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Postharvest Handling and Processing of Pomegranate

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ABSTRACT

Botanically pomegranate is a fleshy berry and is considered to be a non-climacteric fruit. The fruit is rich in sugars, organic acids, minerals, anthocyanins, flavonoids, punicic acid, the sex steroid estrone, the phytoestrogen coumestrol, etc. and because of these properties it has received special attention in recent years. Its wide range of significance, in human health, nutritional and livelihood security, has been recognized. This resulted in increased fruit consumption not only in India but also in the western world where it was not previously popular. The fruit, which is a high-value food product, is used in a fresh form or to produce juices. There is high demand of pasteurized juice in the global market. The isolated arils are used fresh or in dried form as condiments. In addition to these, there are several commercial herbal formulations utilizing pomegranate extract in various parts of the world such as Brazil, India and China. However, in the present review, the main focus is envisaged on maturity indices, fruit physiology, handling and storage of pomegranate fruits and postharvest diseases.

Keywords: fruit physiology, maturity indices, storage, value-added products

CONTENTS

INTRODUCTION

Pomegranate (*Punica granatum* L.) is one of the oldest known edible fruits and has been associated with several ancient cultures of the world. Its commercial cultivation started in many countries, especially in tropical and subtropical dry regions of the northern hemisphere. Its commercial potential and economic impact is enormous considering the different ways in which the fruit may be utilized. The fresh fruit and juice market has grown steadily worldwide and has especially boomed in the US in recent years due to its increased consumer awareness of the potential health benefits (Seeram *et al.* 2006). Other commercial pomegranate products include jams, jellies, isolated arils and wines. However, pomegranate juice is also popularly consumed. In the commercial juicing industry, a large amount of bioactive polyphenols contained in the fruit peel and membrane, consisting predominantly of punicalagin and its isomers, are extracted into fruit juice along with several other phytochemcials found in other parts of the fruit, especially in its arils and seeds. Punicalagin has been shown to be the major contributor to the potent antioxidant activities of fruit juice. It is noteworthy that punicalagin is present in commercial pomegranate juice whereas consumption of the edible fruit part, namely the arils, would not yield this potentially healthy phytochemical. There are several commercial herbal formulations utilizing pomegranate extract in various parts of the world such as Brazil, India and China (Du *et al.* 1975; Gil *et al.* 1996b; Seeram *et al.* 2006). Currently, most of the studies attributing health benefits to pomegranates have been conducted on the fruit (including its arils, peel, and seeds) in beverage forms (juice and wines) and as extracts. By far, the most abundant phytochemicals present in the pomegranate fruit (arils and peels) are polyphenols, while the seeds contain fatty acids and triglycerides (Seeram *et al.* 2006). However, further studies focusing on these

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Invited Review

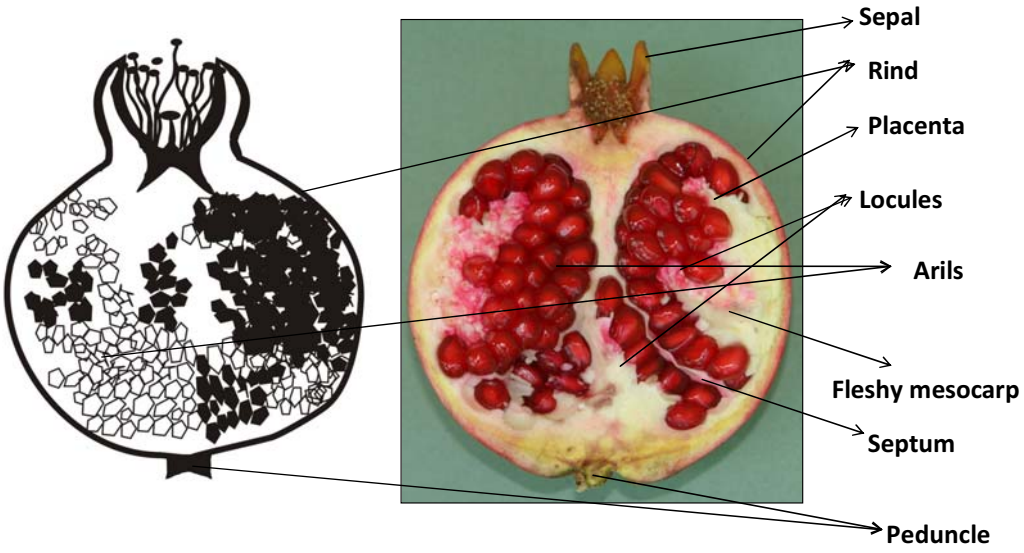

Fig. 1 Different parts of pomegranate fruit.

