jpht

Journal of Postharvest Technology
2017, **05**(2): 1-16
http://www.jpht.info

REVIEW ARTICLE

Physiological and biochemical changes during fruit growth, maturity and ripening of guava: a review

Phani Deepthi V[1]*

[1]Department of Fruit Science, College of Horticulture, Dr.YSR Horticultural University, Anantharajupet, Andhra Pradesh 516105, India.

Received: 15.02.2017 Accepted: 04.04.2017

ABSTRACT

Ripening is one of the most important processes in fruits, which involve changes in colour, flavour and texture, and thereby making them most acceptable for edible purposes. A large number of physiological, biochemical and structural changes occur during ripening of fruits which include degradation of starch or other storage polysaccharides, production of sugars, synthesis of pigments, volatile compounds and partial solubilization of cell wall. Such obvious changes generally occur in a coordinated fashion. An understanding of these changes during ripening is of prime importance in checking post harvest losses for developing technologies in enhancing the shelf life of fruits. In climacteric fruits, these changes take place over a relatively short period of time and guava (Psidium guajava L.) being a climacteric fruit, exhibits a typical increase in respiration and ethylene production during ripening. It softens readily and, therefore has a very short shelf life, which in turn makes transportation and storage difficult. Skin colour is the best maturity index in guava as it could be monitored non-destructively during fruit ripening and storage. Fruits attaining maturity show signs of changing colour from pale green to yellowish green. If the fruit is to be shipped to distant markets it should be mature, full sized and of firm texture, but without an obvious colour-break on the surface. Fruits for local market can be harvested in a more advanced stage of maturity. However, harvesting fruits at appropriate stage of maturity is critical in maintaining the post harvest quality of guava fruits. This article takes a broad look at fruit growth, maturity, post harvest physiology and ripening of guava fruit and the available literature is reviewed under the following heads.

Keywords: Guava, maturity, ripening, harvest, climacteric and skin colour

Citation: Deepthi, V.P. 2017. Physiological and Biochemical changes during fruit growth, maturity and ripening of guava: A review. *Journal of Postharvest Technology*, 5(2): 1-16

INTRODUCTION

Guava (*Psidum guajava* L.) is an important tropical and sub-tropical fruit crop which is grown widely in India. It is known for its nutritional value and an excellent source of vitamin-C and pectin. Guava is the fifth most widely grown fruit crop after banana, mango, citrus and papaya in India and occupies an area of 0.26 million hectares producing 3.66 million tonnes with an average productivity of 13.7 MT/ha (Saxena and Gandhi, 2014). Guava is classified into different varieties based on colour, size and shape of the fruit. Skin colour is one of the major maturity indices for guava which varies from dark green during immature stage to yellow when fully ripened. Guava is a climacteric fruit. It ripens rapidly after harvest and therefore has short shelf life. If the fruit is to be shipped to distant markets it should be mature, full sized and of firm texture, but without an obvious colour-break on the surface. Fruits for local market can be harvested in a more advanced stage of maturity (Singh, 2007). However, harvesting fruits at appropriate stage of maturity is critical in maintaining the post harvest quality of guava fruits (Azzolini et al., 2004 and Patel et al., 2015). The available literature is therefore comprehensively reviewed in this paper on various aspects of fruit growth, maturity, harvest, post harvest physiology and ripening of guava which helps in checking

* *For correspondence: P. Deepthi V (Email: deepthivellaturi@gmail.com)*

ISSN: 2348-4330

post harvest losses for developing technologies in enhancing the shelf life of guava fruits.

GUAVA FRUIT GROWTH, MATURITY AND HARVEST

Fruit set, growth and developmental stages

Guava bears fruits almost round the year with large variation in physical and chemical characteristics (Rathore, 1976 and Dhillon et al., 1987). Fruit setting starts about 5-6 days after flowering (Ali and Lazan, 1997). However, two distinct seasons of flowering, April-May and August-September occur from which fruits ripen during rainy (Aug-Sept) and winter (Dec-Feb) seasons respectively (Mitra et al., 2008). Guava fruit generally takes about 17-20 weeks from fruit set to reach maturity, while Adsule and Kadam (1995) reported that the number of days from full bloom to maturity of guava during rainy and winter seasons is 95-100 days and 120-125 days respectively.

Guava cv. 'Safeda' fruits took nearly 140 days to reach maturity where as 'Lucknow-49' fruits matured between 106-138 days (Mukherjee and Dutta, 1967). Mercado-Silva et al. (1998) reported that guava cv. 'Media China' fruits required 130 and 190 days respectively for spring-summer and autumn-winter seasons from bloom to harvest. Low temperatures (winter season) during the latter stages of development resulted in fruits with a higher content of physico-chemical constituents (Rathore, 1976) and better eating quality (Gupta et al., 1979). Hence winter guava fetches premium price in markets than rainy season.

Fruit growth in guava followed a double sigmoid curve with two periods of rapid growth and a period of relatively slow growth in between. The weight of fruit and fruit size gradually increases at the first phase, then slow down during second phase and finally increases till maturity (Srivastava and Narasimhan, 1967; Mitra and Bose, 1990 and Selvaraj et al., 1999). However, it differed from the sigmoidal growth curve reported by Sastry (1965a), Mukherjee and Dutta (1967), Rodriguez et al. (1971), Paull and Goo (1983) and Yusof and Suhalia (1987) for different cultivars. They described a moderate increase in weight during 50 days after anthesis, followed by a rapid increase in weight from 50 to 110 days, and finally a period of slow growth. Salunkhe and Desai (1984) also observed a sigmoidal growth curve of cv. 'Allahabad Safeda' but with unusual behaviour where initial increase in weight was rapid.

Sastry (1965a) reported that the development of guava (cv. Lucknow-49) fruit in weight and volume may be represented by a sigmoid growth curve which can be divided into three stages. These stages can further be divided into five distinct phases, each having an interval of about 30 days. The five distinct phases were observed as, dark green, hard fruit, soft seeds, astringent (30 DAF), dark green, outer core hard, harder seeds, astringent (60 DAF), dark green, astringent, slightly sour, no flavour (90 DAF) followed by light green, astringent in outer core, inner pulp sweet with slight acid taste, mild guava flavour (120 DAF), yellowish colour, sweet, little astringency in the outer core, characteristic guava flavour (150 DAF) and finally over-ripe at 160 days after flowering. There is approximately a sevenfold increase in volume and weight between the first and last stages. Fruits may be harvested between 120-150 days from bloom for their profitable marketing.

Chaturvedi (1974) studied the variations in the available substrates during different stages (early, enlarging, mature and ripening) of the fruits of guava. He observed that the fruit started (early stage) with protein as a chief constituent, and in enlarging stage, an accumulation of soluble carbohydrates took place. Higher values of total and reducing sugars were maintained in the mature stage. However in the ripening stage, the total disappearance of starch was accompanied by a reduction of glucose content and sucrose continued steadily to increase and there was a reduction in protein and acid contents

during the later stages of fruit.

