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Eco-friendly post-harvest technologies of banana: A review

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Abstract
Banana is one of the most appreciated fruit all over the world because of its multi-purpose use as food. Lack of suitable post-harvest management practices like canopy management, climate condition, water management, nutrient management, Stages of maturity may lead to a huge economic loss for the banana producing regions. Different postharvest management practices are in use to enhance its shelf life by delaying the ripening, reducing respiration rate, and controlling the disease-causing organisms like crown rot, anthracnose, and end rot, during transport and storage. An integrated approach can ensure product safety and quality that reaches the consumer, residing far away from the production area. In this article different pre-storage treatments *viz.* pre-cooling, chemical and biological treatment for disinfection, modified atmospheric packaging, irradiation, and coating for enhancement of shelf life is discussed in brief.

Keywords: Shelf-life, maturity, quality, nutrient, yield

Introduction

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) [38]. Genetic factors Banana breeding has been existing for more than seventy years (Ortiz *et al*., 1995) [29]. 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) [17]. Variety also has an effect on yield, firmness, fibrous Ness, succulence and juiciness (Kader, 1992) [20]. 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 photosynthetic partitioning (Beverly *et al*., 1992) [5]. Increasing the energy supply and decreasing the water content of fruit increases TSS in Banana. Thus, TSS exemplifies a trade-off between yield and quality, since yield generally decreases with increasing TSS (Shewfelt and Prusia, 1993) [37]. The genotypic characteristics of any one cultivar vary in response to environmental effects.

Canopy management Canopy management focuses on the amounts of light and CO2 that fruits receive. For banana fruit, full shade gives a dull yellow peel color whereas partial shade leads to a bright yellow peel color. Low light intensity retards development of carotenoids. 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) [40]. Plant health and leaf/fruit ratio also influences flavor (Hofman and Smith, 1993) [17].

Climatic condition

To classify areas according to a range of suitability criteria for banana production, a spatial modelling procedure was developed and implemented in ArcGIS (Esri Inc.), using Esri Model Builder.

Actual Mean Monthly Temperature and Precipitation (Spatial resolution: – 5 kilometer (km) – 2.5 arc-min) were used for the global classification analysis found in the portal World Climate (Hijmans *et al.*, 2005) [16]. Three categories of lands were indented in the initial round of analysis Areas not suitable for banana production were dined as areas having three or more months with temperatures below 13ºC. Globally suitable areas were classified into tropical and subtropical banana production areas. Tropical areas have a relatively uniform average monthly temperature throughout the year, while subtropical areas were considered those which have a difference between the warmest and coolest months of greater than 8ºC (as well as with fewer than three months below 13ºC).

Water management

In the Tropics Upper Aguan Valley in Honduras (ca. 15°22´N alt. 250 m), an area where the Banana is widely irrigated, attempted to develop a method of determining the water requirements of the cv. Giant Cavendish (AAA Cavendish subgroup). Based on measurements of changes in soil water content (volumetric) over a one-year period they developed a multiple regression equation (without standard errors) relating daily crop water use to mean air temperature and relative humidity. Actual measured rates of water use for irrigated crops ranged from about 5.7 to 9.2 mm d−1. Interestingly they reported that when 'hot dry winds' prevailed rates of water use declined. This they associated with the dryness of the air (saturation deficit) causing transient wilting whenever potential transpiration rates exceeded the capacity of the plants to supply water from the soil to the leaf surface. This tended to occur in those months when the mean air temperatures were about 28° C and the relative humidity of the air, recorded on five occasions during each day (07:00, 09:00, 12:00, 15:00 and 17:30 hours) with a sling psychrometer, averaged about 63%. This corresponds to a saturation deficit value for the air of about 1.5 k Pa. In Mediterranean climates, the leaves of banana die back in the winter months, explaining the low ETc/Epan ratios at this time **(**Lahav and Kalmar 1988) [24]. At Tyr in the south of Lebanon (33°16´N), a large drainage lysimeter (7 × 7 m square × 1.2 m depth of soil) was used to measure the actual water use of five plants (plant crop) spaced 3 m apart in a triangular array, over a 20-month period through 1971 and 1972. At this high latitude location, evapotranspiration rates during the winter months averaged only 1–2 mm d−1 increasing through the spring and early summer before peaking in July and August at 5 mm d−1 in the plant crop, and 6 mm d−1 in the first ratoon, and then declining rapidly through the autumn. During the period covered, the Kc factor for a USWB Class A evaporation pan ranged, on a monthly basis, from 0.41 after planting to a peak of 1.13 late in the first ratoon. Over the 12- month, first ratoon, period Kc averaged 0.78, and 0.82 for the six months (May–October) when irrigation was applied. When compared with the Penman Eo (open water) estimate the corresponding Kc values were 0.90 and 0.85 respectively. Water was extracted from the soil to depths of 0.6–0.8 m, by plants both within and outside the lysimeter (Bovee, 1975) [6].