dietary pomegranate phytochemicals are, therefore, necessary for wider publicity and commercialization. Generally, pomegranate fruits are ready for harvest in 125-180 days after anthesis and possess typical characteristics of non-climacteric fruits. In the recent past, attempts have been made to prolong the shelf life of pomegranate fruits and isolated arils following controlled atmosphere (CA), cold storage and other storage methods (Ben Arie and Or-Mizrahi 1986; Artés *et al*. 2000; Hess-Pierce and Kader 2004; Defilippi *et al*. 2006; Porat *et al.* 2007). Some microorganisms like species of *Botrytis*, *Cladosporia*, *Pboma*, *Phomopsis*, *Rhizopus* and *Sphaceloma punicae* are associated with decay in pomegranate fruits during storage (Sonawane *et al.* 1986; Adaskaveg and Forster 2003) but these diseases can be managed well by chemical treatments using Topsin-M (0.1%) and Bavistin (0.05-0.1%) or Waxol 12%+0.1% Carbendazim (Padule and Keskar 1988; Ram Asrey *et al.* 2008). However, the use of pesticides in the fruits and its products should be avoided using eco-friendly chemicals and natural products.

FRUIT MORPHOLOGY

The pomegranate fruit develops from the ovary and is botanically classified as a fleshy berry (Holland *et al.* 2009). It is nearly round, varying in diameter from about 6.25 to 12.5 cm, crowned by a prominent and persistant calyx and a hard, leathery skin (rind or husk). The apex of the crown is almost closed to widely opened, depending on the variety and the ripening stage. In later stages of fruit maturation, the colour changes until it reaches its final characteristic colour as the fruit ripens. The external rind colour ranges from yellow, green or pink overlaid with pink to deep red or indigo to fully red, pink or deep purple cover, depending on the variety and stage of ripening (Adsule and Patil 1995; Kader 2006; Holland *et al.* 2009). However, exceptionally black skin pomegranate has also been reported (Levin 2006b). The rind thickness varies in different cultivars. The multi-ovule chambers (locules) are separated by membranous walls (septum) and a fleshy mesocarp (**Fig. 1**). The chambers are organized in a nonsymmetrical manner. Usually the lower part of the fruit contains 2 to 3 chambers while the upper one has 6 to 9 chambers. The chambers are filled with many seeds (arils). The aril contains 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 colour of the edible juicy layer may vary from white to deep red, depending on the variety. The seeds in some pomegranate varieties are very soft, while in others they are large and hard. The seed coat varies in hardness, the softer-seeded varieties known as seedless. Lack of lignification of the testa is the main cause of seedlessness in pomegranate (Saxena *et al.* 1987). Pomegranate fruits should be handled with utmost care during harvesting and postharvest handling for maximum shelf life during storage.

FRUIT COMPOSITION

Pomegranate is commercially grown for its sweet acidic fruits, which are mainly used for dessert purposes. The edible portion (arils) is about 45-61% of total fruit weight and consists of about 60-85% juice and 15-25% seeds (Lee *et al.* 1974a; Al-Maimam *et al.* 2002; Patil *et al.* 2002; Kader 2006) and 33-40% peel (Jagtap *et al.* 1992). The arils in improved varieties of pomegranate are thick, fleshy and very juicy. The taste of the pulp varies from sweet and aromatic ('Arakta', 'Bhagawa', 'Ganesh', 'Jodhpur Red', 'Jalore Seedless', 'Mridula', 'P-23', 'P-26', 'G-137') to sour and insipid ('Nana', 'Daru', 'VIR-5', 'Eni Krmyzy', 'Alice') . The edible part of the fruit contains considerable amounts of acids (20-75 mg/l), sugars (13.7-14.6%), vitamins, polysaccharides, polyphenols (1800-2100 mg/l) and important minerals. Some chemical changes during storage in pigmentation (45-69 mg/l), sugars, lipids, fatty acid and mineral composition of the edible portion have been reported (Gil *et al.* 1995; Melgarejo *et al.* 1995; Hernández *et al.* 1999; Melgarejo and Artés 2000b; Salah *et al.* 2002; Levin 2006a; NRCP 2008). In general, fresh fruit juice contains 85.4% moisture, 10.67% total sugars, 1.4% pectin, 0.1 g/100 ml total acidity (as citric acid), 19.6 mg/100 ml free amino nitrogen and 0.05g/100 ml ash (Patil *et al.* 2002). Further, Jagtap *et al.* (1992) and Sood *et al.* (1982) reported that the moisture content ranged from 77.0-82.2%, protein 1.6-1.96%, fat 0.1-2.11%, carbohydrates 14.6-20.0%, ash 0.66-0.76%, pectin 0.27-0.55%, total sugars 6.2-9.0%, reducing sugars 5.6-9.93%, non reducing sugars 0.1-3.3%, vitamin C 5.3-16, Ca 10.0-145.0, phosphorus 33-70, iron 0.3-0.69 and sulphur 25-28 mg/100 g edible portion (**Tables 1, 2**). Some organic acids like citric, malic, oxalic, succinic and tartaric acids are present in the fruit juice (Ulrich 1970; Malhotra *et al.* 1983; Melgarejo *et al.* 2000a; Ender *et al.* 2002). Among carbohydrates, glucose (5.46%) and fructose (6.14%) were predominant sugars in the juice (Lee *et al.* 1974) with almost no sucrose (Siddappa and Bhatia 1954) and sour cultivars ('Daru') showed lowest fructose and glucose. The quality of juice is predominantly judged by its sugar and acid content. Interestingly, acidity decreases and soluble solids (mainly sugars), pH and red colour intensity

Table 1 Sugar and acid contents of some pomegranate cultivars*.

