

Review

A review on the integrated agro-technology of papaya fruit

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The aim of this review was first to explore the effect of different pre-harvest factors affecting the quality of papaya including genetic factors, climatic conditions, cultural practices on post-harvest quality of the papaya fruit. Post-harvest physiology of papaya in terms of its respiration, ethylene production and sensitivity and transpiration was reviewed. Post-harvest handling and factors affecting quality of papaya were also examined. Post-harvest biochemistry of papaya including enzyme activity, carbohydrates, organic acids, pigments and volatiles in papaya fruit were assessed. A review on post-harvest handling of papaya fruit including packaging and storage environments (temperature and relative humidity) were presented. On the other hand, the post-harvest microbiology of papaya was reviewed. Papaya supply chain is much limited to local destinations with quite few exceptions mainly due to lack of integrated post-harvest handling technologies. Pre- and post-harvest treatments were found to have a significant effect on post-harvest quality of papaya and the fruit storage stability under dry and hot climatic conditions of Africa. An integrated agro-technology research and development approach aimed at improved yield and quality at harvest as well as the maintenance of qualities of papaya fruit in order to encourage farmers to produce and for marketing of the papaya fruit under African local supply chain conditions and for export market is recommended.

Key words: Papaya fruit, post-harvest, agro-technology, pre-harvest.

INTRODUCTION

In spite of the great potential Africa has, the fruit industry has not been contributing much to the economy of the countries in the regions. Compared to developed countries, production and consumption of fruit is relatively low in Africa (Emana and Gebremedhin, 2007), while the needs for nutritional compositions originating from fruit are high across the continent. Cultivars have not been well identified for various potential agro-ecologies and for different purposes, either for fresh consumption or industrial product development (EARO, 2001). In addition to production problems, post-harvest technologies have also not been well developed for most of the major fruit crops including papaya in Africa (Workneh and Woldetsadik, 2004; Workneh et al., 2011a, b).

Although, several researches have been done on both production and post-harvest handling of papaya elsewhere, there is less adoption or application of the research results to solve both papaya production and fruit post-harvest handling problems under African background. Therefore, the present study was initiated to review the current research development on an integrated agro-technology of papaya fruit including the pre-harvest treatments and the post-harvest handling aspects of the papaya, aiming at producing recommendations for future shelf life improvement research and development activities.

The papaya crop

Papaya (*Carica papaya* L.), is native to tropical America and is now cultivated in every tropical and subtropical

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countries (Samson, 1986; Paull, 1993). It is the most economically important fruit in the *Caricaceae* family. The plant can be monoecious, dioecious or hermaphrodite. Papaya is cultivated for its fruits, consumed both fresh and as a processed product worldwide (Sankat and Maharaj, 2001; Chonhenchob and Singh, 2005). A variety of products such as jam, jelly, nectars, icecream sherbet, yogurt, fruit leather and dried slices may also be made from the ripe fruit. Unripe papaya makes a good concoction of vegetable stew, salad or pickle. The milky latex of the unripe fruit, leaves and other parts of the plant contains papain, a proteolytic enzyme that digests proteins. Papain is used as a meat tenderizer and for medical and industrial purposes (Desi and Wagh, 1995; Sankat and Maharaj, 2001).

Fruit and seed extracts have pronounced bactericidal activity. The seeds of unripe fruits are rich in benzyl isothiocyanate, a sulphur containing chemical that has been reported to be an effective germicide and insecticide. Carpaine, an alkaloid found in papaya leaves, has also been used for medicinal purpose (Sankat and Maharaj, 2001). Papaya can be used as a diuretic (the roots and leaves), anthelmintic (the leave and seed) and to treat bilious conditions (the fruit). Parts of the plant are also used to combat dyspepsia and other digestive disorders and a liquid portion has been used to reduce enlarged tonsils. In addition, the juice is used for warts, cancers, tumors, corns and skin defects while the root is said to help tumors of the uterus. Root infusion is also used for syphilis, and the leaf is smoked to relieve asthma attacks. The Javanese believe that eating papaya prevents rheumatism and in Cuba, the latex is used for psoriasis, ringworm and the removal of cancerous growth (Dawson, 1998).

Papaya is a very wholesome fruit, and it is an excellent source of vitamin C and A. It is relished for the attractive pulp color, flavor, succulence, and characteristic aroma (Desi and Wagh, 1995). The fruit contains about 85 to 90% water, 10 to 13% sugar and 0.6% protein, as well as vitamins A, B₁ and B₂, iron, calcium, and phosphorous. The nutritional value of the fruit depends on the cultivar, ecological factors during the developmental phases of the fruit and the stage of maturity at which it is consumed (Sankat and Maharaj, 2001). Major commercial production of papaya is found primarily between 23° N and S latitudes. Papayas are grown in a variety of soil types, with most essential soil requirement being drainage. A porous loam or sandy loam soil is preferred. Optimum temperature range is between 21 and 33°C. Papaya is extremely sensitive to frost and if the temperature falls below 12 to 14°C for several hours at night, growth and production are severely affected (Nakasone and Paull, 1999).

Emana and Gebremedhin (2007) indicated that papaya is widely grown, followed by orange, mandarin and bullock's heart in Eastern Ethiopia. Early works on papaya were carried out at Melkasa, Woror and Jimma,

including adaptation trials on cultivars such as Solo and Coorg Honey. Solo fruits at Melkasa were found to be superior in taste as well as in keeping quality. Effort were also made to collect, evaluate and maintain different papaya materials from central rift valley to come up with superior materials that are resistant/tolerant to the existing diseases, suitable for fresh and processing and high in fruit yield (EARO, 2001). Currently, papaya production in Ethiopia is estimated to be about 230000 tons from about 11000 ha of land (FAO, 2005b).

PRE-HARVEST FACTORS AFFECTING THE QUALITY OF PAPAYA

The provision of good quality produce starts with the use of good planting material and the growing of cultivars acceptable to the market (Burdon, 1997). While the post-harvest handling system starts with the harvest, pre-harvest factors can influence the final quality. Post-harvest product quality develops during growing of the product and is maintained, not improved, by post-harvest technologies (Hewett, 2006). The nutritional composition of a fruit at harvest can vary widely depending on cultivar, maturity, climate, soil type, and fertility. For example, the ascorbic acid content of different cultivars may differ by a factor of 2 to 3 or higher in many fruits and vegetables (Lee and Kader, 2000). Bananas and papayas increase in carotenoid content with maturation and ripeness, but ascorbic acid content can decrease in bananas and increase in papayas during ripening (Lee and Kader, 2000). Also, ascorbic acid levels in fruit are influenced by the availability of light to the crop and to individual fruits. Even within a cultivar, there is large plant-to-plant variation and within-plant variation in nutrient composition for fruit harvested from the same field (Shewfelt, 1990).

