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Papaya: Nutritional and pharmacological characterization, and quality loss due to physiological disorders. An overview

Jurandi Gonçalves de Oliveira [a], Angela Pierre Vitória [b,*]

[a] Laboratório de Melhoramento Genético Vegetal, Universidade Estadual do Norte Fluminense, Campos dos Goytacazes, 28013-602, Rio de Janeiro, Brazil
[b] Laboratório de Ciências Ambientais, Universidade Estadual do Norte Fluminense, Campos dos Goytacazes, 28013-602, Rio de Janeiro, Brazil

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ABSTRACT

The papaya (*Carica papaya* L.) is a tropical fruit that is widely cultivated and consumed, both for its agreeable flavor as well as its many pharmacological properties. This review will discuss the fruit's origin and principal growing regions in the world and will briefly explore its nutritional and pharmacological attributes. In addition, we will identify and comment on some of the most common physiological disorders that occur postharvest. Such disorders compromise the quality of the fruit, bringing financial losses to the productive sector, along with serious economic and social consequences to papaya-growing countries. Among these disorders, physiological bruising, also known as "skin freckles", characterized by the appearance of blemishes on the fruit while still in its growth stage, is one of the main problems associated with the crop. Possible causes of and current information on bruising are dealt with in this article. Other physiological disorders of the papaya such as pulp flesh translucency, pulp softening, and hard lumps in papaya flesh are also discussed.

1. Introduction

The first mention of the existence of the papaya tree (*Carica papaya* L.) was made in Europe in 1535 by the Spanish author, G. H. de Oviedo, in his book, "La natural hystoria de las Indias" in which he informed the King of Spain of the discovery of papayas growing between the south of Mexico and the north of Nicaragua. It is believed that it was from this region that the first seeds were taken to Panama, Santo Domingo, certain Caribbean islands, and parts of South America (De Candolle cited by Lassoudiére, 1968).

Some reports maintain that this species originated in the south of Mexico and Nicaragua (Chan & Paull, 2008), while others suggest an origin in the northwest of South America (Serrano & Cattaneo, 2010). After the discovery of the New World, the papaya tree spread widely throughout the tropics, most notably in Africa and Asia.

This species is typical of tropical and subtropical regions, require temperatures of between 21 and 33 °C and does not tolerate cold weather (less than 15 °C) (Crane, 2005; Fuggate, Wongs-Aree, Noichinda, & Kanlayanarat, 2010; Rivera-Pastrana et al., 2010; Yadava, Burris, & McCrary, 1990). Prolonged dry periods reduce crop output (Almeida, Bernardo, Souza, Marin, & Grippa, 2003). Papaya is grown in nearly all countries of the tropical Americas (Central and South America and the state of Hawaii). It is also cultivated in India, Sri Lanka, various Asian countries, as well as the Antilles and tropical Africa (Chan & Paull, 2008).

Brazil stands out as the world's biggest producer, supplying 25% of the world demand, followed by Mexico at 14%, Nigeria at 11%, India and Indonesia at 10%; other papaya growing nations include Venezuela, China, Peru, Congo, and Ethiopia, all of which contribute less than 3% of the papaya supply (Benassi, 2010). Brazil is the world's third biggest exporter of the papaya (FAOSTAT, 2010) and the principal markets for consumption are the USA and Europe.

Papaya crops require year-round labor, which has made it an excellent choice from a socio-economic perspective in countries that produce it. However, the quality of the papayas grown can be compromised by conditions and practices adopted during commercialization (Nunes et al., 2010). Physiological disorders or disturbances can at times result in restrictions against exportation of this fruit *in natura* and cause production losses and, in turn, a negative financial impact throughout the chain of papaya production (Campostrini, Pommer, & Yamanishi, 2010). In Brazil the principal commercial papaya varieties belong to two large groups: Solo and Taiwan (Trindade, Dantas, Almeida, & Maia, 2001).The Solo varieties present a pear-shaped or oval appearance and are characterized by their small size (ranging between 400 and 600 g) (Fagundes & Yamanishi, 2001). As the name suggests, a Solo papaya is about the right amount of fruit for one person. The Taiwan varieties are plants that produce a pear oblong-shaped fruit that is larger in size (weighing between 800 and 2000 g), with higher sugar levels, and an increased resistance during transport (Costa & Pacova, 2003). There are another genotypes of papaya with importance in the world such as 'Maradol', originates from Cuba and very cultivated in Mexico, the 'Sekaki' (also known as 'Hong Kong') and 'Eksotika' cultivated in Malaysia, and 'Khack Dum' cultivated in Thailand (Chan & Paull, 2008).

* Corresponding author.
E-mail address: apvitoria@gmail.com (A.P. Vitória).

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Ripening of papaya fruit affects sensorial, pharmacological and nutritional quality and some problems in pre or postharvest can be identified during ripening stage. This manuscript highlights some important factors in the growth of this fruit and describes the principal physiological disorders that can compromise the production and quality of the fruit.

1.1. Papaya composition: nutritional characteristics, pharmacological properties and volatile compounds

Papaya is a climacteric fruit, which grows year-round, is an elongated berry of various sizes with a smooth thin skin and a greenish-yellow color (Calegario, Puschmann, Finger, & Costa, 1997; Fagundes & Yamanishi, 2001; Fuggate et al., 2010). Its flesh is thick with a color ranging from yellow to red and offers a pleasant, sweet, mellow flavor (Devitt, Sawbridge, Holton, Mitchelson, & Dietzgen, 2006; Fuggate et al., 2010).

