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Review

Review on postharvest technology of banana fruit

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The aim of this review is in threefold: First, to explore the effect of different preharvest treatments on postharvest quality of fruits and vegetables. Second, the principles of biological, chemical and biochemical changes in banana during development, maturation, ripening and storage were reviewed. Third, postharvest handling and factors affecting quality of banana were examined. These include disinfecting, packaging and storage temperature. Pre- and postharvest treatments were found to have an effect on postharvest quality of banana, suggesting that postharvest quality of produce subjected to preharvest treatments should be assessed from a quality improvement, maintenance and consumer safety point of view. Literature recommends an integrated agro-technology approach towards improving quality at harvest and maintenance of qualities of banana.

Key words: Banana, fruit, postharvest handling, packaging, storage.

INTRODUCTION

Banana, cooking banana and plantain (*Musa spp*. AAA, AAB and ABB groups) are major starch staple crops of considerable importance in the developing world. They are consumed both as an energy yielding food and as a dessert (Dadzie and Orchard, 1997). They are giant perennial herbs that originated in Southeast Asia. They evolved by natural hybridization between the two species *M. acuminata* (contributing genome A) and *M. balbisiana* (contributing genome B). All important bananas and plantains are triploid. Banana and plantain are monocotyledonnous plants belonging to the section Eumusa within the genus *Musa* of the family Musaceae in the order Scitamineae. Most edible-fruited bananas, usually seedless, belong to the species *Musa acuminata* Colla. *Musa balbisiana* Colla of southern Asia and the East Indies bears a seedy fruit but the plant is valued for its disease-resistance and therefore, plays an important role as a "parent" in the breeding of edible bananas (Morton, 1987).

Bananas and plantains are today grown in every humid tropical region and constitute the 4th largest food crop of the world after rice, wheat and maize (Picq et al., 1998; Arias et al., 2003). Moreover, with increasing urbanization, bananas and plantains are becoming more and more important as cash crops, in some cases providing the sole source of income to rural populations. Thus, playing an important role in poverty alleviation. Bananas and plantains are one of the cheapest foods to produce. The cost of production of one kg of plantain is less than that for most other staples, including sweet potato, rice, maize and yam. Consequently, bananas and plantains can be a very cheap food to buy and are, hence, an important food for low-income families (Picq et al., 1998). Bananas and plantains also grow in a range of environments and produce fruit year-round. Thus, it provides energy during the “hungry-period” between crop harvests. They are particularly suited to intercropping systems and to mixed farming with livestock and they are also popular as a backyard crop with urban populations. When grown in perennial production systems, they maintain soil cover throughout the year and if their biomass is used for mulch, soil fertility and organic matter remain stable. In mixed farming systems, bananas are used as a ground shade and nurse-crop for a range of shade-loving crops including cocoa, coffee, black pepper and nutmeg (Picq et al., 1998).

Banana ranks third place in world fruit volume production after citrus fruit and grapes at 64.6 Mt (FAO, 2000), and second place in trade after citrus fruit, at 14.7 Mt

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(FAO, 1999). Banana fruit is grown in more than 100 countries, mainly in sub-tropical areas (Stover and Simmonds, 1987). The biggest markets for banana are North Ameri-ca and Europe, followed by Japan and Eastern Europe (Caussiol, 2001).

Ethiopia lies entirely in the tropics where vast areas are suitable for banana growing. Banana production in Ethiopia ranges from homestead to large commercial plantations. At present, bananas are the leading fruit crops produced in the country both in terms of area coverage (28,695 ha) and production (1,245,615.60 q year^{-1}) (CSA, 2004) where the bulk is produced in traditional agricultural system. Due to its relatively little requirement of land preparation, care, maintenance, and a comparatively high yield per given area and time, bananas are well suited to traditional agricultural system. It is recently reported that (Seifu, 1999) bananas are replacing other fruit crops such as lime and mango and the most important food crops like maize and sweet potato in some parts of the southern areas of the country.

In Ethiopia, research work on fruit and vegetables was started in early 1970s at major research centers, and cultivar development was the major research activity (Awole et al., 2011; Tigist et al., 2011). From introduced and locally collected varieties, Dwarf Cavendish, Poyo, Giant Cavendish and Ducasse hybrid were recommended for production (Seifu, 1999). Over all, banana research in the past and even at present, mainly focused on varietal development, selecting of disease resistant variety, fertilizer trial, clump management practices as well as irrigation trials in different centers. Even though theses preharvest practices are compulsory they must be coupled with the postharvest management practices because postharvest loses are of major concerns in many developing countries including ours (Tadesse, 1991; Workneh et al., 2010).

Ethiopia has a wide range of climate and soil types that enable it to produce a variety of agricultural products (Haidar and Demisse, 1999; Workneh et al., 2010). In addition, there is a vast potential of the internal market for bananas, primarily in densely populated urban areas, such as Addis Ababa. In addition, there is potential for export, being located close to important markets, such as Saudi Arabia, Djibouti, Somalia, etc (Workneh et al., 2011). Despite these facts, marketing of fresh produce including bananas is complicated by postharvest losses both in terms of quantity and quality between harvest and consumption. Both the fresh market and processing plants for fruits are located in towns away from farms and producers in rural areas. The quality of the fresh and processed fruit depends on the postharvest handling during harvesting, transportation, and storage, and should be monitored effectively to keep the best quality of fruit at harvest. Due to a rain-fed farming system, lack of storage facilities, limited access to transportation, and risk of high losses, growers in Ethiopia are often forced to dispose off their produce over a short period of time (Haidar and Demisse, 1999; Workneh et al., 2010) which causes an economic loss of horticultural crops in general and fruits in particular.

