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Quality Evaluation of Mango Stored in Evaporative Coolers

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Authors' contributions

This work was carried out in collaboration among all authors. Author AAB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author CCA managed the analyses of the study. Author JSA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Postharvest loss of fruit and vegetables especially mango, is a major challenge of agriculture. A research was therefore conducted to evaluate the quality of fresh mango fruits stored in two evaporative coolers, a non-cladded burnt-clay-brick (NBBEC) and an aluminum-cladded burnt-clay-brick evaporative coolers (ABBEC) to reduce postharvest loss. The physicochemical, microbiological and sensory attributes of mango stored in the coolers and in ambient were evaluated. Metabolic rates of mango were highest in ambient storage, intermediate in NBBEC with least values obtained in ABBEC. Beta carotene, ascorbic acid and acidity decreased while total soluble solids, pH and microbial load increased during storage. Mango stored in aluminum-cladded burnt-clay-brick evaporative cooler exhibited lower biochemical and physiological reaction rates hence tissue breakdown, colour changes, pH and titratable acidity were lower in ABBEC than in NBBEC and ambient storage conditions. ABBEC is therefore recommended for stop gap extension of shelf life of mango.

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1. INTRODUCTION

Mango (*Mangifera indica*) belongs to the Anacardiaceae family. It is an important fruit grown in many tropical and subtropical regions of the world. Global production of mango is concentrated mainly in Asia with India being the highest producer (11.5 m MT) while Nigeria produced only about 0.73 m MT [1]. According to Bhushan [2], India is the major mango producing country, contributing 40.48 percent of world's production while Nigeria occupied the 10th position in the world ranking of mango producing countries with 2.13 percent of the world's production.

According to Bhushan [2], nutritionally, mango contains substantial quantity of appreciable beta carotene, vitamin C and dietary fibre as well as soluble sugars and different minerals which are good sources of nutrition readily available and easily assumable in human body. Islam et al. [3] observed that both vitamins A and C are important antioxidants with vitamin C promoting healthy immune function while vitamin A is important for vision and bone growth. The dietary fibre is associated with a reduced risk of some types of cancer, protecting against heart disease and cholesterol build-up.

Although Benue State has contributed greatly in the production of mango which has earned Nigeria its 10th position in the chart of mango producers in the world, there has not been significant economic benefit resulting from this production. This is because a greater part of the mango produced is lost to poor postharvest management and lack of good preservation techniques [4].

While refrigerated cold stores are the best methods of preserving some fruits and vegetables, they are expensive to buy and run by poor resource farmers. According to Nair and Singh [5], mango fruits are also susceptible to chilling injury when stored below 13°C. Consequently, in developing countries, there is an interest in simple, low-cost alternatives many of which depend on evaporative cooling which does not require external power supply [6].

Evaporative cooling is an adiabatic cooling process whereby the air takes moisture which is cooled while passing through a wet pad or across a wet surface [7]. Evaporative cooling has been found to be efficient and economical in reducing the temperature and increasing the relative humidity in an enclosure, which has been extensively tried for increasing the shelf life of horticultural produce in some tropical and subtropical countries [8]. According to Munoz et al. [7], ambient temperature and relative humidity are the main parameters to be considered in proper storage and preservation of fruits and vegetables. Towards this end, they developed an automated electronic evaporative cooler which increased the shelf lives and quality of horticultural produce stored in it. Similarly, Kamaldeen et al. [9] developed a pot-in-pot and tin-in-pot evaporative coolers wherein mango was stored. The results showed that tin-in-pot was better than the pot-in-pot for mango storage as it retained freshness. Dirpan et al. [10] also conducted an experiment on the evaporative cooling of mango. The results showed that mango stored inside the zero energy cool chamber (ZECC) were acceptable in quality and sensory evaluation after eleven days of storage. The ZECC was able to maintain the quality and extend the shelf life of mango compared to ambient storage. The objective of this study therefore was to evaluate the physicochemical, microbial and sensory parameters of mango stored in evaporative coolers in comparison with those in ambient storage.