Genetic factors

Wide variability is shown by the papayas grown in various countries. It is true that the physico-chemical parameters of papaya varieties differed from one another, which are supposed to be due to different genetic makeup of the variety and also because of the difference in their total fruit development and ripening period (Selvaraj et al., 1982; Desai and Wagh, 1995). The authors indicated that Solo cultivars that are known to have desirable characteristics and are the most important commercial varieties have variations in their fruits. Cultivars, such as Kapoho, Sunrise, Sunset and Waimanalo, have different characteristics. Sunrise has red flesh color while others are yellow. Of these, Waimanalo was indicated to have higher fruit mass and higher marketable fruit (Nakasone and Paull, 1999; Sankat and Maharaj, 2001).

For cultivation, papaya cultivars with only hermaphrodite trees are generally preferred because the

andromonoecious types are heterozygous and their phenotypic form is much affected by environment. Temperature, soil moisture and plant vigor all affect this variability (Desai and Wagh, 1995). In hermaphroditic cultivars, proper selection and self pollination can stabilize characteristics at more rapid rate. Fruits from bisexual plants are usually cylindrical or pyriform with small seed cavity and thick wall of firm flesh which stands handling and shipping well. In contrast, fruits from female flowers are nearly round or oval and thin-walled (Nakasone and Paull, 1999).

Climatic conditions

Climatic factors, in particular temperature and light intensity, have great impact on the nutritional quality of fruits and vegetables. Consequently, the location of production and the season in which plants are grown can determine their ascorbic acid, carotene, riboflavin, thiamine, and flavonoid contents (Knee, 2002). In general, the lower the light intensity, the lower the ascorbic acid content of plant tissues; best quality papaya fruit, which is determined largely by sugar content, develops under full sunlight in the final four to five days to full ripeness on the tree (Samson, 1986).

Temperature influences the uptake and metabolism of mineral nutrients by plants, since transpiration rates increase with increasing temperature. Lower temperature (less than 10°C) decreases fruit growth, sweetness, and fruit size of papaya. It also influences flower sex and fruit setting (Desai and Wagh, 1995). For example, stamen carpelody is expressed under cool temperatures, with increasing severity at lower temperatures in the coming 40 days before anthesis. The fruit that develop from this carpelody are severely misshapen and unmarketable (Sankat and Maharaj, 2001). At higher temperatures (>35°C), there is a tendency of bisexual cultivars to form functional male flowers with poorly developed and non functional female parts. This tendency varies with cultivars and within a cultivar (Nakasone and Paull, 1999). The results by Nunes et al. (2006) indicate that fluctuating and/or high or low temperatures that are often encountered for as little as a few hours during handling operations, may result in a considerable amount of papaya rejected.

Rainfall affects water supply to the plant, which may influence the composition of the harvested plant part and its susceptibility to mechanical damage and decay during subsequent harvesting and handling operations (Sankat and Maharaj, 2001). Papaya responds well to adequate irrigation, which helps rapid fruit development and regular fruit yield. Adequate moisture levels result in normal growth; lower levels shift the plants toward sterility, while higher levels result in production of misshaped carpelodic fruit (Desai and Wagh, 1995; Nakasone and Paull, 1999).

Cultural practices

Soil type, mulching, irrigation, and fertilization influence the water and nutrient supply to the plant, which can in turn affect the nutritional quality of the harvested plant part. The effects of mineral and elemental uptake from fertilizers by plants are, however, significant and variable. High calcium uptake in fruit has been shown to reduce respiration rates and ethylene production, delay ripening, increase firmness, and reduce the incidence of physiological disorders and decay, all of which result in increased shelf life. High nitrogen content, on the other hand, is often associated with reduced shelf life due to increased susceptibility to mechanical damage, physiological disorders, and decay (Kader, 2002; Kader and Rolle, 2004). Over feeding of papaya with nitrogen results in soft fruit (Desai and Wagh, 1995).

Papaya fruit diseases generally occur after harvest. The incidence of some of these diseases can be minimized by field sanitation and field application of appropriate fungicides. The use of pesticides and growth regulators does not directly influence fruit composition but may indirectly affect it due to delayed or accelerated fruit maturity (Paull and Armstrong, 1994; Nakasone and Paull, 1999). Fruit quality and storage behavior are influenced greatly by maturity of fruit at harvest. Immature fruits are more subject to shriveling and mechanical damage, and are of inferior flavor quality when ripe. Overripe fruits are likely to become soft and mealy, with insipid flavor soon after harvest. Fruits picked either too early or too late are more susceptible to post-harvest physiological disorders than fruits picked at the proper maturity. Most of the fruits reach their best eating quality when allowed to ripen on the plant. However, some fruits are usually picked mature but unripe so that they can withstand the post-harvest handling system when shipped long-distance (Wills et al., 1989; Kader and Płocharski, 1997).

One of the major problems facing papaya fruit marketing is identification of optimum harvest maturity to ensure adequate fruit ripening to good eating quality. Hawaii specifies a minimum total soluble solid of 11.5% and fruit showing at least 6% surface coloration at the blossom end region (Quinta and Paull, 1993). Subjective evaluation based on change in color is usually used in practice to judge maturity. Softness to touch is also used as a ripening index. The change of latex color (from white to watery), is an indication of maturity (Sankat and Maharaj, 2001). Papaya fruits should be harvested when the color of the skin changes from dark green to light green and when one yellow streak begins development from the base upwards. Fruits in this condition will continue to ripen normally after harvest. Those fruits harvested before this stage could fail to show complete ripening while those harvested later could be more susceptible to damage and bruising during handling (Paull, 1993). So, fruit should have started ripening

before harvest, as indicated by some skin yellowing. Less mature fruit are lower in sugar and ripen poorly (Kader, 2006).

Depending on the cultivars' ripening characteristics and season, papayas are usually harvested at color break of $\frac{1}{4}$ yellow for export or at $\frac{1}{2}$ to $\frac{3}{4}$ yellow for local markets. Flesh color changes from green to yellow or red (depending on cultivar) as the papayas ripen (Paull et al., 1997; Kader, 2006). Desi and Wagh (1995) reported that Solo papayas picked at three-quarters-ripe stage, according to color development, can be stored for 21 days at 7°C while less ripe papayas stored at temperatures below 20°C were subjected to chilling injury and loss in quality (Quinta and Paull, 1993). Paull, (1993) reported ripening rate variation among cultivars, with a range of 7 to 16 days from the color break stage. The rate of softening could differ between cultivars with respect to the rate of respiration, ethylene production, skin greening and flesh color development (Paull, 1993).