Worldwide, postharvest losses in fruits and vegetables range from 25 to 40% (Raja and Khokhar, 1993) or even greater (Iqbal, 1996) in developed countries and up to 50% in developing tropical countries (Anon, 1989). Postharvest losses of fruits and vegetables in Ethiopia are estimated to vary between 25 and 35% (Tadesse, 1991). This high loss is due to lack of packaging, storage faciletes, and poor means of transportation (Kebede, 1991; Workneh et al., 2010).There is no proper means of postharvest handling of fruits and vegetables at the retail and wholesale levels, which results in poor quality of fruits and vegetables at the consumer level. Although the country is experiencing huge postharvest losses of fruits and vegetables, very little or no emphasis is given to postharvest handling of perishable produces (Tadesse, 1991).

For the fresh bananas to reach the consumer in the right condition, it must be marketed properly, bearing in mind the application of most suitable temperature and humidity as well as appropriate packaging and handling methods. Good handling during harvesting can minimize mechanical damage and reduce subsequent wastage due to microbial attack (Wills et al., 1998).

Low tempera-ture handling and storage are the most important physical method of postharvest management (Johnson et al., 1997). Mostly, the traditional packaging method for bana-na is nested packaging in which dried banana leaf are used but the effectiveness of these packaging materials even has not yet been well investigated.

Plastic films have also been found to increase the shelf life of banana fruit. Modified atmosphere packaging (MAP) of fresh fruit refers to the technique of sealing actively respiring produce in polymeric film packages to modify the O_2 and CO_2 levels within the package atmosphere. It is often desirable to generate an atmosphere low in O_2 and/or high in CO_2 to influence the metabolism of the product being packaged or the activity of decay-causing organisms to increase storability and/or shelf life. In addition to atmosphere modification, MAP vastly improves moisture retention, which can have a greater influence on preserving quality.

Furthermore, packaging isola-tes the product from the external environment and helps to ensure conditions that if not sterile, at least reduce ex-posure to pathogens and contaminants there extends the shelf life of the produce (Mir and Beadry, 2004).

So in Ethiopia, the research work on banana has focused mainly on varietal development and field management practices and little work has been done on postharvest management banana.

As a result, the quality of fruits is reduced and considerable amount is wasted, from harvesting to final consumption. This loss can be kept mini-mum by improving postharvest handling techniques. Therefore, this study aimed at reviewing the integrated agro technology of banana under Africa context fruit handling.

THE BANANA CROP

Banana production is restricted to tropical or near tropical regions, roughly the area between latitudes 30°N and 30°S (Morton, 1987). Within this band, there are varied climates with different lengths of dry season and different degrees and patterns of precipitation. A temperature range of 15 to 38°C occurs in most production areas, with the optimum temperature being 27°C (Nakasone and Paull, 1999). Yields are higher when temperatures are above 24°C for a considerable period. In cooler climate, the crop requires longer time to mature. Plants exposed to low temperature and humidity during active growth stage show reduced growth and yields. Banana crop requires a mean rainfall of 100 mm per month and there should not be more than 3 months of dry season (Morton, 1987).

Banana is just more than a crop. The ripe banana is utilized in a multitude of ways in the human diet from simply being peeled and eaten out of-hand to being sliced and served in fruit cups and salads, sandwiches, custards and gelatins; being mashed and incorporated into ice cream, bread, muffins, and cream pies. Ripe bananas are often sliced lengthwise, baked or boiled, and served (perhaps with a garnish of brown sugar or chopped peanuts) as an accompaniment for ham or other meats. Ripe bananas may be thinly sliced and cooked with lemon juice and sugar to make jam or sauce, stirring frequently during 20 or 30 min until the mixture jells. Whole, peeled bananas can be spiced by adding them to a mixture of vinegar, sugar, cloves and cinnamon which has boiled long enough to become thick, and then letting them cook for 2 min (Morton, 1987). On the other hand, banana is the cheapest source of carbohydrate. In addition, ripe banana fruit is a good source of vitamins (A, B and C) and minerals (Ca and Fe) and it is a known source of potassium (Samson, 1991).

PREHARVEST FACTORS THAT INFLUENCE THE POSTHARVEST QUALITY OF BANANA

The quality of fresh fruits and vegetable offered to consumers is constrained by the level of quality achieved at harvest, and generally cannot be improved by postharvest handling, rather can be maintained. Myriads of preharvest genetic and environmental factors affect the growth, development and final quality of fresh fruits and vegetables (Shewfelt and Prusia, 1993).

Genetic factors

Banana breeding has been existing for more than seventy years (Ortiz et al., 1995). Smith (1995) suggested that future developments in the banana fruit sector would depend upon cultivar selection, plant breeding and genetic engineering. Varieties differ in many characteristics, including visual appearance (example size), yield and quality. Size, for example small, medium or large, is a matter of consumer preference (Hofman and Smith, 1993). Variety also has an effect on yield, firmness, fibrousness, succulence and juiciness (Kader, 1992). For certain tree crops, rootstock selection may cause differences in fruit total soluble solid (TSS) and acidity via influences on nutrient and water uptake and translocation or differences in photosynthate partitioning (Beverly et al., 1992). Increasing the energy supply and decreasing the water content of fruit increases TSS in tomatoes. Thus, TSS exemplifies a trade off between yield and quality, since yield generally decreases with increasing TSS (Shewfelt and Prusia, 1993). The genotypic characteristics of any one cultivar vary in response to environmental effects.

Canopy management

Canopy management focuses on the amounts of light and CO_2 that fruits receive. For banana fruit, full shade gives a dull yellow peel colour whereas partial shade leads to a bright yellow peel colour. Low light intensity retards development of carotenoids (Caussiol, 2001). An important determinant of banana fruit quality is row spacing and the associated plant population. Plant density consists of selecting the most vigorous suckers located in the best places and eliminating undesirable ones. This method can increase the number of leaf and fruits exposed to sunlight. Removal of leaf can also help prevent fruit scaring. Bunch thinning reduces inter-fruit competition and improves fruit size. An average banana plant population is around 2, 500 per ha (Stover and Simmonds, 1987). Plant health and leaf/fruit ratio also influences flavor (Hofman and Smith, 1993).