Hegde (2001) illustrated the different stages of guava growth curve (Figure 1). They are IG (Immature green) stage that was about 45 days after fruit set while the fruits at 90 and 135 days after fruit set were at MG (Mature green) and T (Turning) stages respectively. This sigmoidal pattern of the curve suggests that fruit development can be divided into three distinct phases. The initial phase of about 70-75 days after fruit set was of rapid cell division with no deposition of stored material. During this phase, fruit fresh weight increased moderately. The second phase, which lasts upto 135 days after fruit set, consists of rapid accumulation of stored material, which was accompanied by rapid increase in fresh weight, while during the third phase; fresh weight of the fruit remained almost constant with a slight or negligible decline after 155 days after fruit set because of dehydration or desiccation.

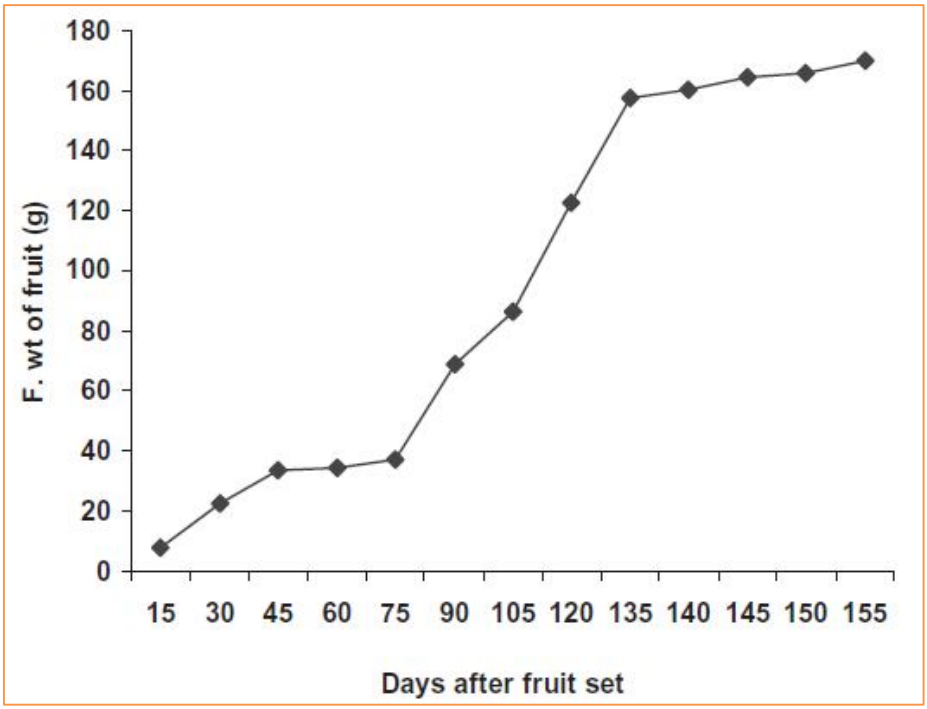

Figure 1: Growth curve of guava fruit

El-Bulk et al. (1997) studied the changes in chemical composition of four guava cultivars (Shambati, Pakistani, Shendi and Ganib) at three developmental stages, immature (15-33 days), mature (51-88 days) and ripe (106-126 days) after fruit set during development and ripening of fruits. They observed that the substances responsible for calorie and vitamin characteristics of the fruit (sugars and ascorbic acid respectively) reached their maximum values near 106 days from fruit set, and also emphasized that guava fruit at that stage had excellent nutrient resources.

Selvaraj et al. (1999) studied the changes in chemical composition of guava fruits during growth and development at four stages of maturity *viz.,* green mature (GM -150 and 140 DAF), peel colour turning (CT -155 and 145 DAF), yellow hard (YH - 160 & 150 DAF) and ripe stage (R -165 & 155 DAF) respectively for 'Safeda' and 'Sardar' cultivars. They also confirmed that compositional changes during fruit ontogeny and changes in physico-chemical, biochemical and mineral constituents were associated with ripening.

Maturity

Chundawat et al. (1978) have pointed out that maturity stage at the time of harvest determined the quality and storage life of guava fruits. The recommended optimum stage for harvesting of guava fruits is 2-3 weeks prior to attaining full growth since they experience changes associated with ripening such as skin yellowing and decrease in tissue firmness. Based on pigmentation guava fruits can be categorized into five stages of maturity or ripeness, IG- immature green (dark green), MG- mature green (skin colour changes from dark to light green), CT- colour turning (skin colour changes from light green to yellow or yellowish green), R- ripe (complete yellow) and OR- over-ripe (yellowish brown) as shown in Figure 2. Besides fruit age, detachment force, texture and specific gravity are also useful maturity indices (Paull and Goo, 1983). Chundawat et al. (1978) have also pointed out that maturity stage at the time of harvest determined the quality and storage life of guava fruits.

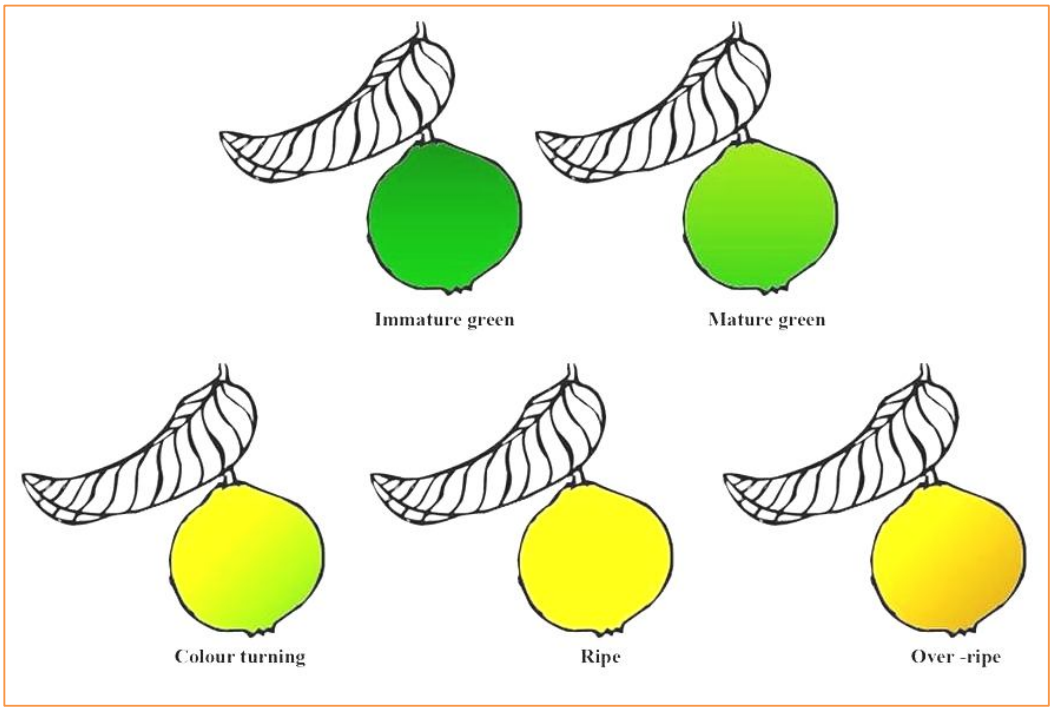

Figure 2: Different stages of fruit maturity and ripeness in guava based on skin colour

Vazquez-Ochoa and Colinas-Leon (1990) reported three stages of maturity (ripeness) in guava. Mature Green stage (I) is when maximum growth of fruits had been attained, their skin colour changes to light green from dark green; Colour Turning (stage II) is when the skin colour turns slightly yellow from light green (this is the usual commercial harvest stage) and Ripe stage (III) is when the fruits are completely yellow and ready to eat. Visual appearance and firmness test are important attributes for establishing maturity index of guava (Adsule and Kadam, 1995).

