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Prospective and Retrospective Approaches to Postharvest Quality Management of Fresh Guava (*Psidium guajava* L.) Fruit in the Supply Chain

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ABSTRACT

Increasing consumer concerns about fruit flavour, nutrition, safety, and sustainability issues bring to light critical challenges that guava industry will encounter in the near future. Guava fruit has high perishability, susceptibility to chilling injury (CI) and diseases, and quarantine restrictions in world trade; these constraints are of similar nature as for other tropical fruits. This review briefly describes the commercial importance, postharvest constraints, harvest maturity, and postharvest physiology of guava fruit. The main focus is to review the existing and prospective postharvest technologies that can potentially increase the postharvest life with minimal loss in fruit quality and to meet the consumer expectations and the regulatory requirements imposed by various countries. The possible application of controlled/modified atmospheres (CA/MA) in conjunction with low temperature for storage and transportation of guava is reviewed. Modified atmosphere packaging (MAP) can be very helpful for storage and long distance transportation of this fruit, but risks associated with the use of this technology are also underlined. The possibility of use of edible coatings to modify internal atmosphere of guava fruit has also been reported to be partially successful. The integration of 1-methylcyclopropene (1-MCP) into postharvest handling system may be beneficial for ethylene management in guava fruit to extend shelf-life, reduce decay and CI symptoms. Irradiation is an approved phytosanitary treatment to provide quarantine security against many regulatory insect-pests of guava, and is also beneficial to extend marketability by delaying fruit ripening and reducing decay. A wide range of technologies hold promise in extending the postharvest life, retaining the quality in supply chain, and enhancing the market potential of guava fruit. In future, the guava industry will need to position itself to proactively address future challenges through a system approach and popularize the fruit to expand its market potential.

Keywords: CA storage, edible coatings, irradiation, MAP, 1-MCP, quality, storage

Abbreviations: **AA**, acetaldehyde; **CA**, controlled atmosphere; **CI**, chilling injury; **CO_2**, carbon dioxide; **DCA**, dynamic controlled atmosphere; **EMA**, equilibrium modified atmosphere; **HPC**, hydroxypropylcellulose; **HWT**, hot water treatment; **ISW**, individual shrink wrapping; **kGy**, kilo Gray; **kPa**, kilo Pascals; **LDPE**, low density polyethylene; **MA**, modified atmosphere; **MAP**, modified atmosphere packaging; **1-MCP**, 1-methylcyclopropene; **N_2O**, nitrous oxide; **O_2**, oxygen; **RH**, relative humidity; **SSC**, soluble solids concentration; **TA**, titratable acidity

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INTRODUCTION

Guava (*Psidium guajava* L.), a native of tropical America, is the most important fruit crop of the Myrtaceae family. Guava is commercially grown in the sub-tropical and tropical regions of the world. India is the world's largest producer of guava fruit with annual production of 1.85 million tonnes (Anonymous 2008) followed by Pakistan, Mexico, Brazil, Egypt, Thailand, Columbia, Indonesia, Venezuela, Sudan, Bangladesh, Vietnam, and Malaysia (Pommer *et al.* 2006). The most popular cultivars of guava grown in different countries have been listed in **Table 1**.

The guava fruit is a berry, round or oval in shape, with rough to smooth green colour skin (**Fig. 1**) and many small,

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Invited Review

Table 1 The most popular cultivars of guava in various countries (in alphabetical order) (Sources: Morton 1987; Pommer *et al*. 2006).

Country	Cultivar(s)
Australia	Indonesian Seedless, Allahabad Safeda, Lucknow-49, Beaumont, Ka Hua Kula, GA-11
Bangladesh	Swarupkathi, Mukundapuri, Kanchannagar, Kazi
Brazil	Paluma, Rica, Pedro Sato, Kumagai, Ogawa, Sassaoka, Yamamoto, Século XXI
Columbia	Puerto Rico, Rojo Africano, Extranjero, Trujillo
Costa Rica	Tai-kuo-bar
Cuba	Enana Roja Cubana, EEA 1-23
Ecuador	Roja, Blanca, Crema
Egypt	Bassateen El Sabahia, Bassateen Edfina, Allahabad Safeda
India	Allahabad Safeda, Lucknow-49 (Sardar), Banarsi Surkha, Apple Colour, Chittidar, Nasik, Dholka, Dharwar, Habshi, Seedless, Red Fleshed, Behat Coconut
Indonesia	Indonesian Seedless, Indonesian White
Israel	Ben-Dov
Ivory Coast	Supreme, Elisabeth
Malaysia	Kampuchea, Jambu Kapri, Hong Kong Pink, Jambu biji, Putih; Maha 65, Bentong Seedless, Taiwan Pear
Mexico	Media China, Regional de Calvillo, China, la Labor, Acaponeta, Coyame, Kumagai, Paluma, Rica, White Ogawa, Red Ogawa
Pakistan	Safeda, Allahabad, Red-Fleshed, Seedless, Karela, Apple Colour
Puerto Rico	Corozal Mixta, Corriente; Seedling57-6-79
South Africa	Fan Retief, Frank Malherbe, TS-G2
Taiwan	Tai-kuo-bar, Chung-Shan, Shih-Chi, Li-Tzy, Red, Jen-Ju, Shuei-Jing
Thailand	Glom Sali, Glom Toon Klau, Khao Boon Soom
Trinidad	Centeno Prolific, Cayenne, Elisabeth
USA (Hawaii)	Beaumont, Ka Hua Kula, Hong Kong Pink, Indonesian Seedless
USA (Mainland)	Redland, Supreme, Red Indian, Ruby X, Miami Red, Miami White, Blitch, Patillo, Webber, Rolfs, Hart, Detwiler, Turnbull
Vietnam	Xa Ly Nghe, Ruot Hong Da Lang, Xa Ly Don

Fig. 1 Guava fruit on the tree. Courtesy: Mr. Gurjinder Singh, Punjab State Department of Horticulture, Muktsar, India.

hard or semi-hard seeds embedded in the centre of the pulp (Ali and Lazan 1997). Depending on the cultivar, ripe fruit have either a pale green or bright yellow skin with or without a red blush. Flesh colour may be whitish, deep pink or salmon-red. Guava fruit has a strong characteristics aroma due to esters and terpenes. In mature fruit, the esters (*Z*-3-hexenyl acetate, *E*-3-hexenyl acetate, ethyl hexanoate, and ethyl butanoate), 1,8-cineole, monoterpenes (myrcene and limonene), and sesquiterpenes (caryophyllene, α-humulene and β-bisabollene) are the predominant aroma volatiles compounds (MacLeod and Troconis 1982; Chyaui *et al.* 1992; Soares *et al.* 2007). The aroma profiles vary with maturity stage and cultivar. Guava is an excellent source of dietary antioxidants such as ascorbic acid and phenols (Kondo *et al.* 2005; Lim *et al.* 2007) and the skin is richer in ascorbic acid and phenols than the flesh (Bashir and Abu-Goukh 2003; Kondo *et al.* 2005; Lim *et al.* 2007). White fleshed cultivars have been reported to contain higher concentrations of ascorbic acid, phenols and sugars (sucrose, fructose, and glucose) compared to the red fleshed cultivars (Bashir and Abu-Goukh 2003; González-Aguilar *et al.* 2004). A comparison of the seeded and seedless cultivars showed that total phenols were higher in seedless cultivar, while ascorbic acid concentration was found higher in seeded cultivar (Lim *et al.* 2007). Therefore, guava can be ranked among the tropical fruits that are rich sources of antioxidants.

The world trade in guava fruit is limited. Its consumption as fresh fruit is mainly restricted to the production regions. However, if the consumers in non-producing countries show interest in diversifying their fruit basket, guava can be a great choice due to its high antioxidant properties and flavour-rich fruit. Consumers' concerns over the '*food miles*' may hamper the global trade of tropical fruits as these are often transported over long distances. The distance travelled by fruit, of course, is an inadequate measure of the sustainability because it does not consider emissions associated with the mode of transportation, fruit production, packaging, or disposal (Saunders *et al.* 2006). Future trends may turn consumer preferences against tropical fruits including guava in the European and North American markets. In this review, the postharvest constraints, harvest maturity, and postharvest physiology of guava fruit will be considered. In the subsequent sections, the focus will be on the most recent and promising technologies that may be useful to retain the quality of fresh guava fruit in the postharvest supply chain.

POSTHARVEST CONSTRAINTS

The inherent postharvest constraints of guava fruit are quite similar to other tropical fruits (Ali and Lazan 1997). Guava has a short postharvest life of 5-8 days at ambient conditions depending on the cultivar and harvest maturity (Brown and Wills 1983; Ali and Lazan 1997). It suffers from chilling injury (CI) if stored below 8-10°C which limits its storage and transportation at low temperature. The delicate nature of fruit due to thin skin further aggravates the problem of physical injuries during harvesting and postharvest operations, and also limits its suitability for postharvest heat treatments for quarantine purposes. Injuries and punctures on the fruit serve as the entry points for various micro-organisms which can possibly enhance the rate of deterioration. Guava is also considered to have significant risk of carrying fruit fly, eggs, and larvae which are frequently regulated pest species in many countries' phytosanitary requirements (Singh and Pal 2007). Sanitary and phytosanitary requirements act as a guava-trade barrier. Guava fruit must be subjected to an approved postharvest phytosanitary treatment to eliminate the risk of pest entry into a new territory. Deve-

loping countries, the primary producers of this fruit, therefore have limited access to world markets. In summary, the major postharvest constraints, impeding wider distribution of guava fruit include high perishability, susceptibility to CI and diseases, and insect-pest disinfestation requirements. It is axiomatic that postharvest quality of guava cannot be improved but it is possible to slow down the fruit metabolism by following appropriate postharvest procedures to maintain fruit quality.