Climatic condition

Temperature is the most important factor in affecting growth and development of banana crop. Bananas flourish under uniformly warm to hot conditions. Shoot growth is best between 26 to 28°C and fruit growth at 29 to 30°C. Plant growth slows below 16°C and stops at 10°C. The optimum for dry matter accumulation and fruit ripening is about 20°C and for the appearance of new leaf about 30°C (Nakasone and Paull, 1999).

Theoretical determination of the harvesting stage of Cavendish banana showed that increased fruit diameter in the absence of limiting soil factors is a function of the total daily temperature from the appearance of the last hand of the bunch up to the harvest stage (¾ full or 34 mm grade). The total daily temperature is defined from a 14°C threshold, which represents the minimum temperature permitting the growth of bananas. In optimal conditions without constraints other than temperature, a total cumulative temperature of 900°C is required to obtain the theoretical optimum harvest stage of dessert bananas (Chang et al., 2000).

Also, a relationship between natural production conditions and physical fruit traits (texture and colour) were reported by Bugaud et al. (2007) that the peel of green bananas harvested during the hot humid season was not as hard as that of bananas harvested during the cool dry season. In ripe bananas, a decreasing correlation was also noted between the mean daily temperature and the fruit yellowness. This interaction could be responsible for the yellower colour banana pulp and of bananas harvested during the coolest seasons. The green life of bananas harvested during the hot humid season was shorter than that of bananas harvested during the dry and intermediate seasons (Bugaud et al., 2007).

The effect of high temperature is the function of time in which at 48°C the damage occurred in 3 h and 45 min, at 57°C it took 7 min and at 62°C it took only 1 min (Gowen, 1995). Under peel discolouration, the fruit was observed with air temperature of 33 to 35°C but was associated with high light intensity and moderate to low rainfall. A more widely occurring effect of high temperature is bleaching of the chlorophyll in both leaf and fruits.

Another important effect of temperature is chilling damage during crop development. It includes reddish brown streaking on the skin of the fruit, reduced latex flow, slow colour development of the fruit during ripening, a dull or grayish yellow colour in ripe fruits and brown skin in advanced stages. More subtle changes are reduced production of volatiles during ripening and disturbances to the evolution of CO_2 and ethylene (Gowen, 1995). In addition, Crane et al. (2005) reported that a tem-perature below 16°C but above 0°C resulted in failure of the flowering stalk or fruit bunch to emerge from the pseudostem (called choking) and an increase in fruit rotting during ripening.

Water management

Banana plant must be irrigated immediately after planting and about 30 to 40 weekly irrigation is required. Inadequate irrigation to banana leads to delayed flowering, bunch size, delayed maturity of reduced fingers, induces physiological disorders and also poor keeping quality of fruits (Lopez, 1998). However, excess water also has detrimental quality consequences for plant. The photosynthetic rate decreases with overly high water availability and low transpiration rates. High moisture content in fruit also tends to dilute the soluble solids leading to low flavor intensity. During dry periods, soluble solids accumulate rapidly inside plant structure. When the water supply increases suddenly, by irrigation or rainfall, water moves quickly to the plant cells in response to the osmotic gradient. The rapid rise in hydro-static pressure can rupture cell membranes and walls, leading to splitting of fruits and other structures (Shewfelt and Prussia, 1993). Furthermore, a high relative humidity during fruit development shortens the storage life and increases the incidence of finger drop and crown rotting (Munasque et al., 1990). Generally, the water regime in the early stage of growth had a more pronounced effect both on dry matter accumulation and nutrient uptake than it did after bunch emergence (Gowen, 1995).

Nutrient management

For growth and fruit production, bananas require high amount of nutrients which are often supplied only by the soil. Since large amount of nutrients are removed from the soil and these nutrients have to be replaced to permit continuous production of high yield and this is achieved through application of organic manure and/or mineral fertilizers (Gowen, 1995).

Nitrogen is considered second only to potassium for growth and production. Beyond its effect on growth and production, it also affects bunch maturation period and fruit quality in which as nitrogen level increases the length of the maturation period also increases. In addition, nitrogen also affects bunch weight through its effect on number of hands and fingers, fruit circumference and weight. It also affects fruit quality by reducing total sugars and total soluble solids, and increasing acidity (Gowen, 1995).

On the other hand, potassium is found to be the key element in banana nutrition. It increases both the yield and quality of fruits. High potassium and calcium will give high dry matter and glucose content in the peel and pulp of banana fruit (Caussiol, 2001). Respiration was lower in potassium deficient plants and therefore the main effect of low potassium supply on dry matter production would be through reduction of photosynthesis. On the contrary, low levels of nitrogen, phosphorus and magnesium give high dry matter in the pulp. Low potassium produces thin fruits and fragile bunches. Excess potassium over nitrogen causes a premature ripening of fruits (yellow pulp). In addition, a potassium supply above that which influence growth and yield, changes in reducing and total sugars have reported. As potassium supply increases, the amount of sugar will increase and the acidity decreases. Thus potassium supply has an effect on fruit quality over and above its influence on yield (Gowen, 1995).

Phosphorus requirement of banana is not large as opposed to its demand for potassium and nitrogen, this can be explained by the facts that bananas accumulate the phosphorus they require over extended period of time; and a relatively small quantity of phosphorus is exported with the fruit and that phosphorus is easily redistributed from old to young leaf (Gowen, 1995).

Stage of maturity and ripeness

The bananas are harvested at a specific maturity stage in which the maturity indices are based on the age of the bunch, the interval between flowerings and harvesting, the filling of the fingers or the colour of the skin and pulp and brittleness of the flower end of the bunch. The filling of the fingers is the criterion mostly used. This standard is typically completed by other visual criteria like the evolution of the peel colour of the fruits. Most of these criteria depend on the cultivar. If the filling of the fingers was combined with the colour of the pulp, evaluating harvest maturity could become more objective (Chang et al., 2000). The interval between flowering and harvesting is also an objective criterion, which can be grounds for harvest decision.

