum gloeosporioides*, *Sphaceloma punicae*, *Coniella granati* Sacc. Petr. & Syd., *Phytophthora* spp., *Glomerella cingulata*, *Rhizopus* spp., *Nematospora* spp., and *Pestalotiopsis versicolor* (Holland et al., 2009; Palou and del Rio, 2009). *Penicillium digitatum* and *Botrytis cinerea* are likely the most frequent pathogens of pomegranate fruit and the most damaging (Palou and del Rio, 2009). In most cases, calyx is the entry point of gray mold, resulting in light brown, tough, and leathery skin as it progresses (Salunkhe and Desai, 1984). Heart rot is another disease caused by *Aspergillus* spp. and *Alternaria* spp. (Salunkhe and Desai, 1984). The disease progresses while on the tree; symptoms of the diseases are slightly abnormal skin color and blackened arils (Salunkhe and Desai, 1984). A noninvasive crown mold could develop on the stamen remains, leading to loss of aril color and off-flavor development and to ethanol buildup (Nerya et al., 2006).

Fludioxonil®, a synthetic analogue of pyrrolnitrin (Rosslenbroich and Stuebler, 2000) and a member of the class of phenylpyrroles, has been recently registered for controlling postharvest decay of pomegranates and other horticultural crops in the United States (Tedford et al., 2005). Fludioxonil alone or in combination with film wrapping has been shown to quite effectively control mold development, leading in 50–67% of cases to less decay than control fruit after 12 weeks at 8°C plus 1 week at 20°C (D'Aquino et al., 2010). Fenhaxamig® was also very effective in reducing natural incidence of *Botrytis cinerea* (Holland et al., 2009).

Current storage and shipping practices

Pomegranate fruit can be easily stored for a period of 2–3 months at 5°C; longer storage should be at approximately 7°C to avoid chilling injury (Crisosto et al., 2010). Water loss and decay are, however, accelerated by storage at temperatures over 5°C; hence the use of chilling temperature is necessary to extend storability despite chilling injury occurrences (Mirdehghan et al., 2007a). Some postharvest treatment regimes mentioned above, along with the use of chilling temperature, may be applied to the produce to delay or decrease chilling injury symptoms such as CA storage. In traditional storage, pomegranates are stored until the rind completely dries and turns brown as long as the arils stay fresh.

Cold storage

Although the optimum storage temperature varies by cultivar, production area, and postharvest application (Hardenburg et al., 1990; SeaLand, 1991; Onur et al., 1995), pomegranates are generally kept at 5°–8°C and 90% relative humidity (RH). The optimum storage conditions for 'Hicaznar,' the leading commercial cultivar in Turkey, are 6°C with 90% RH (Onur et al., 1992; Pekmezci et al., 1998) and for 'Wonderful,' around 7°C and 90–95% RH (Kader, 2006). RH of 90–98% is recommended for all pomegranates since fruit peel desiccates easily at low RH, causing a hard and darkened rind that reduces marketability (Salunkhe and Desai, 1984).

Controlled atmosphere

Among the postharvest conditions for an extended storage, the most successful one seems to be the CA storage at or below 7°C. CA, compared with the cold storage, has some superior advantages such as arresting/delaying the spread of certain diseases and decreasing the incidence of physiological disorders (Ben-Arie and Or, 1986; Kupper et al., 1995; Artés et al., 1996; Holcroft et al., 1998, Nerya et al., 2006). Optimal CA storage conditions for 'Hicaznar' pomegranate are 3% O_2 + 6% CO_2 (Kupper et al., 1995), and 2% O_2 + 6–15% CO_2 for 'Wonderful' (Hess-Pierce and Kader, 2003; Nerya et al., 2006). The 'Hicaznar' and 'Wonderful' cultivars can be stored up to 6 months at 6°C and up to 4–5 months at 6°–7°C, respectively, under CA storage (Hess-Pierce and Kader, 2003; Kupper et al., 1995; Nerya et al., 2006).

Shipping

Pomegranate fruit should be packed with cushioning within the shipping containers to reduce incidence and severity of scuffing during shipping and transportation. Pomegranate fruit within the shipping containers may be forced-air cooled to 7°C and kept at this temperature with 90–95% RH before shipment and transportation to the retail stores at 7°C and 90–95% RH (Kader, 2006). Pomegranates should not be mixed with other fruits or vegetables during storage or shipping since the sensory quality may be impaired by aromatic or other volatiles emitted from those commodities.

Innovative postharvest technologies

Few innovative postharvest technologies have been documented in the literature; the most promising ones are polyamine application (Mirdehghan et al., 2007a) and magnetic resonance imaging technology (Khoshroo et al., 2009).

Polyamine application

Prestorage application of polyamines (putrescine and spermidine) by pressure of 0.05 bar for 4 min, or immersion at 25°C for 4 min, might prolong the shelf life of pomegranate stored at chilling temperatures (Mirdehghan et al., 2007a). These researchers reported that the loss of firmness, color, SSC, TA, and the increase in respiration rate were significantly delayed in 'Mollar de Elche' pomegranate by the polyamine application during 60-day storage at 2°C plus 3 days at 20°C.