The papaya tree and green fruits produce latex, which remains isolated in lactiferous cells. When these cells rupture coagulation occurs, and this represents an important defense mechanism of the plant against pathogens and other harmful attacks. The latex contains a mixture of endopeptidases rich in cysteine: papain (Mitchel, Chaiken, & Smith, 1970), chymopapain A and B (Watson, Yamaguchi, & Lynn, 1990), endopeptidase papain III and IV (Barret & Buttle, 1985; Ritonja, Buttle, Rawlings, Turk, & Barrett, 1989). Recently, Paull et al. (2008) described the genes for these proteinases. Papain, whose proteolytic action is similar to that of pepsin and trypsin, is employed as a meat tenderizer in cooking and in applications in the food industry (in cheeses and beer), as well as in the textile, pharmaceutical, and cosmetic industries (Su, Nie, Zhu, & Chen, 2009).

The seeds of the papaya also contain a substance that reduces male fertility. Monkeys, rabbits, and rats treated with a water- or chloroform-based extract of papaya seeds exhibited reversible azoospermia and reduced spermatozoid mobility symptoms, causing brief periods of sterility. This effect is post-testicular, altering the functional capacity of the spermatozoid without affecting the libido. This substance is non-toxic. It has been suggested that the compound responsible for this contraceptive effect could be an alkaloid, steroid, triterpenoid, or flavonoid (Lohiya, Pathak, Mishra, & Manivannan, 2000; Lohiya et al., 2002; Pathak, Mishra, Manivannan, & Lohila, 2000).

Other pharmacological effects attributed to the papaya seed are a cytotoxic effect on vascular contraction (Wilson, Kwan, Kwan, & Sorger, 2002), as well as antibiotic (Bennett, Roger, & Wallsgrove, 1997) and antihelmintic properties (Kermanshai et al., 2001). Benzyl isothiocyanate is the predominant antihelmintic agent in papaya seed (Kermanshai et al., 2001)and is responsible for its cytotoxic action that increases the membrane permeability to Ca^{++} (Wilson et al., 2002). Cyanogenic glucosides (Bennett et al., 1997) are responsible for the antibiotic properties of these seeds. The fruit has also been widely used as a laxative (Sharma, Chhangte, & Dolui, 2001).

The papaya is a good source of Ca^{++} and an excellent source of vitamins A, B_1, B_2 and C. Its protein content is approximately 5%. The nutritional value of the fruit depends on the variety, growing conditions, and ripeness upon consumption (Sankat & Maharaj, 1997).The principal carbohydrates encountered in the fruit are glucose, sucrose, and fructose, with glucose being the carbohydrate most present during the initial stages of development (Zhou & Paull, 2001), while sucrose, fructose and glucose are more abundant after ripening, when the percent of sugars varies between 10 and 13% (Chan, Hibbard, Goo, & Akamine, 1989; Zhou & Paull, 2001).

The papaya's sensory characteristics (principally taste and aroma) involve, in almost all cases, volatile compounds (benzylisothiocyanate, terpenes, hydrocarbons, esters, aldehydes, ketones, alcohols, and organic acids) (Almora et al., 2004; Flath & Forrey, 1977; Fuggate et al., 2010). The volatile compounds of various papaya cultivars have been extensively investigated during forty years of published research, leading to the identification of close to four hundred fruit volatile components (Pino, Almora, & Marbot, 2003).Among the hydrocarbons that make up papaya, monoterpenes, which generally contribute aroma to fruit, are scarce, while other groups, such as aliphatic and aromatic hydrocarbons have been detected at higher levels (Flath & Forrey, 1977).

Among the volatile alcohols, linalool is the papaya's most abundant volatile compound (Flath & Forrey, 1977). In Solo group varieties, this compound makes up around 94% of the volatile compounds, while in the Taiwan hybrids the oxide cis-linalool is the most abundant with linalool presenting the second highest concentration (Franco & Rodrigues-Amaya, 1993). Almora et al. (2004) reported that when the papaya, cv. Maradol Roja, reaches the edible ripe stage, butanol, 3-methylbutanol, benzyl alcohol and terpineol are at their maximum concentrations.

Mature papaya fruit contains over a hundred detected volatile compounds, including numerous esters (Flath & Forrey, 1977; Idstein, Keller, & Schreier, 1985; Sankat & Maharaj, 1997). Most of these compounds are only present at low concentrations (Flath & Forrey, 1977). Papaya is one of the fruits with the largest varieties of esters. Using techniques combining gaseous chromatography and mass spectrometry, Flath and Forrey (1977) identified over one hundred volatile compounds in Hawaiian papayas of the Solo group, thirty two of which were esters. The composition and proportion of esters varies among the different species of *Carica*, among different varieties of *C. papaya*, and depending on the growing region of the fruit. Among the one hundred and three esters that compose the fruit, Idstein et al. (1985) identified butyl acetate as the most abundant ester in *C. pubescens*, while in *C. papaya* (of the Solo group) from Sri Lanka, methyl butyrate is found at the highest concentration (MacLeod & Pieris, 1983). These low molecular weight esters play an important role in the composition of the aroma and flavor in papayas.

The volatile compounds of the “Sri Lankan” and “Colombian” papaya are dominated by esters, particularly methyl butanoate (Heidlas, Lehr, Idstein, & Schreier, 1984; MacLeod & Pieris, 1983). In addition to the high concentration of linalool in the volatile compound composition of the Solo variety of papayas, other components, such as benzyl isothiocyanate (Flath & Forrey, 1977; Flath, Light, Jang, Mon, & John, 1990) and terpene hydrocarbons (Heidlas et al., 1984), are also found at high levels in these fruit.