2. MATERIALS AND METHODS

2.1 Study Area/Scope of Research

Makurdi is the capital of Benue State, Nigeria. The town is dominated by guinea savannah type of vegetation. The mean annual rainfall is favourable for food production. Makurdi has a sub-humid, semi-arid tropical climate with mean annual precipitation at 1200-1300 mm. About 90% of total annual rainfall occurs in the months of June to September [11]. Temperature rarely falls below 22°C with peaks of 40 and 30°C in February/March. In the wet season, the average temperature is within the range of 23.0-32.7°C. Data generated were the average for 2014 to 2017 for the evaporative coolers located beside the College of Food Technology Complex at the University of Agriculture, Makurdi (Latitude: 07.78915°N, Longitude: 008.61864°E).

2.2 Design and Construction of Evaporative Coolers

Two almost identical burnt-clay-brick evaporative coolers were designed and constructed adjacent

and about 1 m apart under two trees. One had two internal aluminum claddings and was designated as aluminum cladded burnt-clay-brick evaporative cooler (ABBEC); the outer aluminum wall was perforated. The other cooler had no internal aluminum cladding and was referred to as non-cladded burnt-clay-brick evaporative cooler (NBBEC). The pictorial views of the cooling structures are shown in Plate 1. Essentially, the evaporative coolers consist of double jacketed rectangular burnt-clay-brick wall. The cavity between the inner and outer walls of each cooler was filled with river-bed sand. The floors were cemented with mortar (cement, sand and water mixture) to an even 2 cm thickness. The doors to the storage spaces were made of white wood with zinc roofing sheet cladding for protection against rodents and termites. A make-shift thatched roof cover was built above each of the coolers to provide extra protection against direct sunlight in addition to the shade provided by the trees so that the fullest advantage of evaporative cooling could be harnessed. In order to maintain the sand completely wet during the study, 500 litres of water was used to wet the sand twice a day [12].

Plate 1. Evaporative coolers 1 & 2
EC1= Non-Cladded Burnt-Clay-Brick Evaporative Cooler (NBBEC); EC2=Aluminum-Cladded Burnt-Clay-Brick Evaporative Cooler (ABBEC)

2.3 Commodity Storage Test

10 kg of ripe mango fruits (Julie vf) were purchased from Makurdi Wurukum market and transported to the laboratory in jute bags. They were then washed with tap water to remove adhering sand and other foreign matter.

2.3.1 Weight loss

Weight loss was measured before and after storage using an electronic weighing balance (Model: Mettler P1210). Ten mango fruits were drawn at random on the 1st, 5th and 10th days of storage. Weight loss for each sample of known initial weight was calculated as follows:

$$PWL\ (\%)\ =\ (Wo - Wt)\ /\ Wo\ x\ 100 \quad (1)$$

Where, PWL= product weight loss; W_o= initial weight of sample and W_t= weight of sample at time, t. The mean for the ten samples were then reported.

2.3.2 Chemical analyses

Chemical analyses were performed according to the standard official methods described in [13]. Clear juice of mango fruit was extracted by pulping 100 g of edible portion in a household electric blender followed by straining using double-layered muslin cloth.

2.3.3 Ascorbic acid and total carotenoids

Ascorbic acid and carotenoids were determined by AOAC [13] methods. Ascorbic acid content was determined on each 10 mL of juice extract (previously adjusted to pH 1.2 with 1.0M metaphosphoric acid solution by titration with 0.1% 2,6-dichlorophenol indophenol dye solution. The ascorbic acid equivalent of the dye was estimated as follows:

$$\text{Ascorbic acid (\%)= mL dye} \times 100\ /\ weight\ of\ extract \quad (2)$$

Total carotenoids were determined by mixing 2 g extract with 20 mL ethanol and 2 mL n-hexane and 30 mL diethyl ether in a 150 mL separatory glass funnel. The mixture was shaken vigorously about 10 times and then allowed to settle for 1 hr. Then, 5 mL each of the upper organic layer was carefully transferred into clean and labelled test tubes. The absorbance of each organic extractive was read at 450 nm wavelength using 1 cm cuvette of an ultraviolet/visible spectrophotometer (Model Jenway 7305).