Jain et al. (2003) reported that guava fruits can be categorized into four different stages of ripeness on the basis of visual observations of fruit firmness and pigmentation. Mature green (MG) fruits are 100% green, while colour turning (CT) fruits are 50% green and 50% yellow, ripe (R) fruits are 80% yellow and 20% green and over-ripe (OR) fruits are 100% yellow.

The stage of maturity (point of collection) influenced significantly the quality of guava fruits cv. 'Pedro Sato' after storage

(Azzolini et al., 2004). They observed that guava fruits harvested at maturation stage 3 (green yellow) and stored at room temperature (25 ±1^{0}C and 85 ±5% RH) have superior quality to those harvested at stage 2 (green light) or stage 1 (green dark) stored in same conditions. The maximum shelf-life period was 6, 4 and 2 days after harvest for stages 1, 2, and 3 respectively. Mondal et al. (2008) identified immature green (IG), mature green (MG) and turning (T) stages of guava fruits based on number of days taken after fruit set (45, 90 and 135 days respectively) and these stages differed for their visual observations of size, firmness, liquefaction and pigmentation. However after harvest at T stage, ripe (R) and over-ripe (OR) stages occurred after 3rd day and 5th day respectively at room temperature.

Harvest

Skin colour is widely used as a visual maturity index in many fruits (Reid, 2002). The change in skin colour from deep green to yellowish green is attributed to the disappearance of chlorophyll and is considered as a criterion in judging harvest maturity in guava (Kumar and Hoda, 1974). Hence it is the best maturity index in guava (Mercado-Silva et al., 1998; Kader, 1999 and Asrey et al., 2008) as it could be monitored non-destructively during fruit ripening and storage.

The highest ripe fruit quality after harvest could be achieved when mature green guava (cv. Media China) fruits harvested with L*, a* and Hue values of 65±3, -15±2 and 110±2 respectively, very similar to yellowish green fruit (Mercado-Silva et al., 1998). Mangaraj and Goswami (2009a) reported that highest quality during storage was achieved when guava fruits were harvested with L*, a*, b*, hue angle and chroma values of 57.83±5.16, -17.58±2.59, 39.41±3.47, 114.00±3.20 and 43.15±2.52 respectively. The negative value of a* indicates the greenness of guava fruits at maturity. The skin colour (Hunter L, a and b) of guava cv. 'Corbitel' for immature, intermediate and mature stages of maturity were reported to be 53.83, -9.78 and 22.25; 64.05, -2.99 and 28.90 and 71.87, 4.23 and 32.28 respectively. The loss of green colour and increase of yellow colour was evidenced by the increase in chroma from 24.30 to 33.10 and a decrease in hue angle values from 113.73 to 82.66 (Soares et al., 2007).

Some researchers suggested that TSS (Teaotia et al., 1970), specific gravity (Kumar and Hoda, 1974), and fruit development period (Rathore, 1976) could be used as auxiliary tools for judging maturity. Tandon et al. (1989) recommended specific gravity as a maturity index. A continuous decrease in specific gravity (<1.0) was observed with ripe fruit. Kumar and Hoda, (1974) found similar specific gravity values for fully mature fruits developed during rainy season, but fruits harvested during winter had a specific gravity of >1.0. Effect of grading on specific gravity basis of guava cv. L-49 fruits was studied by Kumar et al. (2001). They reported that fruits harvested at colour break stage were divided into specific gravity groups of I, II & III (< 1.0, 1.00 -1.02 and >1.02 respectively). The fruits with specific gravity < 1.00 were found best in prolonging the shelf life (Tripathi and Gangwar, 1971).

Harvesting of guava needs extra care because the fruit has soft, thin skin. It is normally carried out by hand to avoid physical injuries. Generally picking is done 2 to 3 times in a week. The complete harvesting season is about 8 to 10 weeks (Yadav, 2007). The fruits should not be allowed to over-ripe on the trees as they deteriorate in quality and are more liable to be damaged by birds (Simrat, 2009).

The physical, physiological and biochemical changes taking place during ripening of guava fruits were more pronounced during ripening in-storage as compared to ripening on-tree. Also the changes were rapid in rainy season than in winter season (Sharma, 2006). Pre-harvest bagging of guava cv. Safeda fruits, one month prior to harvest included advancement in maturity followed by ripening resulted in full attractive yellow colour development and improved quality in

terms of high vitamin 'C' and TSS with low level of acidity. However, these fruits have short shelf life than non-bagged fruits (Singh et al., 2007).

GUAVA FRUIT RIPENING AND SENESCENCE

During ripening, a fruit passes through a series of overt changes in colour, flavour and texture, indicating that compositional changes are taking place. Attainment of maximum eating quality of a fruit necessitates completion of such chemical changes. These changes generally coincide with the peak rate of respiration in most fruits and vegetables.

Respiration, ethylene production and transpiration

The marked rise in oxygen uptake and carbon dioxide output (respiration) is a characteristic phenomenon of ripening process. It marks a transition phase between development and the onset of functional breakdown, between ontogeny and senescence (Biale et al., 1954). Respiration is a metabolic process that provides the energy for plant biochemical processes (Meyer et al., 1973). The rate of these metabolic processes is generally directly proportional to the storage temperature, thus increasing the shelf life to a certain level at lower temperatures. For perishable commodities, both O_2 and CO_2 concentrations have an influence on quality and shelf life (Mangaraj and Goswami, 2009b).

Ethylene is a plant hormone controlling a wide range of physiological processes in plants. It is produced by the ACC (1-amino cyclopropane, 1-carboxylic acid) synthase pathway (Hoffman and Yang, 1980). During post harvest storage of fruits and vegetables, ethylene can induce negative effects including senescence, over-ripening, accelerated quality loss, increased fruit pathogen susceptibility and physiological disorders (McGlasson, 1985). Apart from the endogenous ethylene production by plant tissues, external sources of ethylene occur along the food chain in packages, storage chambers during transportation, and in domestic refrigerators. Thus, it is a great goal in post harvest to avoid ethylene action.

Guava is a climacteric fruit, exhibiting a typical increase in respiration and ethylene production during ripening (Mukherjee and Dutta, 1967; Akamine and Goo, 1979; Brown and Wills, 1983) which may be compared with climacteric rise in tomato, mango, banana, apple etc. Bashir and Abu-Goukh (2003) also found similar pattern with respiration rate and ethylene production in white and pink guava types during ripening.