Cultivar	TSS (°Brix)	Total sugar (%)	Reducing sugar (%)	Non-reducing sugar (%)	Acidity (%)
P-23	17.67	14.78	14.42	0.36	0.3239
Dholka	18.00	14.88	14.37	0.51	0.4128
GKVK-1	18.00	14.99	14.73	0.26	0.3298
Jodhpur Red	15.33	13.86	13.39	0.47	0.1895
G-137	17.16	14.88	13.97	0.87	0.3823
P-26	17.33	14.49	13.56	0.93	0.3969
Jalore Seedless	18.33	14.56	13.35	1.21	0.3950
Ganesh	17.00	14.36	13.35	1.01	0.3950

*Mali and Prasad (1999)

Table 2 Chemical composition of some pomegranate cultivars.

Parameters	Cultivars			
	Bhagawa [1]	Ganesh [1]	Taifi [2]	Mridula [3]
Moisture (%)	81.27	81.17	83.65	78.0
Total ash (%)	0.53	0.46	0.32	0.7
Protein (%)	1.41	1.21	1.03	1.6
Fat (%)	0.31	0.24	-	0.1
Crude fiber (%)	1.6	1.40	-	5.1
Carbohydrates (%)	14.88	15.52	-	14.6
Glucose	-	-	7.72	-
Fructose	-	-	6.66	-
Calorific value (K cals/100 g)	67.95	69.08	-	-
Minerals (mg/100 g)				
Iron	0.39	0.30	2.21	0.3
Zinc	0.26	0.19	0.3	-
Calcium	2.50	2.71	24.5	10.0
Magnesium	10.22	7.78	5.13	12.0
Copper	0.26	0.28	0.07	0.17
Manganese	0.13	0.13	-	-
Phosphorus	34.73	28.23	6.25	70.0
Vitamins (mg/100 g)				
Thiamine	0.09	0.06	-	0.06
Niacin	0.22	0.25	-	0.30
Ascorbic acid	23.38	22.42	-	16.0
Total carotenoids (µg/100 g)	26	27	-	-

[1] NRCP (2008); [2] Salah *et al.* (2002); [3]Jagtap *et al.* (1992)

of the juice increase with the fruit maturation and ripening (Lee *et al.* 1974; Elyatem and Kader 1984; Prasad *et al.* 2000; Roy and Wasker 2005). However, harvesting time influences TSS and acidity to a considerable extent as in 'Wonderful' fruits harvested in mid-October had TSS and acidity 18.1 °Brix and 1.58%, respectively as compared to the fruits harvested in late September which had 17 °Brix TSS and 1.8% acidity. In general, larger fruits (> 250 g) were lower in acidity than smaller ones (Kader *et al.* 1984; Kader 2006). It has also been noted that deciduous varieties are more acidic than evergreen ones. Citric acid is the predominant organic acid found in pomegranate juice and its acidity ranges from 1-2% on a fresh weight basis (Kader *et al*. 1984). Six anthocyanin pigments were found to be responsible for the red colour of pomegranate juice. These were identified as delphinidin 3-glucoside, delphinidin 3, 5-diglucoside, cyanidin 3-glucoside, cyanidin 3,5-diglucoside pelargonidin 3-glucoside and pelargonidin 3, 5-diglucoside. But, the fruit skin contained only cyanidin and pelargonidin derivatives (Gil *et al*. 1995; Alighourchi *et al.* 2008). The common anthocyanins (ACs) in pomegranate juice are the 3-glucosides and 3,5-glucosides of delphinidin, cyanidin and pelargonidin (Lee *et al.* 1974b; Du *et al.* 1975). Pomegranate ACs are labile compounds that are easily susceptible to degradation during storage and processing (Marti *et al.* 2000; Miguel *et al.* 2004; Alighourchi *et al.* 2008). The other phenolic compounds in pomegranate include ellagic acid derivatives and hydrolysable tannins (punicalagin, punicalin). There is a strong positive correlation between total phenolics and antioxidant activity of pomegranate (Gil *et al*. 2000; Seeram *et al*. 2006). However, above a certain concentration phenolic compounds can render the juice less desirable because of astringencies. Besides, fruit and its different parts contain several phytochemcials like ellagic acid, catechin and procyanidins, fatty acids and triglycerides (linoleic acid, linolenic acid, palmitic acid, punicic acid, tri-*O*-punicylglyceriol), sterols and terpenoids (betulinic acid, estrone, stigmasterol, testosterone), flavonols etc. that have been associated with a reduced risk of chronic human illnesses such as certain types of cancers, inflammation, and cardiovascular and neurodegenerative diseases (Seeram *et al.* 2006).