In Sub Tropics Ghavami (1974) [14] reported the results of an irrigation experiment conducted in the Sula Valley, Honduras (ca. 15°20´N alt. 30m) over a three-year period (1968– 1971) with cv. 'Valery' (AAA Cavendish subgroup). Variable amounts of water were applied through under-tree sprinklers (from 25 to 83 mm weekly, inclusive of rainfall (average annual total 1140 mm), or half these quantities twice a week), but independent of evaporation rates. There was no unirrigated control treatment. They concluded from an analysis using third order polynomial equations that a gross weekly water application need not exceed 44 mm, and that there were no benefits from irrigating more often than once a week. Yields of fresh fruit averaged across treatments were 55 t ha^{-1}.

In Bangalore, India (13°58´alt. 868 m), Hegde and Srinivas (1989) [15] compared the responses of cv. 'Robusta' (AAA Cavendish subgroup) to irrigation at four different m values (from −25 to −85 k Pa; sandy clay loam soil) as measured at depths of 0.15 m at 0.30 m from the stem. Fruit yields declined from 52 to 41 t ha^{-1} as the frequency of irrigation decreased. Actual evapotranspiration was measured using a water balance approach and annual totals ranged from 1100 to 1860 mm, giving corresponding water use efficiencies of 37 to 28 kg ha^{-1} mm^{-1}. Although the experiment ran from 1984 to 1986, it is assumed that these values are annual average responses. Unfortunately, the amounts of irrigation water applied are not recorded. Mid-day leaf water potentials (measured with a Scholander pressure chamber in the pre-flowering period) fell to −0.20 MPa in the wettest treatment, and to −0.62 MPa in the driest. There was some evidence that osmotic adjustment-maintained pressure potentials in the leaf. There was no evidence of an interaction between responses to irrigation and to nitrogen fertilizer.

Nutrient management

Effect of Integrated Nutrient Management on Growth Parameters of Banana cv. Rajapuri Banana (Musa spp.) is one of the important fruit crops of the tropics. The fruits are rich source of carbohydrate and energy. The research on effect of integrated nutrient management practices on banana with commercial formulations of organic fertilizers is new under the soil and climatic conditions of arid dry zone of Karnataka. The cv. Rajapuri is the commercial variety used for the study. The objective of experiment includes to study the effect of integrated nutrient management on growth parameters of banana. The experiment contains six treatments and four replications laid in a randomized block design. The treatments consist of T1-RDF 100% (200:100:300 g NPK + 20kg FYM per plant) T2-RDF100% (200:100:300 g NPK + 20kg FYM per plant) + PSB (20g) + Azospirillum (20g) T3 - RDF 75% + 25%, N and P through organic sources T4 - RDF 50%+ 50%, N and P through organic sources T5 - RDF 25%+75%, N and P through organic sources T6-100%, N, P and K through organics sources. The treatment received 100% recommended dose of fertilizers (RDF) along with Vermicompost (2kg) + Neemcake (250g) + Azospirillum (50g) + PSM (50g) + VAM (250g) recorded the highest plant height, pseudo stem girth, number of functional leaves, total leaf production, total leaf area and leaf area index. The consumption pattern of banana is increasing day by day due to its nutritional value and high economic returns. Higher productivity in banana is possible through quality planting material, proper nutritional management, and other novel culture practices.