In summary, the esters are very important to the aroma of papaya fruit (Flath & Forrey, 1977), while ethyl butanoate, ethyl acetate, ethyl hexaonate and ethyl 2-methylbutanoate are reported to be the most potent odor compounds in papaya (Balbontín, Gaete-Eastman, Verara, Herrera, & Moya-León, 2007).

1.2. Physiological disorders

Physiological disorders of the most varied causes are common in many fruit species (Chatenet et al., 2000; Paull & Reyes, 1996; Roper, 1999), and the papaya is not an exception (Kaiser, Allan, White, & Dehrmann, 1996; Oliveira et al., 2010; Reyes, Eloisa, & Paull, 1994; Schripsema, Vianna, Rodrigues, Oliveira, & Franco, 2010). These disturbances are almost always related to environmental factors (Campostrini et al., 2010; Oliveira, Pereira, Martelleto, & Ide, 2005; Oliveira et al., 2004; Oliveira et al., 2002) which, in certain cases, are difficult for growers to prevent.

Among the most important physiological disorders of the papaya are skin freckles, pulp translucency, pulp softening, and hard lumps in the pulp. All of these disorders appear seasonally, whereby peak occurrences are followed by periods when the disorder is not observed, suggesting an influence of climactic factors on their presence.

1.2.1. Papaya skin freckles

Skin freckles are a disorder of an inorganic nature that occurs most intensely on fruit surfaces directly exposed to solar radiation. Their

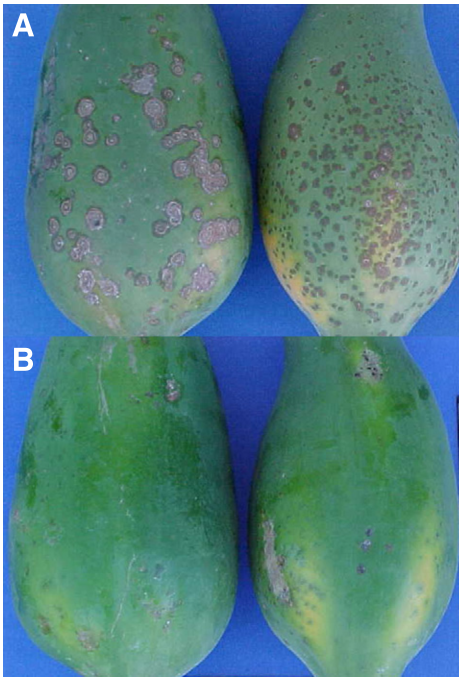

Fig. 1. Photos showing standard symptoms of skin freckles. A — Photo shows the fruit surface that was directly exposed to the sun, exhibiting an increased presence of blemishes. B — Photo shows the other side of the same fruit, which was not exposed to the sun, featuring reduced blemish incidence.

cause is not well-understood despite documentation of this disorder in commercial crops since the 1960s (Ishii & Holtzmann, 1963). Blemishes are visible in both unripe and ripe fruit; the freckles develop during the later stages of fruit maturations and not seen in young fruit. This disorder occurs with minor incidence on cv. Golden of the Solo group. This disturbance appears as superficial dark brown spots on the skin of the fruit. Frequently, these spots increase in size and may engulf several smaller spots forming large circular areas with a corky aspect on the fruit skin, thus causing it to be called "frog skin" or "skin freckles." These discolorations are concentrated on the parts

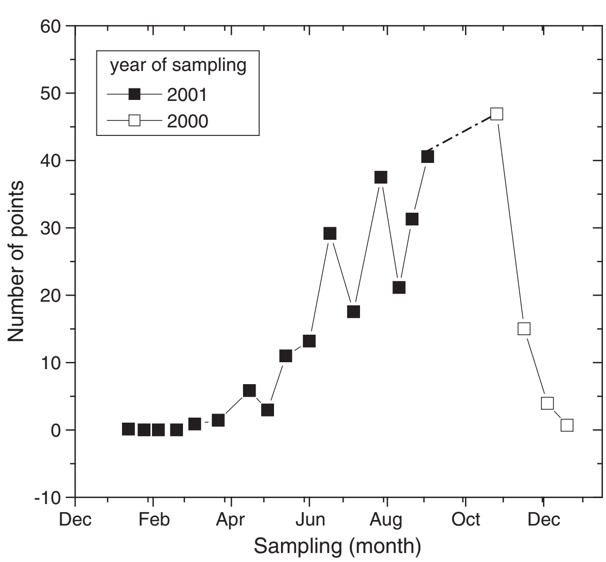

Fig. 2. Standard symptoms for skin freckles in papayas cv. Tainung 01 samples in a commercial orchard in the city of São Francisco de Itabapoana, Rio de Janeiro, Brazil, between the years 2000 and 2001. The number of points is an estimation of the fruit area sampled stricken with the blemish. Each point has an area of 6.25 mm^2.

of the fruit most directly exposed to direct sunlight (Fig. 1) and are most frequently found in the midface of the fruit.

The soil water status for different irrigation depths (Gomes Filho, Oliveira, Pio Viana, & Pereira, 2008) or climatic factors such as rainfall, and solar intensity, in association with plant characteristics, such as transpiratory capacity and fruit development stage, determine the frequency of physiological skin freckles in papaya (Oliveira et al., 2005; Reyes et al., 1994).The genetic feature is predominant in the susceptibly to skin freckles (Oliveira et al., 2005). In Hawaii, Reyes et al. (1994) observed a positive correlation between the occurrence of this disorder and the beginning of the rainy season. Corroborating this information, our research team determined that, in papaya crops in Rio de Janeiro, Brazil, the peak period for skin freckles occurred at the start of spring (Fig. 2).