Magnetic resonance imaging

Magnetic resonance imaging may be used for visualizing the internal structure of a pomegranate fruit with respect to ripening stage and internal quality. A study conducted on 'Malas-e Torsh,' an Iranian cultivar, to determine the ripening stage and internal defects this technique resulted in detection rate accuracy of over 95% (Khoshroo et al., 2009).

Shelf life extension and quality

To extend storability and marketing of pomegranates, significantly better results are obtained when waxing (Waskar et al., 1999), film wrapping (Nanda et al., 2001; D'Aquino et al., 2010), packaging under modified atmosphere (MAP) (Porat et al., 2008), using thermal treatments (Artés et al., 1998, 2000; Mirdehghan et al., 2007a, 2007b), or applying

1-methylcyclopropene (1-MCP) gas treatment (Zhang et al., 2008).

Thermal treatment (air)

Intermittent heating has been proved useful for pomegranate fruit stored at chilling temperatures. Fruit treated retained better anthocyanins and TA, presented a reduction of decay, and an alleviation of chilling injury (Artés et al., 2000). 'Mollar de Elche' pomegranate fruit under cycles of intermittent warming of 1 day at 20°C every 6 days at 2° or 5°C showed longer shelf life than pomegranates continuously stored at 2° or 5°C (Artés et al., 2000). Conditioning 'Ganesh' pomegranate fruit at 55°C for 60 or 120 min significantly reduced chilling injury symptoms and electrolyte leakage (Rahemi and Mirdehghan, 2004).

Thermal treatment (water)

Pomegranates stored at chilling temperatures may benefit from hot water treatment. 'Mollar de Elche' pomegranates dipped in hot water (25°C for 4 min) and stored 60 days at 2°C followed by 5 days at 20°C showed less extensive chilling injury than fruit without treatment (Mirdehghan et al., 2007b). The heat-treated fruit showed higher total antioxidant activity, which correlated to the high levels of total phenolics and to lesser extent to ascorbic acid and anthocyanin contents; in addition, the level of sugars (glucose and fructose) and organic acids (malic, citric, and oxalic acids) were higher, too (Mirdehghan et al., 2006a). The optimum temperature of hot water dips for pomegranate may vary from 25° to 45°C, while temperatures of >50°C might damage the fruit skin (Mirdehghan and Rahemi, 2005; Mirdehghan et al., 2006).

Modified atmosphere packaging (MAP)

As stated in several postharvest studies, MAP with appropriate films can be used to generate a favorable atmosphere during storage and shipping of pomegranate fruit. Passive MAP (*X*tend® and Easy-Tear® bags, StePac Ltd., Israel) generated beneficial effects in the form of alleviating weight loss and shrinkage, decay development, appearance of skin blemishes (especially scald), and impaired taste for 'Wonderful' cultivar for a period up to 16 weeks at 6°C plus 1 week at 20°C (Porat et al., 2008). 'Ganesh' pomegranates shrink-wrapped with BDF-2001® (25 μm thick, multilayered coextruded polyolefin) could be stored for a period of 12 weeks at 8°C without significant loss of quality with respect to weight loss and firmness loss or changes in acidity, sugars, and vitamin C (Nanda et al., 2001). In another study, passive film wrapping (polyolephenic 25 μm thick, heat-shrinkable) of 'Primosole' pomegranate was shown to completely control water loss and husk scald and maintain freshness for 12 weeks at 8°C and 90% RH for 2 weeks and an additional 1 week at 20°C (D'Aquino et al., 2010).

Waxing

Similar to the effect of MAP, pomegranate fruit may benefit from waxing. 'Wonderful' pomegranate fruit waxed with Zivdar® wax (18% dry matter) showed a delay in quality losses by preventing fruit shrivel and drying of the stamens as well as preventing the development crown mold after months at 6°C (Nerya et al., 2006). After 4 months cold storage, the waxing increased husk scald incidence (Nerya et al., 2006), suggesting that long-term storage (more than 3 months) may not be appropriate for the 'Wonderful' cultivar.

1-Methylcyclopropene (1-MCP)

As an ethylene inhibitor, 1-MCP may be applied to pomegranate fruit before storage. Senescence and development of fruit skin browning of 'Dahongpao Chinese' pomegranate stored at 20°C for 7 weeks were delayed by 0.25–1.0 μL/liter 1-MCP treatment for 12-hour duration at 20°C prior storage (Zhang et al., 2008).

Salicylic acid

Salicylic acid (2 mM) was very effective in reducing chilling injury, electrolyte leakage from the rind, and loss of ascorbic acid in 'Malas-e-Saveh' Iranian pomegranate stored at 2°C for a period of 1, 2, or 3 months plus 2 days at 20°C (Sayyari et al., 2009). Therefore salicylic acid could be used for extending storage and shelf life of pomegranates stored at chilling temperatures.