Integrated nutrient management (INM) is the system of rationalization of the plant nutrition management to upgrade the efficiency of plant nutrient supply through adequate association of local and external nutrient sources accessible and affordable to the farmers. Combined application of organic manures and chemical fertilizers generally produces higher crop yields than their sole application. This increase in crop productivity may be due to the combined effect of nutrient supply, synergism, and improvement in soil physical and biological properties. Locally available various organic sources like coir pith, press mud, FYM and copper ore tailings (COT) can be judiciously used to enhance the yield and profitability of crops. Application of AM 250 g + phosphate solubilizing bacteria (PSB) 50 g + Azospirillum 50 g/ plant along with 100% recommended dose of fertilizers (110:35:330 NPK/ plant is recommended to get high yield potential of 65 t/ha. Foliar application of $ZnSO_4$ 0.2% + $FeSO_4$ 0.2% + $CuSO_4$ 0.2% + Boric acid 0.1% at 3rd, 5th, and 7th month after planting along with recommended dose of fertilizers is recommended to improve the yield and quality traits. Covering bunches with 150gauge white polythene bunch cover with 2% vent holes immediately after opening of the last hand is recommended to enhance the bunch maturity by 20 days, reduce the blemished fruits by 19.26% and attractive colored fruits. Soil application of pseudomonas fluorescens 10 g/plant at the time of planting is recommended of nematodes. Foliar spray of propiconazole 0.1% + pseudomonas flourescens 0.5%, three times at 15 days' interval is recommended to effectively control sigatoka leaf spot disease. Pseudo stem injection of monocrotophos or dimethoate @ 1 ml + 5 ml water mixture administered @ 4 ml/ plant has to be adopted for the management of pseudo stem borer in banana and to obtain benefit cost ratio of 2.85 and 2.79 for monocrotophos and dimethoate respectively. Spraying mancozeb 0.25% starting from 3rd month onwards with one-month interval is recommended to reduce the leaf spot incidence. (TNAU Agri portal).

Stages of maturity

Time of harvest based on maturity indices is very important for fruit quality. Fruits harvested before optimum maturity may not ripe adequately and may not develop adequate flavor, while fruits harvested late (over-matured) have a shorter postharvest life and deteriorate rapidly. Climacteric fruits can be harvested after reaching full maturation, and before reaching the ripening stage. The tissue culture suckers of BARI Kola1 and Sabri Kola varieties were used for the study. The experiment was conducted at the Farm Machinery and Postharvest Process Engineering Division, Bangladesh Agricultural Research Institute, Gazipur in 2009-10. Optimum maturity stage of banana fruits reduced the postharvest losses and extended the storage life of fruits. BARI Kola 1 and Sabri Kola reached to flowering stages 10 and 15 months after planting, respectively. The optimum maturity stages of BARI Kola 1 and Sabri Kola were found to 120 and 100 days after emergence of flowering (DAEF) in summer and 130 and 110 DAEF in winter seasons, respectively. Higher pulp to peel ratio and yield of both the varieties was found in summer than those of winter season. The pre- harvest loss of banana fruits started at the point when it just exceeded the optimum maturity stage. Decreasing trend of shelf-life and firmness of fruits for both the varieties were observed with the advancement of maturity. On the other hand, dry matter content, angularity, pulp to peel ratio, and yield of banana fruits increased with the advancement of harvesting days. Degree days of these varieties were found to be 1750 and 1620, respectively.

Post-harvest factors of banana

Ripening and storage: Banana fruits continue to grow while attached to the parent plant and accumulate starch in the pulp. When maturation begins after 80-90days of flowering, the fingers stop elongating and the fruit starts getting rounded, bloated up width wise. Unless the fruits are harvested when they are ¾thquarters round, the fruits split while still green. The harvested banana passes through three physiological stages of growth i.e. pre-climacteric or 'green stage', climacteric or 'ripening stage' and finally senescence stage (Robinson, 1996). Unripe banana shows allow level of ethylene, a natural plant hormone that regulates every facets of plant growth. During ripening stage, higher ethylene production induces higher metabolic rates of starch to sugar conversion; chlorophyll degradation and unmasking of carotenoids, thus the green banana turns progressively yellow and dark colored. This also brings about decrease in astringency, decrease in polyphenol content, increase in polyphenol oxidase activity, attributing to browning of peels, increased respiration rate, loss in firmness and increase in moisture content in the pulp. Artificial ethylene, application canals enhance the polyphenol oxidase activity and respiration rate. For local consumption, the fruits can be treated with ethylene or ethephon (Vendrell, 1985; Domínguez and Vendrell, 1994) [11, 43] but for long distance transport it is desirable to have longer green period or para-climactic phase. The ripening phase thus can be delayed by controlling storage environmental conditions and using different methodologies as discussed in the following sections. (Debabandya Mohapatra 2010) [10]