Initiation of ripening activities in climacteric fruit is controlled by the threshold level of internal ethylene concentration. Exogenous ethylene application to immature or mature fruits can induce ripening and softening without the involvement of the respiratory climacteric (Hansen, 1966). Ethylene regulates fruit ripening by coordinating the expression of genes that are responsible for a variety of processes, including rise in respiration, autocatalytic ethylene production and changes in colour, texture, aroma and flavour (Oetiker and Yang, 1995).

The time to reach climacteric, however, was related to growth season. Fruits produced in spring-summer had climacteric peaks of carbon dioxide and ethylene production 5 days after harvest, while autumn-winter fruits had their climacteric peaks 8 and 7 days respectively indicating a slower fruit development during winter (Mercado-Silva et al., 1998). Generally, the peak for ethylene production in guava fruit occurs at the half ripe or colour break stage or fourth day of harvest thus leading to early softening and spoilage (Simrat, 2009).

Selvaraj et al. (1998) studied the changes in respiration rate and ethylene production during guava fruit ripening in

cultivars, 'Safeda' and 'Sardar' (Figure 3). They found that guava fruit followed a typical climacteric peak in respiration. Ethylene content in guava increased from green to colour turning stage. The climacteric peak in respiration was preceded by maximum ethylene production during ripening.

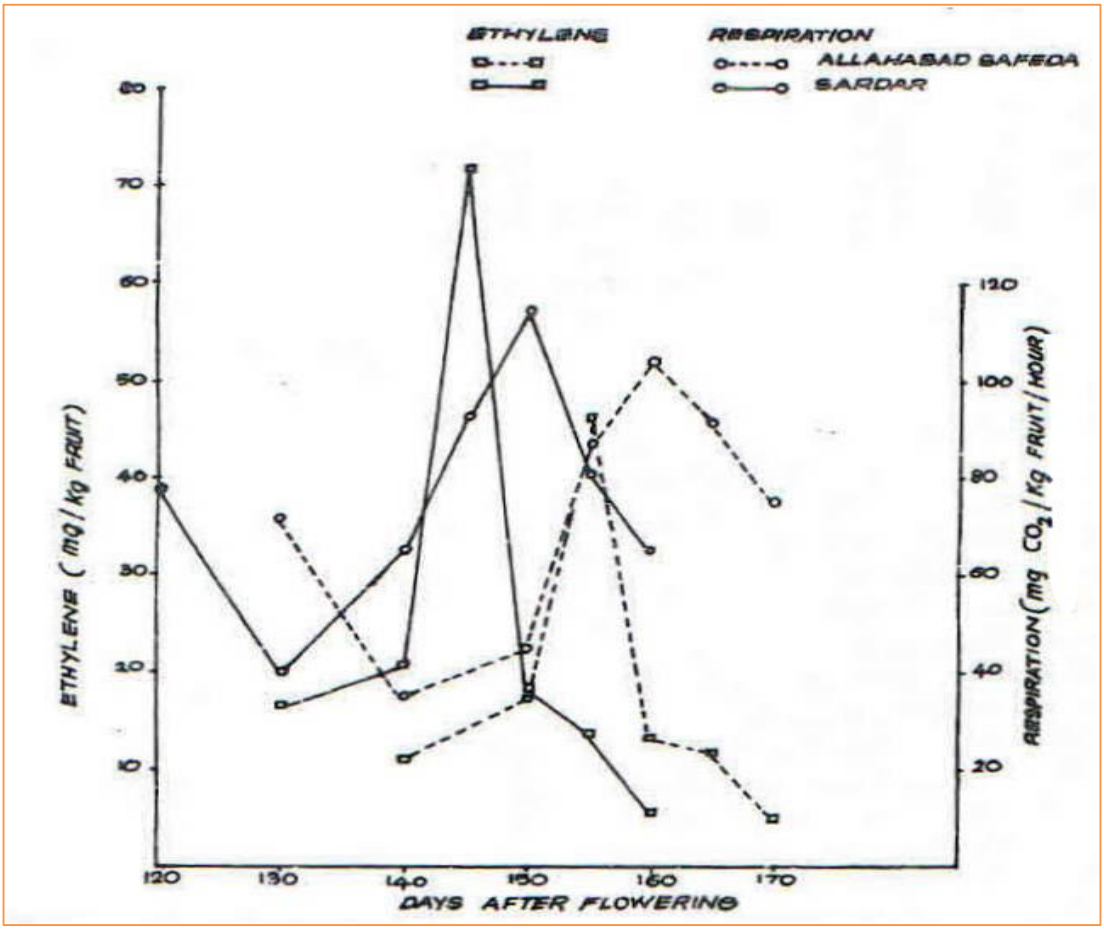

Figure 3: Respiration and ethylene changes in ripening fruits of two guava cultivars

Azzolini et al. (2005) reported that 'Pedro Sato' guavas presented a gradual increase in both respiratory rate and ethylene production rate after harvest and completed ripening with changes in quality attributes. Ethylene was necessary for skin colour development and loss of firmness during ripening. These characteristics would classify guava as a climacteric fruit. However, maximum respiratory activity, as well as ethylene production was observed when the fruits were already ripe.

Among the three cultivars (Allahabad Safeda, Sardar and Lalit), Sardar and Lalit had a longer shelf life of 9 days with minimum rates of respiration and ethylene production under ambient conditions (18 ± 3^0C, 60-70% RH). However, 'Allahabad Safeda' had a shorter shelf life of 6 days only (Killadi et al., 2007). Further, they reported that the pattern of respiration and ethylene production of guava fruits exhibited typical climacteric nature, which was found to be inversely proportional to shelf life. Ethylene evolution and ACC oxidase activity were substantially high at turning (T) stage and low at later stages of guava fruit ripening, indicating the climacteric nature of the fruit (Mondal et al., 2008).

As measured by the closed system method, the respiration rate of guava fruit is depressed with storage time as expected by

the in-pack accumulation of CO_2 and depletion of O_2 (Wang et al., 2009; Mangaraj and Goswami, 2009b). The changes in the rate of respiration positively relates with the circum-ambient temperature in the range from 5 to 30^0C. They recommended the ANN (artificial neural network) method for predicting the respiration rate of guava fruit which is crucial for designing and operating post harvest storage systems.

Bron et al. (2005) studied the respiratory activity (RA), ethylene production (EP) and Q_{10} of guava cv. 'Paluma' fruits at different storage temperatures *viz.,* 1, 11, 21, 31 and 41^0C. The RA and EP rates at 1 and 11^0C were lowest, while guavas stored at 21^0C and above, a gradual increase in RA and EP rates was noticed. For 1-11^0C range, the mean Q_{10} value was around 3.0, whereas Q_{10} values almost duplicated at 11-21^0C range (5.9). But for 21-31^0C and 31-41^0C, Q_{10} was 1.5 and 0.8 respectively. Thus, by knowing Q_{10}, respiratory variation and ripening behaviour in response to different temperatures, fruit storage and retail conditions can be optimized to reduce quality losses.