2.3.4 Total soluble solids (TSS)

TSS in degree brix was directly measured using Abbe refractometer (Model: Bellingham & Stanley Limited, England) by placing a drop of supernatant on the prism of refractometer.

2.3.5 pH and titratable acidity determination

The digital pH meter (Model pH 211, HI Hanna Instruments, Italy) was used to measure the pH of the mango juice while total titratable acidity (expressed as citric acid %) was determined by titrating 5 ml of mango juice with 0.1N sodium

hydroxide-using phenolphthalein as an indicator [13].

2.4 Microbiological Analysis

Samples for total plate counts and fungal counts were prepared as described by Harrigan and McCance [14]. Triplicate 2 g portions of mango fruit were sliced and homogenized in a Warring blender which was previously washed and sterilized with 100 ppm sodium hypochlorite solution and rinsed with sterile deionized water. Serial dilutions of homogenate ranging from 10^{-1} to 10^{-5} were obtained using sterile saline solution. Total aerobic plate counts and fungal counts were performed on nutrient agar and Saboraud dextrose agar respectively using the pour-plate method described by Harrigan and McCance [14].

2.5 Sensory Evaluation

A consistent panel of 12 semi-trained judges was used to evaluate the appearance, texture and overall acceptability of mango sample using the descriptive sensory profile developed based on perceptions of the judges for quality of fruits and vegetables. Sensory evaluation was conducted under fluorescent light in a special sensory testing room with partitioned booths. The degrees of preference based on the descriptive terms were then converted to scores with 7=very firm and 1=Putrid/mushy for texture, 7=very fresh and 1=extremely mouldy for appearance and 7=highly acceptable and 1=disgusting for overall acceptability [15].

2.6 Statistical Analysis

The results obtained were evaluated using the analysis of variance with the aid of Statisca 6.0 software package (Stafso, Inc. USA). The means of factors showing significant (p=0.5) differences were separated using Tukey's LSD test [16]. For this storage studies with mango, the variables evaluated were influences of 3 storage times (0, 5^{th} and 10^{th} days) and 3 storage conditions (Atmosphere, NBBEC and ABBEC).

3. RESULTS AND DISCUSSION

3.1 Physiological Loss in Weight

In this study, significant differences (P>0.05) were found in mango fruits stored in the evaporative coolers (NBBEC and ABBEC) and at ambient storage conditions. Mango had the highest weight loss at ambient (25%), 13.4% in NBBEC and the least value of 6.7% in ABBEC storage on the tenth day of storage (Fig. 1). According to Ubwa et al. [4], water loss through lenticel seems to be the possible reason for physiological weight loss in mango during storage. Esguerra and Rolle [17] explained that when harvested, mango fruit can no longer replace the water that is lost through respiration, it is therefore subjected to shriveling and weight loss, and consequently loss in marketable weight resulting in deteriorative appearance. According to [18], weight loss is primarily associated with the fruit respiration and evaporation of moisture. The percentage weight loss increased with increase in storage period [19]. The increase in weight loss with storage period may be due to reduction in moisture content on respiration [10].