POST-HARVEST PHYSIOLOGY OF PAPAYA

Following harvest, the quality of papaya fruit may be considerably reduced by several factors. Similar to other fruits, shelf life of papaya can be affected by intrinsic factors such as respiration, biological structure, ethylene production and sensitivity, transpiration, compositional changes, developmental processes and physiological breakdown (Proulx et al., 2005; Irtwange, 2006).

Respiration

A major metabolic process taking place in harvested produce or in any living plant product is respiration. Respiration is a process by which stored organic materials, carbohydrates, proteins, fats and other organic materials are broken down into simple end products, with a release of energy. During the respiration process, there is a loss of stored food reserves in the commodity. This leads to hastening of senescence because the reserve that provides energy is exhausted (Wills et al., 1989; Paull, 1993; Kays, 1997). The energy released as heat could affect post-harvest technology considerations, such as estimations of refrigeration and ventilation requirements. The rate of respiration of harvested commodities is inversely proportional to the shelf life of the product; a higher rate decreases shelf life (Lee et al., 1995). Respiratory activity is markedly affected by temperature and modified atmosphere. Respiration rates alter during a commodity's natural process of ripening, maturity and senescence (Desi and Wagh, 1995; Irtwange, 2006).

Based on post-harvest respiratory patterns, fruits are classified as climacteric and non-climacteric. Climacteric fruits like papaya experience a marked and transient increase in respiration during their ripening, which is

associated with increased production of and sensitivity to ethylene (Desi and Wagh, 1995). The sudden upsurge in respiration is called the 'climacteric rise', which is considered to be the turning point in the life of the fruit. After this, the senescence and deterioration of the fruit begin. To extend the post-harvest life of climacteric fruits, their respiration rate should be reduced as far as possible (Paull, 1993; Irtwange, 2006).

Generally, the loss of freshness of perishable commodities depends on the rate of respiration. An increase in respiration rate hastens senescence, reduces food value for consumers and increases the loss of flavor and salable weight. The loss of substrate from stored plant products results in a decrease in energy reserves within the tissue, which in turn decreases the length of time the product can effectively maintain its existing condition (Kays, 1997; Workneh, 2002). The removal of oxygen from the storage environment is another important effect of respiration. If the ambient oxygen concentration is allowed to be excessively depleted, anaerobic conditions occurs that can rapidly spoil many plant products. As a consequence, the rate of respiration is important for determining the amount of ventilation required in the storage area. It is also critical in determining the type and design of packaging material that can be used, as well as the use of artificial surface coatings on the product (Kays, 1997).

The post-harvest life of fruit can thus be extended through low oxygen concentration and slightly high carbon dioxide level and decreasing the storage temperature. The optimum gas composition is the range of oxygen and carbon dioxide level that would minimize physiological disorder, reduce respiration rate and ethylene production during storage (Kays, 1997). A decrease in the rate of respiration increases the shelf life of fruits (Wills et al., 1989).

Ethylene production and sensitivity

Physiologically, papaya is a climacteric fruit with typical respiratory and ethylene production patterns during ripening. At the onset of ripening, respiration rises to a maximum (the climacteric peak) and subsequently declines slowly. The respiratory climacteric is just preceded with a similar pattern of increased ethylene production (Sankat and Maharaj, 2001; Bron and Jakomino, 2006). The increase in ethylene production parallels the respiration rise and reaches a maximum of the same time as the respiratory climacteric (Tuker, 1993). One of the effects of storage under modified atmosphere packaging is for levels of ethylene produced by the fruit to diminish, along with changes in color and texture changes, while changes in sugars and acids responsible for some of the flavor proceed normally (Wills et al., 1989). Lazan et al. (1990) reported that there was a concomitant decrease in internal ethylene concen-

tration of papaya fruit packaged with polyethylene film, which may be instrumental in delaying ripening of the sealed fruit.

The rate of ethylene production of papaya fruit stored at 20°C ranges from 10 to 100 $\mu\text{l kg}^{-1} \text{h}^{-1}$ (Nakasone and Paull, 1999). Studies on ethylene production in papaya have involved measurement of ethylene forming enzyme activity in different tissues of the fruit during ripening (Paull, 1993). Ethylene forming enzyme activity was found to be maximum in the exocarp of three-quarter-ripe fruit (Sankat and Maharaj, 2001). The level of 1-amino-1-cyclopropane carboxylic acid (ACC), the substrate for ethylene forming enzyme, is initially low in fruit mesocarp tissue during ripening, increasing three-fold when the peak of ethylene synthesis occurs (Sankat and Maharaj, 2001). Ethylene treated papayas ripened faster and more uniformly in terms of skin degreening, softening and flesh color. Since papaya ripens from the inside outwards, the effect of ethylene treatment is to accelerate the rate of ripening of the mesocarp tissue nearer the skin that has not started to soften. The already well-softened mesocarp that is near to the seed cavity is not responsive to ethylene. Ethylene is not recommended commercially, as the rapid softening severely limits marketing time (Paull et al., 1997). Thus, fruits can be kept in pre-climacteric (non-ripened state) by controlling atmospheric gas composition in special storage or modifying the atmosphere with in a package. Packaging that absorbs ethylene, carbon dioxide, or oxygen is being developed to control or retard the ripening process (Desi and Wagh, 1995).

Transpiration

Transpiration is the evaporation of water from plant tissues. It is a very important cause of produce deterioration, with severe consequences. Water loss is first, a loss of marketable weight and then adversely affects appearance (wilting and shriveling). Also, the textural quality is reduced by enhanced softening, loss of crispness and juiciness, followed by reduction in nutritional quality (Wills et al., 1989). The nature of the epidermal system of the commodity governs the regulation of water loss that is affected, as well as by environmental factors. Eventually, transpiration is a result of morphological and anatomical characteristics, surface-to-volume ratio, surface injuries and maturity stage on the one hand, and relative humidity, air movement and atmospheric pressure on the other (Wills et al., 1989; Irtwange, 2006).