In practice, harvest maturity of fruits will depend mostly on the target market or the duration of the required postharvest life. Banana to be marketed locally can be harvested at a more mature stage than those which are to be exported. They are harvested at 75 to 80% maturity for long distance transport taking some three weeks and at full mature stage for local domestic market (Gowen, 1995). If the fruits are to mature at harvest they may well split during handling, especially if they have recently been irrigated or it has rained.

According to the study of Ahmad et al. (2007), speed of ripening was independent of harvest maturity at the ripening temperature of 16°C but that it was reduced at 13°C for more immature fruit. Also chilling injury occurred at 13°C which reduced the acceptability of the fruit. The symptoms of chilling injury progressed as the fruit ripened and were more apparent at colour stage 6 than early colour stages. Bananas from the early stage of maturity showed increased levels of chilling injury symptoms. Early harvesting resulted poor quality ripe fruit in terms of the total soluble solids and eating quality. Therefore, the variation in the quality of ripe fruit on a commercial scale could be due to the difference of harvest maturity.

POSTHARVEST PHYSIOLOGY OF BANANA

Respiration

Respiration is a process by which stored organic materials (carbohydrates, proteins, and fats) are broken down into simple end products with a release of energy. Oxygen is used in this process and carbon dioxide is produced. Under normal atmospheric conditions, aerobic respiration takes place. During the respiration process there is a loss of stored food reserves in the commodity. This leads to hastening of senescence because the reserves that provide energy are exhausted. Also, there is loss of flavor quality, especially sweetness. The rate of deterioration of harvested commodities is generally, proportional to the respiration rate (Irtwange, 2006).

Bananas are harvested green and ripened in market areas. Fruits that are allowed to ripe on the tree often split, and tend to be mealy. The preclimacteric period after harvesting is vitally important for importers and ripeners because banana is transported before it is ripened. During this period, mature green fruit have a low basal respiration rate and ethylene production is almost undetectable. This period is also called the “green life” and the longest practical preclimacteric period is desired. Green life can be extended by decreasing temperature to 14°C, and storage under low O_2 (≤ 8%) and high CO_2 (≥ 2%) (Marriott and Lancaster, 1983).

Since banana is a climacteric fruit it exhibits a respiretory peak during ripening, after harvest at 20°C. Within a couple of days, respiration rate of about 20 mg $C0_2$ Kg^{-1} h^{-1} in the hard green banana fruit may rise to about five times at the climacteric peak and then fall as the ripening advances and there is also a considerable water loss through transpiration after the initiation of ripening (Salunkhe and Kadam, 1995).

The loss of substrate from stored plant product result in a decrease in energy reserves with the tissue, which in turn decrease the length of time the produce, can effectively maintain its existing condition. Respiration also reduces the total food. Finally, in marketing systems based on weight, respiratory losses of carbon represent weight losses in the product; hence, a decreased value (Kays, 1997).

Another extremely important effect of respiration is the removal of oxygen from the storage environment. If the ambient oxygen concentration allowed being excessively depleted, anaerobic conditions occur that 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. The respiratory reduction in oxygen concentration in the storage environment can also be used as a tool to extend the storage life of a product. On the other hand, elevated ambient levels of carbon dioxide resulting from the respiratory process can be used to decrease respiration since its accumulation impedes the rate at which the process proceeds (Kays, 1997). The two major respiratory substrates found in fruit are sugars and organic acids.

Both sugars and organic acids are found largely sequestered within the vacuole, and form a major contribution to the overall flavor of the fruit and the balance between sugars and organic acid can markedly affect the taste of the fruit. Both sugars and organic acids originate from photosynthetic assimilates. Fruits differ in how they assimilate, accumulates during development and ripening. Some fruits have accumulated the bulk of their carbohydrate prior to the onset of ripening. This is either stored primarily as starch, as in banana, or as sugars, as in tomato. Fruits which accumulate their assimilate prior to ripening can be harvested at the mature green stage and still attain acceptable flavor on ripening. This is important when considering the need for early harvest to optimize shelf life (Tucker, 1993).

Effect of ethylene on ripening

Ethylene production rates increase with maturity at harvest, physical injuries, disease incidence, increased temperatures up to 30°C and water stress (Pesis, 2004). On the other hand, ethylene production rates by fresh horticultural commodities are reduced by storage at low temperature, by reduced O_2 levels, and elevated CO_2 levels around the commodity (Irtwange, 2006). Exposure of climacteric fruits to ethylene advanced the onset of an irreversible rise in respiration rate and rapid ripening. Various packages can delay the onset of climacteric and prolong shelf life of fruits by reducing ethylene production and sensitivity.

Ethylene appears to be intimately involved in the initiation of ripening in banana, as in other climacteric fruit, but its mode of action is unknown (Seymour, 1993). Unripe banana show a constant, but low level of ethylene production until the onset of ripening. Ethylene production then increased and is followed by a rise in the rate of respiration. During ripening peak ethylene is normally reached while the rate of respiration is still increasing. As the rate of ethylene production declines, the rate of respiration reaches its maximum at around 125 mg CO_2 Kg^{-1} and then declines slightly, but remains at high level (Seymour, 1993). So to achieve optimum fruit quality, postharvest techniques like the application of controlled atmospheric storage and modified atmospheric packaging are used in order to modulate the physiological processes of ripening of banana fruits.

Transpiration loss

According to the study of Irtwange (2006) transpiration is the evaporation of water from plant tissues. Water loss 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, and reduction in nutritional quality. The nature of the epidermal system of the commodity governs the regulation of water loss that is affected as well 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 hand. As a physical process, it can be controlled by applying waxes and plastic films as barriers between the produce and the environment, as well as by manipulating relative humidity, temperature and air circulation.