Two varieties of guava *viz.,* 'Lucknow-49' and 'Hisar Safeda' differing in their shelf life was analyzed for various components of oxidative stress and of enzymatic and non-enzymatic antioxidative system at five stages (immature, mature, colour turning, ripe and over-ripe) of fruit ripening. They reported that ripening of guava fruit accompanied by a progressive increase in oxidative / peroxidative stress which induced antioxidant system in the early but not until the later stages of ripening. However, the extent of oxidative stress is more pronounced in varieties with shorter shelf life than Lucknow-49 which has an average shelf life of 7-8 days. The activities of antioxidative enzymes *viz.,* catalase, peroxidase, ascorbate peroxidase and glutathione reductase increased upto colour turning stage and decreased thereafter. Superoxide dismutase and lipoxygenase activities however, increased respectively upto ripe and over-ripe stages followed by a decline. They also observed that the contents of ascorbic acid and glutathione (total, oxidized and reduced) were found to be maximum at colour turning and mature stages respectively. Over-accumulation of ROS (reactive oxygen species) due to dysfunctioning of ROS scavenging system at later stages of fruit ripening appears to be responsible for loss of tissue structure as observed in ripe and over-ripe fruits (Mondal et al., 2009a).

Changes in colour and texture

Ripening of guava fruit starts on the tree and continues even after harvest. It is associated with a change of skin colour from green to yellow. The colour of the flesh changes from white to creamy white, yellowish pink, deep pink to salmon red (Wilson, 1980). The total chlorophyll and total anthocyanin content decrease to the minimum as the fruit reaches maturity (Selvaraj et al., 1999). The loss in chlorophyll during ripening is due to increased activities of chlorophyll degrading enzymes including chlorophyllase, chlorophyll oxidase and peroxidase. The decrease in chlorophyll content was accompanied by increase in carotenoid content in over-ripe fruits (Jain et al., 2001).

Pectic molecule is essentially a long chain, ploygalacturonic molecule combined through intermolecular forces and anhydride structure to form insoluble protopectin layer of cell wall and middle lamella (Elwell and Dehn, 1939). Guava fruit is a rich source of pectin. The total pectin content of guava fruit is in the range of 0.5-1.8%. Peel, flesh and core of guava contain 1.68, 0.60 and 0.51% pectin respectively (Simrat, 2009). Pectins form about 1/3rd of the total dry matter of the fruit during the final stages of ripening (Sastry, 1965b).

Fruit texture might differ among cultivars. The stone cells are responsible for the gritty or granular texture of guava fruits. Fruit firmness is closely associated with maturity stage. Mature green fruits reported to have higher penetration values than yellow ripe fruits (Mercado-Silva et al., 1998). In 'Beumont', 'Banaras' and 'Baladia' cultivars of guava, loss of tissue

firmness during ripening was accompanied by a decrease in the level of total pectin content (El-Zoghbi, 1994). In cultivars such as 'Allahabad Safeda', 'Red Flesh' and 'Triploid', total pectin increased initially and then decreased later in over-ripe fruits (Pal and Selvaraj, 1979).

Dhillon et al. (1987) also observed that total pectin content increased during early developmental stages but decreased as fruit approached ripe stage in cultivars, 'Safeda' and 'Sardar'. Sachan et al. (1969) reported a pectin content of 0.65, 0.68 and 0.55 percent respectively in mature, ripe and over-ripe guava (cv. Allahabad Safeda) fruits of rainy season. Singh (1980) observed a decrease in pectin content with the progress of storage period where the decrease was much faster at higher temperature than at lower temperature.

The starch content of guava fruit gradually declines with maturity (Sharaf and El-Saadany, 1986). Total fibre content of flesh also decreased and this might be due to decrease in the level of hemicellulose, cellulose and lignin fractions of the cell wall (El-Zoghbi, 1994). The decline in firmness in white and pink guava types was about eight fold from the hard mature green stage to final soft ripe stage (Bashir and Abu-Goukh, 2003). On the other hand, the total, soluble and insoluble protein content (which represents the protoplasmic content of the cell) of the developing guava fruit showed a gradual increase throughout the ripening period (Sastry, 1965b).

Fruit softening during ripening and for cell wall extension during cell growth, pectin methyl esterase (PME) is considered to be the enzyme of physiological relevance to plant metabolism. It also participates in cell wall pH regulation by generating protons and thus enhances the activity of cell wall hydrolases. PME, an enzyme which acts on pectin liberating methoxyl groups, has found to increase its activity during development and maturation of fruits (Hobson, 1963). Shastri and Shastri (1975) reported that maximum PME activity appears to correspond with so called hard green stage in guava cv. 'Lucknow-49' fruit development. Peak total pectin content was observed to correspond with the peak PME activity.

Pal and Selvaraj (1979) studied the pectin content and pectin esterase (PE) activity at immature, mature, ripe and over-ripe stages in seven varieties of guava. They observed that pectin content was maximum in cultivars, 'Allahabad Safeda', 'Banaras' and 'Red flesh' in ripe fruits and in all other four varieties when immature. PE activity in all the seven varieties was high at immature and ripe stages. El-Zoghbi (1994) reported that polygalacturonase (PG) and cellulase activities of the fruit tissues of guava increased markedly during ripening. Pectin esterase (PE) activity decreased during ripening in guava.

The activities of enzymes involved in fruit softening (cell wall hydrolyzing enzymes) *viz.,* PME, PG, cellulase and B-galactosidase showed considerable variability during ripening. The PME activity declined from green to yellow hard stage making pectins more susceptible to hydrolysis by PG while the PG activity decreased from green mature to colour turning stage and increased considerably at yellow hard stage followed by a decline at ripe stage. Cellulase and B-galactosidase showed high activity at green stage, followed by decline with marginal changes until ripe stage (Selvaraj et al., 1998). The enzyme activities are much more dependent on storage temperature of the fruits (Pantastico, 1975).

Changes in chemical composition and hydrolytic enzyme activities in guava fruits cv. Lucknow-49 (Jain et al., 2001) and cv. Banarasi Surkha (Jain et al., 2003) at four different stages of maturity *viz.,* mature green (MG), colour turning (CT), ripe (R) and over-ripe (OR) were studied. They concluded that maximum metabolic changes in ripening of guava occur during transition from MG to CT stage. Thus, for desired post harvest fruit handling guava fruits may be harvested at CT stage or for suppressing the expression of specific enzymes, the phase from MG to CT stage need to be exploited (Hussain and Shah, 1975). Among the cell wall hydrolyzing enzymes (cellulase, polygalacturonase and pectin methyl esterase), PG and cellulase

exhibited progressive increase in activity throughout ripening, while PME activity increased upto CT stage and then decreased upto OR stage. Also the activities of starch hydrolyzing enzymes, α- and β-amylase decreased initially and then increased abruptly at over-ripe stage (Mondal et al., 2009b).