Coating

Various type coatings have been in and the market is flooded with such packaged food materials. Some of the packaging materials are biodegradable, and some of them are composites. Some of the biodegradable as well as composite packaging materials are edible. For fresh whole banana fruits, edible coating will not be a suitable option as the banana is usually consumed after being peeled. In such cases both biodegradable and non-biodegradable or composite films with distinct potential to delay the ripening and reduce the respiration rate as well as microflora population, will be of utmost importance. Coating the fruit prior to ripening initiation delays the rapid ethylene production, thus delaying the ripening process and the chlorophyll loss which normally accompanies ripening (Banks, 1985) [4]. Modified atmospheric storage/controlled atmospheric storage/active packaging Storage techniques like controlled atmospheric storage and modified atmospheric packaging involves manipulation of respiration rate of the stored produce, by altering the CO_2:O_2 in the packaging system. For fruits and vegetables, a modified atmospheric packaging environment with 3-8% CO_2, 2-5% O_2 and 87-95% N_2 has been found suitable (Phillips, 1996)[31]. Respiration rates governed by storage temperature and composition of storage atmosphere. Post-climacteric nitrogen storage is not a suitable method for increasing shelf life, as it causes skin browning and decomposes the banana aroma ethyl acetate to 3-methylbutyl ester and 1-butanolthat renders overripe aroma in the banana. Banana stored under modified atmospheric package at lower temperature, with silicon membrane can reduce the respiration rate to a significantly lower level, impairing minimum damage to the product quality in terms of harvest-fresh appearance, color, texture, in addition to improvement in the shelf-life (Stewart *et al.*, 2005) [40]. Senescent spotting of banana peel can also be inhibited by modified atmospheric packaging through maintenance of low oxygen level in the packaging system. This reduces the phenylalanine ammonialyase activity in the peel and increases polyphenol oxidase that might have attributed to the increase in potentially active protein, thus limiting the senescent spotting. At the same time higher oxygen level promotes spotting in banana peel. The negative impact of higher concentration of carbon dioxide in thepackaging system can be evaded by the inclusion of suitable oxygen scavenger, carbon dioxide scrubber and ethylene absorbents, which do not have any effect on spotting (Choehom *et al.,* 2004) [9]. Chitosan based coating and some polymers like vinyl chloride with antioxidants, essential oils through either director indirect contact, have the capability of removing off odor, ethylene absorption and oxygen scavenging properties (Phillips1996) [31].

Ripening

Ripening behavior and postharvest quality play a significant role in the commercialization of banana fruits. Postharvest life ranging from 11 to 28 days and the local variety took 11 days to reach the final stage of ripening whereas Dwarf Cavendish (23 days) and Grand Nain (27 days) took the longest. Weight loss during the postharvest period recorded high for Poyu and Butazu varieties, but small weight loss was measured for the local variety. The mean finger lengths of banana fruit scored high were for William-I and Dwarf Cavendish. Grand Nain, Butazu had the heaviest mean finger weight. Fruit circumferences are used mainly to determine the size and shape of packaging. The local variety showed the largest pulp diameter followed by Dwarf Cavendish. When pulp weight is compared, William-I had the highest mean pulp weight followed by Butazu, but the local variety had the least. High peel weight can be considered advantageous because it offers protection against mechanical damage and peel can also be used as animal feed. However, the high peel can also be considered as a disadvantage as it results in lower edible portions. Mechanical damage is an important factor that can lead to downgrading of banana fruits. Present quality rating in the European union takes into account the percentage of peel damage due to bruising, scarring and scratching. The high peel weight of William I, Dwarf Cavendish and Butazu could be an advantage in offering protection against mechanical damage during transport, handling and shipping and thus fruits of these varieties can suit for international trade.