The banana skin bears stomata and transpiration continues after the bunches has been cut. The magnitude of transpiration depends on temperature and relative humidity and absolute values for it are not worth reporting here for this reason. In trend, however, it shows a very marked relation to ripening which may briefly be described as follows. The green fruit, immediately after cutting, shows an initial fall in transpiration rate and then settles down to a steady state at level depending upon temperature and humidity; at the climacteric there is a sharp peak followed, as the fruit ripens, by the attainment of a new steady state (Simmonds, 1959).

There is usually a final rise in water loss which is related to degenerative changes of the skin caused by fungal attack; since the skin in this stage is senescent the loss can hardly be described as transpiration. These facts were established for individual fruits; because the bunches ripens progressively from the top hand to the bottom, the climacteric transpiration peaks of individual fingers are concealed and whole bunches (or bigger bulks of fruit) show simply a steady rising curve of water loss during ripening (Simmonds, 1959).

POSTHARVEST BIOCHEMISTRY OF BANANA

The ripening process, at the fruit level involves several biochemical pathways like degradation of starch to sugar, change in the peel and pulp colour, cell wall changes, change in the concentration of volatiles and acids (Gowen, 1995).

Texture

Most fruit soften during ripening and this is a major quality attribute that often dictates shelf life. Fruit softening could arise from one of the three mechanisms: Loss of turgor; degradation of starch; or breakdown of the fruit cell walls. Loss of turgor is largely a non-physiological process associated with the postharvest dehydration of the fruit, and as such can assume commercial importance during storage. Degradation of starch probably results in a pronounced textural change, especially in those fruit like banana, where starch accounts for a high percentage of the fresh weight (Tucker, 1993; Turner, 2001).

Carbohydrates

Starch forms about 20 to 25% of the fresh weight of the pulp of unripe bananas. During ripening this starch is degraded rapidly and the sugars sucrose, glucose and fructose accumulate; traces of maltose may also be present. Sugars are present in the green fruit only very small amounts, average about 1 to 2% of the fresh pulp; they increase to 15 to 20% at ripeness, the beginning of the increase coinciding with the respiration climacteric. Starch disappears concurrently, dropping from about 20 to 25% in the green fruit to about 1 to 2% in the ripe fruit; it is higher in the ripe plantain (6%) than in the dessert bananas (Simmonds, 1959). In the banana pulp sucrose is the predominant sugars, at least at the start of ripening, and its formation precedes the accumulation of glucose and fructose. The peel tissue also contains starch, about 3% fresh weight, and appears to show similar changes in carbohydrate during ripening. These characteristic patterns of carbohydrate metabolism can be altered under certain environmental conditions such as exposure to elevated temperatures during ripening (Seymour, 1993; Turner, 2001).

Pigments

There is a decrease in chlorophyll content from between 50 to 100 µg per gram fresh weight to almost zero in ripe fruit, while caroteniod levels (xanthophylls and carotene) remained approximately constant at 8 µg per gram fresh weight. There is reduction in total caroteniod content in the peel during the early stage of ripening followed by caroteniod biosynthesis at the yellow-green to yellow-ripe stage (Seymour et al., 1987).

Cell wall change

Softening of fruits appears to be closely linked with changes in their cell walls structures. In bananas, the changes in texture of the fruit during ripening probably result from alterations in both cell wall structure and the degradation of starch (Seymour, 1993).

Hemicellulose and pectin are components of cell wall and their concentration during ripening follows a trend similar to that of starch, dropping from 7 to 8% of the fresh pulp in the green fruit to about 1% at ripeness. There are indications of interconversion of starch and hemicellulose in the early phases of storage of green fruit. In behavior, however there is an important difference from starch, for the hemicellulose disappear whether or not the fruit is normally ripened; in fruit kept in prolonged cool storage, starch concentration declines slowly so that a high starch content is characteristic of “chilled” fruit until a very advanced stage of ripeness. The hemicelluloses, however, disappear at the normal rate under such treatment and their fate is still mysterious and they may be connected with loss of dry weight of the fruit which, it will be remembered, excess the loss that can be accounted for by respiration (Simmonds, 1959).

Organic acids

Pulp pH and total titratable acidity are important postharvest quality attributes in the assessment of fruit ripening quality. Generally, when fruits are harvested at matured green stage, the pulp pH is high but as ripening progresses pH drops. Thus, the pulp pH could be used as an index of ripening (Dadzie and Orchard, 1997). The skin of the fruit shows similar trend but is slightly delayed with respect to the pulp; this is not surprising in view of the fact that ripening proceeds from the core of the pulp outwards. Various measurements of pH range between about 5 to 5.8 for the pulp of the green fruit and between about 4.2 and 4.8 for post climacteric fruit (Simmonds, 1959).

The levels of organic acids in a fruit can markedly affect its taste. Generally, in banana the pulp shows an increase in acidity during ripening and the main organic acid present are malic, citric and oxalic. As ripening advances, acidity declines presumably due to the utilization as respiratory substrates. The astringent taste of unripe bananas is probably attributed at least partly to their oxalic acid content, which undergoes significant decarboxylation during ripening probably by the action of oxalate oxidase (Seymour, 1993). Despite the increase in acid with ripening, is less that the rate of increase of sugars and total soluble solids (Gowen, 1995; Abbas et al., 2012).

Enzyme activity

Banana fruit contains several hydrolytic and oxidative enzymes. The relative activities of α-mylase, starch phosphorylase, acid phosphate, and catalase increased considerably in banana fruits stored for 5 weeks at 20°C. The stage of maturity of banana fruit at harvest significantly influenced most of the physical and biochemical constituents and the activities of some enzymes. Banana fruits harvested at mature or early mature stage had a longer storage period and better quality. The potential storage life of banana fruits decreased with an advance in stage of maturity (Salunkhe and Kadam, 1995).