FRUIT RIPENING AND MATURITY INDICES

In general, the fruit ripens 5-8 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 (Holland *et al.* 2009). The pomegranate varieties reach full ripeness between 125 and 180 days after anthesis, depending on climatic conditions (Lee *et al*. 1974a; La Rue 1980; Ben-Arie *et al*. 1984; Khodade *et al.* 1990; Roy and Waskar 1997; Prasad and Mali 2002; Ram Asrey *et al.* 2008). Pomegranate fruit has a typical characteristic of non-climacteric fruits. Even ethylene treatments to fruits after harvest do not affect its fruit parameters (Kader *et al.* 1984; Holland 2009) and these results indicate that it does not ripen once removed from the tree. Therefore, in order to ensure the best eating quality, the fruit should be picked at the fully ripened stage. As the pomegranate fruit matures on the tree, a reduction in the acidity and parallel increase in TSS, pH and colour intensity is observed (Kader 2006). Maturity indices are dependent on variety and include external skin colour (changes from yellow to red) and juice colour, acidity and TSS content (Kader *et al*. 1984; Ben-Arie *et al*. 1984; Elyatem and Kader 1984; Al-Maiman and Ahmed 2002). The maximum acidity may be 1% in sweet varieties and 1.5-2% in sweet-sour varieties. However, in Indian and Chinese market sweet varieties are preferred while in European and American countries sweet-sour varieties have better demand. The fruits of 'Wonderful' are ready for harvest when TSS ranges between 15 and 17 °Brix. The minimum maturity indices for 'Wonderful' are red juice colour equal to or darker than the Munsel colour chart 5R-5/12 and acidity below 1.85% (Elyatem and Kader 1984; Kader *et al.* 1984). In Rajasthan (India), 'Jalore Seedless' (**Table 3**) is a popular cultivar with red juice with dark red arils and 0.3-0.4% acidity (Prasad *et al.* 2000).

Table 3 Some quality parameters of pomegranate cultivars*.

Cultivars	Fruit weight (g)	Fruit juice (%)	Aril colour	Aril (%)	Rind (%)	Juice in arils (%)	Seed in aril (%)	Acidity (%)
P-23	309.73	50.91	Creamy	61.97	38.03	81.09	18.91	0.32
Dholka	259.37	51.23	Creamy	63.85	36.32	80.97	18.73	0.41
GKVK-1	271.17	43.51	Creamy	60.14	45.95	71.08	20.16	0.33
Jodhpur Red	222.33	40.85	Light pink	54.51	39.85	68.28	31.43	0.19
G-137	273.83	46.52	Creamy	57.37	42.85	78.49	20.37	0.38
P-26	285.47	51.09	Creamy	62.00	37.57	79.73	20.24	0.40
Jalore Seedless	322.17	52.68	Red	61.53	36.40	83.67	16.33	0.40
Ganesh	297.80	48.33	Light pink	59.57	38.92	81.45	17.88	0.40

*Mali and Prasad (1999)

Fruit quality indices

In pomegranate, fruit quality depends on the following indies:

- Freedom from internal and external decay;
- Freedom from preharvest defects like cracking/splitting and sun-burn (Melgarejo *et al.* 2004);
- Skin colour and smoothness;
- Aril colour intensity and uniformity;
- Fruit size may be considered a quality index, depending on the intended use of the fruit;
- Flavour depends on sugar/acid ratio, which varies among cultivars. TSS contents above 17 °Brix and total phenolics contents below 0.25% are desirable for optimal levels of sweetness and astringency, respectively (Kader *et al.* 1984; Kader 2006).