The most consistent hypotheses with respect to the cause of skin freckles focus on the rupture of the branched laticifers in the sub-epidermal layer as a result of sudden alterations in the internal pressure of these secretory cells (Kaiser et al., 1996; Reyes et al., 1994). The increase in internal pressure of the laticifers' or laticifer's cells could be associated with environmental factors such as excess water in the soil and/or high relative humidity in the air (Reyes et al., 1994), low temperatures, or very high daily thermal amplitudes (Downton, 1981). However, environmental factors alone, acting upon the vegetable tissue, do not appear able to trigger skin freckle symptoms. There is also a greater predisposition of the tissue as a result of the higher number of the laticifer arms near the epidermis (Kaiser et al., 1996) and higher latex soluble solids (Reyes et al., 1994). All of these factors, associated with the genetic characteristics of plant material, may increase the internal pressure of the laticifer cells and consequently increase the occurrence of physiological blemishing.

Some experiments were conducted in Brazil to protect fruits while they were still on the tree, in an attempt to prevent skin freckles. Fruits were bagged in a sheet of aluminized polyethylene (Fig. 3) thirty days before the harvest, reducing the incidence of freckles on the fruit that were bagged when compared to the unbagged fruit. Besides being impractical in the daily management of the crop, bagging of the fruit also increased the incidence of black-spot (*Asperisporium caricae*[Speg.] Maubl.), probably due to the increase in relative humidity in the fruit's immediate environment. Nevertheless, the protection of the fruit with an aluminized layer played an important role in disproving the hypothesis that skin freckles start from cuts or ruptures in the skin fruit, possibly caused by solid particles such as grains of sand carried by the wind.

1.2.2. Papaya pulp flesh translucency

Another disturbance known as pulp flesh translucency is characterized by a translucency or "jelly-like" appearance of the mesocarp (Campostrini et al., 2010; Oliveira et al., 2004; Oliveira et al., 2002, Oliveira et al., 2010; Schripsema et al., 2010). Symptoms gradually spread from the endocarp to the exocarp, yet show no visible outward signs of their presence (Fig. 4). The fruit becomes denser due to the accumulation of low quantities of water in the seed cavities, which

Fig. 3. A and B — Photos showing the bagging of papaya fruit in an orchard in São Francisco de Itabapoana, RJ. The fruit, without any sign of skin freckles, were bagged approximately 30 days before their harvest date.

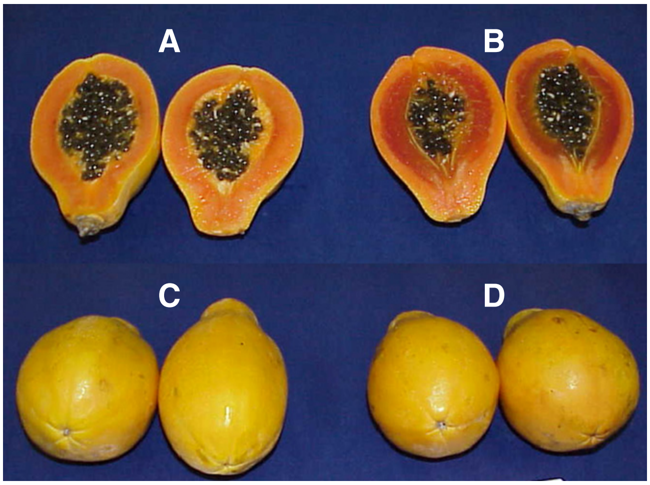

Fig. 4. Top photo shows a cv. Golden papaya fruit with symptoms of pulp flesh translucency (B) compared with a healthy fruit (A). Lower photo shows the outer appearance of the fruit with no symptoms that distinguish it from healthy fruit (C) and from those with flesh translucency (D).

makes the disorder's identification easier in the packinghouse wash tank. Papaya pulp flesh translucency appears from color breakers stage, until the later stages of fruit development while it stay in tree and not seen in mature green fruit (Oliveira et al., 2010). Another typical characteristic of pulp flesh translucency fruit is a kind of "detachment" of the skin and outer layer mesocarp from the rest of the pulp making it possible to remove the skin by hand, not unlike peeling a banana (Fig. 5). Currently, it is believed that only cv. Golden of the Solo variety presents the pulp flesh translucency disorder.

Observation of pulp flesh translucency fruit suggests that, as mentioned earlier, low quantities of water fill the intercellular spaces, resulting in soaking of the mesocarp tissues (Oliveira et al., 2010). Scanning electron microscopy analyses of cuts made on the surface revealed that, in healthy papayas, the pulp tissue shows turgid cells and has normal intercellular spaces (Fig. 6A). However, on pulp flesh translucency, the tissue suggests the loss of water with cells showing loss of content and these cells demonstrate larger spaces between them (Fig. 6B, arrow). The physical state of the pulp flesh translucency can be confused with the process of fruit ripening since ripe fruit loses its pulp firmness. However, the wilting state of the cells as well as the firmness of the pulp (Oliveira et al., 2010) allow one to distinguish pulp flesh translucency from premature ripening of the tissue (Oliveira et al., 2004; Oliveira et al., 2002). By comparing tissue samples of pulp flesh translucency with those of healthy fruit under light microscopy, it is possible to observe larger spaces between the cells in pulp flesh translucency tissue (Fig. 6C and D). Transmission

Fig. 5. Photo showing a cv. Golden papaya fruit with pulp flesh translucency symptoms. It is possible to observe that the skin of the fruit detaches easily from the pulp, a condition not typically found in healthy fruits.

electron microscope analyses did not reveal degeneration of the cell walls, although these images did suggest a reduced rigidity of these cell walls in papayas with pulp flesh translucency (Fig. 6F), when compared to those of healthy fruits (Fig. 6E).