Tiwari et al. (2007) determined that there is a decrease in the level of ASP (alkali soluble pectin) and an increase in WSP (water soluble pectin) fraction, while OSP (Ammonium oxalate soluble pectin) remains at low level during cold storage (5^0C) of guava fruits. The activities of PG and PME also increased during low temperature storage. PME activity is required to initiate pectin degradation. Polygalacturonase (PG) cannot degrade pectin until PME has de-esterified the pectin molecule, PME activity was more during the early ripening period (Porter et al., 2000).

PME is known to catalyze demethoxylation of C-6 carboxylic groups of pectin compounds and thereby providing the substrates to be depolymerized by polygalacturonase (PG) which preferentially degrades de-esterified (demethoxylated) rather than esterified (methylated) pectin. Thus, during fruit ripening, PME plays an important role in determining the extent to which pectin is accessible to degradation by PG and in reducing intercellular adhesiveness and tissue rigidity. Mondal et al. (2009b) also suggested that the increased susceptibility of fruit cell walls to PG during ripening is due to the action of PME.

Changes in flavour

The flavour of guava fruit has been described as sweet, musky and highly aromatic attributed to both volatile and non-volatile constituents. The flavour of guava is determined by the types and amounts of sugars, acids, phenolics and volatile compounds that are present in the fruit (Lazan and Ali, 1998).

As many as 270 compounds comprising hydrocarbons, alcohols, aldehydes, ketones, acids, esters, basic sulphur compounds, ether, phenols, furans and epoxides have been identified in guava pulp and peel (Simrat, 2009). Chen et al. (2006) reported that the presence of C6 aldehydes, C6 alcohols, ethyl hexanoate, (Z)-3-hexenyl acetate, terpenes and 1, 8-cineole contribute to the unique flavour of guava fruit. The aldehyde compounds are predominant in immature guava fruits, while the relative proportion of esters increased in mature fruits or with the advancement of maturity (Soares et al., 2007). Caryophyllene is the major sesquiterpene hydrocarbon in the volatile compounds of mature fruits of guava (Chyaui et al., 1992).

Sastry (1965b) reported that major activities during growth of guava fruit appear to be the synthesis of cell wall materials and sugars. Predominance of fructose over glucose is maintained throughout the growth period. Also the relative combination of non-reducing sugars (sucrose) is rather low in guava when compared to reducing sugars (fructose and glucose). The total sugars generally increased during ripening of detached fruits and fructose was found as the major component of total sugars followed by glucose and sucrose (Wilson, 1980).

Total acid level calculated as citric acid, which is the major acid in guava fruit, ranged from 0.2 to 1.1% on fresh weight basis (Bashir and Abu-Goukh, 2003). Total acidity initially increases with progressive maturity and then decreases at full maturity after climacteric peak. The fruits of ‘Sardar’ had higher citric acid than those of ‘Safeda’ together with malic, tartaric, pyruvic, succinic, fumaric, oxaloacetic, α-ketoglutaric and malonic acids at various ripening stages (Selvaraj et al., 1999). Depending upon the cultivar, titratable acidity either increased (Lazan and Ali, 1998) or decreased (Paull and Goo, 1983).

Total soluble solids (TSS) were attributed mainly to sugars and organic acids, considerably increased during ripening (Rodriguez et al., 1971; Khedkar et al., 1982; Bashir and Abu-Goukh, 2003). The total soluble solids concentration was low in immature and mature fruits initially and increased later in ripe stage (Gangwar, 1972 and Hussain and Shah, 1975). In guava cv. 'Kampuchea' the TSS level increased from about 5 to 7^0 Brix (Lazan and Ali, 1998). However, in Indian cultivars, 'Allahabad Safeda' and 'Sardar' the increase in TSS was from 10 to 13^0 Brix until ripe stage (Tandon et al., 1983 and Selvaraj et al., 1999).

The presence of polyphenols gave an astringent taste to fruits and their content significantly decreased during ripening (El-Bulk et al., 1997). Young guava fruits had 620mg/100g tissue of total phenol, with about 65% present in the form of condensed tannins. As fruit matured, the tannin content decreased considerably (Itoo et al., 1987). The decrease in phenolic compounds was seven and three folds in the pulp of white and pink guava types, respectively (Bashir and Abu-Goukh, 2003).

The decrease in astringency in guava during ripening was associated with increased polymerization of leucoanthocyanidins and hydrolysis of arabinose ester of hexahydrodiphenic acid (Misra and Seshadri, 1968). Polyphenol oxidase, the enzyme responsible for oxidation of polyphenols, showed increased activity during ripening which resulted in reduction in astringency of ripe guavas (Mowlah and Itoo, 1982). Differences in season, geographical region and horticultural practices might have resulted in variable ascorbic acid levels in guava fruits (Rathore, 1976). It generally increases with ripening, reaching the maximum when fully mature and starts declining at the onset of ripening (Mukherjee and Dutta, 1967; Dhillon et al., 1989 and El-Bulk et al., 1997). The peel of guava fruit was reported to contain most of the ascorbic acid content (Wilson, 1980). The ascorbic acid retention at the ripe stage was comparatively better in white fleshed guavas than pink fleshed types (Bashir and Abu-Goukh, 2003).

CONCLUSION

Physiological and biochemical changes of the fruit are of major concern for understanding metabolic processes such as fruit ripening, softening and general senescence. Moreover, they are of importance in determining commercial practices and post harvest requirements. Though it is not possible to improve the quality of produce after harvest, but it is possible to slow down the rate of undesirable changes. The post harvest handling system must aim to ensure that the fruit reaches the market in the condition required by the consumer or importer. The maintenance of physical and chemical attributes that confer quality to harvested fruits depends mainly on harvest maturity and partly upon the ability to impose conditions that minimize changes of these attributes. Harvest time is fundamental to obtain a high quality fruit with good storage potential. Generally, the harvest of mature, unripe fruit has been reported to improve the storability and transportability, while fruit harvested at ripe stage will have a shorter life and flavour loss may occur before completion of the marketing process. On the other hand, fruit harvested at a less mature stage will not develop typical full-flavour, and their taste is, therefore, strongly impaired.

REFERENCES

Adsule RN and Kadam SS. 1995. Guava. In: Hand book of fruit Science and Technology. Salunkhe D K and Kadam S S (eds.) Marcel Dekker Inc., New York. pp 419-434.

Akamine EK and Goo T. 1979. Respiration and ethylene production in fruits of species and cultivars of *Psidium* and species of *Eugenia*. *Journal of American Society of Horticultural Science*. 104(5): 632-635.

Ali ZM and Lazan H. 1997. Guava In: Postharvest physiology and storage of tropical and subtropical fruits. Mitra S K (ed.) CAB international Willingford, UK. pp 145-165.

Asrey R, Patel VB, Singh SK and Sagar VK. 2008. Factors affecting fruit maturity and maturity standards - A review. *Journal of Food Science and Technology*. 45(5): 381-390.