HARVEST MATURITY VS. FRUIT QUALITY

Harvesting at optimum stage is a key to providing consumer with a flavour-some and nutritious fruit. Fruit flavour in guava is improved with the advancement of fruit maturity that might be attributed to accumulation of sugars, decrease in phenols and acids, and biosynthesis of aroma volatile compounds (EL Bulk *et al.* 1997; Bashir and Abu-Goukh 2003; Soares *et al.* 2007), but at the expense of shelf-life (Tandon *et al.* 1989). In a number of South-East Asian countries mature-green guava are eaten as an apple-like fruit and ripe fruit are not preferred. Concentration of ascorbic acid, a vital functional component in guava, also increases during fruit maturation and ripening (El Bulk *et al.* 1997; Kondo *et al.* 2005; Soares *et al.* 2007; Gomez and Lajolo 2008). Therefore, determining harvest maturity is a critical step towards ensuring flavour and nutritional quality of guava fruit. The changes in fruit skin colour from dark green to light green coupled with fruit size constitute the best harvest maturity indices (Mercado-Silva *et al.* 1998; Jain *et al.* 2003; Singh and Pal 2008a, 2008b). However, other maturity indices such as specific gravity, chemical attributes, and fruit detachment force have been reported to be beneficial for determining the optimum harvesting stage (Kumar and Hoda 1974; Rathore 1976; Paull and Goo 1983; Yusof and Mohamed 1987; Tandon *et al.* 1989; Mercado-Silva *et al.* 1998). Specific gravity of guava fruit decreases during fruit development, and reaches <1.0 at the ripe stage (Mercado-Silva *et al.* 1998). Tandon *et al.* (1989) observed that guava fruit, harvested at specific gravity of <1.00, had higher ascorbic acid and better consumer acceptability as compared to those harvested at 1.00 to 1.02 specific gravity stage, but shelf-life of former is 6 days against 8 days in case of later. Fruit having specific gravity >1.02 were smaller in size with poor colour development and low ascorbic acid content (Tandon *et al.* 1989). A large variation in specific gravity among fruit and also seasonal variation pose a difficulty to sort fruit for maturity using it as a single maturity index (Kumar and Hoda 1974; Mercado-Silva *et al.* 1998). Furthermore, it is not a practical approach due to cumber-some procedure of specific-gravity grading. Chemical attributes such as SSC, titratable acidity (TA), tannin content may be used as additional maturity indices (Yusof and Mohamed 1987). But seasonal and cultivar variation in SSC and other chemical attributes limits their application in making harvest decisions (Rathore 1976). Paull and Goo (1983) observed decline in the fruit detachment force parallel to the decline in fruit deformation force, loss of skin colour and pulp acidity. In general, under a given set of production conditions, the visual appearance of fruit on the basis of skin colour and size serves as the best harvest index.

POSTHARVEST PHYSIOLOGY

Guava is a climacteric fruit (Akamine and Goo 1979; Brown and Wills 1983; Mercado-Silva *et al.* 1998; Singh and Pal 2008a), but some cultivars are non-climacteric (Biale and Barcus 1970; Azzolini *et al.* 2005). The rate of respiration depends upon the cultivar, season, and maturity (Brown and Wills 1983; Reyes and Paull 1995; Mercado-Silva *et al.* 1998; Singh and Pal 2008a). For example, pink-fleshed cultivars respire faster than white-fleshed ones (Bashir and Abu-Goukh 2003; Singh and Pal 2008a). The climacteric peaks in respiration and ethylene production were observed after 7–8 days in autumn-winter fruit as compared with 4–5 days in spring-summer fruit (Mercado-Silva *et al.* 1998). During fruit ripening, ethylene production and respiration rate of fruit harvested at full sized-pale green stage were reported higher than those harvested at small or medium dark green stage (Brown and Wills 1983). Fruit harvested at advanced maturity reach their climacteric in 4–6 days accompanied by rapid changes in skin colour and flesh firmness (Brown and Wills 1983).

Ethylene production behaviour of guava is strongly influenced by the harvest maturity (Mercado-Silva *et al.* 1998), cultivar (Brown and Wills 1983), and storage atmosphere (Pal *et al.* 2007). The response of guava to exogenous application of ethylene also depends upon the maturation stage and climacteric or non-climacteric nature of cultivar (Reyes and Paull 1995; Azzolini *et al.* 2005). The exogenous application of ethylene, for example, enhanced the skin colour evolution and softening in immature-green fruit of 'Beaumont' cultivar, but did not influence the ripening behaviour of quarter yellow fruit of this cultivar (Reyes and Paull 1995), while 'Pedro Sato' guavas harvested at mature light green stage did not respond to postharvest ethylene treatment (Azzolini *et al.* 2005). However, postharvest exposure to 1-methylcyclopropene (1-MCP), an ethylene action inhibitor, reduces the ethylene production rate in guava (Azzolini *et al.* 2005; Bassetto *et al.* 2005; Singh and Pal 2008b). Thus, interference with the capacity of fruit to perceive ethylene retards the ripening process and extends the marketability period.

POSTHARVEST TECHNOLOGIES

Many postharvest technologies are currently available to improve the storage potential and shelf life of guava fruit. The characteristic of a good postharvest technology include the ability to maintain fruit quality during postharvest supply chain, cost-effectiveness, value addition, environmentally- and consumer-friendly in perspective of safety, and versatility in terms of other associated benefits such as quarantine security (Watkins 2008b). None of the available technologies possesses all these characteristics. In the following sections, the potential of low temperature storage, CA/MA storage, MAP, edible coatings, 1-MCP and irradiation technologies to retain quality of guava fruit in supply chains will be reviewed.

Low temperature storage

Temperature and relative humidity (RH) are the most important postharvest factors that affect the shelf-life and fruit quality during the supply chain (Paull 1999). Low temperature storage is the simplest and easiest way to slow down the fruit metabolism and suppress the activity of decay causing micro-organisms. Storage temperatures, low enough to significantly slow down fruit metabolism, cause chilling CI in tropical fruits and, if high enough to avoid CI, often accelerate or do not affect the process of fruit ripening and do not increase shelf-life or maintain quality. The most effective strategy is to maintain a fruit at the ideal storage temperature range during the supply chain. Storage at 8-10°C, 90% RH, is recommended for guava fruit for 2-3 weeks storage period (Reyes and Paull 1993; Kays and Paull 2004). Fruit develops symptoms of CI if stored below the critical storage temperature of 8-10°C (Reyes and Paull 1995; González-Aguilar *et al.* 2004) and also if stored at 8-10°C for prolonged duration (Singh and Pal 2008a, 2008b). The tolerance to chilling temperature depends upon many factors including cultivar, harvest season, maturity status, and length of storage. Therefore, fruit harvested at colour turning stage, a commercial practice in most of the guava producing countries, may be stored for 2-3 weeks at 8 to 10°C.

Controlled/modified atmosphere storage

CA/MA storage is known to extend the postharvest life and maintain fruit quality in addition to other benefits such as alleviation of CI in many tropical and subtropical fruits (Singh *et al.* 2009; Yahia and Singh 2009). CA storage involves the precise maintenance of low O_2 and higher CO_2 concentrations in the storage atmosphere in combination with an optimum storage temperature. The response of guava fruit to short and long-term CA storage have been tested, and found useful to extend shelf-life and maintain quality.

Short-term MA exposure

A few early reports suggested that short-term treatment of guava fruit in low O_2 (<1-10 kPa) and high CO_2 (5-40 kPa) atmospheres has potential to improve postharvest life. Short-term exposure of guava fruit to high CO_2 levels (10, 20, and 30 kPa) did not influence the respiration rates, but reduced ethylene evolution during ripening (Pal and Buescher 1993). Similarly, treating guavas with 10 kPa O_2 + 5 kPa CO_2 for 24 h before storage in air at 4°C for 2 weeks delayed color development and reduced CI, compared to fruit held in air (Bautista and Silva 1997). A preliminary study on the short-term exposure of guava fruit to very low O_2 (<1 kPa) and high CO_2 (40 kPa) at 40°C for 12 h has shown that such treatment is beneficial to extend the shelf-life of fruit by 2 to 3 days at ambient conditions and may find application in postharvest insect-pest disinfestations for quarantine purposes (Singh and Pal 2007). The pre-storage treatment with nitrous oxide (N_2O) has also been reported to be useful in inhibiting decay in guava fruit (Qadir and Hashinaga 2001). Guava (cultivar not given) fruit artificeally inoculated with spores of *Rhizopus stolonifer* (Ehrens.: Fr.), then held in 80% N_2O atm for 6 days show no disease symptoms with the symptoms appearing after 2.2 days when fruit are held in normal air (Qadir and Hashinaga 2001). This study, no doubt, indicated the potential of a non-conventional gas in reducing decay in fresh fruit, but its commercial use is not possible as a postharvest treatment of guava fruit.