MINIMALLY PROCESSED POMEGRANATE ARILS

Consumers' preference for fresh fruits and vegetables is on the rise due to their health-promoting properties. Minimally processed or fresh-cut produce has been getting a lot of attention firstly owing to its freshness, original flavor, and nutrients, and secondly, to its easy-to-eat nature, leading a rapid and excessive augmentation in terms of variety and quantity. Beyond having a unique flavor, considered as a functional food and thus constantly publicized by scientists, minimally processed pomegranate is on the rise, in the same line with juice. Owing to fruit botany, only one type of minimally processed product is possible from the pomegranate fruit, which is minimally processed aril.

Pomegranate, due to its exceptional and unique sensory and nutritional properties, is highly valued. The consumption, however, is not very easy due to the difficulty

Figure 27.2. Minimally processed pomegranate arils.

presented in removing arils from the fruit. For that reason, minimally or fresh processed pomegranates, in ready-to-eat form, have been developed (Fig. 27.2). Having intact sensory and nutritional properties, the minimally processed pomegranates are attracting more consumers. On the other hand, pomegranate fruit is very susceptible to sunburn, cracking, splitting, cuts or bruises, and chilling injuries if stored at temperatures lower than 5°C. These defects make the pomegranate fruit unmarketable even though their interior quality may still be acceptable. For export markets, shippers package pomegranates in cartons with cushioning material to minimize damage during long-distance shipments (Fig. 27.3). The defected fruit is eventually destined to industrial use or animal consumption. Therefore, minimally fresh processing of the externally damaged pomegranates may be an excellent way to gain commercial benefit from unmarketable whole fruit (López-Rubira et al., 2005).

Manual extraction of the arils is laborious and difficult; consequently, several machines extracting the arils are already on the market and in use. However, after the peeling and extracting process, unwanted materials, such as white segment and defective arils (broken, abnormally shaped or colored, or other physiological disorders), are extracted

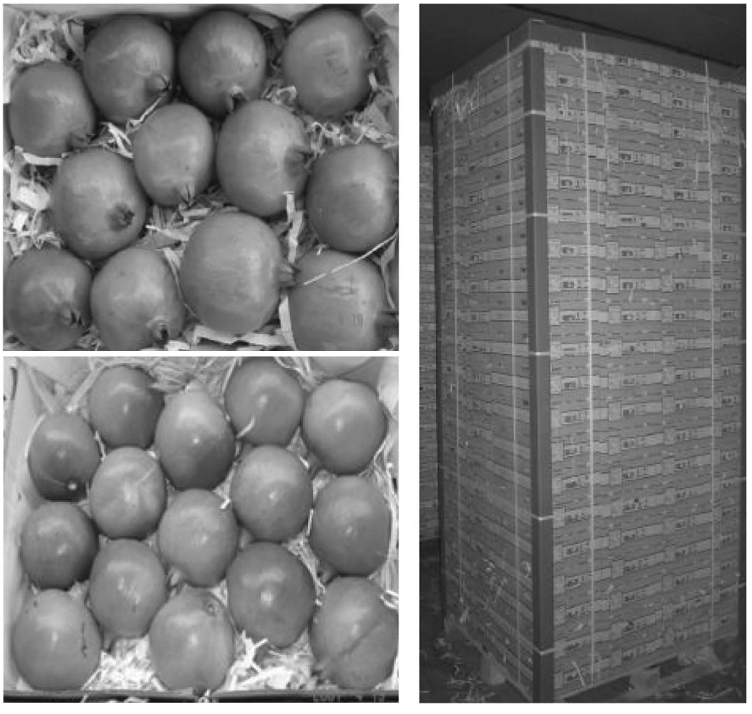

Figure 27.3. Pomegranates packaged for export markets (top left, 12-count box; bottom left, 15-count box; right, a pallet of 200 cartons packed together in 20 layers of 10 cartons each) (source: UNCTAD, 2010).

together. These unwanted media must be removed on the packing line since they decrease the shelf life and value of the minimally produced products. To overcome this problem, a computer-based machine capable of detecting and removing unwanted materials and sorting the arils by color has been developed (Blasco et al., 2009). This machine may be used commercially to sort minimally processed arils. On the other hand, a novel method that enables opening the fruit without cutting, extracting the arils with minimum damage, separating arils from the extraneous materials, and providing clean arils to the package line has been invented, patented, and implemented commercially in Israel (Schmilovitch et al., 2009).

Pretreatments and sanitizer use

To avoid or delay microbial development, washing minimally processed produce with chlorine solutions is widely accepted and used, with the concentration of chlorine mostly limited to <300 ppm (Schilimme, 1995). Washing arils with chlorine (100 mg/kg) followed by ascorbic acid (5 g/liter) and citric acid (5 g/liter) dip may be used to extend the shelf life of arils (Gil et al., 1996b). The UV-C radiation, however, may not be used as a pretreatment for prolonging the shelf life since López-Rubira et al. (2005) reported that UV-C at 0.56, 1.13, 2.27, 4.54, and 13.62 kJ/m^2 had no significant effect on the shelf life of 'Mollar de Elche' fruit stored under MAP at 5°C.