Azzolini M, Pedro AJ and Spot MHF. 2004. Maturation stage and post harvest quality of 'Pedro Sato' guavas. *Revista Brasileria de Fruitcultura*. 26(1): 29-31.

Bashir HA and Abu-Goukh AA. 2003. Compositional changes during guava fruit ripening. *Food chemistry*. 80: 557-563.

Biale JB, Young RE and Olmstead AJ. 1954. Fruit respiration and ethylene production. *Plant Physiology*. 29(2): 168-174.

Bron IU, Ribeiro RV, Cavalini FC, Jacomino AP and Trevisan MJ. 2005. Temperature related changes in respiration and Q_{10} coefficient of guava. *Scientia Agricola*. 62(5): 458 -463.

Brown BI and Wills RBH. 1983. Post-harvest changes in guava fruit of different maturity. *Scientia Horticulturae*. 19: 237-243.

Chaturvedi SC 1974 Changes in substrates during growth and development of the fruit of *Psidium guajava* L. *Indian Food Packer*. 28: 29-32.

Chundawat BS, Singh JP, Kainsa RL and Gupta OP. 1976. Post harvest studies on guava fruits. 1: Effect of packing and storage period on the quality of fruits. *Haryana Journal Horticultural Science*. 5(3/4): 130-136.

Chyaui CC, Chen S and Wu M. 1992. Differences in volatile and non-volatile composition of guava fruits during development and ripening. *Food Chemistry*. 59(3): 395-399.

Dhillon KS, Singh SN and Gill SS. 1987. Developmental physiology of guava I. Physical characters. *Punjab Horticulture Journal*. 27: 28-33.

Dhillon KS, Singh SN, Kundal GS and Minhas PPS. 1989. Studies on the developmental physiology of guava II. Biochemical characters. *Punjab Horticulture Journal*. 29: 212-221.

El-Bulk RE, Babiker EE and El Tinay AH. 1997. Changes in chemical composition of guava fruits during development and ripening. *Food Chemistry*. 59(1): 395-399.

Elwell WE and Dehn WM. 1939. Pectin content of plant materials. *Plant Physiology*. 14: 809-816.

El-Zoghbi M. 1994. Biochemical changes in some tropical fruits during ripening. *Food Chemistry*. 49(1): 33-37.

Gangwar BM. 1972. Biochemical studies on growth and ripening of guava. *Indian Food Packer*. 26: 13-15.

Gupta OP, Singh BP and Gupta AK. 1979. Studies on the shelf life of different guava cultivars. *Haryana Agriculture University Journal of Research*. 9: 247-250.

Hansen E. 1966. Postharvest physiology of fruit. *Annual Review of Plant Physiology*. 17: 459-480.

Hegde MV. 2001. Studies on fruit growth, development and ripening and effect of radiation on storage of guava (*Psidium guajava* L.) fruits. Ph.D. Thesis submitted to C.C.S. Haryana Agricultural University, Hisar.

Hobson GE. 1963. Pectin esterase in normal and abnormal tomato fruit. *Biochemistry Journal*. 86: 356.

Hoffman NE and Yang SF. 1980. Changes in 1-aminocyclopropane-1-carboxylic acid content in ripening fruits in relation to their ethylene production rates. *Journal of American Society of Horticultural Science*. 105(4): 492-495.

Hussain A and Shah AH. 1975. Activity of pectic enzymes (Pectinesterase and Polygalacturonase) during the ripening of guava fruit. Pakistan *Journal Agriculture Science*. 12: 191-194.

Itoo S, Matsuo T, Ibushi Y and Tamari N. 1987. Seasonal changes in the levels of polyphenols in guava fruit and leaves and some of their properties. *Journal of Japanese Society of Horticulture Science*, 56: 107-113.

Jain N, Dhawan K, Malhotra SP and Singh R. 2003. Biochemistry and fruit ripening of guava (*Psidium guajava* L.) Compositional and Enzymatic changes. *Plant Foods for Human Nutrition*. 58: 309-315.

Jain N, Dhawan K, Malhotra SP, Siddiqui S and Singh R. 2001. Compositional and enzymatic changes in guava (*Psidium guajava* L.) fruits during ripening. *Acta Physiology Plant*. 23(3): 357-362.

Jain SK and Mukherjee S. 2011. Enhancing keeping quality of fruits in mango cv. Langra. *Indian Journal of Horticulture*. 68(1) : 142-144.

Kader AA. 1999. Guava-produce facts. Perishables Handling Quarterly. University of California, Davis. 97: 19-20.

Khedkar DM, Ansarwadkar KW, Dabhade RS and Ballal AL. 1982. Extension of storage life of guava variety L-49. *Indian Food Packer*. 36(2): 49-52.

Killadi B, Singh MD, Singh BP and Singh RA. 2007. Shelf life evaluation of guava (*Psidium guajava* L.) cultivars. *Acta Horticulturae*. 735: 603-607.

Kumar R and Hoda NN. 1974. Fixation of maturity standards of guava (*Psidium guajava* L.). *Indian Journal of Horticulture*. 31: 140-144.

Lazan H and Ali ZM. 1998. Guava In: PE Tropical and subtropical fruits. Shaw et al. (eds.) Ag. science Inc. Auburndale FL. pp 446-485.

Mangaraj S and Goswami TK. 2009a. Determination of maturity indices if fruits based on Physico-chemical properties. *Indian Food packer*. 63(1): 67-79.

Mangaraj S and Goswami TK. 2009b. Kinetics based modelling of respiration rate of guava for CA/MA Storage. *Journal of Food Science and Technology*. 46(6) : 525-531.

McGlasson WB. 1985. Ethylene and fruit ripening. *Hort Science*. 20(1): 51-54.

Mercado-Silva E, Benito-Bautista P and Garcia-Velasco MA. 1998. Fruit development, harvest index and ripening changes of guavas produced in central Mexico. Postharvest *Biology and Technology*. 13: 143-150.

Meyer BS, Anderson DB, Bohling RH and Fratianne DG. 1973. In: Introduction to plant physiology. Second edition Van Nostrand, New Jersy USA.

Misra K and Seshadri TR. 1968. Chemical components of the fruit of *Psidium guajava*. *Photochemistry*. 7: 641-646.

Mitra SK and Bose TK. 1990. (eds.) Guava. In: Fruits: Tropical and subtropical. Naya Prakash Publishers, Kolkata, India. pp 280-303.

Mitra SK, Gurung MR and Pathak PK. 2008. Guava production and improvement in India: An overview. *Acta Horticulturae*. 787 : 59-65.

Mondal K, Malhotra SP, Jain V and Singh R. 2009a. Oxidative stress and antioxidant systems in guava (*Psidium guajava* L.) fruits during ripening. *Physiology and Molecular Biology of Plants*. 15 (4): 327 – 334.

Mondal K, Malhotra SP, Jain V and Singh R. 2009b. Partial purification and characterization of pectin methylesterase from ripening guava (*Psidium guajava* L.) fruits. *Acta Physiology Plant*. 31: 81-87.