Oliveira et al. (2010) reported that 'Golden' papaya pulp flesh translucency is not related to premature ripening of tissue, and not directly related to a Ca^{++} deficiency in the fruit. Data suggest, rather, that this physiological disorder is caused by a reduction in water entering the vacuole and consequently a loss of cellular turgescence. The presence of soaked tissue may be related to an accumulation of water in the apoplast due to an inability to accumulate intracellular water (Oliveira et al., 2010).

In preliminary analyses, the functions of the pumps present in the plasmatic membrane of the papaya pulp flesh translucency tissues showed a reduction in the supply of energy made available for the transport of ions and other solutions such as sucrose into the cytoplasm (Azevedo et al., 2007), partially explaining the lower concentration of K^{+} and total soluble solids reported by Oliveira et al. (2010) in the pulp tissue of fruits with flesh translucency. According to Azevedo et al. (2007), tissue with pulp flesh translucency presented an increase in the permeability of the tonoplast. These data demonstrate a reduced efficiency of the tonoplast in maintaining the turgor pressure in the cell in the tissue of pulp flesh translucency, which is in keeping with the anatomical characteristics of fruits with plasmolized cells (Fig. 6).

Papaya pulp flesh translucency has been compared to several physiological disorders of fruits, such as internal breakdown or "soft heart," a physiological disorder that occurs in mango fruit. In the case of mangoes, the determining factor in this disorder is a deficiency of Ca^{++} (Saure, 2005; Torres & Saúco, 2004). The Ca^{++} ion is often related to disorders of a physiological nature (Saure, 2005; Chatenet et al., 2000; Ferguson, Volz, & Woolf, 1999; Roper, 1999; Marlow & Loescher, 1984), and is also responsible for the texture of fruits (Liu et al., 2009; Sams, 1999). Marlow and Loescher (1984) reported watercore disturbance in the apple as a direct association with Ca^{++}. Apples with sufficient Ca^{++} are less prone to watercore than those with low Ca^{++} (Roper, 1999). Another important relationship is the accumulation of sorbitol-rich solutions in the intercellular spaces of fruits with watercore. The sorbitol that is transported by the phloem must be converted into fructose to be transported into the cells; when sorbitol is not transported into the cells it concentrates in the intercellular space, causing accumulation of water in this region. The cause is not completely known, although it is hypothesized that the fruit is incapable of converting these sugars at the same velocity as that by which sorbitol is unloading to the fruit (Marlow & Loescher, 1984; Roper, 1999).

Chatenet et al. (2000) describe a physiological disorder in melon called 'water soaking' that is very similar to the flesh translucency of papaya pulp. Using nuclear magnetic resonance (NMR) imaging they showed that water mobility increased in the diseased tissues with increased intercellular spaces and few interconnections. The Ca^{++}concentration in the cell wall of the affected tissue was 100 times less than that of the cell wall of healthy tissue. A calmodulin-binding protein (CaM-BP) was identified as a possible signal marker or determinant of this disorder because it was absent in the tissue that presented water soaking. Another disorder, pineapple translucency (or water soaking) is similar to disorders observed in apples and pears and implies leakage or loss of membrane integrity (Paull & Reyes, 1996).

The symptoms of internal collapse in mangoes, watercore in apple, and water soaking in melon and pineapple, appear slightly similar to those related to papaya pulp flesh translucency. However, fruits with flesh translucency could have multiple causes that lead to same symptoms. Oliveira et al. (2010) showed that Ca^{++} levels were neither different ($P<0.05$) in seeds nor the pulp of the flesh translucency of the papaya when compared with healthy fruit. Similarly, pulp firmness was also not found to differ from that of healthy material (Oliveira et al.,

2010) implying that papaya pulp flesh translucency is unrelated to the Ca^{++} deficiency, but more specifically to the proton pumps (Azevedo et al., 2007).

1.2.3. Pulp softening in papayas

During fruit ripening, intense biochemical changes in cell wall degradation, aroma and color occur (Calegario et al., 1997; Chong, Simsek, & Reuhs, 2009; Devitt et al., 2006; Karakurt & Huber, 2003; Paull, Gross, & Qiu, 1999). In climacteric fruits, physico-chemical changes take place very quickly and are triggered by differential gene expression, enzyme activation and plant hormone ethylene (Fabi, Mendes, Lajolo, & Nascimento, 2010; Fabi, Lajolo, & Nascimento, 2009; Qiu, Lu, Li, & Toivonen, 2009). Fabi et al. (2009) studied cloning and characterization of transcripts differentially expressed in the pulp of unripe and ripe papaya with exogenous ethylene suggested that a DNA sequence of 633 bp may be strongly induced during ripening. This sequence showed high similarity to an endopolyglacturonase (endoPG) from plum (*Prunus persica*), and seemed to correspond to an up-regulated papaya gene. This induction was highly inverse-correlated to the firmness of the fruit pulp, suggesting a role of this endoPG in the pectin degradation process, which could lead to loosening of cell adhesion and pulp softening. However, other's research shows that endoPG is not a major cause of papaya softening. Thumdee, Manenoi, Chen, and Paull (2010) suggest that in normal papaya ripening conditions the softening was dependent upon the expression and activity of endogluconase, β-galactosidase and endoxylanase. These authors show high relationships between endoxylanase activity and papaya softening and its complete activity suppressed in 1-MCP treated fruit. Fruit ripening can be confused with the physiological disorder of pulp softening, since this disorder is generally characterized by a loss of firmness of the entire papaya fruit. However, this loss of firmness can occur in a premature manner, with the fruit still unripe (25–50% ripe). This disorder is of extreme importance in terms of the handling of the fruit postharvest. The manner in which fruit are handled in the packinghouse and especially during transport to the marketplace can compromise any fruit that do not have sufficient firmness to resist mechanical pressure.