3.2 Chemical Analysis

3.2.1 Ascorbic acid and total carotenoids

Fig. 2 shows the effect of storage condition on the ascorbic acid content of mango. The ascorbic acid content of fresh mango fruits before storage was 22.09 mg/100 g which decreased significantly ($p<0.05$) to 15.52 mg/100 g in ambient, 17.15 mg/100 g in NBBEC and 19.38 mg/100 g in ABBEC storage. There was no significant difference ($p<0.05$) between mango stored in ABBEC on the 7^{th} and 21^{st} days of storage. However, mango fruits stored at NBBEC and ambient recorded significant differences ($p>0.05$) on day 7^{th} and 21^{st}. Similarly, the ascorbic acid content of mango fruits stored in ABBEC were significantly higher than those in NBBEC and ambient storage conditions. This could be due to the relatively lower temperature and higher relative humidity which retards senescence through reduced respiration rate and other undesirable metabolic changes [10]. Bhushan [2] and Hossain et al. [20] reported slightly lower values of 16 mg/100 g and within the range of 2.1 to 10.4 mg/100 g respectively. The retention of ascorbic acid has been used as an estimate of the overall nutrient retention in food product as it is the most unstable nutrient [21]. Previous studies Morris et al. [22] and Lee and Nagy [23] have reported that storage duration and condition are important parameters in ascorbic acid degradation.

The effect of storage conditions on the beta carotene content of mango is shown in Fig. 3. There were significant differences between the beta carotene values of mango at the different storage conditions. The beta carotene content ranged between 1013.1 to 2119 µg/100 g in this

study. Badifu et al. [24] reported slightly higher value of 2400 µg/100 g for mango in their study. According to Bolanle et al. [25], differences in beta carotene may be a reflection of differences in species/cultivars which is genetically determined.

3.2.2 Total soluble solids

Total soluble solid is a measure of the degree of ripeness in fruits. According to [26], increase in total soluble solids during ripening is due to the degradation of polysaccharides to simple sugars. The total soluble solids of mango (10.56 – 14.51 ^{o}Brix) were significantly ($p<0.05$) different at all the storage conditions. The results indicated that ABBEC stored mango fruits increased to 12.00^{o}Brix while ambient stored mangoes increased to the highest value of 14.51^{o}Brix after ten days of storage. Akhter et al. [27] reported similar values which ranged between 5.1 to 12.9%. Naz et al. [28] reported slightly higher values that ranged between 11.60 to 19.83%. According to Okoth et al. [29],