CA storage

1. Effects of CA storage on fruit physiology and quality. Kader (2003) recommended 2-5 kPa O_2 and 0-1 kPa CO_2 for CA storage of guava at 5-15°C. CA storage has been found useful in maintaining the harvest freshness and alleviating CI in guava fruit (Singh and Pal 2008a). Singh and Pal (2008a) reported that atmospheres containing O_2 concentrations less than 5 kPa were detrimental for visual and flavor quality of two commercial cultivars, 'Lucknow-49' and 'Allahabad Safeda', while 'Apple Colour', a pink-fleshed cultivar, does not tolerate O_2 concentration below 8 kPa. The ideal CA storage conditions at 8°C for three cultivars, 'Lucknow-49', 'Allahabad Safeda', and 'Apple Colour' were 5 kPa O_2 + 2.5 kPa CO_2, 5 kPa O_2 + 5 kPa CO_2, and 8 kPa O_2 + 5 kPa CO_2, respectively. Under these CA conditions, fruit were stored for 30 days at 8°C without significant CI symptoms and ripening took place at ambient conditions in 5 days. Respiration and ethylene production rates in CA-stored fruit were suppressed during post-CA storage period of 5 days at ambient conditions (25-29°C).

Concentration of ascorbic acid in the fruit can serve as a good indicator of the postharvest life and quality of guava fruit. CA storage was found effective in reducing the ascorbic acid loss during 30 days storage. The extent of ascorbic acid loss decreased as O_2 level decreased, but CO_2 did not favour the retention. Singh and Pal (2008a) found that an increase in O_2 concentration in CA resulted in increase of ascorbic acid loss. Fruit firmness was retained in CA-stored fruit for 30 days, but the differences in the firmness, irrespective of storage atmosphere, were non-significant after 5 days at ambient conditions. CA extends the storage life of guava fruit at temperature slightly below optimal and may also help to overcome CI problem (Singh and Pal 2008a).

2. CA storage and fruit flavour. Partial anaerobic conditions during CA storage can potentially cause accumulation of anaerobiosis metabolites, ethanol and acetaldehyde (AA), in guava fruit. Ethanol and AA contribute significantly to inhibit fruit ripening and biosynthesis of flavour compounds; but the excessive amounts lead to the off-flavor development in fruit (Pesis 2005). Guava has been suggested to be very sensitive to anaerobiosis damage (McGuire and Hallman 1995; Pesis 2005). Atmospheres low in O_2 (2.5 kPa) cause an increase in the concentrations of ethanol and AA in three guava cultivars during 30 days storage period (**Figs. 2, 3**). No information is currently available on the gas exchange properties of peel and flesh tissue of guava fruit. The differences in peel/flesh anatomies of guava cultivars might be a reason for differences in the accumulation pattern of anaerobiosis metabolites. For example, 'Apple Colour' fruit stored in atmospheres with 5 kPa levels of both O_2 and CO_2 had higher ethanol concentration than 'Lucknow-49'

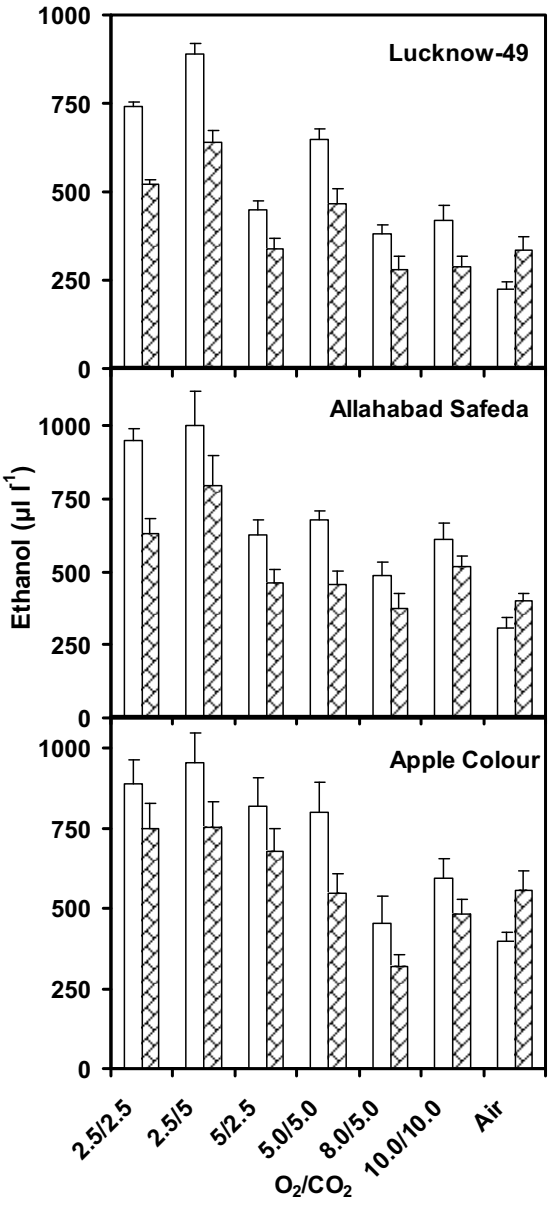

Fig. 2 Ethanol concentrations (µl l^{-1}) in three guava cultivars after 30 days storage either in controlled atmospheres or air at 8°C (empty bars) and plus 5 days at ambient conditions (25-28°C and 60-70% R.H.) (filled bars). Vertical bars represent ± S.E. LSD ($P \leq 0.05$). (From **Singh SP, Pal RK** (2008a) Controlled atmosphere storage of guava (*Psidium guajava* L.) fruit. *Postharvest Biology and Technology* **47**, 296-306, with kind permission of Elsevier, Ltd., ©2008).

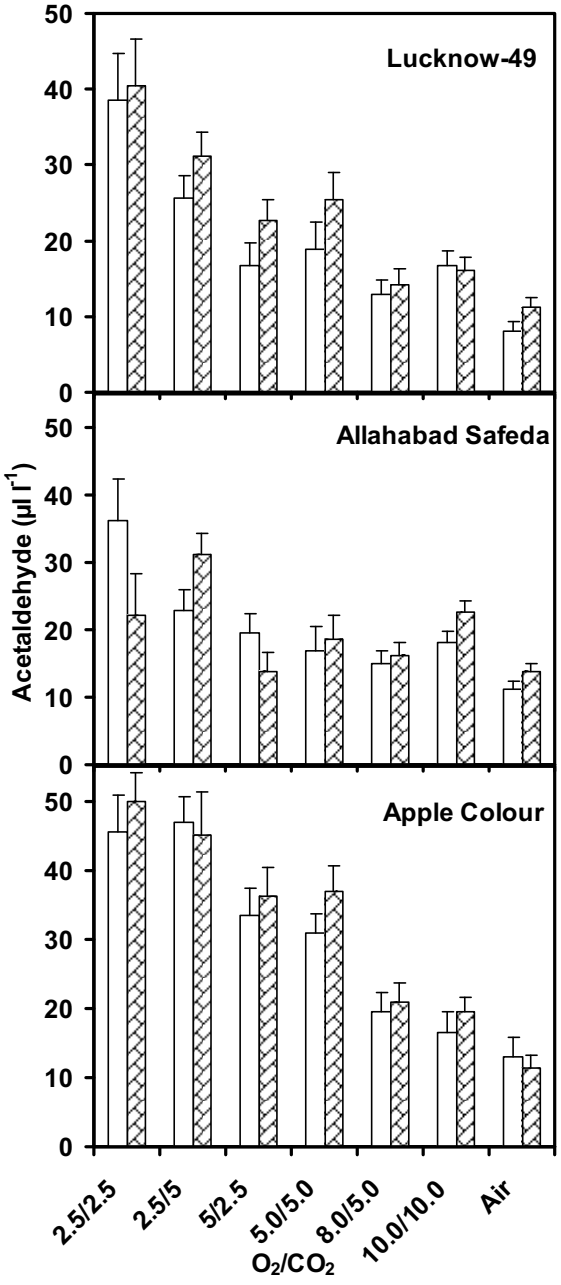

Fig. 3 Acetaldehyde concentrations (µl l^{-1}) in three guava cultivars after 30 days storage either in controlled atmospheres or air at 8°C (empty bars) and plus 5 days at ambient conditions (25-28°C and 60-70% R.H.) (filled bars). Vertical bars represent ± S.E. (From **Singh SP, Pal RK** (2008a) Controlled atmosphere storage of guava (*Psidium guajava* L.) fruit. *Postharvest Biology and Technology* **47**, 296-306, with kind permission of Elsevier, Ltd., ©2008).

and 'Allahabad Safeda' fruit held under similar conditions, indicating its high susceptibility to the low O_2 atmospheres compared to other two cultivars (**Fig. 2**). Fruit held in atmospheres with similar levels of O_2 but differing in CO_2 concentrations show a variation in the concentrations of ethanol and AA symbolizing the contributory effect of CO_2 to anaerobiosis in the fruit. The concentration of AA content increased during fruit ripening as compared to immediately after CA storage which was opposite to ethanol (**Fig. 3**). Acetaldehyde accumulation and its increase during ripening may contribute to the aroma volatile compounds biosynthesis in guava in addition to its role in the removal of astringency from guava fruit. This speculation is supported by the significant reduction in the total phenols was observed during ripening. There is also a possibility that suppression of ethylene production and respiration during ripening of CA-stored guavas and alleviation of CI could be due to the high ethanol and acetaldehyde concentrations in fruit as the role of these anaerobic metabolites in modifying these physiological processes has already been recognized (Pesis 2005). Based on these observations and some speculations, a model showing the beneficial effects of either long-term CA storage or short-term CA-exposure on guava fruit is proposed (**Fig. 4**). More research is required to elucidate the roles of these compounds in fruit ripening and physiology.