The texture of the fruit is the result of the water content and of the composition and/or integrity of the cell walls of the cells of this tissue. Environmental factors, crop management (irrigation, mineral

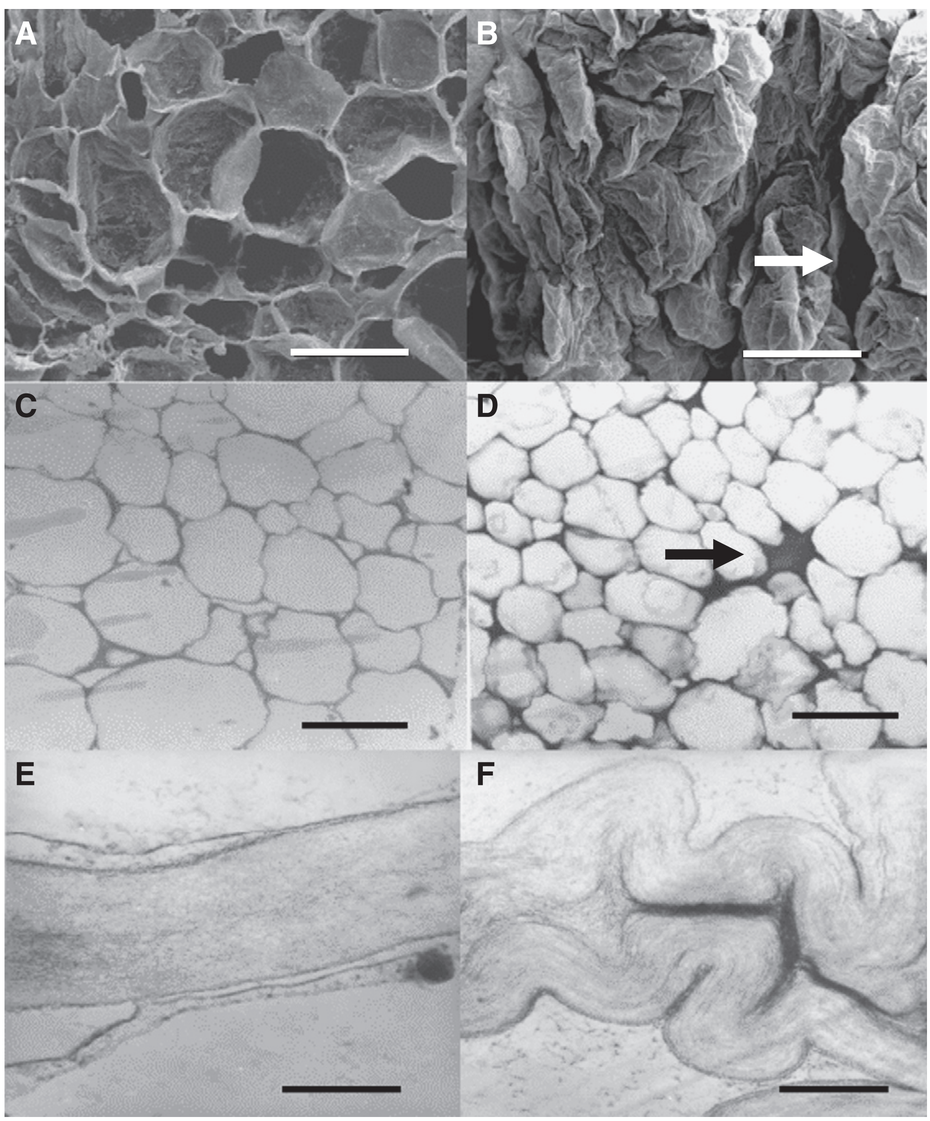

Fig. 6. Samples of healthy (A, C, and E) and flesh translucency (B, D, and F) papaya fruit mesocarp. Scanning electron micrographs (A and B) show plasmolized cells and intercellular spaces in pulp flesh translucency (arrows), Bars = 100 μm. Light microscopy (C and D) shows the intercellular space in pulp flesh translucency (arrow), Bars = 20 μm. Transmission electron microscopy from cell wall (E and F) showing disestablished cell wall in pulp flesh translucency, bars = 0.5 μm. Source: Oliveira et al. 2010.

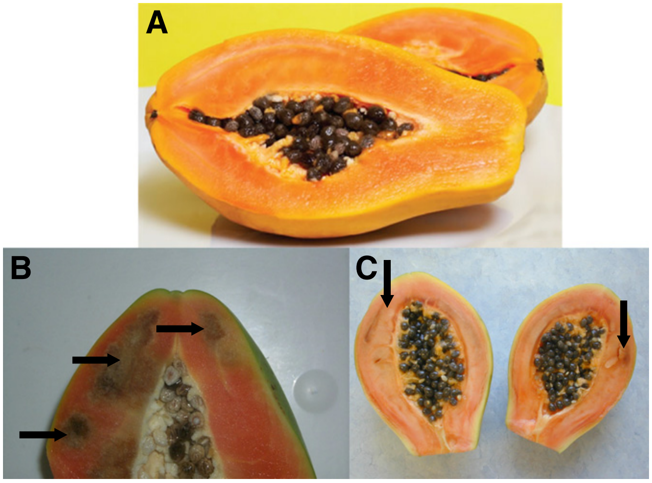

Fig. 7. Photos showing healthy papaya (*C. papaya* L.) fruit (A), and with symptoms of hard lumps in the pulp (B and C, arrows). Photos B and C were kindly provided by Dr. M. Suzuki, Caliman Agrícola S/A, Linhares, ES.

nutrition, etc.), and physiological and genetic factors are among the principal components related to fruit texture (Devitt et al., 2006; Fabi et al., 2009; Paull et al., 1999).