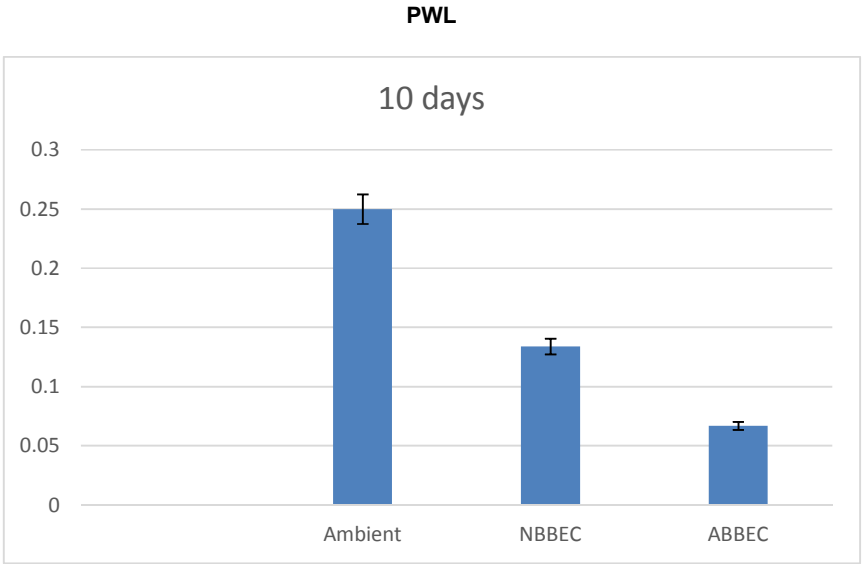

Fig. 1. Effect of storage conditions on physiological loss in weight of mango

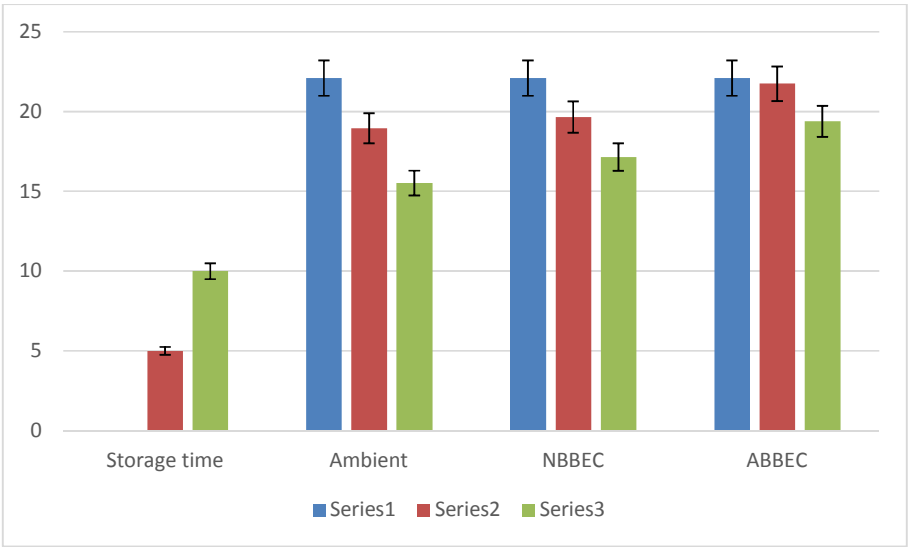

Fig. 2. Effect of storage conditions on the ascorbic acid content of mango

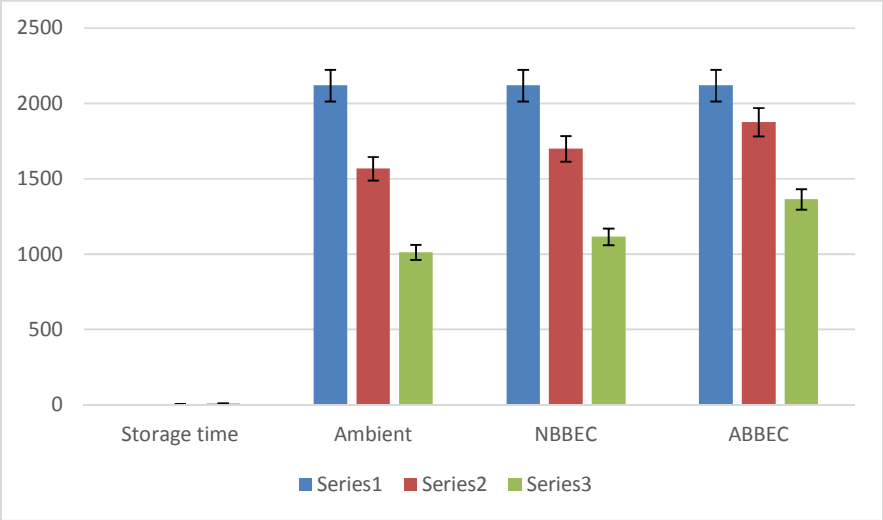

Fig. 3. Effect of storage conditions on the beta carotene of mango

TSS has a strong implication on the choice of fruit for processing as well as fresh consumption. The authors suggested that the variability in TSS of mango at different stages of maturity is attributed to the alteration occurring in structure during ripening processes at various hydrolytic processes resulting in the breakdown of complex carbohydrates to smaller ones like sucrose, glucose and fructose.

3.2.3 pH and total titratable acidity

A slight significant increase in pH ($p<0.05$) was observed during storage of mango (Table 1). Higher increase in pH was observed at ambient higher temperatures. The mango had initial pH value of 3.64 before storage which increased to 4.70 in ambient, 4.07 in NBBEC and 3.94 in ABBEC storage conditions. Metabolic activities of the fruit could lead to changes in pH. This result compared closely with the findings of Ilesanmi et al. [30] who reported pH values between 4.02 and 5.47. pH in the fruit pulp plays an important role in flavour promotion as well as a preservation factor.