Arils, similar to whole fruit, have a relatively low rate of respiration and ethylene production. Minimally processed fruit may be stored up to 14 days at 7°C without compromising too much quality loss (Kader, 2006). During the aril extracting process, some arils are damaged, thus making them susceptible to decay. Therefore minimizing physical damage to arils is a critical factor in this process. To extend shelf life of minimally processed arils, several postharvest applications, such as MAP (Gil et al., 1996a; Sepúlveda et al., 2000), CA storage (Holcroft et al., 1998), antioxidants (Gil et al., 1996a; Sepúlveda et al., 2000), or honey coating (Ergun and Ergun, 2009), have been put into practice. Gil et al. (1996b) reported that pomegranate arils packaged in polypropylene films should be stored at 0°–1°C to get optimum shelf life.

Packaging of minimally processed products

MAP is one of the successful methods of prolonging the shelf life of arils (Gil et al., 1996a, 1996b). Under the MAP, where the initial atmosphere was actively modified to 20 mL/liter O_2 and 0 ml/liter CO_2, minimally processed pomegranate arils (cv. Mollar, Spain) may be stored up to 7 days at 1°C without fungal growth or off-flavor development (Gil et al., 1996b). Furthermore, semipermeable packages may be used for pomegranate aril (Chilean 'Wonderful') storage at 4°C for 14 days, with good physicochemical and microbiological quality (Sepúlveda et al., 2000).

Microbiological issues and food safety aspects

Many countries demand that minimally or fresh-cut produce not carry more than 7 log CFU/g aerobic bacteria. Consequently, minimally processed arils should be kept at 0°–5°C to maintain their microbial safety below the 7 log CFU/g aerobic level.

Quality attributes: physical, chemical, sensory

Since pomegranates are rich in both organic acids and phenolic compounds, their contribution to sensory attributes is closely followed during and after processing. In pigmented products like pomegranate, the discoloration generated by oxidation of phenolic compounds catalyzed by pheonolases and peroxidases causes an additional problem (Babic et al., 2006). As the color of pomegranate arils is one the most important quality attributes, their stability must be conserved (Gil et al., 1995). Dip/washing in antibrowning or antioxidant solutions might be therefore useful to preserve arils' characteristic attractive color.

PROCESSING AND PROCESSED PRODUCTS

Pomegranate is physically divided into different tissues, each of which can be processed into value-added products. The rind represents 28–30% of the fruit and is rich in tannins and other beneficial polyphenols; white segments, connective tissues with a porous structure, represent about 10% of the fruit, while internal membranes represent about 1–2%; and arils about 60% of the fruit (Borgese and Massini, 2007). These portions, however, can vary depending on cultivar, soil, plant nutrition, and climate.

Pomegranates, mostly unpeeled, may be crushed for juice, concentrated juice, and syrup or may be used for making jelly or other products (Artés and Tomás-Barberán, 2000). Arils may be employed for making cake and dessert. Pomegranates, especially sour types, may be processed into vinegar, as well as citric acid. Dried and ground fruit is also used as spice in some parts of Asia. In northern India, arils are dried in the sun for 10 to 15 days and then sold as a spice (Morton, 1987).

No specific grading, washing, and cutting procedures exist for pomegranate fruit, but extracting arils with the minimum physical damage and sorting arils by color and defects on the packaging or processing line is very important for the quality of processed products.

Juice, concentrate, and juice blends

Juice content of pomegranate varies from 45% to 65% of the intact fruit or from 76% to 85% of the arils (Pekmezci and Erkan, 2010). Organic acids, red color, tannin content, and SSC, higher in the fruit picked up late in the season, seem to be the major contributors to the quality of pomegranate juice (Crisosto et al., 1996; Dafny-Yalin et al., 2010). Juice quality and properties are also highly affected by aril mash quality from aril separators from which high juice yield and preventing oxidation are expected. The juice extraction is carried out using a screw-type press, belt press, or bladder press; each system has some advantages or disadvantages in terms of yield, pulp content, mash enzymation, filtration, antioxidant extraction, and color degradation. To produce a clear preferable pomegranate juice, enzymatic process is necessary for pectin breakdown pectins, and clarification is needed to eliminate cloudiness resulting from unstable proteins or protein-phenolic compounds. Thermal treatments may also be used for reducing bacterial contamination, inactivating enzymes responsible for color loss, and denaturizing flocculating proteins involved in hazing (Borgese and Massini, 2007). If the juice is extracted from whole fruit, excessive tannin may be precipitated out by a gelatin process (Morton, 1987). After filtration, the juice may be pasteurized or may be preserved by adding sodium benzoate, allowed to settle for two days, then strained and bottled (Morton, 1987).

Sediments in fruit juice may result from microbial growth (Borgese and Massini, 2007); therefore the source of the gaze must be clarified to get a safe pomegranate juice. Thermal treatments are necessary for controlling pathogenic microorganisms for especially juice and other product types.

Drying and dehydration

Very little has been reported in the literature on drying or dehydration of pomegranate arils; however, in Turkey, arils may be locally and traditionally sun-dried to make snacks, and in India to make spice (Morton, 1987).