Fruits are organs of low transpiratory capacity (Paull & Chen, 1989). In the case of the papaya, which is a fleshy fruit, the alterations in the texture of the fruit are most likely more related to transformations in the constituents of the cell wall (cellulose, pectins, and hemicellulose) than to a loss of water associated with environmental conditions (Fabi et al., 2009; Karakurt & Huber, 2003; Paull et al., 1999).Among the environmental factors that affect fruit texture, light intensity and the temperatures at which fruits develop are the most important to consider (Sams, 1999). In regards to temperature and its effect on texture, the periods of the year that register the most moderate temperatures (average of 22 °C) are those that produce fruits of the highest firmness. This response pattern derives from a reduction in cell size resulting in a denser tissue in fruits that developed at lower temperatures (Sams, 1999).

A determining factor in the final texture of papaya fruit is the nutritional aspect of the papaya plant. The elements most closely related to pulp firmness are: N, P, K^+, and Ca^{++} (Sams, 1999; Saure, 2005). Often the imbalance in the supply (availability in the soil) of one of these mineral elements can result in an alteration in assimilation with the others, causing undesirable effects in the pulp firmness of the fruit (Ferguson et al., 1999; Saure, 2005). A relationship between the supply of high doses of N and a loss of firmness has been documented (Campostrini et al., 2010; Ferguson et al., 1999; Sams, 1999). By all indications, this is caused by a negative action of an excess of N on the capacity of mesocarp tissue to accumulate Ca^{++} (Qiu, Nishina, & Paull, 1995; Saure, 2005). Calcium is a fundamental cell wall element, forming Ca^{++}cross-linking between complex structures that are part of the pectin molecule, promoting the stability of this intricate component molecule of the primary cell wall and the middle lamellae (Willats, Knox, & Mikkelsen, 2006). Loss of pulp firmness during fruit ripening can be preceded by a loss of Ca^{++}, or of its binding sites, of the cell wall structure, and of the middle lamellae (Qiu et al., 1995). A phosphorous deficiency was also correlated to a loss of pulp firmness, but only in fruits that also had low levels of Ca^{++} (Sams, 1999), which suggests once more that the final determining factor in the maintenance of pulp consistency is the Ca^{++} content of the tissue.

Research has shown that K^+ is not directly related to alterations in fruit texture in papayas (Qiu et al., 1995). This element has an important participation in the hydraulic potential of the tissue. Together with the sugars, K^+ is the main solute-osmotic component of the cell, capable of promoting a reduction in the hydraulic potential of the mesocarp tissue,