POSTHARVEST MICROBIOLOGY OF BANANA

Postharvest diseases can cause serious losses of fruits both in terms of quantity and quality. Fruits infected with disease have no market value. There are many postharvest diseases of banana, cooking banana and plantain. Among these important ones are crown rot, anthracnose and cigar-end rot (Dadzie and Orchard, 1997).

Crown rot

Crown rot is one of the most important postharvest diseases of banana/plantain. It is characteristically a disease complex caused by several fungi, sometimes in association with other micro-organisms such as bacteria. The most common pathogens associated with crown rot are *Colletotrichium musae* (*Gloesporium musarum), Fusarium roseum, Fusarium semitectium and Botryodiplodia theobromae.* When the hands are cut from the stems, the massive open wound is an ideal weak spot for crown rot fungi to enter and grow. Fungal spores on the fruit in the field are carried along (after harvesting bunch) to the packing house. Spores follow the fruit right into delatexing baths, where they are drawn deeply into the weak spot, the wound on the crown tissue (due to dehanding). Spores also remain on the outside of the fruit and are packed (Dadzie and Orchard, 1997; Dionisio, 2012). Symptoms of crown rot include softening and blackening of tissues at the cut crown surface, white, grey or pink mould may form on the surface of the cut crown and infected tissue turns black and the rot may advance into the finger stalk. The control of crown rot starts in the field with the regular removal of leaf trash. Proper field sanitation can greatly reduce the number of crown rot fungi spores present and not keeping rotting fruits or plant waste materials near the packing station. Dehanding should be done carefully with a sharp knife so as to avoid leaving a ragged cut. Finally, postharvest treatment of fruits with an effective fungicide is essential (Gowen, 1995; Dionisio, 2012).

Anthracnose

Anthracnose is one of the important postharvest diseases of banana, cooking banana and plantain. It is caused by the fungus, *C. musae*. Anthracnose is common on wounds, but it is capable of attacking sound fruit as well. Occasionally, it invades the necks of the fingers when they are damaged. It is characterized by numerous small circular and brown to dark brown spots (Gowen, 1995; Dadzie and Orchard, 1997). Preventive measures begin in the plantation. It is important to maintain strict hygiene or sanitation in the plantation and pack house, in order to minimize the number of spores available for infection. All cultural practices that reduce scarring and injury to the fruit will prevent anthracnose (Dadzie and Orchard, 1997).

Cigar-end rot

Cigar-end rot of banana and plantain is an important postharvest disease caused by the fungi, *Trachysphaera fructigena*. Cigar-end rot is essentially a plantain disease (but it is also found in banana and cooking banana), the fruits being apparently most subject to attack in their more immature stages. The number of fingers affected in the bunch varies. The infection which starts with localized darkening and wrinkling of the skin originates in the perianths and spreads slowly backwards along the finger. The darkened area is bordered by a black band and a narrow chlorotic region which separates infected and healthy tissues. The principal method of control is frequent manual removal and burning of dead flower parts and infected fruits. Use of fungicide to control the disease is also recommended. In the pack house, care should be taken to cull infected fruits to avoid contaminating the washing water with spores. Cigar-end rot is effectively controlled by covering the flower (immediately after emergence) with a polyethylene bag before the hands emerge (Dadzie and Orchard, 1997).

POSTHARVEST HANDLING

According to the study of Kader (1992), as cited by Irtwange (2006), microbiological, mechanical and physiological factors cause most of the losses in perishable crops. Other causes of losses, according to the study of Fallik and Aharoni (2004) as cited by Irtwange (2006) may be related to: inadequate harvesting, packaging and handling skills, lack of adequate containers for the transport and handling of perishables, storage facilities inadequate to protect the food and transportation inadequate to move the food to market before it spoils.

Banana fruit is very susceptible to both abrasion and impact injury. The major marketing problem of export bananas is mechanical injury, which shows itself as black sunken areas on the skin after ripening. So during harvesting, care should be taken not to let the bunch fall on the ground and get damaged. During transportation the thin plastic liner in export cartons minimize chafing damage to fingers that rub against the side of the carton during handling. Latex allowed to dry on the skin oxidizes as brown and black stains and can also lead to downgrading of fruit. Other concerns are diseases, particularly crown rot, which may affect the whole carton and promote uneven fruit ripening. Because of weak pedicels, the fingers of some cultivar also fall from the hand during ripening, exposing the pulp (Nakasone and Paull, 1999).

Transport

Banana bunches after harvest, are transported to the packing shed on padded trailers or on an overhead cable system. Dehanding can be performed in the field, with the hands transported to the packing shed on padded trailers. Care is essential in these steps to avoid any mechanical injury that would reduce fruit quality (Nakasone and Paull, 1999). Dehanding plantains in the field and the use of plastic forms is recommended to protect bunches of plantain during harvesting and transportation to the packaging site in the same manner as exportation from industrial plantations. This reduces mechanical damage and avoids reduction of fruit quality of plantains for exportation (Chang et al., 2000). The utility of this packaging is not obvious in many producing countries as peasants and intermediate wholesalers are accustomed to bunch. In addition, they are not prepared to bear additional costs or extra investment to buy plastic cages for local sales but the loss from mechanically damaged fruits was far higher than the cost of plastic cages (Chang et al., 2000).

In most countries, markets located in the production area, the bunches of plantains bought from the villages are piled up on one another then loaded in bulk in trucks or vans for travel to big distribution and consumption centers situated at times hundreds of kilometers away. The bunches are piled up to maximize loading and to expedite transportation. They are unloaded without caution at the destination. These different modes of packaging and transportation expose the fruits to damage and low market quality (Dadzie, 1998; Chang et al., 2000).