Harvested fruits continue to respire and lose water the same way they do when they are attached to the parent plant, the only difference being that losses are not replaced in the post-harvest environment. Loss of mass in tropical fruits, mainly as loss of water, is dependent upon the commodity, cultivar, pre-harvest conditions, water-vapor pressure deficit (WVPD), wounds, post-

harvest heat treatments and the presence of coatings or wraps (Burdon, 1997; Nakasone and Paull, 1999). After harvest, continuing transpiration in the absence of a supply of water may soon dehydrate plant tissue, since the water potential of warm and relatively dry air is much lower than the plant tissue. This increased transpiration demand is the result of an increasing vapor pressure deficit, associated with increasing temperature and falling relative humidity. When water containing material, such as fruit placed in an enclosure filled with air, the water content of the air increases or decreases until the equilibrium relative humidity is reached; that is when the number of water molecules entering and leaving the vapor phase is equal (Wills et al., 1989).

Tropical fruits water loss varies between about 0.1 and 0.3% $\text{day}^{-1} \text{mbar WVPD}^{-1}$ (Irtwange, 2006). Fruit that have lost 6 to 8% of their fully turgid initial weight begin to show signs of mass loss. Papaya belongs to fruits with high moisture loss rate (Nakasone and Paull, 1999). Gradient in water deficit which is a parallel gradient in tissue softness, occurs in the mesocarp tissue of papaya fruit (Lazan et al., 1990). The authors noted that, packaging of papaya with polyethylene film retard the development of water stress and softness in the fruit tissues.

Mechanical damage can greatly accelerate the rate of water loss from produce. Bruising and abrasion damages the surface organization of the tissue, thereby allowing much greater flux of water vapor through the damaged area. Loss of mass, besides affecting overall appearance, is also an economic loss if fruit is sold by weight. Transpiration rates (water loss from produce) are determined by the moisture content of the air, which is usually expressed as relative humidity. At high relative humidity, produce maintains salable weight, appearance, nutritional quality and flavor, while wilting, softening and juiciness are reduced (Nakasone and Paull, 1999).

POST-HARVEST BIOCHEMISTRY OF PAPAYA

Enzyme activity

During papaya fruit ripening, there is a good relationship between measures of ripening, respiration, ethylene production and skin color, and wall-degrading enzymatic activity. The enzymes reported include polygalacturonase (PG), pectin methylesterase (PME), xylanase and cellulase. There is a relationship between PG and xylanase and fruit softening (Paull et al., 1999). The peak in xylanase and PG activity occurs when the fruit has 40 to 60% skin yellowing (Paull, 1993).

In papaya, the rapid loss in firmness during ripening at ambient (25°C) temperature was associated closely with increase in activity of PG, PME and β -galactosidase, as well as depolymerisation of cell wall pectins. Modified atmosphere packaging and moderately low temperature

treatments delayed as well as retarded firmness decrease, with the former being more effective than the later in retarding texture change, particularly when the fruit was stored below ambient (15°C) temperature (Lazan et al., 1993). In a similar way, Lazan et al. (1990) noted that fruit softening was retarded in papaya fruit packed with polyethylene film. This was attributed partly to decrease both in PG activity and in polyuronide solubilization.

Pectinesterase activity showed an increase in the later stages of ripening coinciding with softening of the pulp. Cellulase and pectin methylesterase activity were reported to increase from the start of the climacteric peak in respiration, declining when the fruit becomes over ripe (Sankat and Maharaj, 2001). The activity of β -galactosidase also increased during ripening, but unlike PG activity it was found to be consistently higher in the outer mesocarp than inner mesocarp. In line with this, it was thought that β -galactosidase significantly contributes to pectin and hemicellulose modification and thereby softening of fruits (Paull et al., 1999; Sankat and Maharaj, 2001).

According to Lazan et al. (1995), PG and PME activities increased continuously concomitant with pectin solubilization. It was suggested that solubilization and depolymerization are two independent events and that PG has an important role only in pectin solubilization, without intervention in softening. Also, it was observed that β -galactosidase activity increased rapidly only during last ripening stages, coincident with the most accelerated firmness drop. However, they were not able to relate this enzyme to the softening mechanism, once its activity in the internal mesocarp was found to be lower than in the external portion, contrasting with degree of softening observed in these tissues.

Carbohydrates

The largest quantitative change associated with ripening is usually the breakdown of carbohydrate polymers, especially the near total conversion of starch to sugars. This alters both the test and texture of the produce. The increase in sugar renders the fruit much sweeter and therefore, more acceptable (Wills et al., 1989).

Carbohydrates are the most abundant biochemical constituents in fruits and represent about 80 to 50% of the total dry weight. They function as form of stored energy reserves and make up much of the structure framework of the cells (Kays, 1997). Ripe papaya contains 10 g of carbohydrate per 100 g of edible portion of raw fruit (Sankat and Maharaj, 2001). The principal carbohydrates in papaya fruit are sucrose, glucose and fructose. In the early stages of fruit development, glucose is the predominant sugar while at pre ripe and ripe stages, sucrose increases by two to five-fold, reaching higher level in the fruit than those of fructose and

glucose. Total sugar content of the fruit showed positive correlation with fruit weight. The invertase activity increases during ripening, causing the breakdown of sucrose to fructose and glucose (Sankat and Maharaj, 2001). Starch declines during fruit development to 0.1% dry weight in ripe papaya mesocarp tissue (Paull, 1993). In some fruits, approximately equal quantities of glucose and fructose are formed due to hydrolysis of starch. However, as storage time advances, especially in fruits, the content of all three free sugars (sucrose, glucose and fructose) declines. Several factors contribute towards the excessive decline of sugars during storage, such as fruit maturity, storage temperature, concentration of O₂, N₂, ethylene and CO₂. Higher temperature favors faster utilization of sugars as substrate in the respiration process (Willey, 1994).

Organic acids

Non-volatile organic acids form the major portion (80 to 90%) of total acidity in fruits. Citric acids and malic are the predominant acids, but tartaric, malonic, fumaric and succinic acids could also be present (Sankat and Maharaj, 2001). The authors have observed a slight increase in total acidity during ripening, which is believed to be associated with an increase in free galacturonic acid. Camara et al. (1993) reported an increase in total acidity of Solo papayas from 0.34 to 1.04 g100⁻¹ g during 20 days of storage at ambient condition.

The pH of papaya pulp ranges from 4.55 to 5.9, and the total titratable acidity (TA) calculated as citric acid is 0.2 to 1.4% (Senait et al., 1992; Camara et al., 1993). According to Paull (1993), 80% of the titratable acidity of papaya is made up of ascorbic acid which together with malic, citric and α -ketoglutaric acid make the total titratable acid. Total volatile acids contribute 8% of the total titratable acidity. Malic and citric acid are formed in about equal amounts; being ten times more abundant than α -ketoglutaric acid, malonic acid, fumaric acid and succinic acid. Ascorbic acid of papaya quadruples during fruit ripening. Bron and Jacomino (2006) reported that ascorbic acid (AA) content of papayas increased 20 to 30% during ripening, independent of the maturity stages at harvest. Wills and Widjanarko (1995) also noted that the AA content increased till before the fruit developed full yellow color. TA showed increasing trend to a maximum about the time of attaining full yellow color. Lazan et al. (1990) indicated that, seal packaging of papaya with polyethylene film reduced the amount of titratable acidity during ripening at 24 to 28°C.