POSTHARVEST PHYSIOLOGY

Influence of temperature and relative humidity on fruit spoilage

The control of relative humidity (RH) is critical in storage of pomegranate fruits. At low humidity, the skin desiccates readily and the rind becomes dark and hard. And thus, the fruits become less attractive with poor marketability (Roy and Wasker 2005). The fruits can be kept well for a long time after harvesting under appropriate storage conditions. Earlier, it was reported that the fruits could be stored between 0 and 4.5°C at 85% RH for several months (Mukharjee 1958; Or-Mizrahi and Ben-Arie 1984). Now, reports are available in which low temperature storage caused skin browning (husk scald) which are attributed to many factors, including chilling injury (Elyatem and Kader 1984; Kader *et al.* 1984; Saxena *et al.* 1987). However, delaying harvest reduced the percentage of fruit developing husk scald (Saxena *et al.* 1987; Zhang and Zhang 2008). Generally, respiration and ethylene production rates in pomegranate fruits increase with an increase in temperature. The Q_{10} values for respiration were 3.4 between 0 and 10°C, 3.0 between 10 and 20°C, and 2.3 between 20 and 30°C. Storage at 5°C or lower resulted in chilling injury; the severity increased with time and with lowered temperature. Chilling injury symptoms, which became more visible after transfer to 20°C for 3 days, included brown discoloration of the white locular septa separating the arils. Pomegranate can be stored at 5°C for up to 2 months, but longer storage should be at 7°C to avoid chilling injury (Kader *et al*. 1984). The fruits are very susceptible to water loss resulting in shrivelling of the rind. The higher the temperature and the lower the relative humidity, the greater will be the water loss. Ideally, the fruit should be kept at 90 to 95% RH (Kader *et al*. 1984; Kader 2006). Use of plastic liners and waxing can reduce water loss, especially under conditions of lower RH (Prasad *et al*. 1995; Artés *et al*. 2000b; Nanda *et al*. 2001).

Respiration and ethylene production

Pomegranate fruits have a relatively low respiration rate that declines with time during storage after harvest (Kader *et al.* 1984; Ben-Arie *et al.* 1984; Elyatem and Kader 1984). The ranges of respiration (CO_2 production) rates for 'Wonderful' were 2-4, 4-8, and 8-18 ml/kg/hr at 5, 10, and 20°C, respectively, while ethylene production rates remained below 0.2 µl/Kg/hr. Nanda *et al.* (2001) reported that in 'Ganesh' respiration rates were 220, 215, 210, 205 nmol/Kg/S at 5, 10, 15, 20 days after storage of the fruit, respectively and thus showed declining trend in respiration rate with shrink film wrapping and no detectable ethylene release was detected during storage under ambient and low temperature conditions.

Responses to modified atmospheres

Storage of fruits in modified atmosphere (MA) improves the shelf life of the fruits. Earlier, Holcroft *et al*. (1998) evaluated the efficacy of atmospheric modification in controlling decay and maintaining quality of pomegranate fruit 'Wonderful' keeping at 5, 7.5 or 10°C during one season using air, 2% O_2, air + 10% CO_2 and 2% O_2 + 10% CO_2. During the next season they tested the following atmospheric conditions at 5 and 7.5°C: air, 5% O_2, air + 10% CO_2, 5% O_2 + 10% CO_2, air + 15% CO_2, 5% O_2 + 15% CO_2. They reported that it is possible to store pomegranate fruits at 7.5°C in 5% O_2 + 15% CO_2 for 5 months, provided the degree of latent fungal infections at the time of harvest is low. Interestingly, CO_2-enriched atmospheres resulted in a lower synthesis rate of anthocyanins and other phenolic compounds and higher concentrations of acetaldehyde, ethanol and ethyl acetate, especially after 4 and 5 months of storage (Hess-Pierce *et al*. 2003). Accumulation of these volatiles was grater at 7.5°C than at 5°C, but in both cases the highest concentrations were below the threshold values for detection of off-flavours. Even so, MA packaging with appropriate polymeric films has also been found to create a beneficial atmosphere of 5-10% O_2+ 10-15% CO_2 during transport and storage of fruits (Artés *et al*. 2000a). However, fruit scald, a physological disorder, has been reported in pomegranate during long-term storage of the fruits (Ben Arie and Or-Mizrahi 1986; Defilippi *et al*. 2006). The scald symptoms developed mainly on the stem end of the fruit as brown discoloration on up to 60% of the skin without affecting the internal tissues. Among treatments tested, storage in CA was the only treatment that successfully controlled this disorder (Defilippi *et al*. 2006). Recently, for CA storage, 5% O_2 + 15% CO_2 at 7°C and 90-95% relative humidity was found to be optimal (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-term storage experiments were conducted by Porat *et al.* (2005, 2006, 2007). These authors developed new storage technology (MA packaging) that involves the usage of special bags (Xtend®) which have small pores or micro-perforations (Porat *et al*. 2006; Sachs *et al.* 2006). These bags result in the development of 5% O_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 the scald from 38 to 21% and reduces crown decay when fruits of 'Wonderful' 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 4-5 months with acceptable commercial quality. However, antifungal pretreatment (Bavistin 0.05-0.1%) of the pomegranate fruit was recommended before storage began. Data on storage experiments reported by Hess-Priece and Kader (2003) and Porat *et al.* (2005, 2006) were based on 'Wonderful'. Different pomegranate cultivars contain different levels of secondary metabolites that have antioxidant activities (Tzulker *et al.* 2007; Holland *et al.* 2009). 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 as commercial cultivars in addition to 'Wonderful'. Therefore, it has been suggested that special postharvest experiments should be carried out separately for each cultivar in different parts of the world.