A decrease in titratable acidity was observed in mango at the three storage conditions. However, ambient condition with higher temperature showed higher decline in titratable acidity. The changes in total titratable acidity were significantly affected by the rate of metabolism especially respiration which consumed citric acid. The titratable acidity result (0.78 - 0.90%) for mango obtained in this study had a similar trend with that of Ilesanmi et al. [30] whose values were between 0.36 to 0.87%, while the result of [28] were slightly lower (0.12 - 0.49%). The decrease recorded in this study might be due to the inhibited activities of enzymes to change the titratable acidity contents due to the reduced temperature and high RH of the evaporative coolers.

3.3 Microbiological Analysis of Mango

The effect of storage conditions on the microbial load of mango as presented in Table 2 indicated that the total plate count ranged between 1.40 to 3.32 Log_{10} CFU/g while yeast and mould count ranged between 1.05 and 2.44 Log_{10} CFU/g. In this study, the microbial load on mango fruit was lowest on ABBEC stored fruits and highest on ambient stored fruits. Similarly, there were no significant difference between the mango fruits at the initial storage and day 7 in ABBEC storage conditions. This could be due to the lower temperature and high relative humidity of ABBEC. Also, the aluminum incorporated in ABBEC storage further improved the microbial load due to its lower heat sink and being a good thermal and electrical conductor. These values were much lower than the bacterial counts of 4.90 to 5.90 Log_{10} CFU/g and fungal counts of 4.0 Log_{10} cfu/g reported by Ogbogu et al. [31]. Akinmusire [32] observed that numerous microbial defects of fruits and vegetables are characterized by the types of microorganisms responsible for the deterioration. Spoilt mango is characterized by tissue softening, formation of rot and mycelia, moisture loss, unpleasant odour and shrinkage.

Table 1. Effect of storage conditions on TTA, TSS and pH of Mango fruit

Parameter	Storage time (Days)	Ambient	NBBEC	ABBEC	LSD
TSS (^{o}Brix)	0	10.56^{c}	10.56^{c}	10.56^{c}	0.83
	5	12.35^{b}	11.47^{d}	11.25^{d}	
	10	14.51^{e}	12.10^{b}	12.00^{bd}	
TTA (%)	0	0.90^{b}	0.90^{b}	0.90^{b}	0.21
	5	0.81^{b}	0.87^{b}	0.88^{b}	
	10	0.78^{b}	0.84^{b}	0.83^{b}	
pH	0	3.64^{b}	3.64^{b}	3.64^{b}	0.88
	5	3.99^{b}	3.97^{b}	3.75^{b}	
	10	4.70^{a}	4.07^{a}	3.94^{ab}	

Each value is the mean of triplicate determinations for 2014-2017
Values for each parameter with common superscripts are not significantly (p>0.05) different
NBBEC= Non-cladded burnt-clay-brick evaporative cooler,
ABBEC= Aluminum-cladded burnt-clay-brick evaporative cooler
TSS= Total Soluble Solids, TTA= Total Titratable Acidity
LSD = Least Significant Difference

Table 2. Effect of storage conditions on microbial load of mango

Microbial parameter	Storage time (Days)	Storage condition ambient	Storage condition NBBEC	Storage condition ABBEC
Total plate count (Log_{10} cfu/g)	0	1.40^{a}	1.40^{a}	1.40^{a}
	5	1.89^{a}	1.60^{ab}	1.74^{a}
	10	3.32^{c}	2.18^{d}	2.11^{d}
Yeast & mould count (Log_{10} cfu/g)	0	1.05^{b}	1.05^{b}	1.05^{b}
	5	1.29^{a}	1.15^{b}	1.12^{b}
	10	2.44^{d}	2.32^{d}	1.24^{a}

