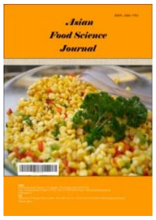

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Quality Evaluation of Fresh Papaya Fruits Stored in Evaporative Coolers

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Authors' contributions

This work was carried out in collaboration between both 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 AAB managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

A study was conducted to assess the performance of evaporative coolers for the storage of fruits and vegetables. The evaporative coolers used for this study consist of double-walled rectangular brick construction (1.29 × 2.55 × 2.56) m external and (1.13 × 1.27 × 2.08) m, internal, (length × width × height) with the inter-space filled with river bed sand saturated with water. In this study, ambient storage temperature ranged from 26.6 to 28.7°C with relative humidity which ranged from 64.7 to 85.2 percent. However, NBBEC storage recorded lower temperature within the range of 24.3 to 25.3°C and relative humidity which ranged from 88.8 to 91.2 percent while ABBEC storage recorded the least temperature which ranged from 23.0 to 24.1°C with highest relative humidity which ranged from 91.4 to 92.8 percent. The papaya fruits stored in the coolers and in ambient were evaluated for weight loss, total soluble solids, pH, total titratable acidity, ascorbic acid, beta carotene content and microbial load. TTA, ascorbic acid, beta carotene decreased; while pH and TSS increased with storage period. In ambient storage, fresh papaya fruits stored in evaporative coolers have lower microbial load compared to ambient storage with aluminum cladding of the

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cooler (ABBEC) further improving microbial quality and shelf life. The pawpaw fruits stored in the aluminum cladded burnt-clay-brick evaporative cooler (ABBEC) remained fresh and firm for ten days compared to three days in non-cladded burnt-clay-brick evaporative cooler (NBBEC) and four days in ambient storage.

Keywords: Pawpaw (Carica papaya); evaporative coolers; ambient storage.

1. INTRODUCTION

Pawpaw (*Carica papaya*), a member of small family (*Caricacea*), is one of the major fruits produced and consumed throughout the world. Evans et al. [1] Reported a worldwide papaya production of approximately 11.2 million tonnes in 2010. According to FAOSTAT [2], Nigeria ranked sixth in pawpaw production after India, Brazil, Mexico, Indonesia and Dominican Republic with a production figure of about 775000 metric tonnes. Nigeria has a world share of 6.4% and is the main producer in the African continent and together with South Africa, Mozambique and Democratic Republic of Congo are the most important producers, but none of them reports any export activity [3]. Gaining in popularity among tropical fruits worldwide, papaya is now ranked fourth in total tropical fruit production after bananas, oranges and mango [4]. However, about 30-100% of fruits and vegetables are being wasted in Nigeria [5].

Papaya fruit is rich in essential nutrients and can be consumed fresh, processed or used in variety of products such as jams, jellies, preserves, fruit juices, candies and ice-cream [6]. Practically, every part of the pawpaw plant is of economic value and its use ranges from nutritional to medicinal. Papaya fruit has a restricted storage time due to rapid pulp softening and fungal growth. It is a climacteric fruit whose respiratory rate and ethylene production increase considerably after harvest [7]. During the storage of papaya, biochemical reactions promote changes in respiratory rate, mass loss, chlorophyll breakdown, production of carotenoids in the skin and loss of firmness [8]. Proper control of temperature and relative humidity is essential to maximize storage life and marketable quality of fruits and vegetables. These parameters should therefore be monitored with accuracy and maintain the necessary values for specific commodity to preserve the freshness and prolong the shelf life.

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. During evaporation, there is a simultaneous heat and mass transfer. The heat in the air is utilized to evaporate the water which changes from liquid to vapour resulting in a drop in temperature and rise in relative humidity of air [9]. Evaporative coolers can be used for all types of fresh produce but subtropical fruits respond best because their optimum storage temperatures are closer to those achieved by evaporative coolers [10]. Previous studies by Ubani and Okonkwo [11] have shown that papaya fruit stored in evaporative coolers had a shelf life of 23 days compared to control fruits stored at ambient which had a shelf life of only 9 days. Azene et al. [4] studied the effect of packaging materials and storage environment on postharvest quality of papaya fruit. The authors observed that packaging combined with evaporative cooler storage were more effective in maintaining the quality and prolonging the shelf life and marketability of papaya fruits compared to fruits stored at ambient. Similarly, [12] in their study on the effect of opuntia cactus mucilage extract and storage under evaporative coolant system on the shelf life of papaya fruits reported that the combined method was effective in extending the shelf life of papaya fruits when compared to the control at ambient storage.