Pigments

The progressive increase in softness of the tissue together with a change in color of the skin or flesh and a

production of a wide spectrum of aroma compounds are some of the most easily recognizable changes that accompany ripening in climacteric fruit (Hobson, 1981). Many changes in pigments may occur during development, maturation and ripening on the plant. Some may continue after, or start only at harvest. These changes, which may be either desirable or undesirable, occur as a result of loss of chlorophyll, development of carotenoids (yellow, orange and red colors), and development of anthocyanins and other phenolic compounds (Irtwange, 2006).

During ripening, the color of the pulp of papaya fruit turns yellow or reddish. The carotenoids (provitamin A) content estimated as β -carotene, could increase to five to ten fold in yellow fleshed cultivars between the mature green stage and the full-ripe stage. In red-fleshed cultivars, however, the change in color is associated with a marked increase in lycopene content (Wills et al., 1989); lycopene was found to be absent in yellow fleshed fruit. On the other hand, it was found to be a major pigment, accounting for 61% of the total in 'Solo', 56% in 'Formosa' and 66% in 'Tailandia' cultivars, while β -cryptoxanthin was the major pigment, representing 62% of the total carotenoid content in a common cultivar of Brazil (Paull, 1993). The β -zeacarotene and cryptoflavin were also found in this cultivar while carotene was found in Solo fruits. On the other hand, skin chlorophyll declined to one-sixteenth of its content in ripe compared to immature fruit (Wills et al., 1989; Paull, 1993).

Volatiles

Many volatile flavor compounds have been identified from papaya fruit. According to Sankat and Maharaj (2001), there are about 106 volatile compounds in papaya fruit. The amount of each component varies with both cultivar and locality, with linalool as a major component. There were smaller amounts of benzyl isothiocyanate and phenylacetonitrile with butyric, hexanoic and octanoic acid, and their methyl esters being minor components (Paull, 1993).

Fruits of Solo cultivar had a high percentage of linalool (up to 94%) (Sankat and Maharaj, 2001). The amount and relative content of volatiles has been shown to vary with stage of ripeness. A nearly 400-fold increase of linalool and seven fold increase of benzyl isothiocyanate production was found in the head space of Solo papayas during ripening (Sankat and Maharaj, 2001). The volatile compound methyl butanoate is considered responsible for the sweetish odor quality of papaya (Sankat and Maharaj, 2001). Flath et al. (1990) reported that the content of phenolic compounds in the flesh fell to one-quarter in the harvest value during ripening. Very little free linalool or isothiocyanate were present in intact tissue, but were produced following injury. The acid and methyl esters of butyric, hexanoic and octanoic acid were

also produced following maceration due to enzymatic activity. The formation of free acid was indicated to be probable cause of off-odor and off-flavor in puree. Numerous esters and monoterpenes appeared only in ripe fruit at low levels.

POST-HARVEST MICROBIOLOGY OF PAPAYA

Wastage of horticultural commodities by microorganisms between harvest and consumption can be rapid and severe, particularly in tropical areas where high temperature and high relative humidity favor rapid microbial growth. Furthermore, ethylene produced by rotting produce can cause premature ripening and senescence of other produce in the same storage and transport environment, and sound produce can be contaminated by rotting organisms. Fruits may be infected by direct penetration of certain fungi through intact cuticle or through wounds and/or natural opening in their surface (Wills et al., 1989).

Papayas at all ripeness levels are susceptible to scratches and punctures when in contact with rough or sharp surfaces. These wounds can serve as an infection sites for numerous pathogens that result in many of the post-harvest diseases. Wounds also cause moisture loss and excessive shriveling (Paull et al., 1997). Papaya is particularly susceptible to post-harvest losses as a result of high susceptibility to bruising and disease infection, as it is high in moisture and nutrients. The development of fungal infection during the post-harvest phase can depend on the physiological age of the host, mechanical injuries and storage conditions (Salunkhe et al., 1991; Sankat and Maharaj, 2001).

Handling and market preparation requirements of papaya are greatly influenced by the susceptibility to certain diseases. The most important of these is anthracnose, caused by the fungus *Colletotrichum gloeosporioides*. Anthracnose is a pre-harvest infection, and fruit-surface rot and stem-end rot, a harvest-wound rot, are the two most common post-harvest rots of papaya. Anthracnose becomes evident in ripe or ripening fruits. The presence of the disease is characterized by small black or light brown spots, which gradually enlarge and may coalesce and sink. Other important diseases include *Ascochyta caricae-papayae*, *Phomopsis caricae-papayae* and *Phytophthora nicotiana* var. *parasitica* (Nakasone and Paull, 1999; Sankat and Maharaj, 2001).

Decay reduction and disease control is through sanitation, careful handling, cooling of produce and use of approved chemicals (fungicides which prevent or delay the appearance of rots and molds in the products). Others include use of metabolic inhibitors that block certain biochemical reactions that normally occur, ethylene absorbents, fumigants to control insects or sometimes molds, physical treatments such as heat treatments, and controlled and modified atmosphere

(Irtwange, 2006). Modifications of the storage atmosphere, along with their effects on the physiological life of the host, can also be advantageous in retarding post-harvest disease development. The effect of atmosphere modification on post-harvest disease development can be direct by suppressing various stages of the pathogen growth and its enzymatic activity, or indirect by maintaining the resistance of the host to infection as a result of keeping it in a superior physiological condition (Irtwange, 2006). Modified atmosphere (MA) has been a solution to improve quality of either whole or fresh cut-products by reducing microbial decay. Lichanporn and Kanlavanarat (2006) noted that, shredded green papaya in MA conditions had longer shelf life by reducing respiration rate, ethylene production, color change and microbial growth.