In Ethiopian, large trucks are used to transport unripe banana from major growing areas to big cities. Bunches are piled on the truck loosely and then covered with banana leaf. Due to the distance from the growing area to the cities, fruits may stay a day or two and crating or boxing is not practiced, which results in mechanical damage which is not clearly visible on unripe fruit. However, on ripening it may greatly reduce the market value (Seifu, 1999).

While transporting banana for export purpose, boxing was experimented in the previous times but now abandoned because of various types of spoilage. Modern means of combating the organisms that cause such problems, as well as better systems of handling and transport, quality control, and good container design, have made carton packing not only feasible but necessary. First, the hands are graded for size and quality and then packed in layers in special ventilated cartons with plastic padding to minimize bruising (Morton, 1987). There are several advantages of boxing over naked bunch transport. Transport of hands in boxes has compelled growers to produce particular size of bunch. This has also avoided more handling and export of waste material (Salunkhe and Kadam, 1995).

PACKAGING AND STORAGE

Controlled atmospheric storage

Controlled atmosphere (CA) storage is a technique for maintaining the process quality in an environment that differs from air with respect to the proportion of O_2 and CO_2 (Abdullah et al., 1990). Wills et al. (1998) describe CA storage as the precise control of oxygen and carbon dioxide concentrating usually with a decrease in oxygen and increase in the carbon dioxide to extend the produce storage life. The respiration rate of fresh produce is slowed down with a decrease in oxygen of fresh produce. It has previously been reported by Salunkhe and Desai (1984) as cited by Ahmad et al. (2006) that controlled atmosphere with high CO_2 inhibits the breakdown of peptic substances, retains fruit texture and remains firmer for a longer period. In current research this effect was most dominant at reduced O_2 levels but effect of low O_2 cannot be separated from the effect of increased CO_2. However, firmer ripe fruit is considered one of the benefits of CA storage to reduce the mechanical damage, avoid fungal infection and to increase the shelf life of ripe banana fruit.

CA storage condition inhibits ethylene production and retards the rate of banana ripening (Quazi and Freebrain, 1971). However, care has to be taken because low oxygen can cause fermentation/anaerobic respiration. Therefore, it is necessary to formulate different combinations to delay ripening of banana fruit, while allowing them to subsequently ripen to good quality. Liu (1976) reported that pretreated bananas (ethylene treated) stored for 28 days in 1% oxygen at 14°C remained green and firm until the end of storage, but started to ripen almost immediately after these were placed at 21°C in air without addition of ethylene treatment. Acedo and Bautista (1993) reported that fruit can be successfully stored under low oxygen conditions without raising the carbon dioxide in the atmosphere. According to the study of Ahmad et al. (2006) unripe fruit did not synthesize significant amount of ethylene at 18°C unless the oxygen level was above 7.5 to 8.0. Storage in reduced oxygen and increased carbon dioxide reduced the respiratory activity and slowed down the ripening processes. Nair et al. (1992) observed that oxygen and carbon dioxide quickly equilibrated when bananas were removed from lower oxygen to normal air.

Generally, the application of controlled atmosphere storage has a considerable significance in the proper shipment, storage and ripening of banana as a result, respiretion rate of the produce slowed down as a consequence processes associated with ripening were slowed (Thompson, 2001).

Modified atmospheric storage

Due to the complexities involved with produce, that is, varying respiration rates which are product and temperature dependent, different optimal storage temperatures for each commodity, water absorption, by-products, and so on, many considerations are involved in choosing an acceptable packaging technology. One of the areas of research that has shown promise, and had success, is that of modified atmosphere packaging (MAP). This technique involves either actively or passively controlling or modifying the atmosphere surrounding the product within a package made of various types and/ or combinations of films (Farber et al., 2003).

A modified atmosphere can be defined as one that is created by altering the normal composition of air (78% nitrogen, 21% oxygen, 0.03% carbon dioxide and traces of noble gases) to provide an optimum atmosphere for increasing the storage length and quality of food/produce. This can be achieved by using controlled atmosphere storage (CAS) and/or active or passive MAP. Under controlled atmospheric conditions, the atmosphere is modified from that of the ambient atmosphere, and these conditions are maintained throughout storage. MAP uses the same principles as CAS; however, it is used on smaller quantities of produce and the atmosphere is only initially modified. Active modification occurs by the displacement of gases in the package, which are then replaced by a desired mixture of gases, while passive modification occurs when the product is packaged using a selected film type, and a desired atmosphere develops naturally as a consequence of the products' respiration and the diffusion of gases through the film (Farber et al., 2003).

Development of an extended shelf life of banana process should be possible by applying treatments of MAP storage. Once ripening was triggered by not exposing the bananas to large concentrations of ethylene as is normally done, MAP storage conditions decreased respiretion and extended ripening of the bananas up to at least one month (Basel et al., 2002). According to the study of Hassan (2004), the development of modified atmosphere technology has allowed the bananas to be stored for more than eight weeks in combination with refrigeration at 14°C.

Modifications of the storage atmosphere, along with their effects on the physiological life of the produce, can also be advantageous in retarding postharvest disease development. The effect of atmosphere modification on postharvest 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).

Unripe bananas subjected to ripening in polyethylene bags of 150 gauge thickness at ambient temperature had significantly lower values of pulp: peel ratio, moisture total soluble solid, total sugar, titrable acidity, and total yellow pigments and higher values of alcohol insoluble substances , ascorbic acid, starch, and total chlorophyll, indicating that the ripening in these fruits was retarded to the extent of about 6 to 7 days, followed by those fruits stored in polyethylene bags of 200 gauge with 15 holes per bag (Salunkhe and Kadam, 1995).

Chamara et al. (2000) reported that packaging of a banana cultivar called ‘Kolikuttu ‘ as individual hands in low density polyethylene (LDPE) bags with a wrapped ethylene absorber could be recommended to extend their shelf life at ambient temperature. This could be of considerable economic importance in countries where cold storage is not readily available or expensive.