In developing countries such as Nigeria, papaya is largely wasted due to its high perishability and poor postharvest handling. Research on postharvest handling of papaya has been limited in Benue State, Nigeria. Therefore, the objective of this study was to evaluate the quality of papaya fruits in evaporative coolers compared to those stored in ambient in order to reduce its postharvest loss.

2. MATERIALS AND METHODS

2.1 Experimental Site/Fruit for Test

The experiment was conducted beside the College of Food Technology and Human Ecology, University of Agriculture, Makurdi within the period of January 2014 to December, 2017. The site is located at 07.78915^{o}N latitude and

008.61864°E longitude. The mean annual precipitation is between 1200 to 1300 mm. Temperature rarely falls below 22°C with peaks of 40 and 30°C in February/March. In the wet season, temperature is within the range of 23.0 to 32.7°C [13].

Pawpaw (Red royale variety) (20 kg) was purchased from Makurdi Wurukum market, Benue Stata, Nigeria.

2.2 Design and Construction of Evaporative Coolers

Two almost identical burnt-clay-brick evaporative coolers were designed and constructed adjacent and about 1m apart under two trees. One cooler (store) (Plate 1) had two of its walls cladded with aluminum sheet and designated as aluminum-cladded burnt-clay-brick evaporative cooler (ABBEC). The outer aluminum wall was perforated. The second cooler (Plate 1) had no aluminum claddings on the walls and referred to as non-cladded burnt-clay-brick evaporative cooler (NBBEC). Pictorial view of the evaporative coolers is shown in Plate 1.

Essentially, the evaporative coolers consisted of double-walled rectangular burnt-clay-brick structure. The cavity between the inner and outer walls of each cooler was filled with river-bed sand, which was used as wetting medium. Shelves were built in the storage spaces where the papaya fruits were kept in three trays. 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 [14].

2.3 Physiological Weight Loss

Weight loss was measured periodically using a scale as described by Pereira et al. [15]. The analyses were performed on each of ten samples of papaya fruit 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:

$$PWL\ (\%) = \frac{Wo - Wt}{Wo} x\ 100 \qquad (1)$$

Where,

PWL = Product weight loss, W_o = initial weight of sample and W_t = weight of sample after storage for time, t. The mean for the ten samples of each commodity was then reported.

2.4 Moisture Content

Moisture content was determined by weighing 5 g of sample in crucibles whose weights have been determined. The crucibles and the samples were heated at 110°C in a Gallenkamp oven until constant weights were obtained after eight hours. The dishes and their contents were cooled in a dessicator and then reweighed. The loss in weight was expressed in percentage:

$$\%\ Moisture = \frac{Loss\ in\ weight\ on\ drying \times 100}{Initial\ sample\ weight} \qquad (2)$$

2.5 Chemical Analyses

Chemical analyses were performed according to the standard official methods described in [16]. Clear juice of papaya sample was extracted by pulping 100 g of edible portions in a house-hold electric blender followed by straining using double-layered muslin cloth. Triplicate analyses were performed on papaya juice extracts of the edible portions as follows:

2.5.1 Ascorbic acid and total carotenoids

Ascorbic acid of papaya juice was determined by the 2,6-dichloropheol indophenol method [16]. 10ml of juice extract (previously adjusted to pH 1.2 with 1.0 metaphosphoric acid solution) was titrated with 0.1% 2,6-dichlorophenol indophenol dye solution to a pink endpoint which persisted for 15 seconds.

Total carotenoids were determined by mixing 2 g extracts 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).

2.5.2 Total soluble solids

The TSS were determined using an Abbe refract meter (Model: Bellingham & Stanley Limited, England) which was previously calibrated with deionized water (refractive index= 1.3330 and 0°Brix at 20°C). A drop of the extract was placed on the refractometer prism, covered, read and the result expressed as °Brix.