Nutritional compositions of papaya fruit: An overview

Papaya contains relatively high levels of vitamins A, B1, B and C (Marisa, 2006; Jurandi and Angela, 2011; Laura et al., 2011; Savarni et al., 2011). The papaya fruit is also known to be an excellent source of glucose, fructose and sucrose (Jurandi and Angela, 2011). Savarni et al. (2011) presented the nutritional composition of Rainbow papaya which was the first commercialized transgenic fruit crop. Ralf et al. (2011) showed that esterified xanthophylls such as β -cryptoxanthin laurate and caprate were the most abundant pigments during incipient carotenoid biosynthesis during the developmental stage of papaya fruit. The result indicated that the building up of carotenoids such as β -cryptoxanthin laurate and total lycopene contents positively correlates with a subsequent fruit maturation. On the other hand, the papaya aroma is principally due to esters, where ethyl butanoate, ethyl acetate, ethyl hexanoate and ethyl 2-methyl butanoate are the most potent odor compounds. Papaya is also considered as a functional food fruit since consumption of ripe papaya fruit has been associated with a curing effect to a certain diseases. For example, Jurandi and Angela (2011) reported that from a pharmacological point of view, the papaya has been cited as a laxative, antifertility agent, and meat tenderizer, among other uses.

POST-HARVEST HANDLING OF PAPAYA

The quality of the harvested fruits and vegetables depend on the condition of growth, as well as physiological and biochemical changes they undergo after harvest. The harvesting of fruit at an appropriate stage is important from post-harvest shelf life and quality points of view (Desi and Wagh, 1995). During normal handling procedures such as loading, unloading, air or truck transportation, warehouse storage and retail display, fruit and vegetables are often exposed to inappropriate

temperatures either due to difficulties in controlling temperature, absence of refrigerated facilities, or lack of information about the produce characteristics and needs (Paull et al., 1997; Nunes et al., 2006).

Fruits bring to our daily diet variety, flavor and aesthetic appeal while also meeting certain essential nutritional requirements. However, appearance, flavor and nutritional value may decline greatly due to the way the fruit are handled after being harvested (Nunes et al., 2006). The rate at which changes occur in harvested fruit may be influenced by a range of environmental conditions, including temperature, humidity and atmospheric composition. All may be manipulated by careful management of the post-harvest handling system to obtain the best possible quality and storage life for the produce. All fruits and even different cultivars of the same fruit have highly specific requirements and tolerances to storage environments (Wills et al., 1989; Burdon, 1997).

The post-harvest handling system must aim to ensure that the fruit reaches the market in the exact condition required by the customer. For those climacteric fruit, there can be benefit of a longer storage life, greater resistance to damage and still having the capacity to ripen to a good quality through the correct temperature and possibly ethylene management. Appropriate post-harvest handling can minimize moisture loss, slow down respiration rate and inhibit the development of decay causing pathogens (Paull et al., 1997; Burdon, 1997).

Papaya fruits are sensitive to poor quality out turns and high post-harvest losses if harvesting, treatments and handling techniques are inadequate or inappropriate. From harvest, a shelf-life of four to six days under tropical conditions can be achieved with the correct harvest maturity, disease control measures, handling techniques and storage conditions (Irtwange, 2006).

Packaging

Packaging of fresh produce is needed not only to provide containment for ease of handling but to preserve post storage product quality during distribution and in certain cases, to add value to the commodity during marketing. Packaging systems are product specific but may benefit quality retention through protection from handling abuse and moisture loss and restriction of metabolism. Packaging provides protection from physical damage during storage, transportation and marketing (Wills et al., 1989; Irtwange, 2006).

Azene et al. (2011) reported on the effects of different packaging materials and storage environment on post-harvest quality of papaya fruit. There are variety of packages, packaging materials and inserts available. The earliest packages were mostly constructed of plant materials such as woven leaves, reeds and grass stems (Wills et al., 1989). Quinta and Paull (1993) indicated that foam mesh sleeves, foam padding on the bottom of

Table 1. Permeability characteristics of some plastic films with potential for use as MAP of fresh and lightly processed produce (Schlime and Rooney, 1994).

Film type	Transmission rate		
	O ₂ ¹	CO ₂ ¹	H ₂ O Vapor ²
Low –density polyethylene (LDPE)	3900 - 13000	7700 - 77000	6 - 23.2
Medium- density polyethylene (MDPE)	2600 - 8293	7700 - 38750	8 - 15
High- density polyethylene (HDPE)	52 - 4000	3900 - 10,000	4 - 10
Polypropylene (PP)	1300 - 6400	7700 - 21000	4 - 10.8
Polyvinylchloride (PVC)	620 - 2248	4263 - 8.138	>8

¹Expressed in terms of cm³m⁻²day⁻¹ at 1 atm. ²Expressed in terms of gm⁻² day⁻¹ at 37.8°C and 90 percent relative humidity.

cartons, or paper wrapping are used to prevent abrasion injury of papaya. Desi and Wagh (1995) also reported that papaya fruits placed stem end down in a box padded with paper or wood wool, prevent bruising. Nowadays, produce is transported and sold in an enormous way of packages constructed of wood, fiber board, jute or plastics.

An important supplement to proper temperature and relative humidity management is the use of modified (MA) atmosphere (Irtwange, 2006; Azene et al. 2011). When used as supplements to keeping fresh horticultural perishables within their optimum ranges of temperature and relative humidity, MA can serve to extend their post-harvest life. Modified atmosphere packaging (MAP) of fresh produce relies on modification of the atmosphere inside the package, achieved by the natural interplay between two processes, the respiration of the product and transfer of gases through the package, which leads to an atmosphere richer in CO₂ and poorer in O₂. This atmosphere can potentially reduce the respiration rate, ethylene sensitivity and production, decay and oxidation and hence delay ripening and senescence (Kader, 1985; Kader and Rolle, 2004). Modified atmosphere packaging (MAP) also relates to packages and film box liners with specific properties that offer a measure of control over the composition of the atmosphere around the produce (Wills et al., 1989; Irtwange, 2006). A modified atmosphere can be defined as one that is created by altering the normal composition of air to provide an optimum atmosphere for increasing the storage length and quality of produce (Lee et al., 1996).

The MAP can be generated by either active or passive systems. In the passive system, respiring fruit over time self-generate an atmosphere of elevated CO₂ and reduced O₂. Passive modified atmosphere is created as a result of the produce respiratory activity; consumption of oxygen (O₂) and emanation of carbon dioxide (CO₂) occurring within a sealed plastic package (Irtwange, 2006). If the concentration of the respiration gases around the outside of the crop is changed by surrounding it with the package, this will change the concentrations of the gases inside the crop. The concentration of these gases will then vary with such innate crop characteristics

as mass of produce inside the bag, type of the crop, temperature, maturity and activity of microorganisms. The actual concentration of gases in the fruit will also be affected to a limited degree by the amount of space between the fruit and the plastic film, but mainly by the permeability of the film (Lee et al., 1996). Active MAP is the replacement of air in a pack with a single gas or mixture of gases; the proportion of each component is fixed when the mixture is introduced. In the active system, desired end point concentrations of O₂ and CO₂ are established by flushing the fruit with a desired mixture of gases (Irtwange, 2006). For fresh fruits and vegetables, MAP usually involves the use of flexible plastic films, with specific permeability to different gases and/or water vapor. The principal plastic materials for MAP that can be used with fruits and vegetables include polybutylene, low density polyethylene (LDPE), high density polyethylene (HDPE), PP, PVC, polystyrene, ionomer, pliofilm, and polyvinylidene chloride (Schlimme and Rooney, 1994).