1. Post-harvest microbiology

Banana is the common name for the members of the genus Musa belonging to the family Musaceae. It is a climacteric fruit and gives off large amounts of ethylene during ripening phase. It is the second most important horticultural crop of Sindh, cultivated on almost 66,000 acres with an average yield of 5-6 tons per acre (Qureshi, 2011) [32]. Around 126,000 metric tons of bananas are produced in Sindh annually and represents 85% of country's total banana production (SDF, 2009) [36].

About 50% production losses among the supply chains of fruits and vegetables are reported in South East Asia (FAO, 2011) [13]. Post-harvest diseases are reported to destroy 10-30% of the total yield of crops especially in developing countries **(**Agrios, 2000; Ilyas *et al.,* 2007; Kader, 2002) [21, 1, 19]. In Pakistan post-harvest losses are up to 35-40% of the total production (SDF, 2009) [36]. Different post-harvest diseases reduce the quality and post-harvest life of banana. The most important of these include anthracnose (Colletotrichum musae), cigar-end rot (Trachysphaeria fructi Gena and Verticilliumtheo bromine), crown rot (Ceratocystis paradox, *C. musae*, *Fusarium pallidoroseum*, *Lasiodiplodia theobromae* and *V. theobromae*), finger rot (*L. theobromae*), Johnson spot (*Magnaport hegrisea*) and squirter disease (*Nigrosporasphaerica*) (Sholberg and Conway, 2004) [39]. Rot producing fungi *viz. Lasiodiplodia theobromine*, *Colletotrichum musae*, *Fusarium moniliformin* and *Verticilliumtheobromine* are reported from banana during transport and storage in Pakistan (Ilyas *et al*., 2007) [19]. During the present studies, an emphasis was laid on the banana post-harvest disease assessment along with improvement of quality and was screened for the isolation of rot producing organisms. The effect of temperature on post-harvest rots of banana was investigated by artificial expensive of green mature banana to different temperature regimes.

Crown Rot

Banana is one of the most important tropical crops and is affected by several fungal diseases, such as crown rot postharvest disease. Crown rot is responsible for significant losses in banana fruits Predominantly, *Colletotrichummusae* and *Fusarium* spp. are its causative agents Inoculum sources include mainly infected flowers but also decaying leaves, and fungal transfer can occur from banana stalks onto the crown surface during the cutting of banana bunches (knife-induced) as well as when the bunches are cleaned in contaminated water. Fungal infection starts at harvest, and the first symptoms of crown rot appear only after packaging and shipping from producing countries to consuming countries. Crown rot begins with a mycelium development on the crown surface, followed by an internal development. This internal development can, subsequently, affect the peduncle and the whole fruit, leading to softening and blackening of the fruit tissue. Postharvest fungicidal treatments are applied to control crown rot disease, though severely affected banana fruits are still found in consumer markets. Moreover, onset and spreading of the disease is unpredictable and can also induce early ripening of banana fruits during transport.

Anthracnose

Anthracnose is a postharvest disease of banana caused by the fungus *Colletotrichum musae* that results in major economic losses during transportation and storage. For the management of banana anthracnose, antifungal effects of Arabic gum (AG) (5, 10, 15 and 20%), chitosan (CH) (1.0%), and the combination of AG with CH were investigated *in vitro* as well as *in vivo*. CH at 1.0% and 1.5% had fungicidal effects on C. musae. AG alone did not show any fungicidal effects while the combination of 1.0% CH with all tested AG concentrations had fungicidal effects. However, the potato dextrose agar (PDA) medium amended with 10% AG incorporated with 1.0% CH showed the most promising results among all treatments in sup- pressing the mycelial growth (100%) and conidial germination inhibition (92.5%).

In vivo analysis also revealed that 10% AG incorporated with 1.0% CH was the optimal concentration in controlling decay (80%), showing a synergistic effect in the reduction of C. musae in artificially inoculated bananas. The 10% AG incorporated with 1.0% CH coatings significantly delayed ripening as in terms of percentage weight loss, fruit firmness, soluble solids concentration and titrable acidity. The results showed the possibility of using 10% Arabic gum incorporated with 1.0% chitosan as a bio fungicide for controlling postharvest anthracnose in banana **(**Mehdi Maqbool 2010) [26].