3. CA Recommendations and future research. Guava's response to CA has potential commercial applications. Indian guava cultivars, 'Lucknow-49', 'Allahabad Safeda', and 'Apple Colour' may be stored for 30 days at 8°C supplemented with atmospheres containing 5 kPa O_2 + 2.5 kPa CO_2, 5 kPa O_2 + 5kPa CO_2, and 8 kPa O_2 +5kPa CO_2, respectively. The most significant effects of CA include a reduction of respiratory rate and ethylene production, delayed ripening, alleviation of chilling injury, and good quality (Singh and Pal 2008a). CA storage could be used for marine transport of guava to distant markets which may take 2 or 3 weeks. However, the CA requirements need to be evaluated for storing and transporting guavas at temperatures other than 8°C as changes in storage temperature may possibly alter the CA optima conditions. Genotypic variation in the responses of guava to CA conditions warrants further investigations for other cultivars.

In the future, more research is required to explore the possibilities of application of advanced CA technologies such as dynamic controlled atmosphere (DCA) called HarvestWatch™. DCA storage involves the continuous monitoring of fruit responses to low O_2 and adjusting O_2 levels in response to fruit metabolism as indicated by the changes in ethanol production, respiration rate, or chlorophyll fluorescence (Watkins 2008b). This technology provides an opportunity to keep fruit at much lower O_2 levels to retard postharvest changes. Guava fruit is a potential candidate for DCA storage due to ease of monitoring chlorophyll fluorescence changes as the fruit skin at harvest contains abundant chlorophyll. Except for mango and banana, CA research as well as commercial application in tropical fruits including guava is lagging behind the temperate fruits. This delay is due in part to the small volumes shipped and no clear cost benefit advantage.

Modified atmosphere packaging (MAP)

MAP involves the packaging of an individual or a group of fruit in polymeric films in that gaseous atmosphere is altered either actively or passively. In passive MAP, the O_2 levels are depleted and CO_2 levels increase inside the package due to fruit respiration. MAP extends the shelf life of fruit due to reduced respiration and ethylene production rates (Kader *et al.* 1989). MAP also enriches the surrounding atmosphere with high humidity that results in reduced water loss, increased shelf-life and better textural properties. The atmospheric conditions inside the MA-packs is dependent upon several factors such as film permeability to O_2, CO_2, and water vapour, product respiration and the influence of temperature on these processes. If the respiration rate of the fruit matches the film permeability characteristics at the same temperature, it is easy to establish the beneficial equilibrium modified atmosphere (EMA). Therefore, choice of an appropriate packaging film is a key factor in order to maintain optimum MA.

Effects of MAP on fruit physiology and quality

Many studies have revealed that guava fruit benefits from the MAP technology (Combrink *et al.* 1990; Gaspar *et al.* 1997; Jacomino *et al.* 2001a, 2001b). Guava fruit cv. 'Fan Retief' packed into non-perforated polyethylene bags (35 µm thickness) impregnated with a natural mineral compound could be stored for 1 week at 20°C or for 2 weeks at 4.5°C without appreciable loss of quality (Combrink *et al.* 1990). The fruit inside polyethylene bags without mineral

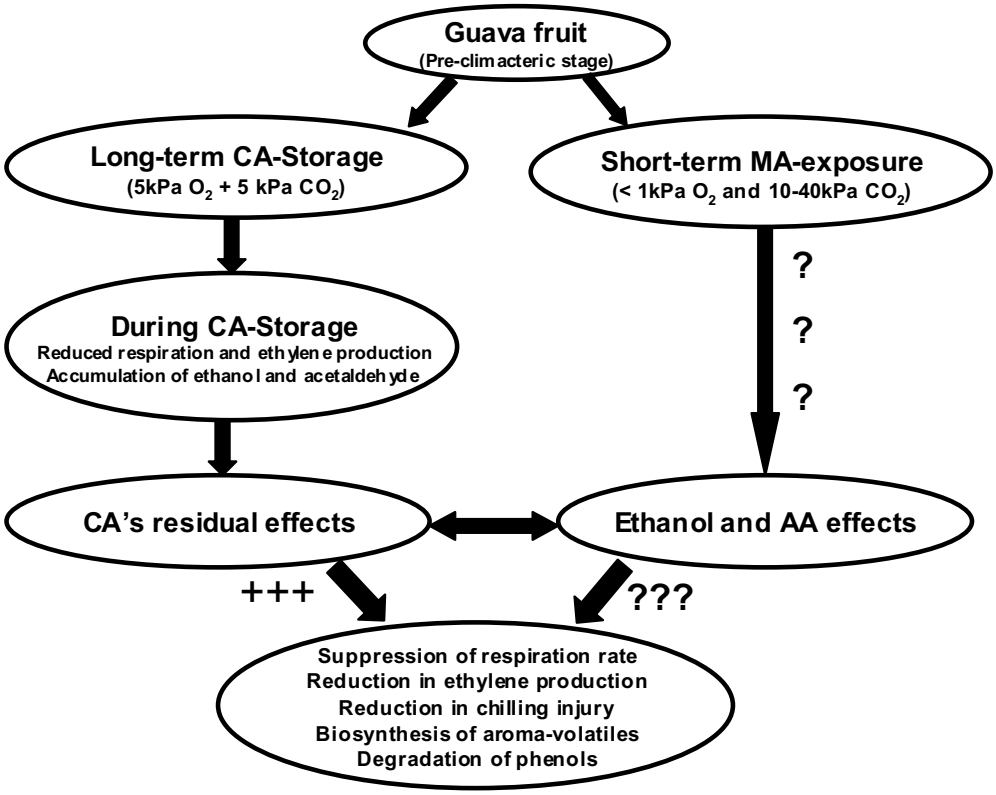

Fig. 4 A proposed model for effects of either long-term CA storage or short-term CA exposure on postharvest guava fruit. Plus signs (+++) indicate the beneficial effects derived while question marks (???) denote the role which is still not elucidated.

impregnation under similar storage conditions were obscured by moisture condensation and exhibited heavy decay. The perforation of polyethylene bags neither modified the atmosphere in the bag nor extended the shelf life of guava fruit (Combrink *et al.* 1990). The inconsistency of the results from MAP studies may be due to variation in the storage conditions, and the thickness of the same film used by different researchers. For example, MAP of guava fruit cv. 'Kumagai' in 24.7 µm thick LDPE film resulted into reduced weight loss, lower acidity and SSC, and lower CI symptoms during 3 weeks of storage at 8°C (Gaspar *et al.* 1997). While fruit of the same cultivar packed a thicker LDPE film (69 µm) and stored at 10°C for 3 or 4 weeks lead to an environment of 0.1 kPa O_2 and 19 kPa CO_2 and the fruit developed an intense off-flavour in addition to a substantial loss of ascorbic acid caused by high CO_2 (Jacomino *et al.* 2001a, 2001b). However, when a mineral is incorporated into a LDPE film (24µm thick) had a favorable MA (3 kPa O_2 and 4.5 kPa CO_2) that maintained higher flesh firmness and skin colour for 2 weeks at 10°C (Jacomino *et al.* 2001a, 2001b). A comparative account of the materials and methods used in these two studies clearly demonstrate the importance of the thickness of packaging film in creating favourable or unfavourable MA and its eventual impact on the fruit quality.

The time required to attain EMA passively depends upon the rate of respiration of fruit and film permeability characteristics. The active achievement of EMA through flushing with a desired gaseous mixture to replace normal air is rapid and more beneficial to enhance the shelf life of guava fruit (Singh 2006, unpublished results). The active modification of atmosphere with a gas mixture containing 5 kPa O_2 and 2.5 kPa CO_2 in 25 µm LDPE bags was more effective than passive MAP with the same film in reducing firmness loss and skin colour evolution in guava fruit during storage at ambient conditions and cold storage (Singh 2006, unpublished results).