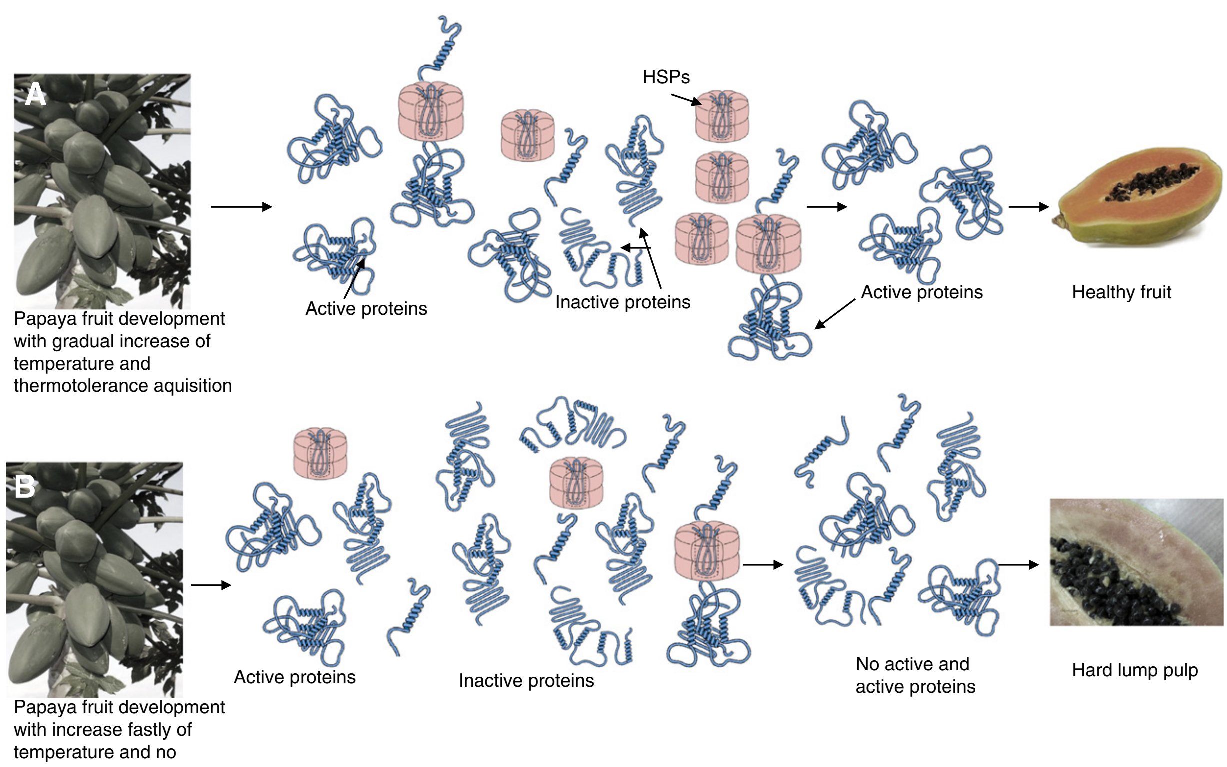

Fig. 8. Schematic diagram shows the role of the heat shock proteins (HSPs) in ripening papaya fruit. (A) Papaya fruit development with gradually increase of temperature and thermotolerance acquisition: ripening fruit normally with softness pulp. (B) Papaya fruit development with fast increase of temperature and no time for thermotolerance acquisition: disruption of the ripening with hard lump. Note the higher presence of HSPs and active proteins in A.

thus promoting water movement toward the fruit and, with it, Ca^{++}. As can be seen, the main effect of K^+ is an indirect one on the hydraulic potential and/or Ca^{++} content in the fruit.

1.2.4. Hard lumps in papaya pulp

The disorder known as "hard lump in pulp" has been reported by some authors (Paull, 1995; Paull & Chen, 1990; Woolf & Ferguson, 2000). It is caused by the inactivation of the degradation enzymes in the cell wall in response to stress brought on by high temperatures. These same enzymes inhibit the emission of ethylene and alter the color of the papaya skin and pulp (Paull, 1995). The disturbance is characterized by the formation of clearly marked areas on the mesocarp in which the tissue is much firmer than in the neighboring areas (Fig. 7). The fruit does not present external symptoms that would distinguish it from unaffected fruits.

High temperature stress can be minimized when the organism develops tolerance to this factor. This thermotolerance can be stimulated artificially (Paull & Chen, 1990) or result from naturally occurring conditions in the growing environment; i.e., from pre-harvest climatic conditions (Paull, 1995; Woolf, Bowen, & Ferguson, 1999). One of the factors thought to cause thermotolerance is the synthesis of more heat shock proteins (HSPs), low molecular weight proteins able to revert or impede the denaturing and/or aggregation of other proteins (Fig. 8) when thermal stress occurs (Queitsch, Hong, Vierling, & Lindquist, 2000; Voet & Voet, 1995). However, the HSPs are not produced only under conditions of thermal stress. During the study of differentially expressed genes associated with papaya ripening (exposed or not to exogenous ethylene), Fabi et al. (2010) showed that the genes related to the productions of HSPs (such as involved in ethylene biosynthesis and regulations of transcription) are the most expressed during ripening.

In many cases the seasonal nature of physiological disorder occurrences related to high temperatures is purely a differential response due to the acquisition of thermotolerance (or lack thereof) induced by natural temperature oscillations that occur during fruit formation and ripening. When climatic conditions (temperature) favor the occurrence of thermal stress and(or) when there is insufficient time to develop thermotolerance, the organism will be under stress, a situation which can trigger hard lumps in the pulp. Paull (1995) related the thermosensitivity of papaya fruit (cv. Sunset) to the occurrence of moderated temperatures during the three days before these fruit were harvested. According to the author, exposing papaya fruit for three days in the field to minimum temperatures above 22.4 °C was responsible for the acquisition of thermotolerance in these fruit, preventing the disruption of the softening process in the pulp induced by standard hydrothermal treatment (42 °C for 30 min followed by 20 min at 49 °C).

Another fruits as banana, tomato, apples and pear when exposed to elevated temperature, presented a disruption of fruit ripening with failure to develop normal pigmentation, little softening, and significant decline in ethylene production (Liu, 1978; Lurie, Handros, Fallik, & Shapira, 1996; Maxie, Mitchell, Sommer, Snyder, & Rae, 1974; Yang et al., 2009). According to Picton and Grierson (1988), high temperature may lead to inhibition and or reduced expression of softening and ripening-related mRNAs. At the same time as to Paull and Chen (2000), the amount of sensitivity or tolerance to heat stress of a commodity is related to the level of heat protective proteins at harvest and the postharvest production of heat shock proteins. Finally, according those authors the site of the injury lesion is still unknown and could be associated with transcription, translation and cellular recovery capacity after an injury threshold has been exceeded.

2. Conclusion

Papaya consumption occurs worldwide, with the U.S. and Europe constituting the main consumer markets. The fruit is grown in various tropical countries of the world, led by Brazil, with 25% of world production, Mexico (14%), Nigeria (11%), India (10%), and Indonesia (10%). Among its notable nutritional characteristics, elevated levels of vitamins A, B_1, B_2 and C are commonly cited, as well as being an excellent source of sugars; glucose, fructose, and sucrose compose a total of up to 13% of the fresh fruit weight. The papaya aroma is principally due to esters, where ethyl butanoate, ethyl acetate, ethyl hexaonate and ethyl 2-methyl butanoate are the most potent odor compounds. From a pharmacological point of view, the papaya has been cited as a laxative, antifertility agent, and meat tenderizer, among other uses. Despite this, some physiological disorders compromise the quality of the fruit. The principal culprits are: 1) skin freckles, which seem to be related to latex leaking, 2) pulp flesh translucency, possibly promoted by a reduction in the entrance of water in the vacuole and accumulation of water in the apoplast, 3) pulp softening, which occurs in response to Ca^{++} deficiencies in the development of the fruit, and 4) hard lumps in the pulp, caused by the inactivation of cell wall hydrolases enzymes as a result of stress brought on by high temperatures. These disorders contribute negatively to crop development, diminish the quality of the fruit, and reduce their shelf life.

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