Post-harvest handling

Transport

Banana bunches after harvest, are transported to the packing shed on padded trailers or on an overhead cable system. De-handing 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) [28]. De-handing 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) [8]. 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) [8]. 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 **(**Chang *et al.,* 2000) [8]. 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) [37]. 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) [27]. There are several advantages of boxing over naked bunch transport. Transport of hands in boxes has compelled growers to produce size of bunch. This has also avoided more handling and export of waste material (Salunkhe and Kadam, 1995) [35].

Pre-cooling after Harvest

Field heat is usually high and undesirable at harvesting stage of many fruits and vegetables and should be removed as quickly as possible before any postharvest handling activity. Excessive field heat gives rise to an undesirable increase in metabolic activity and immediate cooling after harvest is therefore important. Precooling minimizes the effect of microbial activity, metabolic activity, respiration rate, and ethylene production, whilst reducing the ripening rate, water loss, and decay, thereby preserving quality and extending shelf life of harvested Bananas. The suitable temperature range of about 13–20 °C for Banana handling can be attained either in the early hours of the morning or late in the evening. Harvested fruit must be precooled to remove excessive field heat if harvested at times other than the recommended periods. A cheap but effective way of precooling harvested Bananas for producers of developing countries can be by dipping fruits in cold water (hydro cooling) mixed with disinfectants such as thiabendazole and sodium hypochlorite if availability of clean water is not a challenge. This method is effective in removing field heat whilst reducing microbial loads on the harvested fruits. Banana producers in developing countries especially those from Africa assemble their harvested produce under tree shade to reduce field heat. Tree shade, however, is not a reliable and effective way of reducing field heat in harvested produce. (Arah *et al.,*) [20] therefore, suggested that the adoption of a simple on-farm structure like a small hut made of thatch can be very beneficial in precooling of harvested Banana.

Packing

Packaging is also one of the important aspects to consider in addressing postharvest losses in fruits and vegetables. It is enclosing food produce or product to protect it from mechanical injuries, tampering, and contamination from physical, chemical, and biological sources. Packaging as a postharvest handling practice in Banana production is essential in putting the produce into sizeable portions for easy handling. However, using unsuitable packaging can cause fruit damage resulting in losses (P.A. Idah *et al.,*) [30] Some common packaging materials used in most developing countries include wooden crates, cardboard boxes, woven palm baskets, plastic crates, nylon sacks, jute sacks, and polythene bags. Most of the abovementioned packaging materials do not give all the protection needed by the commodity. Whilst the majority of these packaging materials like the nylon sacks do not allow good aeration within the packaged commodity causing a build-up of heat due to respiration, others like the woven basket have rough surfaces and edges which cause mechanical injuries to the produce. The wooden crate and the woven palm basket are some of the common packaging materials used in many developing countries especially those in Africa for packaging Banana. The major shortcoming of the wooden crate is in its height which creates a lot of compressive forces on fruits located at the base of the crate. These undesirable compressive forces cause internal injuries which finally result in reduced postharvest quality of the Bananas. There have been suggestions of modifying the wooden crate to make it more suitable for packaging Banana. Kitinoja has therefore suggested that the depth of the crate should be reduced considerably to reduce the build-up of compressive forces which can cause mechanical injuries to fruits at the base of the crate after packaging. The palm woven baskets used by Banana handlers have sharp edges lining the inside which puncture or bruise the fruit when they are used. It has also been recommended by (Idah *et al.,*) [30] that woven palm baskets should be woven with the smooth side of the material turned inward.

Storage

Banana has very high moisture content and therefore is very difficult to store at ambient temperatures for a long time. Meanwhile, storage in the value chain is usually required to ensure uninterrupted supply of raw materials for processors.

Storage extends the length of the processing season and helps provide continuity of product supply throughout the seasons. For short-term storage (up to a week), Banana fruits can be stored at ambient conditions if there is enough ventilation to reduce the accumulation of heat from respiration. For longer-term storage, ripe Bananas can be stored at temperatures of about 10–15°C and 85–95% relative humidity. At these temperatures, both ripening and chilling injuries are reduced to the minimal levels. These conditions are also difficult to obtain in most tropical countries and therefore losses of appreciable quantities of harvested Bananas have been reported. This is consistent with the claim that the quality of Banana is compromised when exposed to high temperatures and high relative humidity. Very low temperature storage too is detrimental to the shelf life and quality of many tropical fruits like Banana. For instance, refrigerating a Banana will reduce its flavor, a quality trait of Banana which is largely determined by the total soluble solids (TSS) and pH of the fruit. An understanding of the correct temperature management during storage of Banana is vital in extending the shelf life of the fruit whilst maintaining fruit qualities. Banana handlers in tropical countries can store Bananas for short to intermediate time by using evaporative cooling system made from woven jute sacks.