Effects of shrink-wrapping on fruit physiology and quality

Individual shrink wrapping (ISW) is a form of MAP that reduces weight loss and maintains flesh firmness in tropical fruits (Singh and Sudhakar Rao 2005b; Yahia and Singh 2009). ISW has been widely used to augment the postharvest life of many non-climacteric fruit and vegetables but its application in climacteric fruits is limited due to development of off-flavour (Singh and Sudhakar Rao 2005b). ISW has been found useful to reduce the weight loss and maintain fruit quality of guava. Mohamed *et al.* (1994) reported that shrink-wrapping of 'Vietnamese' guavas with LDPE (25 µm thickness) film was the more effective in reducing weight loss, maintaining flesh firmness and retarding skin colour changes compared to cling-wrap packaging (10 µm thick LDPE) during 7 weeks storage at 10°C. Ascorbic acid content was lower in MA-packed fruit compared to control. Sensory evaluation scores of cling-wrapped guava were higher as compared to the shrink-wrapped fruit (Mohamed *et al.* 1994). Pal *et al.* (2004) reported that 'Lucknow-49' guavas individually shrink wrapped using 9 µm linear LDPE film could be stored for up to 12 and 18 days at ambient and in evaporative cool chamber, respectively, with negligible loss in vitamin C content. Shrink-wrapping of a tray containing six guava fruit with a heat shrinkable D-955® film significantly reduced the weight loss, and maintained freshness of fruit without significant retardation of changes in skin color and firmness at ambient conditions for 6-8 days (Singh 2006 unpublished). The display of shrink wrapped fruit at a retail outlet appeals more to the consumer, and may enhance the market potential of fruit.

Risks associated with the MAP technology

It can be concluded that MAP is a proven and effective technology for quality retention of fruit. Therefore, based on various studies, a 10-35 µm thick LDPE film in conjunction with temperature management in the supply chain can be recommended. However, there are some considerations associated with the logistics of MA-packed fruit:

- Difficulty in regulation and monitoring of MA during the supply chain;
- Temperature abuse during handling, storage and transportation may favour large changes in the fruit respiration rate but a small change in film permeability leading to low O_2 and high CO_2 inside the packs;
- Fruit respiration may shift from aerobic to anaerobic metabolism due to low O_2 and high CO_2 which can induce the accumulation of anaerobiosis metabolites, ethanol and acetaldehyde, leading to development of off-flavour in fruit;
- Anaerobic conditions as a result of very low O_2 and high CO_2 may trigger the proliferation of anaerobic micro-organisms posing a serious health risk for consumers;
- Excessive RH may occur causing moisture condensation that promotes microbial growth resulting into consumer safety issues;
- MAP is not a green technology unless the use of biodegradable films. The use of polymeric films is either banned or highly discouraged by the so called *greens* group.

Temperature fluctuations, often encountered in the supply chain, can have a considerable impact on the visual and flavour quality of fruit (Paull 1999). Thus, it is essential to avoid both temperature fluctuations and to design MA packages to compensate for temperature fluctuations with use of high permeable materials (Tano *et al.* 2007). The reliability of MAP will depend upon the physiological status of fruit, film thickness and permeability, and storage conditions. In the future, more research is required to integrate the use of natural compounds/extracts with antimicrobial properties with MAP systems in order to eliminate the use of synthetic fungicides, thus promoting '*green*' postharvest technologies. The application of superatmospheric MAP has also not been evaluated for guava fruit.

Edible coatings

Consumers are demanding safe, healthy and eco-friendly produce. The application of edible coatings is one of most innovative technologies to delay the postharvest senescence of fruit (Vargas *et al.* 2008). Edible coating serves as a protective barrier to decrease respiration and water loss rates through fruit surfaces, retard color changes, maintain texture of fruits and inhibit microbial growth (Kester and Fennema 1986; Baldwin 1994). Depending upon the selective permeability to O_2 and CO_2, coatings modify the internal atmosphere in the fruit tissue without causing anaerobic respiration if applied appropriately. But the internal atmospheres changes in response to environmental conditions such as temperature and RH (Baldwin 1994). Edible coating can also be used as a carrier of functional ingredients such as antioxidants, antimicrobial agents and calcium, etc. (Kester and Fennema 1986; No *et al.* 2007). A wide range of compounds are used in the formulation of edible coatings and include polysaccharides (methylcellulose, hydroxypropyl cellulose, hydroxypropyl methylcellulose, starch, alginate, chitosan, pectin, gum arabic, guar gum, xanthan gum and carrageenan), proteins (zein, gluten, soy, whey proteins), lipids (carnauba wax, candelilla wax, shellac, beeswax, fatty acids), and their mixtures (Vargas *et al.* 2008). Chitosan is becoming a popular coating material due to its antifungal and antibacterial properties, and can reduce the decay incidence in fruits (No *et al.* 2007).

Effects of edible coatings on fruit physiology and quality

Different types of coating materials have been reported to enhance shelf-life, reduce decay, and also to exert some detrimental effects such as uneven ripening and off-flavour development in guava fruit. Combrink *et al.* (1990) reported that application of mixed sucrose esters of fatty acids (Semperfresh®) did not affect the keeping quality of guava fruit in terms of reduction of decay incidence. Coating of mature-green guava fruit with cellulose- or carnauba-based emulsions delayed fruit softening, inhibited skin colour evolution, reduced SSC and resulted in more surface blackening in storage (McGuire and Hallman 1995). Coating with 2 and 4% hydroxypropylcellulose (HPC) retarded softening by 35 and 45%, respectively, compared to uncoated fruit. Coating with 5% carnauba was found the most effective at reducing weight loss and retaining fruit firmness (McGuire and Hallman 1995). McGuire (1997) attempted to apply carnauba wax following the hot water treatment (HWT) of guava fruit. HWT (46.1 ± 0.2°C for 35 min), alone or in combination with waxing, elevated CO_2 levels before the initiation of ripening while waxing reduced the endogenous levels of O_2. Before fruit ripening, the levels of O_2 were inversely correlated with injury, firmness and percentage of fruit ripening and directly correlated with peel colour and concentrations of sugars and acids in the pulp. Therefore, McGuire (1997) suggested that a combination of HWT and waxing is only possible either by delaying waxing of heat-treated fruit or reconditioning them for 24 h at 20°C before cold storage to promote normal ripening and quality of heat-treated fruit. Additionally, coating of guavas with Nature Seal containing 4% HPC reduced the mean survival of Caribbean fruit flies (*Anastrepha suspensa*, Loew) to 9% against 46 and 68% in fruit coated with Nature Seal 2000 and Pac-Rite TFC 213 (carnauba wax), respectively (Hallman *et al.* 1995). Therefore, fruit coating can modify the atmosphere to very low O_2 and high CO_2 levels which are lethal for survival of larvae of fruit flies, and can cause a delay in the time required for their emergence.

The application of Sta-fresh, a carnauba wax-based coating, was effective in reducing weight loss and ethylene production during storage of 'Lucknow-49' guava at ambient conditions as well as in evaporative cool chamber for 7 and 14 days, respectively (Pal *et al.* 2004). However, edible coatings were less effective than individual shrink-wrapping of guava (Mohamed *et al.* 1994; Pal *et al.* 2004). The application of carnauba based coatings (Michem® Emulsion 62125 AM, Michelman, Inc., Cincinnati, Ohio, USA and NiproFresh®, Nipro Technologies, Chandigarh, India) on 'Allahabad Safeda' guava reduced weight loss, maintained fruit firmness, restricted skin colour changes and extended the shelf life by 2–3 days at ambient conditions compared to uncoated fruit (Singh 2006, unpublished results). The application of edible coatings appears to be a very practical approach to enhance the marketability of guava fruit. Nevertheless, none of the coating materials so far tested performed consistently in improving or maintaining all quality attributes of guava fruit. The future expansion of coating materials and formulation techniques offer opportunities for further increase in the use of tailored-edible coatings for retaining fruit quality.