Plate 1. Evaporative coolers 1 and 2
EC1=Non-cladded burnt-clay brick evaporative cooler (NBBEC), EC2= Aluminum cladded burnt-clay brick evaporative cooler (ABBEC)

2.5.3 pH and titratable acidity determinations

pH was determined with the electrode of a previously referenced pH meter (model pH 211, HI Hanna Instruments, Italy) which was placed into 20 ml of each extract in a 50 ml capacity glass beaker.

Titratable acidity was determined by titrating 10ml papaya juice to pH 8.2 with 0.1 M NaOH solution.

2.6 Microbiological Analysis

Samples for total plate counts and fungal counts were prepared as described by Kramer and Twig [17].

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 [18]. Each growth medium was prepared by mixing 5 g portions with 200 mL deionized water followed by sterilization in a bench autoclave at 15psi for 15min. Each molten agar medium was allowed to cool to 40-45^{o}C prior to use for plating.

For each dilution, triplicate 0.1 mL portions were dispensed into separate petri-plates and 10 mL of warm sterile molten agar medium poured. The mixture was swirled gently for even distribution and allowed to solidify. The plates were then inverted and incubated at 37$\pm$ 1^{o}C in an electric oven for 24h for total plate counts and 48-72h for fungal counts. Average counts were obtained from plates having 30-300 colonies multiplied by their respective dilution factors.

2.7 Sensory Evaluation

A consistent panel of 12 semi-trained judges was used to evaluate the appearance, texture and overall acceptability of papaya fruit using the descriptive sensory profiles. The descriptive terms were developed based on perceptions of the judges for quality of fruits and vegetables. 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 [19].

2.8 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 [20].

For the storage studies with papaya fruit, the variables evaluated were influences of 3 storage times (1st, 5th and 10th days) and 3 storage conditions (Atmosphere, NBBEC and ABBEC).

3. RESULTS AND DISCUSSION

3.1 Physiological Weight Loss

Table 1 presents the physiological weight changes in papaya fruit. Physiological weight loss is one of the main factors in determining the quality of stored fruits and vegetables [21]. In this study, weight loss of papaya fruits increased significantly during the storage period under evaporative and ambient conditions. However, weight loss of papaya fruit stored at ambient condition was 47.4% which was higher than weight loss of papaya fruits stored in the evaporative coolers. NBBEC stored papaya recorded weight loss of 13.8% after only three days of storage while those stored in ABBEC recorded minimal weight loss of 6.3% after ten days of storage. Azene et al. [4] reported maximum weight loss of 18.3% in papaya fruit stored at ambient conditions while packaged papaya stored in evaporative cooler had weight losses of 5.34 and 6.15% after 9 days of storage. Holcroft [22] reported that water loss is the factor that contributes most to weight loss and for products sold by weight, this will have economic consequences. Weight loss of fresh produce results in reduction in appearance quality including wilting, shriveling, less gloss, limpness which will reduce market value. According to Nunes et al. [23], loss of weight and development of symptoms resulting from water loss, that is, loss of glossy appearance, softness, shriveling and dryness of the peel in papaya fruits are greatly influenced by the relative humidity and temperature of the storage area which is in agreement with the result of this study.

3.2 Moisture Content of Papaya

Moisture content is an important quality feature that directly influences storability of fruits and vegetables. Water is a critical component of most fruits and vegetables because it adds up to the total weight. Reduction in weight of fresh produce is as a result of water losses; weight loss involves respiratory and evaporative losses [24]. The moisture content of fresh papaya fruit was 85.90%. Similar values within the range of 85.90 and 92.90% was reported by Saran and Choudary [25]. According to Ogbonna et al. [26], fresh papaya had lower moisture content of 82.74% in their study. The observed high values of moisture content of papaya in this study implies that papaya might have a short shelf life because microorganisms that cause spoilage thrive in foods having high moisture content and is also indicative of low total solids. Similarly, the high moisture content provides for greater activity of water soluble enzymes and co-enzymes needed for metabolic activities of fresh produce [27].