The permeability of films to gases (including water vapor) varies with the type of material from which they are made, temperature, in some cases humidity, and the accumulation and concentration of the gas and the thickness of the material (Lee et al., 1996; Thompson, 2001). The characteristics of the main types of plastic films with their potential uses in MAP are summarized in Table 1.

Due to the fact that stored fruits and vegetables are living matter, they use oxygen and give off carbon dioxide and other volatile substances into the storage atmosphere. These gases must be kept within certain limits otherwise damage will result. Moisture loss, if uncontrolled, may result in shriveling, and excessive moisture may contribute to the growth of microorganisms and deterioration (Berard et al., 1990). Modified atmosphere alter the composition of gases in and around fresh produce by respiration and transpiration. Wrapped product, through respiration process, modifies the atmosphere, altering its metabolism. Such a change may extend its shelf life or induce physiological disorders if the film permeability is inadequate (Ben-Yehoshua, 1985; Thompson, 2001). Given an appropriate gaseous

atmosphere, modified atmosphere packaging can be used to extend the post-harvest life of crops in the same way as controlled atmosphere packaging (Lee et al., 1996). A study by Gonzalez et al. (1990) showed that, LDPE and HDPE packaging delayed fruit ripening, reduced weight loss, and did not result in any off flavor both in mango and avocado fruits. Wills (1990) reported that, modified atmosphere packaging in plastic film extended the storage life of papaya. In line with this, Lazan et al. (1990) indicated that plastic film wraps were more effective than waxing in reducing water loss from papaya. The author also noted that, seal-packaging (low-density polyethylene) retarded the development of peel color and reduced the increased titratable acidity during ripening. Fruit softening is also retarded. Similarly, the work of Rohani and Zaipun (2001) reveals that the storage life of 'Eksotika' papaya was extended to 4 weeks when stored at 10 to 12°C under modified atmosphere (low-density polyethylene bags) condition. The fruits were still fresh with little change in the skin color and minimal disease development. As Singh and Rao (2005) indicated, LDPE packed fruits of papaya stored at 13°C showed higher retention of ascorbic acid, total carotenoids and lycopene after 30 days storage at 13°C + 7days in air at 20°C.

The use of polymeric film wraps and waxing of papaya have been successful in retarding color development and water loss before fungal decay becomes the limiting factor (Paull and Chen, 1989). Fruit waxing reduced weight loss of papaya by 14 to 40%, while plastic shrink-wraps reduced it by about 90% (Paull and Chen, 1989). Significantly reduced weight loss were also reported by Maharaj (1988) with papaya cultivar 'Tainug No.1' using plastic film wrap when compared to similarly stored, waxed fruit. Such fruit packed in plastic film exhibited good storage potential for up to 29 days compared with untreated fruit, which were generally unacceptable after 17 days at 16°C.

Seal packaging is reported to modify both internal O₂ and external (in package) atmospheres. A substantial reduction in internal O₂ and a concomitant decrease in internal ethylene concentration appeared to be instrumental in delaying the ripening of sealed fruit (Lazan et al., 1990). Occasionally, off-flavors developed in waxed and wrapped fruits when the fruit cavity CO₂ level exceeded about 7% at the full ripe stage (Sankat and Maharaj, 2001).

Packaging fruits is one of the most commonly used post-harvest practice that puts them into unitized volumes which are easy to handle while also protecting them from hazards of transportation and storage (Burdon, 1997). Modified atmosphere packaging for storage and transportation of fruits and vegetables is commonly achieved by packing them in plastic films. Storage in plastic films with different kinds of combinations of materials, perforation and inclusions of chemicals and individual seal packaging are types of modified atmosphere storage (Burdon, 1997; Irtwange, 2006).

Storage temperature and relative humidity management

The function of a fruit or vegetable storage is to provide an environment that will permit produce to be stored as long as possible without deterioration of quality, which is a composition of flavor, texture, moisture content, and other factors associated with edibility. A desirable environment can be obtained by controlling the temperature and composition of the atmosphere (Berard et al., 1990).

When fruits and vegetables are harvested, they are removed from their source of water and nutrition and soon start to deteriorate. Harvesting stimulates metabolic changes associated with ripening and senescence. The quality and storage life of fruits and vegetables may be seriously affected within a few hours of harvest if the crop has not been pre cooled promptly to control deterioration. All other factors in handling and storage are of secondary importance. However, factors other than temperature, also affect the storage environment (Berard et al., 1990). According to Zhou et al. (1997), room and forced-air cooling are commonly used for papaya.

The optimum temperature for fruit ripening is 20 to 27.5°C, with fruit taking 10 to 16 days to reach full skin yellowing from the color-break stage (Zhou et al., 1997; Sankat and Maharaj, 2001). Severe weight loss and abnormalities such as delayed coloring and ripening, rubbery pulp texture and fruit surface bronzing become significant at temperatures higher than 27.5°C. Display temperatures should not be less than 10°C if not fully ripe. Fully ripe fruit at the edible stage can be held at 1 to 3°C. Fruit should not be stacked more than 2 or 3 layers deep in racks, and weak baskets with uneven bottoms and sides should be avoided, or at least a layer of protection should be placed between racks and fruit. Loss of about 8% of weight from mature green or color break of papaya produces rubbery, low-gloss, unmarketable fruit (Paull et al., 1997; Zhou et al., 1997; Prolux et al., 2005; Azene et al., 2011).

Papaya fruits under ambient tropical condition (30°C) have a maximum storage life of seven days (Sankat and Maharaj, 2001). Temperatures between 10 and 16°C have been found to be adequate for storing papayas (Desi and Wagh, 1995; Thompson, 2001). However, a range of storage temperatures have been reported for different cultivars kept under refrigeration, usually for fruit harvested at color-break stage of maturity. Papayas at 10 and 15°C can be stored for 16 days, while 12°C has been recommended as an optimum storage temperature for two weeks (Sankat and Maharaj, 2001). Workneh and Kebede (2004) also noted the effect of increasing storage relative humidity and reducing the temperature through an adiabatic cooling process where evaporative cooling reduced the physiological weight loss in papaya compared to fruits stored under ambient conditions. Evaporative cooling is an adiabatic cooling process

whereby the air takes in moisture which is cooled while passing through a wet pad or across a wet surface (Thompson et al., 1998; Tefera et al., 2007).