1-Methylcyclopropene (1-MCP)-based technology

1-MCP, an inhibitor of ethylene perception, is known to act by competing for irreversible binding to the ethylene receptors in plant tissue (Watkins 2006, 2008a). The non-toxic mode of action, negligible residues, and very low concentrations (< 1 μL L^{-1}) required for biological effects are major advantages of 1-MCP based technology (Watkins and Ekman 2005). Regulatory approval for use of 1-MCP in guava has been achieved in Brazil and Chile (Watkins 2008a) and is imminent in many other countries. 1-MCP has been implicated in delaying fruit ripening, alleviating CI symptoms and reducing decay in tropical fruits (Watkins 2006 and refs therein). Postharvest exposure of 'Pedro Sato', a Brazilian guava cultivar, to 1-MCP at 300 nL L^{-1} for 6 or 12 h and at 900 nL L^{-1} for 3 h showed the best results in terms of delaying fruit ripening at ambient conditions by 3–4 days against untreated control fruit. In India, Singh and Pal (2008b) concluded that 1-MCP treatment of a climacteric-type cultivar, 'Allahabad Safeda' with 300 nL L^{-1} for 12 and 24 h or 600 nL L^{-1} for 6 h, may be used to provide 4–5 days extended marketability of fruit under ambient con-

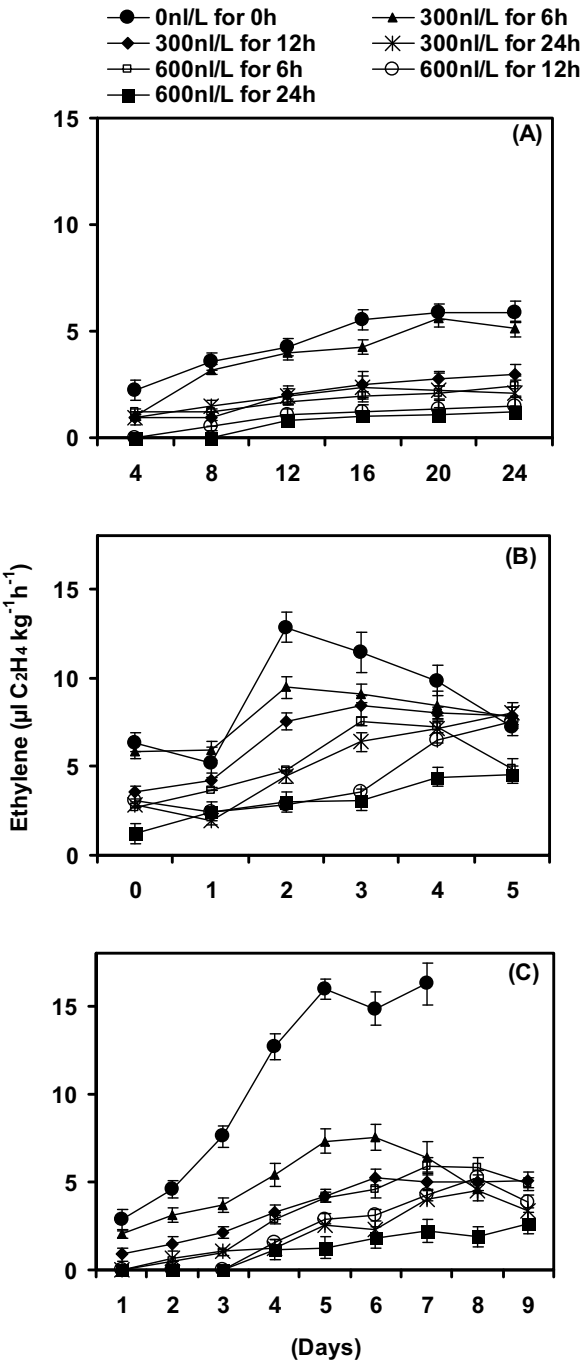

Fig. 5 Effects of 1-MCP application on ethylene production of guava fruit during storage at 10°C for 25 d (A), during ripening at ambient (25-29°C) after 25 d storage at 10°C (B), and during storage at ambient conditions (25-29°C) (C); *n* = 3. Vertical bars represent S.E. of means. (From **Singh SP, Pal RK** (2008b) Response of climacteric-type guava (*Psidium guajava* L.) to postharvest treatment with 1-MCP. *Postharvest Biology and Technology* **47**, 307-314, with kind permission of Elsevier, Ltd., ©2008).

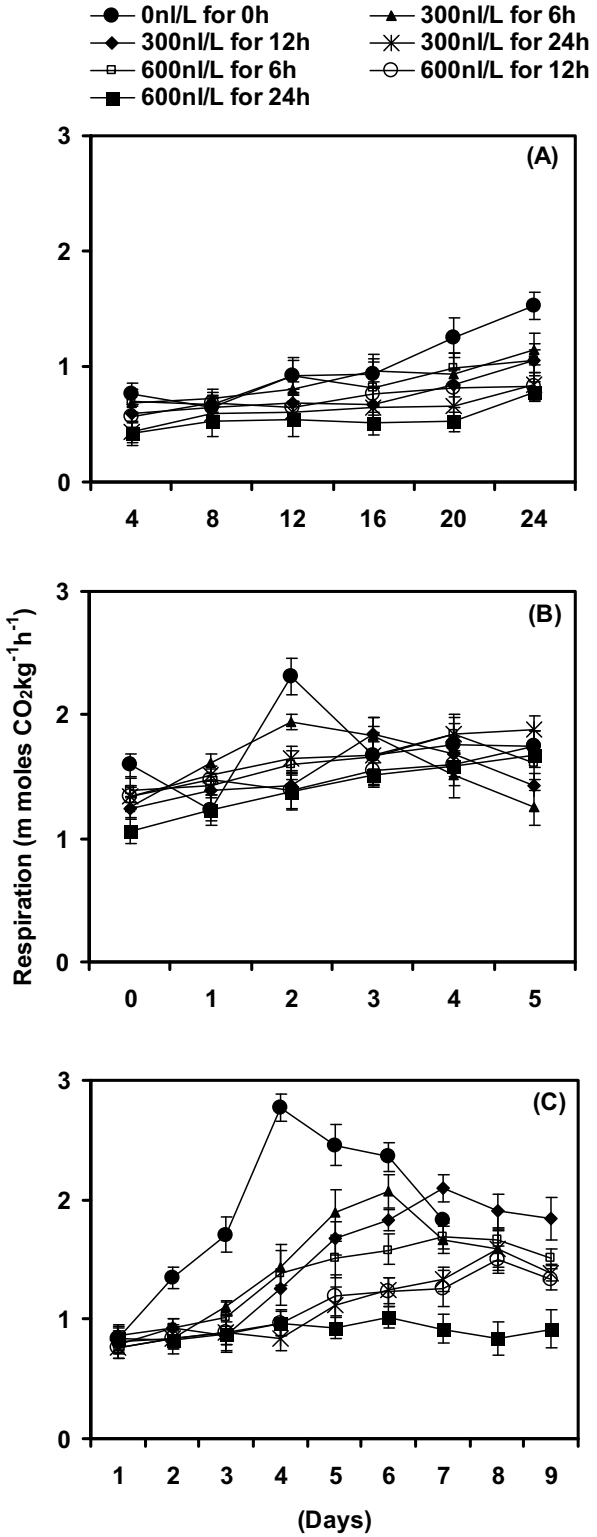

Fig. 6 Effects of 1-MCP application on respiratory rates of guava fruit during storage at 10°C for 25 d (A), during ripening at ambient (25-29°C) after 25 d storage at 10°C (B), and during storage at ambient conditions (25-29°C) (C); *n* = 3. Vertical bars represent S.E. of means. (From **Singh SP, Pal RK** (2008b) Response of climacteric-type guava (*Psidium guajava* L.) to postharvest treatment with 1-MCP. *Postharvest Biology and Technology* **47**, 307-314, with kind permission of Elsevier, Ltd., ©2008).

ditions. Treatment with 600 nL L^{-1} for 12 h is recommended for cold storage of guava fruit at 10°C for 25 days. The responses of 'Lucknow-49', another commercial cultivar in India, to 1-MCP exposure were quite similar to that reported effects in 'Allahabad Safeda' (Singh, 2006 unpublished results).

Effects of 1-MCP on fruit physiology and ripening

The beneficial effects of postharvest exposure of guava to 1-MCP include suppression of respiration and ethylene production, delayed fruit softening, restricted skin colour changes, prolonged cold storage life, and alleviation of CI (Azzolini *et al.* 2005; Bassetto *et al.* 2005; Singh and Pal 2008b). Most of the physiological responses during storage and ripening of guava fruit are dependent upon 1-MCP dose and exposure duration. Increasing the 1-MCP dose and exposure duration results into greater suppression of respiration and ethylene production during storage and ripening in 'Allahabad Safeda' guavas (Singh and Pal 2008b; **Figs. 5, 6**).

'Pedro Sato' guavas also show reduced respiration and ethylene production rates during fruit ripening in response to 1-MCP treatment (Azzolini *et al.* 2005; Bassetto *et al.* 2005) while at higher concentrations of 1-MCP (900 nL L^{-1} for 6 or 12 h) guava fail to degreen during ripening (Bassetto *et al.* 2005). Changes in skin colour from green to yellow and fruit softening are desirable features in order to achieve full eating quality in guava. Cultivar is one of the most important factors affecting the efficacy of 1-MCP in delaying fruit ripening. Responses of climacteric and non-climacteric cultivars of the same fruit species vary to 1-MCP treatments (Watkins 2006, 2008a). 'Pedro Sato' cultivar has been reported to behave as a non-climacteric fruit during ripening in response to ethylene and 1-MCP treatments (Azzolini *et al.* 2005). Therefore, more research is required to investigate the response of commercially important guava cultivars in other countries to 1-MCP treatment.