Canning

Arils may be canned using filling liquids of sucrose syrup, a mixture of sucrose syrup and pomegranate juice (1:1, w/w), stored at 5°C for a period of 8 months (Benli and Fenercioglu, 2005).

Freezing

Pomegranate arils may be frozen at -40°C and stored at −18°C for 9 months (Bilisli and Cevik, 1999). Bilisli and Cevik (1999) reported that 'Izmir 16' is the most suitable variety for freezing among eight most common varieties in Turkey, followed by 'Izmir 1513,' 'Hicaznar,' and 'Izmir 1499.'

Jam

Pomegranate jams may be prepared using low or high methoxy pectins. For 1 kg high methoxy pectin jam, 350 g arils, 1.65 g pectin, 3 g citric acid, 0.5 g ascorbic acid and 1 g sorbic acid are mixed with a final sucrose concentration of 65 °Brix, and for 1 kg low methoxy pectin jam, 7 g pectin is used; the rest of the ingredients are in the same concentration of 65 °Brix (Melgarejo et al., 2009). High methoxy pectin yields better jam, and low temperature (5°C) in darkness may provide the optimal storage over time.

Indigenous processed products, new products

Indigenous products

A homemade grenadine syrup may be prepared by boiling 2 cups of arils and 2 cups of sugar until it reduced in volume and seeds are removed from the final product (Crisosto et al., 1996).

In the Middle East, pomegranate molasses may be made by boiling down the juice of a particular type of tart pomegranate along with some cane sugar and lemon juice, while sumac is added in Turkey.

New products

Honey-coated arils may be seen soon on the market. A study for extending the shelf life pomegranate arils indicated that honey solution dips extended the fresh-like quality of minimally processed arils by delaying quality loss, microbial development, and pigment changes (Ergun and Ergun, 2009). The positive results postulate that honey coating may be an innovative and natural replacement for costly chemical preservatives for some processed products of fruits and vegetables.

Health-promoting dietary products from the rind, juice, and seed have been marketed in the United States, such as pomegranate extracts (containing a minimum of 40% ellagitannin) from Source Naturals®, PomeGrat® pomegranate juice (fourfold concentrated juice) from Jarrow Formulas®, and Pomegranate Plus® (containing 70% ellagic acid) from Pure Encapsulation®. Homemade pomegranate seed oil, for nourishing and improving skin elasticity, is marketed on a limited scale.

In southeastern Turkey, for the preparation of a pizza-type dish called *lahmacun,* red pomegranate juice is used for savoring and coloring.

Besides the use of juice, pomegranate contributes a unique flavor to many Mediterranean and Middle Eastern cuisines such as the Iranian *fessenjan* (Stover and Mercure, 2007).

By-product utilization

A chemical extraction of phytochemical compounds used for nutritional and pharmacological fields is possible from pomegranate. The rind contains about 30% tannin, usable in medicinal and dye industries (Pekmezci and Erkan, 2010). Ellagitanins may be used in dietetic formulation as antioxidants; enzymes and pectins derived from pomegranates may be utilized for different applications in the food industry (Borgese and Massini, 2007). Pomegranate seeds as a by-product of juice processing can be used for oil extraction and for animal food.

NUTRITIONAL PROFILE AND HEALTH BENEFITS

Nutrient composition

Nutritional composition of pomegranates somewhat varies depending on the cultivars, soil, climate, and region. The juice from the arils (75% juice plus 22% seed) comprises approximately 85% water (Table 27.2), a considerable amount of SSC, total sugars, reducing sugars, anthocyanins, phenolics, ascorbic acid and proteins, and antioxidants (Kulkarni and Aradhya, 2005).

The SSC of ripe pomegranate fruit juice is in the range of 8.3 to 20.50 °Brix, and TA is between 0.13 and 4.98% at harvest (Kupper, 1995) (Table 27.2). TA is less than 1% in sweet cultivars, 1–2% in sweet-sour cultivars, and over 2% in sour cultivars (Onur and Kaska, 1985). Protein content of juice is about 1.03–1.13%, showing a diminutive range (Al-Maiman and Ahmad, 2002; Kulkarni and Aradhya, 2005), indicating that pomegranate fruit contains a very low level of protein compared to other fruits. The amount of total sugars is 11.43–20.50 mg/100 mg (Melgarejo et al., 2000; Dafny-Yalin et al., 2010), with fructose and glucose being the most prevalent sugars, followed by trace amounts of maltose, sucrose, mannitol (Table 27.2), and arabinose (Hulme, 1970).

Organic acids

The total organic acid content in pomegranate juice shows a very large variation with a range of 212 to 3959 mg/100 g (Aarabi et al., 2008). The individual organic acids found in pomegranate are as follows (Table 27.3): ascorbic acid, acetic acid, citric acid, fumaric acid, maleic acid, malic acid, oxalic acid, pyruvic acid, shikimik, succinic acid, tartaric acid, and (−)- Quinic acid (Poyrazoglu et al., 2002; Miguel et al., 2006; Aarabi et al., 2008). Citric acid is the predominant organic acid, followed by malic, tartaric, succinic acid, and the others. Individual organic acid composition is strongly variety dependent; moreover, some organic acids are undetectable in some varieties.