The benefits of film packaging include easy to handle (consumer package); protection from injuries; reduction of water loss, shrinkage, wilting; reduction of decay by modified atmosphere, reduction of physiological disorders (chilling injury), retardation of ripening and senescence processes and control of insect in some commodities. Harmful effects of film packaging include enhancement of decay due to excess humidity; initiation and/or aggravation of physiological disorders, irregular ripening in improper concentrations of CO_2/O_2; off-flavors and off-odors and increased susceptibility to decay (Irtwange, 2006).

Packaging can influence temperature management and water loss of the produce. To reduce water loss plastic wraps and liners may be used, but the restriction of ventilation so caused can result in problems of low oxygen, high carbon dioxide or an accumulation of water which can be improved by perforation of the films (Burdon, 2001).

Some of permeable films used for packaging of fresh fruits and vegetables are low density polyethylene, linear low density polyethylene, medium density polyethylene, high density polyethylene, polypropylene and polyvinyl chloride with different permeability for gases and water vapor as well (Thompson, 2001; Schlime 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, the accumulation and concentration of the gas and the thickness of the material.

FACTORS AFFECTING STORAGE

Simple methods intended to reduce the desiccation and the evapotranspiration rate of fruits are occasionally used within the traditional distribution channel to maintain a certain level of freshness and an acceptable quality for a number of days. These measures include precautions to limit mechanical damage to fruits, stocking bunches under shades shielded from the sun, and protection of piles of fruits with leaf of banana or bags regularly moistened with water (Kader et al., 1985).

Banana can be stored at a temperature slightly above 13°C and a relative humidity of 85 to 95% for about three weeks. Keeping the fruit in relatively high concentration of CO_2 and low concentration of O_2 can prolong storage life (Manzur et al., 2007). Generally, fruits must be kept at 13.3 to 15.6°C and 80 to 85% relative humidity after removal from storage and during delivery to markets to avoid rapid spoilage.

Temperature

Green bananas are shipped/stored at 13 to 14°C to delay ripening. Lower temperature can lead to chilling injury, whose symptoms include a dull, grey skin colour, poor ripening, and poor conversion of starch to sugars, poor flavor development and susceptibility to decay. Symptom development is dependent on exposure temperature and time and susceptibility depends mostly on cultivar (Nakasone and Paull, 1999).

Temperature beyond 25°C shortened the duration of the preclimacteric and fruit quality is altered because of modification to metabolism during ripening. Above 35°C the development of the peel and the pulp is desynchronized, with softening of the pulp proceeding faster than the colouring of the peel. This results in fruits with a soft pulp but a green peel and this type of fruit is known as cooked/boiled green and a temperature above 48°C, the climacteric in not triggered and ripening is effectively blocked on the other hand, banana fruit blackens at lower temperatures and should not be placed in a refrigerator (Gowen, 1995).

Relative humidity

The lower the relative humidity, the greater the loss of water and the shorter is the duration of the preclimacteric.

Low humidity brings forward the production of ethylene and the respiratory rise, but its effect on the intensity of ethylene production seems to be dependent on variety. Relative humidity changes in the weight relationship between pulp and peel, in the peel colour, in pulp softening and in the soluble sugar content (Gowen, 1995).

Gas compositions

The composition of gases in the storage atmosphere can affect the storage life of horticultural products. Changes in the concentration of the respiratory gases, oxygen and carbon dioxide may extend storage life. This is generally used as an adjunct to low temperature storage, but modification of the storage atmosphere can usefully substitute for refrigeration for some commodities (Wills et al., 1998). Storage in reduced oxygen and increased carbon dioxide reduced the respiratory activity and slowed down the ripening processes. Ahmad et al. (2006) observed that oxygen and carbon dioxide quickly equilibrated when bananas were removed from lower oxygen to normal air. According to the report of Knee (1980) chlorophyll breakdown was reduced clearly in reduced oxygen.

According to the study of Shorter et al. (1987), the storage life of banana can be increased five times when they are stored in plastic film (where the gas content stabilized at about 2% O_2 and 5% CO_2) with an ethylene scrubber compared to fruit stored with out wraps. If the film was insufficiently permeable, packaging apple bananas in polythene film and storage at 13 to 14°C accumulated levels of CO_2 which could prove toxic to the fruit. Symptoms of CO_2 injury were observed when CO_2 levels were between about 5 and 14%. Injury was characterized by darkening of the skin and softening of the outer pulp while the inner pulp remained hard and astringent.

CONCLUSION

In Africa, huge postharvest losses especially of horticultural produce have been reported due to lack of packaging, storage facilities, and poor means of transportation. In spite of these facts, the attention given to reduce this postharvest loss has been low in the past. However, in recent years the postharvest handling of horticultural crops is becoming the area of research and there are some considerable work done in this area on different crops. Banana is one of the most common and widely grown fruit crops. It is a delicate and highly perishable fruit, and the production is subject to poor handling and storage practices and postharvest diseases. As a result, a huge postharvest loss of banana has been reported every time and these postharvest losses are incurred at different stage from harvesting to the final consumption. Traditionally, farmers use *teff* straw and banana leaf during transportation and storage mainly to avoid mechanical damage during transportation and to avoid water loss during storage. These two materials are better to keep the fruit than keeping in an open air, but there are also other modern packaging materials like polyethylene bags with different permeability to gases and water vapour which improve the shelf life. So, the following aspects should be considered: in order to draw a general recommendation, research should be done on different polyethylene bag packagings and also on the physico-chemical properties of the cultivars at different times and in different locations; there is a need for testing the suitability and application of different types of polyethylene bag packagings for banana and other crops; these packaging treatments should be combined with other pre package treatments like disinfection in order to guarantee the complete post harvest quality of banana fruit and finally, there is also a need to carry out research not only on the preharvest but also on the postharvest approaches hand in hand to reduce losses and maintain quality.

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