Factors affecting storage

Temperature

The result of the experiment indicated that most of the weight loss occurring in the higher temperatures 30 ºC and 25 ºC. The fruits that were kept at lower (15 ºC) temperature took a significantly longer time (32 days) to ripen that the fruits at higher temperatures 30 ºC (14 days) and the control (13 days). This is because climacteric fruits give off ethylene during ripening and the sensitivity of bananas to ethylene is very low, within the range of 0.01 -1.0 ppm and increases with increasing temperatures. Banana kept at higher temperature showed shorter finger length as compared to store at low temperature. Similar trend recorded for fruit volume, fruit weight, peel weight and pulp weight. This indicated that the role of temperature is pronounced in affecting the quality and life of climacteric tropical fruits like banana that are harvested green and eaten after ripened. Therefore, cold storages and transportation and pre-cooling infrastructures need to be setup in the market chains and these commodities need to be handled in the postharvest following their cool chain. Comparably higher pulp/peel ratio was also observed 30ºC and 25 ºC compared to those ripened at lower temperature. Better fruit color was developed from banana fruit samples ripened at 20 ºC and the control, but the poor color development was observed at higher temperature (30ºC). Banana fruits stored at higher temperature and the control soften fast, whereas banana stored at a lower temperature stayed firm. Interims of overall ripening quality of banana fruits ripened at 20 ºC, 25 ºC and the control were preferable, however banana ripened 30 ºC and 15 ºC showed poor overall quality development. The effect of temperature on fruit ripening was studied on banana fruits by Saeed *et al.,* (2001) [34] and similar results obtained.

Relative humidity

High humidity (95%) favors ripening process by preventing browning spot on the peels but it causes the dropping off of the fingers, due to rupture of peel at the pedicel. Pectin degradation at high RH is the cause of rupture of peel. If the fruits are stored under water stress conditions, at lower humidity, that would affect the shelf life of the product through enhanced ethylene production and respiration in the pre-climacteric stage The ideal relative humidity is about 80% at a storage temperature of 20 ºC (Broughton and Wu, 1979) [7].

Irradiation

The ripening process in bananas can be effectively delayed by irradiation at lower dose (0.2 kGy with a dose rate of 7.35 kGy h"1) through retardation of softening and color change. Irradiation decreases sensitivity of the banana to its own endogenous ethylene without causing any phytotoxicity. At the same time, it does not affect ripening using high concentrations of exogenous ethylene. However, a higher dose (0.4-1.0kGy) may cause discoloration, extensive tissue damage and change in respiration rate and reduced sensitivity to exogenous ethylene exposure. Though irradiation has been used for delaying the ripening process, its application in disinfection of banana can be explored, as it has already been proven worth for other fruits (Aziz and Moussa, 2002; Egea *et al.,* 2003) [12, 3]. UV-radiation can cause increase level of antioxidant activities of fresh cur bananas thus can help in reducing the microbial load, ensuring enhanced shelf-life (Alothman *et al.,* 2009) [2].

Conclusion

The extent of post-harvest losses of fresh fruits attributed to mishandling, improper storage practices and lack of modern transport facilities. This invariably leads to qualitative and quantitative losses. Minimization of these losses can safeguard the export potential and will aid to the revenue generation. With post-harvest technological evolution and new practices replacing the older ones, it seems that the treatments for the extension of shelf life through microbial decontamination, insect disinfestations, and metabolic activity inhibiting methods can be applied alone or in coherent with each other to have synergistic effect on the spoilage caused in banana. Several niche technologies have been tried and tested successfully with other fruits and vegetables and are yet to be tried on banana for standardization. This would immensely help the small as well as the large-scale fresh banana retailers and related food processing industries, for further processing applications.

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