Chilling injury

Pomegranates are susceptible to chilling injury if stored longer than 1 month at temperatures between their freezing point (-3°C) and 5°C, or longer than 2 months at 5°C (Kader *et al*. 1984; Elyatem and Kader 1984). Upon transfer to 20°C (simulated marketing conditions), respiration and ethylene production rates increase and other chilling injury

symptoms (brown discoloration of the white locular septa and pale colour of the arils) appear; their severity increases with lower temperature and longer duration. Another consequence of chilling injury is increased susceptibility to decay. However, storage at 10°C is satisfactory if a postharvest fungicide is used (Elyatem and Kader 1984). Several workers have observed that the minimum safe temperature for postharvest handling of pomegranate fruits is between 5 and 8°C, depending on the variety and production area. The fruits are highly perishable due to problem of desiccation and especially chilling injury (CI) symptoms when stored below 5°C. Some heat treatments (hot water dips, forced hot air and vapour) can induce tolerance to low temperature, reducing CI and thus increasing shelf life. The severity of damage due to CI was related to softening and loss of fatty acids with a concomitant reduction in the ratio of unsaturated/saturated fatty acids. Heat treatment could induce tolerance mechanism to low temperature through stimulation of polyamine biosynthesis. Moreover, the exogenous application of polyamines might provide a tool to avoid storage problems of pomegranates at low temperatures. Some studies have shown a reduction in incidence of chilling injury symptoms by conditioning before storage, intermittent warming during storage, or modified atmosphere packaging. Still, relationships of different factors on CI in pomegranate are to be understood (Kader *et al*. 1984; Elyatem and Kader 1984; Koksal 1989; Artés *et al.* 2000b; Kader 2006; Mirdehghan *et al.* 2007).

Skin scald

The scald symptoms (skin scald) appear as a superficial skin browning (**Fig. 2**), similar to superficial scald of apples, which generally develops from the stem end of the fruit and then spreads towards the blossom end as it increases in severity (Ben-Arie and Or-Mizrahi 1986; Defilippi *et al.* 2006; Kader 2006). Moreover, skin scald increases the susceptibility of the fruit to decay. The scald incidence and severity have been reported to be more on pomegranate fruits harvested during late season than those harvested during midseason, indicating that this disorder may be associated with senescence. The fruits from both harvests that were kept in air exhibited some scald after 4 to 6 months of storage at 7°C. Neither diphenylamine (DPA) nor 1-methylcyclopropene (1-MCP) alone or together could reduce scald incidence and severity (Defilippi *et al*. 2006). In contrast, the three CA storage conditions tested significantly reduced scald incidence and severity on the fruits from both harvest dates for 6 months at 7°C (Defilippi *et al*. 2006). However, two CA treatments with 1% O_2 resulted in greater accumulation of fermentative volatiles (acetaldehyde, ethanol and ethyl acetate) than the CA treatment with 5% O_2, especially in mid season harvested fruits. In addition to its fungistatic effects, 15% CO_2 appears to be critical for inhibition of scald development on pomegranate fruits. These results confirmed that 5% O_2 + 15% CO_2 (balance nitrogen) as the optimal CA for pomegranate fruits at 7°C with 90 to 95% relative humidity (Hess-Pierce and Kader 2003). CA storage at 5% O_2 + 15% CO_2 also decreased or prevented changes in carotinoides, acyl lipid and phenylpropanoid metabolism that were associated with the scald development in stem end peel tissue of air stored fruit (Defilippi *et al.* 2006). Earlier, Khan (1983) found that the injured plant surface or the tissue browning was mainly because the phenolic compounds were oxidized into quinine compounds under aerobic conditions by polyphenoloxidase and the quinone compounds under went polymerization forming brown polymeric pigments, leading to browning. Recently, Zhang and Zhang (2008) demonstrated that tannin was the basic substance of pomegranate peel browning. The activities of the browning index of peel were correlated positively with ascorbic acid oxidase, polyphenoloxidase and peroxidase, correlated negatively with catalase activity.

Fig. 2 Skin/sun scald symptom on pomegranate fruit.

Fig. 3 Arils showing internal breakdown symptom.