Effects of 1-MCP on fruit quality

Fruit softening in 1-MCP-treated guavas is significantly delayed during storage at ambient conditions and also during cold storage at 10°C for 25 days and subsequent ripening at ambient conditions (Azzolini *et al.* 2005; Bassetto *et al.* 2005; Singh and Pal 2008b). The loss of green colour in fruit skin was greatly retarded by the 1-MCP treatment (Azzolini *et al.* 2005; Bassetto *et al.* 2005). SSC was not significantly affected by the 1-MCP treatment except for a slight reduction in the increase in SSC during fruit ripening and storage depending upon the cultivar. A reduction in the decrease of TA of 1-MCP-treated fruit has been reported due to the delay in ripening process, which is marked by the loss of TA (Azzolini *et al.* 2005; Bassetto *et al.* 2005; Singh and Pal 2008b). The retention of vitamin C content in 1-MCP-treated fruit has been reported to be significantly higher than in untreated fruit during cold storage of 'Allahabad Safeda' fruit for 25 days at 10°C (Singh and Pal 2008b). CI symptoms mainly appeared in the form of surface pitting during cold storage, and the percentage of fruit surface area affected by CI increased with storage. CI symptoms intensified when fruit were transferred to ambient conditions for ripening. CI symptoms were significantly lower in 1-MCP-treated fruit during ripening at ambient conditions after storage for 25 days at 10°C (Singh and Pal 2008b). A large reduction in decay incidence in guava fruit was another advantage that could be attributed to the 1-MCP treatment (Singh and Pal 2008b).

Commercialization of 1-MCP

Commercial use of 1-MCP in tropical fruits including guava appears to be very limited. Commercialization depend upon many factors including, the cost of 1-MCP application relative to its benefits for the product, response of fruit to 1-MCP treatment, scale of the industry, how well 1-MCP application can be fitted into the postharvest supply chain, competition in market, acceptance of the treated product to market and consumer (Watkins 2006). If this technology can improve the postharvest life of a tropical fruit by 25–50% without compromising quality, it will be the best suited for developing countries in tropics where adequate postharvest handling facilities and cold chain are not available. A multitude of factors including cultivar, maturity stage, time gap between harvest and treatment, treatment temperature, and beneficial effects on quality determine response to 1-MCP (Watkins 2006). To expand its use in guava, the response of other cultivars harvested at different stages of maturity needs to be studied. Further more research is required to investigate the effects of 1-MCP treatment on antioxidant properties, aroma-volatile compounds and its combination with CA storage or MAP or edible coatings in guava fruit. Consumer acceptance of 1-MCP-treated guavas has also not been evaluated in the studies reported in this review.

The gaseous nature of 1-MCP, which is easily released from a stable powder when dissolved in water or buffer, presents operational difficulties due to requirement of a fumigation chamber or an air-tight tent and operator skill for treatment. However, the recent introduction of an aqueous formulation of 1-MCP, AFxRD-038 (Rohm and Haas), can potentially increase its use due to an easy procedure of short-term dipping of fruit in aqueous solution (Manganaris *et al.* 2007). In conclusion, 1-MCP as a postharvest tool may be integrated into the supply chain management of guava fruit to extend its storage life and maintain quality during cold storage and ambient conditions.

Gamma irradiation

Irradiation involves the exposure of a commodity to ionizing radiation for an intended purpose (Kader 1986). Irradiation can delay the postharvest ripening and senescence processes in fresh fruits (Kader 1986). The most useful application of irradiation is for disinfestations of tropical fruits as a quarantine treatment. Irradiation is an approved phytosanitary treatment against most of the insect-pests associated with the fresh produce (Heather and Hallman 2008). The United States Department of Agriculture-Animal and Plant Health Inspection Service (USDA-APHIS) has approved irradiation with a minimum generic absorbed pest dose of 0.15 kGy as a treatment for all tephritid fruit flies in fruit and a minimum dose of 0.4 kGy for all other insects, except Lepidoptera pupae and adults (APHIS 2007). In contrast to thermal and cold treatments for phytosanitation, irradiation is more tolerated by fresh fruits with a minimal loss of quality (Moy and Wong 2002). The relatively short time required for irradiation treatment can help the highly perishable tropical fruits to keep moving fast in the supply chain. Therefore, irradiation is as a proven, safe, versatile, efficient, and effective technology for postharvest disinfestation of fruits. The extended postharvest life of fruit in response to irradiation treatment can be considered as an additional benefit, if it was purely intended for disinfestation purposes.

Guava has been classified among the fruits which are the most tolerant to ionizing radiation doses of less than 1 kGy (Kader 1986). Studies have shown that ionizing radiation treatment extends the postharvest life and reduces decay incidence in guava fruit (Mathur 1963; Sreenivasan *et al.* 1971; Thomas 1988; Baghel *et al.* 2005; Singh and Pal 2009). Recently, APHIS has approved the import of guava from Mexico into the USA, but it must be subjected to irradiation as a phytosanitary treatment (APHIS 2008). According to APHIS (2008), the guavas to be imported must be part of a commercial shipment and irradiated with a minimum dose of 0.4 kGy. The access to USA market will enable the Mexican guava industry to look forward for exports.

Effects of gamma irradiation on physiology and ripening

Maturity, dose level and post-treatment handling conditions influence the physiological response of a fruit to gamma irradiation (Thomas 1988). Similar to heat and chilling stress, irradiation is also a stress factor and its severity can be assessed in terms of respiration and ethylene production rates as the stress indicators (Kader 1986). Postharvest treatment of guava fruit with 0.3 kGy dose delays fruit ripening, reduces weight loss, and substantially reduces decay incidence during storage at ambient conditions (Mathur 1963; Sreenivasan *et al.* 1971; Thomas 1988). Baghel *et al.* (2005) found that irradiation of guava fruit with 0.1 kGy dose increased the postharvest life to 8 days over 4 days for the control. Ionizing radiation treatment (0.25 kGy) suppresses the respiration and ethylene production rates of two guava cultivars, 'Allahabad Safeda' and 'Lucknow-49', during 8 days of shelf life at 27 ± 2°C (Singh and Pal 2009). The suppression of the increase in respiration and ethylene production rates with an increase in irradiation dose from 0.25 to 1.0 kGy suggests that guava can tolerate even high

doses of ionizing radiation without manifesting stress symptoms in the form of burst of respiratory activity and ethylene production (Singh and Pal 2009). Irradiated guavas, particularly cv. 'Lucknow-49', when stored for 22 days at 10°C did not show reduced rate of respiration during their subsequent removal to ambient conditions; but ethylene production rates were significantly lower in irradiated fruit of both cultivars, 'Lucknow-49' and 'Allahabad Safeda' (Singh and Pal 2009). It appears that ionizing radiation significantly interferes with fruit physiology to incur its beneficial effects in terms of enhanced postharvest life. Further research is required to investigate the physiological responses of guava fruit to irradiation treatment.

Effects of gamma irradiation on fruit quality

Irradiation doses, required for achieving phytosanitation, are not detrimental to quality of most of tropical fruits (Moy and Wong 2002). Irradiation treatment of guava fruit has been reported to retard the physical and biochemical changes associated with ripening such as firmness, TA, SSC, and vitamin C (Sreenivasan *et al.* 1971; Baghel *et al.* 2005; Singh and Pal 2009). Ionizing radiation treatment has significant impact on fruit softening in guava during ripening at ambient conditions (Singh and Pal 2009). At ambient conditions, irradiation doses of 0.25 kGy resulted in better firmness retention compared to control, with higher doses of 1.0 kGy increased the rate of fruit softening (Singh and Pal 2009). The changes in SSC and TA of irradiated guavas are retarded during ripening; TA is retained in irradiated fruit (0.25 kGy) than in control and those treated with 0.5 and 1.0 kGy (Singh and Pal 2009). However, the quality of irradiated guavas stored at 10°C for 22 days after transfer to ambient conditions is not superior to non-irradiated fruit, which indicate that the positive effects of irradiation treatment diminish during cold storage. Singh and Pal (2009) concluded that 0.25 kGy is the optimal dose for postharvest life extension of guava fruit, but the quality of fruit in terms of firmness, SSC, and TA is also not adversely affected in fruit treated with 0.5 kGy. Higher doses of irradiation lead to a significant decline in the vitamin C content (Baghel *et al.* 2005; Singh and Pal 2009). More research efforts are required to understand the mechanism of ascorbic acid loss in response to increasing ionizing radiation dose. Sensory attributes of guava fruit such as colour, taste and aroma, were unaffected by various doses of irradiation, except doses > 0.1 kGy were reported to cause injury to fruit skin (Baghel *et al.* 2005). However, Singh and Pal (2009) exposed guava fruit to even ten-folds higher dose than that recommended by Baghel *et al.* (2005), and did not observe any visual injury symptoms on fruit skin and flesh. Some irradiation results on fruit quality are contradictory, with most show clear benefits of irradiation for guava fruit. Therefore, irradiation may be exploited to provide phytosanitary security against many insect-pests apart from enhanced market life.