NBBEC= Non-cladded burnt-clay-brick evaporative cooler
ABBEC= Aluminum-cladded burnt-clay brick evaporative cooler
Values for each parameter with common superscripts are not significantly (p>0.05) different

Table 3. Effect of storage conditions on sensory scores of mango

Sensory attribute	Storage time (Days)	Storage condition Ambient	Storage condition NBBEC	Storage condition ABBEC
Appearance	0	6.71^{a}	6.71^{a}	6.71^{a}
	5	5.18^{b}	5.44^{b}	5.48^{b}
	10	3.55^{d}	4.12^{c}	4.40^{c}
Texture	0	6.40^{a}	6.40^{a}	6.40^{a}
	5	4.85^{c}	5.33^{b}	6.05^{a}
	10	3.05^{d}	4.13^{c}	4.57^{bc}
Overall acceptability	0	6.89^{a}	6.89^{a}	6.89^{a}
	5	4.96^{bc}	5.61^{b}	5.77^{b}
	10	3.03^{d}	4.32^{c}	4.64^{c}

Values for each attribute with common superscripts are not significantly (p>0.05) different.
Each result is the mean of 12 panelists responses on a scale with 7=excellent and 1=very poor.
ABBEC=Aluminum-cladded burnt-clay-brick evaporative cooler NBBEC= Non-cladded burnt-clay-brick evaporative cooler

3.4 Sensory Evaluation of Mango

The effect of storage condition on sensory scores of mango in this study is presented in Table 3. The change in colour was more pronounced on mango kept in ambient. Spoilage of mango due to end rot limited its storage potential to only four days at ambient while mango fruits in ABBEC and NBBEC had shelf life of ten days. Table 3 also shows the texture of mango fruits at the three storage conditions. Fruit firmness showed significant decrease at the different storage conditions. ABBEC storage showed better retention of fruit firmness. Abdalla et al. [33]

reported that mango stored in ambient showed deterioration in fruit firmness while those stored in evaporative coolers showed better retention of firmness. Mango stored at ambient developed black spots, lost their firmness and softened. According to Narayana et al. [18] when mango fruit loses weight, shriveling occurs and the appearance deteriorates thus reducing its market value. In agreement with the present study, the authors observed that mango being a climacteric fruit possesses a very short shelf life and reach respiration peak of ripening process on the third or fourth day of storage at ambient temperature.

The loss of firmness in ambient storage was due to cell wall digestion by pectin esterase, polygalacturonase and other enzymes, and this process increased with increase in storage temperature [10]. According to Narayana et al. [18] and Shahnawaz et al. [34], the loss of water from mango fruit due to respiration and transpiration results in loss of weight, shriveling and deteriorative appearance. On overall acceptability, panelists had higher scores for ABBEC stored mango fruits which ranged from 4.64 to 6.89. Overall acceptability of mango in this study is in agreement with the findings of [35] that lowering temperature reduces respiration while high storage temperature hastens senescence of fruits. Generally, mango stored in ABBEC were superior to mango in ambient storage at the end of the ten-day storage period. The ABBEC stored mango exhibited slower decay and lower water loss as a result of lower temperature and higher relative humidity of the evaporative cooler.

4. CONCLUSION

The use of evaporative coolers for the storage of mango fruits or any other agricultural commodities would maintain their freshness and increase storage life better than in ambient condition due to the lower temperature and higher relative humidity exhibited by the coolers. Mango fruits stored in evaporative coolers showed slower decay and lower water loss than ambient stored fruits. Due to the lower temperature and higher relative humidity of the evaporative coolers during storage, mango quality was better maintained than in ambient storage. ABBEC storage was found to be the most efficient method due to its effects on reducing respiration rate, transpiration, ethylene production and senescence. ABBEC storage is therefore recommended as a stop gap extension of shelf life of mango fruits.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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