Internal breakdown

Aril browning (internal breakdown) is a common phenomenon in Indian pomegranate varieties grown in Maharashtra and its adjoining areas. In this malady, the arils become brown (**Fig. 3**) and somewhat flattened rather than plumb. The aril colour development is arrested and flavour is abnormal. The fruit from the outside looks healthy but after cut open the arils look abnormal (brown or blackish). It originates during growth in some seasons commonly (Ryall and Pentzer 1974; Sharma *et al.* 2006). The incidence of internal breakdown develops 150 days after anthesis in variety 'G-137' and its intensity increases if the fruits are left on the tree up to 165 days (Khodade 1987). The incidence of browning increases with increase in weight of fruit from 150 to 200 g (26.60%) to more than 350 g (60%). Prabhu Desai (1989) reported that TSS, acidity, ascorbic acid, total sugars, reducing sugars, calcium, phosphorus and the enzyme catalase were low whereas nonreducing sugars, starch, tannins, nitrogen, potassium, magnesium, boron, polyphenoloxidase and peroxidase enzymes were high in affected arils of cvs 'Ganesh' and 'P-23' than in healthy ones. The exact cause of this malady is still unknown.

POSTHARVEST DISEASES AND THEIR MANAGEMENT

Some organisms like species of *Botrytis*, *Cladosporia*, *Pboma*, *Phomopsis*, *Rhizopus* and *Sphaceloma punicae* are associated to cause decay in pomegranate fruits in India (Sonawane *et al.* 1986). However, gray mold caused by *Botrytis cinera* and rot caused by *Penicillium implicatum*, *Rhizopus arrhizus*, and *Alternaria solani* have also been reported to cause decay during storage of pomegranate fruits (Kanwar and Thakur 1973; Vyas and Panwar 1976; Morton 1987; Labuda *et al.* 2004; Palou *et al.* 2007; Holland *et al.*

2009). In California, *Botrytis cinera*, is the primary limiting factor for long-term storage (Adakaveg and Forster 2003; Tedford *et al.* 2005). 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 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. *Aspergillus* spp., or *Alternaria* spp. cause heart rot in pomegranate fruits and infection begins in the orchard, especially following rain during flowering and early fruit development. The fungi can grow within the fruit without external symptoms except for slightly abnormal skin color. If the mass of blackened arils reaches the rind, it will cause softening of the affected area; these fruits can be detected and removed by the sorters in the packing house (LaRue 1980).

Appropriate postharvest disease management strategies need to be followed to minimise physical damage during fruit harvesting and postharvest handling. However, maintaining optimal temperature and relative humidity throughout postharvest handling of the fruits are prerequisites. CO_2-enriched atmospheres are fungistatic and inhibit growth of *Bortrytis cinera.* Use of Fludioxonil as a postharvest fungicide is effective in controlling this fungus (Seeram *et al.* 2006). Dipping treatment with aqueous Topsin-M (0.1%) and Bavistin (0.05 to 0.1%) found to inhibit the growth of *Aspergillus niger* (Padule and Keskar 1988). Pretreatment of pomegranate fruits with hot water at 45°C was shown to reduce chilling injury and electrolyte and K leakage (Artés *et al*. 2000b; Mirdehghan and Ragemi 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*. 2005). Recently, Ram Asrey (2008) reported that waxing coupled with 0.1% Carbendazim is common practice for treating export oriented pomegranate fruits in India.

POSTHARVEST HANDLING

In India, improper handling leads to spoilage loss (25-30%) of pomegranate fruits and thus, reduces the profit margin of the growers. Generally, fruits are picked manually and assembled at grading plate farm for on farm grading and packing (Ram Asrey *et al.* 2008). However, in developed countries like USA pickers harvest pomegranate fruits with clippers and place the fruits in picking bags for transfer to harvest bins that will be transported to the packinghouse. Then the fruits are sorted to eliminate those with severe defects like scuffing, cuts, bruises, splitting and decay. And the remaining fruits are separated according the magnitude of the physical defects. The fruits with moderate defects are used for processing into juice and those with slight or no defects are marketed fresh. The latter fruits are washed, air dried to remove surface moisture, fungicide treated, waxed, divided into several size grades and packed in shipping containers. Various ways to immobilize the fruits within the shipping containers have been suggested to reduce incidence and severity of scuffing and impact bruising during handling. However, perforated plastic box liners can be used to reduce water loss during postharvest handling of the fruits. Packed fruits are cooled by forced-air cooling at 7°C and kept at the same temperature with 90-95% relative humidity during storage. Then these packed fruits are transported to retail distribution centres (Kader 2006).

In the last two decades attempts have been made to evaluate storage techniques for long-term storage of pomegranate fruits, including low temperature, delayed harvest, intermittent warming, CA storage, and partial drying (Al-Kahtani 1992). Among these techniques, the most successful in reducing decay and physiological disorders is the use of CA storage (Kupper *et al*. 1995; Artés *et al*. 1996, 2000b; Hess-Pierce and Kader 2003). Under CA storage, a combination of 5% O_2 and 15% CO_2 has been shown to extend postharvest life of pomegranate fruits for up to 5 months at 7°C. This combination also avoids the accumulation of high levels of ethanol, observed under CA conditions with lower levels of oxygen, which limits the marketability of the fruit. However, optimal storage temperature found to be between 5 and 8°C, depending on the variety and climatic conditions. However, 7°C is recommended for 'Wonderful' pomegranate fruits. In all cases, 90-95% relative humidity should be maintained in the surrounding atmosphere. Storage potential ranges from 3-4 months in air and from 4-6 months in CA storage with 5% O_2 + 15% CO_2 (balance nitrogen).