Antioxidant activity, vitamin C, and anthocyanins

Antioxidant activity of pomegranate juice measured as trolox-equivalent antioxidant capacity (TEAC), ferric reducing ability of plasma (FRAP), vitamin C equivalent, or percentage inhibition shows significant differences among varieties, and so do the total and individual anthocyanin levels (Artés et al., 1998, 2000; Drogoudi et al., 2005; Kulkarni and Aradhya, 2005; Ozgen et al., 2008; D'Aquino et al., 2010; Weerakkody et al., 2010) (Table 27.4). The

Table 27.2. Physicochemical composition of pomegranate juice.

Parameters (unit)	Value	Reference
Moisture (%)	83.65	Al-Maiman and Ahmad (2002)
pH	2.98–4.50	Poyrazoglu et al. (2002); Ozgen et al. (2008)
SSC (%)	8.30–20.50	Kupper (1995)
TA (%)	0.13–4.98	Kupper (1995)
Protein (g/100 g)	1.03–1.13	Al-Maiman and Ahmad (2002); Kulkarni and Aradhya (2005)
Total sugars (g/100 g)	11.43–20.50	Melgarejo et al. (2000); Dafny-Yalin et al. (2010)
Glucose (g/100 g)	4.80–7.72	Al-Maiman and Ahmad (2002); Dafny-Yalin et al. (2010)
Fructose (g/100 g)	4.80–8.60	Mirdehghan et al. (2006); Dafny-Yalin et al. (2010)
Maltose (g/100 g)	0.02–0.17	Melgarajo et al. (2000); Dafny-Yalin et al. (2010)
Sucrose (g/100 g)	0.01–0.04	Melgarejo et al. (2000); Ozgen et al. (2008)
Mannitol (g/100 g)	0.05–0.32	Dafny-Yalin et al. (2010)

Table 27.3. Organic acids concentration of pomegranate juice.

Organic Acid	Conc. (mg/100 g)	Reference
Ascorbic acid	0.36–8.78	Aarabi et al. (2008)
Acetic acid	0.81–43.60	Aarabi et al. (2008)
Citric acid	4.30–3763.60	Poyrazoglu et al. (2002); Aarabi et al. (2008)
Fumaric acid	0.24–15.39	Aarabi et al. (2008)
Maleic acid	0.08–19.20	Aarabi et al. (2008)
Malic acid	2.30–366.30	Mirdehghan et al. (2006); Aarabi et al. (2008)
Oxalic acid	0.20–55.10	Poyrazoglu et al. (2002); Aarabi et al. (2008)
Pyruvic acid	1.90–2.50	Miguel et al. (2006)
Shikimik acid	0.38–47.40	Aarabi et al. (2008)
Succinic acid	1.50–134.40	Poyrazoglu et al. (2002); Aarabi et al. (2008)
Tartaric acid	4.20–180.00	Poyrazoglu et al. (2002); Miguel et al. (2006)
(−)- Quinic acid	0.50–8.20	Poyrazoglu et al. (2002)

common anthocyanins in pomegranate juice are delphinidin 3-glucosides, delphinidin 3–5-glucosides, cyanidin 3-glucosides, cyanidin 3–5-glucosides, pelargonidin 3-glucosides, pelargonidin 3–5-glucosides, and cyanidin 3-arabinose, with varying values. Anthocyanins concentration has been reported to increase during cold storage (Gil et al., 1995) but not in CA storage (Holcroft et al., 1998). Vitamin C content of pomegranate juice is about 885.80 μmol/liter (Nanda et al., 2001).

Phenolic compounds

Pomegranate rind possesses high amounts of phenolic compounds in the form of catechin, quercentin, and kaempferol, as shown in Table 27.5. Catechin is also found in pomegranate seed (Park et al., 2010). Total phenolic compounds of pomegranate juice range from 22.50 to 407.78 mg/100 ml (Drogoudi et al., 2005; Ozgen et al., 2008). The phenolic compounds quantified in pomegranate juice are gallic acid, protocatechuic acid, catechin, cholorgenic

Table 27.4. Antioxidant capacity and anthocyanin levels of pomegranate juice.