There are many reports that indicate papayas kept in refrigerated storage are susceptible to fungal decay. Sankat and Maharaj (2001) reported an optimum storage temperature of 16°C for 17 days' storage of 'Tainung No.1' with fungal decay being the limiting storage factor. Storage below 10°C has been known to cause chilling injury. It is reported by Paull (1993) that fruits become less susceptible to chilling stress as they ripen. Symptoms of chilling injury occur after 14 days at 5°C for mature green fruit and 21 days for 60% yellow fruit. The decrease in susceptibility has been related to the stage of the fruit climacteric. The tolerance of papayas to temperatures below 10°C varies with the maturity of the fruit and the duration of exposure (Zhou et al., 1997). High temperatures, low relative humidity and high air velocity increase transpiration rates. Hence, these need to be monitored and controlled in storage (Wills et al., 1989; Irtwange, 2006). As a physical process, transpiration can be controlled by applying waxes and plastic films as barriers between the produce and the environment, as well as by manipulating RH, temperature and air circulation (Irtwange, 2006).

The most important method of reducing the rate of water loss from produce primarily involves lowering the capacity of the surrounding air to hold additional water. This can be achieved by lowering the temperature and/or raising the relative humidity by reducing the vapor pressure difference between the produce and air. Water loss can also be effectively reduced by placing an additional physical barrier around the produce, which also reduces air movement across its surface. Simple methods are to pack the produce into bags, boxes or cartons and to cover stacks with tarpaulins. Materials such as polyethylene film are excellent vapor barriers since their rate of water transfer is low compared with that of paper and fiber board, which have a high permeability to water vapor (Wills et al., 1989). Marketing of fruits and vegetables in Ethiopia is complicated by high post-harvest losses which are estimated to be as high as 25 to 35% (Tadesse, 1991; Azene et al., 2011). It has also been estimated by the FAO (2005a) that the post-harvest loss of perishable commodities in Ethiopia is as high as 50%. This high loss has been attributed to several factors, among which lack of packaging and storage facilities and poor means of transportation are the major ones (Kebede, 1991; Wolde, 1991). In spite of this, very little emphasis was given to research on post-harvest handling of perishable produce (Tadesse, 1991; Workneh, 2002; Azene et al., 2011). The post-harvest losses could discourage farmers from producing and marketing fresh produce, and limit the urban consumption of fresh fruits and vegetables. Hence, development of post-harvest technologies is believed to make great contribution to improve quality and use of these crops.

Reduction of the losses in a systematic way requires knowledge of post-harvest physiology, its applied technical aspect, handling and the appreciation of its biological limitation represented as storage potential (Nakasone and Paull, 1999). Packaging and handling systems have been developed in many countries to move products from farm to consumer expeditiously in order to minimize quality degradation. Procedures include lowering temperature to slow respiration and senescence, maintaining optimal relative humidity to reduce water loss without accelerating decay, adding chemical preservatives to reduce physiological and microbial losses, and maintaining an optimal gaseous environment to slow respiration and senescence (Wills et al., 1989; Desi and Wagh, 1995). The root cause of post-harvest deterioration that needs to be inhibited is enhanced metabolism, whether due to natural senescence physiology or biotic or abiotic stress, with the main technological interventions involving control of temperature and humidity of the atmosphere around the produce (Wills et al., 1989). It is essential to control storage temperature and relative humidity during storage as they are the main causes of fruit and vegetable deterioration during ripening and storage. Temperature of the produce and surrounding air can be reduced by forced air-cooling, hydro cooling, vacuum cooling, ice cooling, and evaporative cooling (Thompson et al., 1998). The evaporatively cooled environment is suggested to be a good alternative for the small-scale peasant farmers, retailers, and wholesalers in Ethiopia, as it require low initial and running cost compared to other cooling methods (Workneh and Kebede, 2004).

Papaya is a fruit with considerable economic potential in the tropics as there are domestic markets in producing tropical countries and export markets in the sub tropical and temperate countries. The fruit has, however, limited shelf life of less than a week under ambient tropical conditions (30°C) (Desi and Wagh, 1995; Sankat and Maharaj, 2001). Papaya has high percentages of post-harvest losses with a range of defects. It is very susceptible to mechanical damage, pest attack and diseases. However, inadequate attention is paid by many producers to the method of harvesting, stage of maturity at harvest, use of fungicidal treatments (both pre- and post-harvest), proper packaging and storage methods (Sankat and Maharaj, 2001). As a result, fruits are often of poor quality and there are considerable wastages. One of the major causes of papayas being rejected at local and export markets is mechanical injuries. The damage can be reduced if the fruits are properly packaged and handled. For example in Ethiopia too, considerable quantity of papaya is wasted before it reach the target markets due to limited shelf life of the fruit and poor post-harvest handling (Emana and Gebremedhin, 2007). Papaya fruits are produced mainly for local markets while some percentage is also exported to neighboring countries such as Djibouti and Somaliland. Similar to

other exported fresh produces, papaya marketing lacks standardization formalities such as grading system and packaging. Hence, information on papaya shelf life and methods of mitigating post-harvest losses can be of high value for growers, distributors and exporters throughout the regions in Africa. So far, research on this crop has been limited; few post-harvest researches have been undertaken in spite of the high post-harvest loss incurred at the various marketing levels between production and consumption in Africa while the agro-climatic conditions in the continent is known to be very suitable for fruit and vegetables production including papaya.

CONCLUSION

Post-harvest losses in fresh fruits and vegetables may occur anywhere from the point where fruit and vegetables have been harvested up to the point of consumption. Papaya is naturally fragile, it is a target to many post-harvest injuries and mechanical damages due to its thin skin and climacteric type ripening nature during post-harvest handling. The papaya fruit has a limited shelf life of less than a week under ambient tropical conditions. Literature review shows that limited work has been done on the development of an appropriate post-harvest handling of papaya fruit for application during storage and post-harvest handling of papaya under Africa climatic conditions. Temperature was found to be the most important environmental factor that determines the levels of papaya fruit and produces deterioration. Proper temperature and relative humidity management are required to solve the high post-harvest losses of papaya fruit under African conditions. With this background, research on the integrated agro-technology combining pre-harvest treatments to increase yield of quality fruit as well as post-harvest technologies for shelf life extension of papaya fruit requires immediate research focus.

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