FRUIT PROCESSING AND UTILIZATION

Sound pomegranate fruits fetch a fairly good price in the market and are not much used for processing purposes. In India, hardly 2% of its total produce is utilized for processing. The pomegranate products like juice, juice concentrate, wine, isolated fresh arils, dried arils (*anardana*), rind powder and other products have great demand (Adsule and Patil 1995; Patil *et al.* 2002; Ann Kleinberg 2004; Seeram *et al.* 2006; Holland *et al.* 2009). Currently, the commercialization of pomegranates as fresh fruit and beverages has a well-established market. The demand of isolated fresh arils is expected to increase in near future. Recently, some efficient machines have been developed to extract intact arils on commercial scale (Rodov *et al.* 2005; Shmilovich *et al.* 2006). The most efficient one has been reported to produce more than 1 tonne of arils a day (Shmilovich *et al.* 2006). Thus, this will provide the consumer with value-added, ready-to-eat pomegranate arils and ultimately its consumption would increase in western countries. Gil *et al.* (1996a, 1996b) and Hess-Pierce and Kader (1997, 2004) investigated the effects of pre-extraction storage duration and post extraction packaging and handling conditions on deterioration rate of pomegranate arils. The arils have relatively low rates of respiration (1.5-3 and 3-6 ml CO_2/Kg/hr at 5 and 7°C, respectively) and ethylene production (5-15 and 15-30 nl ethylene/Kg/hr at 5 and 7°C, respectively). It is possible to produce arils that retain good quality for up to 14 days of shelf life at 5°C from pomegranate fruits that are stored at 7°C for up to 3 months in air or up to 5 months in CA storage at 5% oxygen + 15% carbon dioxide (balance nitrogen). However, mechanical damage to the arils should be minimized during their extraction from the fruit, washing, drying to remove surface moisture, and packaging, since damaged arils are more susceptible to decay-causing fungi. Carbon-dioxide-enriched atmospheres have a fungistatic effect and their optimal range for decay control without including off-flavours in the arils is 15 to 20% CO_2 added to either air or 5%O_2. Interestingly, the intact pomegranate fruits are chilling-sensitive, but the arils are tolerant to low temperature and should be kept at temperatures between 0°C for up to 21 days, at 2°C for up to 18 days, or at 5°C for up to 14 days in marketable condition (Hess-Pierce and Kader 2004). Although, 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. The fruit 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 tasty. The byproducts 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 human beings and animal feed. Therefore, there is a scope for establishment of viable industry that can utilize the spent by-product material generated from the commercial juice industry to generate various botanical extracts. The seeds are a source of oil that contains a rare combination of unsaturated fatty acids (Seeram *et al.* 2006b) and sterols.

Dried seeds (*anardana*) powder is a common component of some Indian food recipes (Holland *et al.* 2009). Although, economic impact of pomegranate on the food and beverage industry is huge, there is high potential for the use of its extracts as ingredients in functional foods, cosmeceuticals, nutraceuticals, phytoceuticals, and botanical dietary supplements (BDS). The consumption of dietary supplements consisting of botanicals or herbals, or vitamins and minerals, adjuvants of complementary and alternative medicine (CAM) therapy is extremely popular and used by more than 60% of Americans (Brevoort 1998; Seeram *et al.* 2006a). In the last 10 years, CAM therapies have grown into a multi-billion–dollar industry in the US alone (Seeram *et al.* 2006a). There is also good demand of BDS in the US due to its safe and non-toxic effect that has been approved by the US food and drug administration.

PERSPECTIVES

Pomegranate is an important fruit crop being grown commercially in many countries. The main problem in this fruit is cracking at maturity stage. About 20-40% cracking is reported. However, these cracked fruits neither look attractive nor fetch good price to the growers. Therefore, development and standardization of processing techniques such as the preparation of RTS (ready to serve), nectar, squash, jelly, *anardana*, wine etc. is the best way to utilize the cracked and undersized fruits. Appropriate postharvest disease management strategies need to be followed to minimise physical damage during fruit harvesting and postharvest handling such as use of recommended dose of pesticide, wax coating, use of oil emulsion etc. There is also a need to use appropriate packaging materials for transport of the fruits to the distant places to avoid the mechanical injury. A low cost zero energy cool chamber and aril separators may be developed and popularized among the growers. Several phytochemicals and phytoharmones present in this fruit help metabolic and endocrine systems to normalize. Thus, there is also a need to isolate bio-chemically active molecules from different parts of the plant and these substances may be used for nutritional supplements or pharmaceutical uses.

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