Parameters	Value	Reference
Antioxidant capacity as:		
TEAC (mmol/TE[1]/liter)	4.38–7.70	Ozgen et al. (2008)
FRAP (mmol/TE[1]/liter)	4.63–11.60	Ozgen et al. (2008); Weerakkody et al. (2010)
Vitamin C eqv. (mg/100 ml)	1.3–31.60	Drogoudi et al. (2005); Borochov-Neori et al. (2009)
% Inhibition	55.05–69	Kulkarni and Aradhya (2005); D'Aquino et al. (2010)
Vitamin C (μmol/liter)	885.80	Nanda et al. (2001)
Total monomeric anthocyanins, as cyanidin-3 glucosides (mg/100 g)	0.60–21.90	Ozgen et al. (2008)
Total anthocyanins, as cyanidin 3–5-glucosides (mg/100 g)	33.80–125.50	D'Aquino et al. (2010); Kulkarni and Aradhya (2005)
Delphinidin 3-glucosides	0.05–5.70	Artés et al. (2000); D'Aquino et al. (2010)
Delphinidin 3–5-glucosides	0.13–5.01	Artés et al. (2000); D'Aquino et al. (2010)
Cyanidin 3-glucosides	0.31–13.83	Artés et al. (2000); D'Aquino et al. (2010)
Cyanidin 3–5-glucosides	0.41–7.53	Artés et al. (2000); D'Aquino et al. (2010)
Pelargonidin 3-glucosides	0.04–2.11	Artés et al. (2000); D'Aquino et al. (2010)
Pelargonidin 3–5-glucosides	0.02–0.65	Artés et al. (1998, 2000)
Cyanidin 3-arabinose	0.33	D'Aquino et al. (2010)

[1]Trolox equivalent

Table 27.5. Phenolic compounds of pomegranate rind, seed, and juice.

Phenolic Compounds	Content (mg/100 ml)[1]
Rind:	
Kaempferol	1261.50
Quercetin	2505.60
Catechin	13867.00
Seed:	
Catechin	976.70
Juice:	
Total phenolics (as GAE)	22.50–407.78
Gallic acid	3.40–308.60
Protocatechuic acid	1.20–20.50
Catechin	1.30–84.40
Chlorogenic acid[2]	0.90–4.72
Caffeic acid[2]	1.00–28.90
p-coumaric acid[2]	0.20–2.10
o-coumaric acid[2]	0.70–3.00
Phloridzin[2]	0.30–49.30
Quercetin	2.30–45.80
Ferulic acid[2]	0.10–0.60

[1] µl/liter for rind and seed
[2]Not detected in some varieties
Source: Rind and seed (Park et al., 2010), juice (Poyrazoglu et al., 2002)

acid, caffeic acid, *p*-coumaric, *o*-coumaric acid, phloridzin, quercetin and ferulic acid (Poyrazoglu et al., 2002). Gallic acid is determined to be the most abundant phenolic, followed by catechin, quercetin, and so on (Table 27.5). Punicalagin A and B, and punicalin (Zhang et al., 2009), castalagin, granatin, and gallacatechin (Seeram et al., 2006) have been reported on the rind of pomegranate as well.

Ash and minerals

Ash and mineral contents of the pomegranate fruit are shown in Table 27.6. Ash contents of seed and juice are 0.45% and 1.05%, respectively. The amounts of potassium, calcium, and sodium are the highest in both seed and juice (Al-Maiman and Ahmad, 2002).

Physiochemical composition of seed

A detailed study on 'Taifi' pomegranate seed done by Al-Maiman and Ahmad (2002) reported seed composition as 77.72% moisture, 4.45% protein, 0.25% fat, 0.18 mg/100 g ascorbic acid, and 1.90 mg/100 g phenolic compounds. This profile indicates that pomegranate seed is also rich in phenolic compounds, some of which have a very strong antioxidant activity.

Table 27.6. Ash and mineral content (mg/100 g) of pomegranate seeds and juice.

Mineral	Seed	Juice
Ash	0.47	0.32
Calcium	59.30	24.50
Iron	1.88	21.21
Magnesium	11.90	5.13
Phosphorus	7.49	6.25
Potassium	243.00	333.00
Sodium	95.70	72.10
Zinc	1.26	0.30
Copper	0.04	0.07

Source: Al-Maiman and Ahmad (2002).

Vitamins and other nutritional compounds

Fibers and vitamins, especially vitamin A and C, are very abundant in pomegranate fruit. A medium-size fresh pomegranate fruit contains daily recommended intake of ß-carotene, a potent antioxidant. Others nutrition values not mentioned above include selenium, thiamin, riboflavin, niacin, pantothenic acid, vitamin B_6, folate, vitamin B_{12}, vitamin E and vitamin K, and α-carotene (TNI, 2010).

Effect of processing on nutrition

Fruit rind is a good source of antioxidant polyphenols. Therefore crushing the fruit with peel enriches the polyphenols of pomegranate juice. On the other hand, many antioxidants are degraded during and after processing by heat or light. Table 27.7 shows the nutritional profile of California 'Wonderful' pomegranate and juice. Some variations in composition are expected based on varietal differences or due to climatic conditions under which fruit is grown.

Medicinal properties and health benefits

The consumption of pomegranate bestows health-promoting effects based on the content of several compounds with antioxidant activity, including ascorbic acid, flavonoids, and phenolic compounds such as anthocyanins (Tomás-Barberán and Espín, 2001).

In various clinical studies, pomegranate juice has been found beneficial in reducing health disease risk factors, atherosclerosis, and cardiovascular diseases (Aviram et al., 2000, 2004; Kaplan et al., 2001). Tannins, found abundantly in pomegranate, have been recognized as one of the major antioxidant compounds. Pomegranate has been reported to

Table 27.7. Nutritional profile of California-grown 'Wonderful' pomegranate fruit and juice (per 100 g).