Limitations of irradiation technology

The greater awareness by consumers of the importance of irradiation to ensure quarantine security and food safety has increased acceptance of irradiated food in the USA (Moy and Wong 2002). Public and political objections to the establishment of irradiation facilities still exist around the world. The cost of establishing irradiation facilities in the developing countries is large. Dosimetry considerations are very important to assure that fruit are exposed to doses of ionizing radiation within legal limits (Mitcham 2005). Fruit in middle of a pallet are more likely not to receive the minimum required dose, while those on the periphery of pallet may be exposed to 2–3 times higher doses, and exceed the current legal limit of 1.0 kGy for fruit irradiation (Mitcham 2005). Either condition (under- and over-dose) is not desirable, former by the regulatory agencies and later by the fruit quality and consumer. The unstacking of pallet for treatment adds costs but ensures more uniform treatment (Mitcham 2005). The irradiation doses approved by USDA-APHIS for fresh fruits are ≤ 0.4 kGy, that does not kill the adult insect, but make it sterile. The presence of live insects in fresh fruit, though sterile, may be unacceptable to the consumer.

POSTHARVEST PHYSIOLOGICAL DISORDER: CHILLING INJURY

Chilling injury (CI) is a physiological disorder which results from exposure of fruit to temperatures below its critical threshold limit (Paull 1999). Sensitivity of guava fruit to CI is a limiting factor in its long-term storage, distribution and handling at low temperatures. Common visual symptoms of CI in guava are surface pitting, water soaking tissue, external and internal discolouration, uneven fruit ripening, and enhanced decay (Reyes and Paull 1995; González-Aguilar *et al.* 2004; Singh and Pal 2008a, 2008b). CI symptoms like surface pitting and water soaking tissue appear during cold storage, but expression of these symptoms including others become more apparent upon removal to ambient conditions (Singh and Pal 2008a, 2008b). The degree of CI depends upon the storage temperature, the exposure duration, and the sensitivity of tissue to chilling temperatures (Kays and Paull 2004). Fruit maturation stage is an important factor influencing its susceptibility to CI. For instance, guava fruit harvested at colour turning stage could be stored for 3 weeks at 7°C with good appearance quality and less decay than those harvested at mature-green stage (Vazquez-Ochoa and Colinas-Leon 1990).

The supplementation of low temperature storage either with some postharvest treatments (chemical, physical, and biological) or with modified atmosphere (low O_2 and high CO_2) may exert some synergistic effects on fruit quality and alleviating symptoms of CI. The alleviation of CI in guava through short-term exposure to CA or long-term static CA and MAP is discussed in the previous sections. Pre-storage treatment of guava fruit with methyl jasmonate vapours (10^{-4} M or 10^{-5} M) and 1-MCP gas (300 nL L^{-1} for 12 h or 600 nL L^{-1} for 6 h) has also been reported to reduce CI symptoms during cold storage (González-Aguilar *et al.* 2004; Singh and Pal 2008b). Heat treatments can induce resistance to CI in some tropical fruits like banana, mango, and papaya (Paull and Chen 2000). Guava is reportedly sensitive to heat treatments as these affect the fruit quality varying from slightly (Gould and Sharp 1992) to adversely (Yusof and Hashim 1992; Monzon *et al.* 2004); thus exposure to high temperature stress can not be used for acquisition of chilling tolerance in guava fruit. The understanding of the biochemical and molecular basis of CI in guava fruit is still not clear, and would be of worth studying. Therefore, it is imperative to maintain guava fruit at optimum temperature to avoid CI during each segment of supply chain.

POSTHARVEST DISEASES

The occurrence and severity of postharvest diseases in tropical fruits such as guava is more due to hot and humid conditions prevalent during the supply chain. Anthracnose, caused by *Colletotrichum gloeosporioides*, is the most common fungal disease of post-harvest importance in guava fruit (Singh and Pal 2008b). The developing fruit may get infected in the orchard and the infection remains quiescent until after harvested fruit are in the postharvest supply chain. The quiescent pathogen resumes activity in response to fruit ripening which results into the decreased levels of antifungal compounds that were present in the unripe fruit, the diminished levels of phytoalexins, and the change in fruit composition facilitating the pathogen penetration and advancement (Prusky 1996). The symptoms of anthracnose appear in the form of small brown spots on the fruit surface, which later grow into large and sunken patches.

The improper postharvest handling procedures may cause puncturing and bruising on the fruit skin, which is

very thin and delicate in guava. Wounding is primarily responsible for the loss of integrity of natural barriers that are otherwise effective to prevent the infection by various surface contaminants. Most of the postharvest pathogens such as *Rhizopus stolonifer*, *Alternaria* spp., *Aspergillus niger*, etc. can easily penetrate through wounds and perpetuate to cause fruit rotting. The proliferation of fruit rots is enhanced by the changes associated with fruit ripening such as increase in sugars that serves as the food base for pathogens, decrease in phenolics that are vital to provide resistance against pathogens, and softening that facilitates the fungal breakdown of tissue.

The increasing concerns about the deleterious effects of synthetic fungicides prompt consumers to buy organic produce and researchers to develop non-chemical solutions for post-harvest diseases. An effective postharvest disease management strategy must integrate various diseases control methods in addition to good pre-harvest management practices. A single postharvest treatment may not be adequate to effectively control all postharvest diseases. A careful handling during harvesting and postharvest operations to prevent the wounding of guava fruit is very essential. To manage anthracnose, pre-harvest fungicide sprays and good orchard management practices may prevent the latent infection in the developing fruit. Postharvest fungicide treatment is an effective disease control method and is widely used. But, the choice of fungicide type and dose for postharvest treatment depends upon the availability of fungicides approved for use in a particular country, the fungicides used in the field sprays, and the destination market for the fruit.

The development of pathogen resistance to key fungicides has stimulated research towards more resilient postharvest disease management practices such as physical treatments and biological control. The storage of fruit at an appropriate low temperature may lead to slow progression of the infection than at ambient conditions. Chilling injury resulting from the storage of fruit at suboptimal temperature enhances the susceptibility of fruit to decay. Storage, transportation and distribution at recommended temperature and relative humidity (10°C; 85-95% RH) may help to maintain the inherent fruit resistance against various pathogens. Postharvest treatment with 1-MCP gas has been reported to reduce the decay incidence in guava fruit during storage and ripening (Singh and Pal 2008). Similarly, exposure of mature unripe guava fruit to gamma-irradiation (250-500Gy) has potential to reduce the fruit decay (Baghel *et al.* 2005; Singh and Pal 2009). Biological control using microbial antagonists can be used as a part of an integrated post-harvest disease management strategy to reduce the use of synthetic fungicides. The efficacy of biological control agents can be improved by applying in combination with low concentration of recommended fungicide and other physical treatments. The information on the application of biological control agents to control postharvest diseases in guava is limited. More research is required on the integrated postharvest disease management in guava fruit.

CONCLUSIONS

Quality retention of fresh fruit in the postharvest supply chain is essential to meet or exceed consumer expectations. Fruit safety, nutrition and flavour are becoming the major concerns for consumers and also for postharvest biologists and technologists. Environment-related issues are further adding up to the list of challenges to be faced by postharvest horticulture industry. Postharvest technology adoption is based upon the triple-bottom-line concept keeping in view the social, economic and environmental aspects (Watkins and Ekman 2005). Not all postharvest technologies meet the triple-bottom-line criteria, but striking a balance among them will be the most appropriate approach.

Guava's nutritional richness and flavour-some characteristics should be exploited to make it popular in non-producing countries. Its highly perishable nature, susceptibility to CI and rots, and delicate nature of fruit are the major postharvest problems. Guava hosts most of the species of fruit flies which infest the fruit and render it unfit for human consumption and trade. Guava fruit being very sensitive to heat and cold can not tolerate most of the temperature-based phytosanitary treatments. Marine transport of guava in refrigerated CA containers can be a practice in future as for other horticultural commodities. MAP of fruit using films of appropriate thickness has potential to increase its shelf-life and maintain quality and should be encouraged for commercial scale adoption. Postharvest application of edible coating is also emerging as the consumer and environmentally friendly future technology. According to Watkins (2008b), DCA storage and 1-MCP are the most successful innovations in the storage technologies during the last decade, and have revolutionized the postharvest horticulture industries. There is currently no information available on the response of guava fruit to DCA storage, but it responds positively to the static CA storage and short-term MA treatments. Studies have shown that the postharvest application of 1-MCP enhances the postharvest life and maintains fruit quality of guava. 1-MCP is already registered for commercial use in guava in Brazil and Chile and may get approval in other countries in the near future. The recent approval of importation of irradiated fresh guava fruit into USA from Mexico is a clear indication of the scope of irradiation technology in overcoming postharvest phytosanitary barriers.

A range of postharvest technologies can potentially maintain the guava fruit quality or minimize the quality loss in supply chain. The adoption of a postharvest technology will mainly depend upon the return-on-investment (ROI) factor, in addition to other factors. The new technologies such as 1-MCP and CA are not currently widely used. A large capital investment in the implementation and operation of CA and irradiation facilities is required. Marine transport of fruit in CA containers can demonstrate ROI positive if it is compared with air transport. Irradiation facilities can only be viable if these are used year around for multiple horticultural commodities. Each and every postharvest operation/technology adds up to the cost and, with the increase in sophistication of technology, the cost is increased. To minimize the costs and maximize the benefits, only selected postharvest technologies should be adopted in developing countries. Therefore, guava fruit industry in most of the tropical countries needs to organize, stimulate fruit marketing, and seek approval for market access to various developed countries.

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