Mondal K, Singh AP, Saxena N, Malhotra SP and Dhawan K. 2008. Possible interactions of polyamines and ethylene during ripening of guava (*Psidium guajava* L.) fruits. *Journal of Food biochemistry*. 32: 46-59.

Mowlah G and Itoo S. 1982. Quantitative changes in guava polyphenols and the polyphenols oxidase at different stages of maturation, ripening and storage. *Journal of Japanese society for food science and technology*. 29: 413-417.

Mukherjee SK and Dutta MN. 1967. Physico-chemical changes in Indian guavas (*Psidium guajava* L.) during fruit development. *Current Science*. 24: 674-675.

Oetiker JH and Yang SF. 1995. The role of ethylene in fruit ripening. *Acta Horticulturae*. 398: 212-216.

Pal DK, and Selvaraj Y. 1979. Changes in pectin and pectin esterase activity in developing guava fruits. *Journal of Food Science and Technology*. 16: 115-116.

Pantastico ER, Chatopadhyay TK and Subramanayam H. 1975. Storage and commercial storage operations. In: Post harvest physiology, handling and utilization of tropical and subtropical fruits and vegetables. Pantastico E R (ed.) AVI Westport. pp 314-338.

Patel RK, Maiti CS, Deka BC, Deshmukh NA, Verma VK and Nath A. 2015. Physical and biochemical changes in guava (*Psidium guajava* L.) during various stages of fruit growth and development. *International Journal of Agriculture, Environment and Biotechnology*. 8(1): 75-82.

Paull RE and Goo T. 1983. Relationship of guava (*Psidium guajava* L.) fruit detachment force to the stage of fruit development

and chemical composition. *Hort Science*. 18(1): 65-67.

Porter GW, Turnbull CGN and Sherman WB. 2000. Fruit firmness and Pectin methyl esterase activity during on tree ripening of peach. *Proceedings of Florida State Horticulture Science*. 113: 32-34.

Rathore DS. 1976. Effect of season on the growth and chemical composition of guava (*Psidium guajava* L.) fruits. *Journal Horticulture Science*. 51(1): 41-47.

Reid MS 2002 Maturation and maturity indices. In: Kader AA (ed.) Postharvest technology of horticultural crops. University of California, Oakland, CA, USA pp 55-62.

Rodriguez R Agarwal PC and Saha NK 1971 Physicochemical changes during development of 'Safeda' guava fruit. *Indian Food Packer.* 25(1): 5-12.

Sachan BP Pandey D and Shanker D. 1969 Influence of weather on the chemical composition of guava fruits variety Allahabad Safeda. *The Punjab Horticultural Journal.* 9: 119-123.

Salunkhe DK and Desai BB. 1984 Guava In: Post harvest Biotechnology of fruits. Volume II CRC Press, Orlando, FL.

Sastry MV. 1965a. Biochemical studies in the physiology of guava Part I: Physical changes. *Indian Food Packer*. 19(1): 11-14.

Sastry MV. 1965b. Biochemical studies in the physiology of guava Part II: Major chemical changes. *Indian Food Packer*, 19(3): 5-10.

Saxena M and Gandhi CP. (eds.) 2014. *Indian Horticulture Database 2014*, National Horticulture Board (NHB), Gurgaon. Department of Agriculture & Cooperation, Govt. of India. pp 76-83.

Selvaraj Y, Pal DK, Raja ME amd Rawal RD. 1998. Biochemistry of guava (*Psidium guajava* L.) fruit ripening: Changes in respiration rate, ethylene production and enzyme activity. *Indian Journal of Horticulture*. 35(1): 1- 9.

Selvaraj Y, Pal DK, Raja ME and Rawal RD. 1999. Changes in chemical composition of guava fruits during growth and development. *Indian Journal of Horticulture*. 56(1): 10-18.

Sharaf A and El-Saadany SS. 1986. Biochemical studies on guava fruits during different maturity stages. *Annals of Agricultural Sciences*. 24: 975-984.

Sharma A. 2006. Identification of biochemical parameters governing ripening and shelf life of guava (*Psidium guajava* L.). Ph.D. Thesis. C.C.S. Haryana Agricultural University, Hisar, India.

Shastri PN and Shastri NV. 1975. Studies of pectin methyl esterase activity during development and ripening of guava fruit. *Journal of Food Science and Technology*. 12: 42-43.

Simrat H. 2009. Production and post harvest technology of guava in India - An overview. *Crop Research*. 38(1, 2 & 3): 113-134.

Singh BP, Singh RA, Singh G and Bharti K. 2007. Response of bagging on maturity, ripening and storage behavior of writer guava. *Acta Horticulturae*. 735: 597-601.

Singh K. 1980. Effect of various chemical as pre and post harvest applications on shelf life of guava of various temperatures. Ph.D. Thesis submitted to C.C.S. Haryana Agricultural University, Hisar.

Soares FD, Pereira T, Marques MOM and Monteiro AR. 2007. Volatile and non-volatile chemical composition of the white guava fruit (*Psidium guajava* L.) at different stages of maturity. *Food Chemistry*. 100: 15-21.

Srivastava HC and Narasimhan P. 1967. Physiological studies during growth and development of different varieties of guava. *Journal of Horticultural Science*. 7: 176-192.

Tandon DK, Singh BP and Kalra SK. 1989. Storage behaviour of specific-gravity-graded guava fruits. *Scientia Horticulture*. 41(1-2): 35-41.

Tandon DK, Kalra SK, Singh H and Chada KL. 1983. Physico-chemical characteristics of some guava varieties. *Progressive Horticulture*. 15(1-2): 42-44.

Teaotia SS, Tripathi RS and Bhan S. 1970. Evaluation of indices for determination of maturity of guava (*Psidium guajava* L.). *Horticulture Advances*. 7: 99-107.

Tiwari S, Elda BE, Abhay D and Tandon DK. 2007. Pectin changes in specific gravity graded guava (*Psidium guajava* L.) fruits cv. Sardar during low temperature storage at 5^0C. *Acta Horticulturae*. 735: 569-577.

Tripathi RS and Gangwar BM. 1971. Biochemical changes as indices of maturity in guava (*Psidium guajava* L.). *Progressive Horticulture*. 3: 17-23.

Vazquez-Ochoa RI and Colinas-Leon MT. 1990. Changes in guavas of three maturity stages in response to temperature and relative humidity. *Hort Science*. 21(1): 86-87.

Wang ZW, Duan HW and Hu CY. 2009. Modelling the respiration rate of guava (*Psidium guajava* L) fruit using enzyme kinetics and artificial neural network. *European Food Research and Technology*. 229: 495-503.

Wilson CW. 1980. Guava In: Tropical and subtropical fruits Compositional, properties and uses. Nagy S and Shaw P F (eds.) Westport, Connecticut: AVE Publ. Co. pp 279.

Yadav PK. 2007. Guava In: Fruit Production Technology. International Book Distributing Company, Lucknow, India.

Yusof S and Suhalia M. 1987. Physicochemical changes in guava (*Psidium guajava* L.) during development and maturation. *Journal of Science of Food and Agriculture*. 38: 31-59.