Nutrient	Unit	Raw Fruit	Juice, Bottled
Proximate:			
Water	g	77.93	85.95
Energy	kcal	83	54
Protein	g	1.67	0.15
Total lipid (fat)	g	1.17	0.29
Ash	g	0.53	0.49
Carbohydrate, by difference	g	18.7	13.13
Fiber, total dietary	g	4	0.1
Sugars, total	g	13.67	12.65
Minerals:			
Calcium	mg	10	11
Iron	mg	0.3	0.1
Magnesium	mg	12	7
Phosphorus	mg	36	11
Potassium	mg	236	214
Sodium	mg	3	9
Zinc	mg	0.35	0.09
Copper	mg	0.158	0.021
Selenium	µg	0.5	0.3
Vitamins:			
Vitamin C, total ascorbic acid	mg	10.2	0.1
Thiamin	mg	0.067	0.015
Riboflavin	mg	0.053	0.015
Niacin	mg	0.293	0.233
Pantothenic acid	mg	0.377	0.285
Folate, total	µg	38	24
Choline, total	mg	7.6	4.8
Vitamin E (alpha-tocopherol)	mg	0.6	0.38
Vitamin K (phylloquinone)	µg	16.4	10.4

Source: USDA (2010).

reduce systolic blood pressure and may be effective against prostate cancer and osteoarthritis (Aviram and Dornfeld, 2001).

Antiviral and antibacterial effects of pomegranate juice against dental plaque have been also documented (Prashanth et al., 2001; Vasconcelos et al., 2003). Pomegranates are rich in ß-carotene, which prevents the buildup of plaque deposits in the arteries, protects the eyes from sun damage, and deactivates free radicals responsible for accelerating aging and increasing the risk of cancer (Aviram et al., 2002; Hora et al., 2003; Afaq et al., 2005). The human body converts ß-carotene to vitamin A, which is a very important compound for vision and helps to maintain eye lubrication. Therefore those with dry eyes should consume plenty of pomegranates in their diet. Recently, the extract of pomegranate, especially from the rind catechin, quercetin, kaempferol, and equol, has been shown to inhibit skin photoaging induced by UVB irradiation (Park et al., 2010). Thus pomegranate juice, which includes the rind extract, could be used for protecting human skin against the harmful effects of sunlight. A recent study has suggested that ellagitannins extracted from pomegranate may have beneficial effects against colon cancer (Sharma et al., 2010). In the stomach and gut, elligatannins hydrolyze to release ellagic acid and are converted by gut microbiota to urolithin A, a metabolite type that inhibits the proliferation of colon cancer cells, induces cell cycle arrest, and modulates key cellular processes linked to colon cancer development (Sharma et al., 2010).

Punicaligan, a common tannin in pomegranate, has strong antibacterial and antifungal activities (Burapadaja and Bunchoo, 1995). Besides punicaligan, castalagin, granatin, catechin, gallocatechin, kaempferol, quercetin, and other phytochemical compounds with small percentages found in pomegranate (Seeram et al., 2006) possess antimicrobial attributes such as gurading, e.g., protection against methicillin-resistant *Staphylococcus aureus* and *Salmonella typhi* (Prashanth et al., 2001), *Candida albicans* (the most common etiological agent for many clinical mycoses which may lead to human and animal death) (Tayel and El-Tras, 2009), as well as against both food-borne pathogens and spoilage bacteria (Alanís et al., 2005). Pomegranate peel extract as an anticandidal compound in the form of aerosol could be used for sterilizing semiclosed places that are suspected of *Candida albicans* contamination such as hospitals, farms, and jails (Tayel and El-Tras, 2009).

Folk medicine

Pomegranate extracts were used to cure a wide variety of ailments in ancient cultures, such as the riddance of tapeworms in Egypt (Wren, 1998), as plaster to reduce eye inflammation, and as an aid to digestion in Greece (Adams, 1849). Pomegranate bark, leaves, and immature fruits have been used against diarrhea and hemorrhage, while dried and crushed flower buds are made into a tea to treat bronchitis (Stover and Mercure, 2007). In Mexico, flower extracts are used as a gargle to alleviate mouth and throat inflammation (Morton, 1987). Many of these uses have been documented by clinical studies (Seeram et al., 2006; Stover and Mercure, 2007).

SUMMARY

The pomegranate has a deep connection with Mediterranean, Middle East, and Near East culture, where the fruit has been long consumed as an important dietary constituent, venerated in symbolism, and greatly appreciated for its medicinal remedies. Recent trends demonstrate that the health-promoting effects and flavor-rich attributes of pomegranates are being appreciated and cherished by not only by the Western world but also by the rest of the world. Increased interest in pomegranate, in the view of postharvest physiology and technology, comes with the quests as to how to extend storage life, to maintain quality in terms of not only physical (firmness, color, etc.) but also chemical (phytonutrients) attributes, and to expand use of the fruit extract into the food industry.

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