3.2.1 Ascorbic acid and total carotenoids

The results presented in Fig. 1 revealed a significant decrease in the ascorbic acid values of papaya fruits in the different storage conditions along with the storage period. However, the rate of decrease was significantly higher in papaya stored in ambient as compared with evaporatively stored papaya fruits. The vitamin C values decreased from 33.50 mg/100g to 13.18 mg/100g in ambient storage while evaporative cooler storage recorded a decrease from 33.50mg/100g to 17.15mg/100g and from 33.50mg/100g to 25.91mg/100g in NBBEC and ABBEC storage conditions respectively. The high rate of ascorbic acid loss could be due to oxidation which may be caused by several factors including exposure to oxygen, light, heat and alkaline pH. This is in agreement with the findings of Adetunji et al. [12] who reported that ascorbic acid decreased significantly higher in control papaya fruits stored at ambient than fruits stored in the evaporative cooler. Values obtained in this study were similar to those of oblong papaya pulp (36.37mg/100g) reported by Nwofia et al. [28]. However, [12] reported lower ascorbic acid values within the range of 3.96 to 6.00mg/100g). According to Vanderslice and Higgs [29], the ascorbic acid content of fruits varies with fruit maturity, genetic variety, climate and sunlight; and may be responsible for the variation in the ascorbate content reported.

Beta carotene content of fresh papaya fruit decreased significantly ($p<0.05$) from 3488.10 µg/100g to the least value of 1044.50µg/100gin ambient storage, 1840.30µg/100g in NBBEC and 2046.70µg/100g in ABBEC storage conditions. Maisarah et al. [30] reported lower beta carotene value of 520.21µg/100g.

Table 1. Physiological weight loss of papaya

Storage period (Days)	Ambient	NBBEC	ABBEC
10	47.4^{a}%	11.7^{b}%	6.3^{c}%

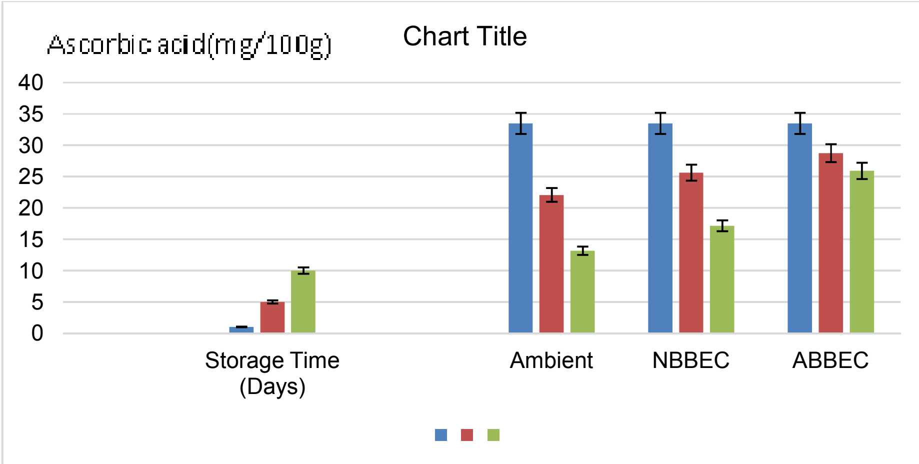

Fig. 1. Effect of storage conditions on the ascorbic acid content of papaya

Carotenoids appear to be less adversely affected in ABBEC storage compared to NBBEC and ambient storage conditions. This could be due to the relatively low temperature and high humidity in the evaporative coolers as a result of evaporative cooling in which the surrounding air serves as a heat sink where sensible heat is exchanged for latent heat.

3.2.2 Total soluble solids of papaya

There was no significant (p>0.05) difference within the TSS values obtained on the fifth and tenth days of storage (Fig. 3). The initial total soluble solids content of fresh papaya fruit was 11.08^{o}Brix which increased to the highest value of 12.40^{o}Brix in ambient storage, 11.23^{o}Brix in NBBEC and 11.11^{o}Brix in ABBEC storage conditions. Othman [31] reported slightly higher values within the range of 12.94 to 13.62% while Idoko and Achusi [32] reported lower TSS value of fresh pawpaw as 7.04%. Azene et al. [4] recorded similar values (8.87-12.5^{o}Brix) with the present study. In agreement with this study, these authors observed that on day 3 and 6 of storage, papaya fruits stored in ambient condition had more TSS content compared with fruits stored in the evaporative coolers. This could be due to increased respiration and accelerated ripening because of higher temperature at ambient conditions. This is due to starch hydrolysis and pectin degradation. There could also be a concentration effect due to water loss in control fruits under ambient storage conditions.

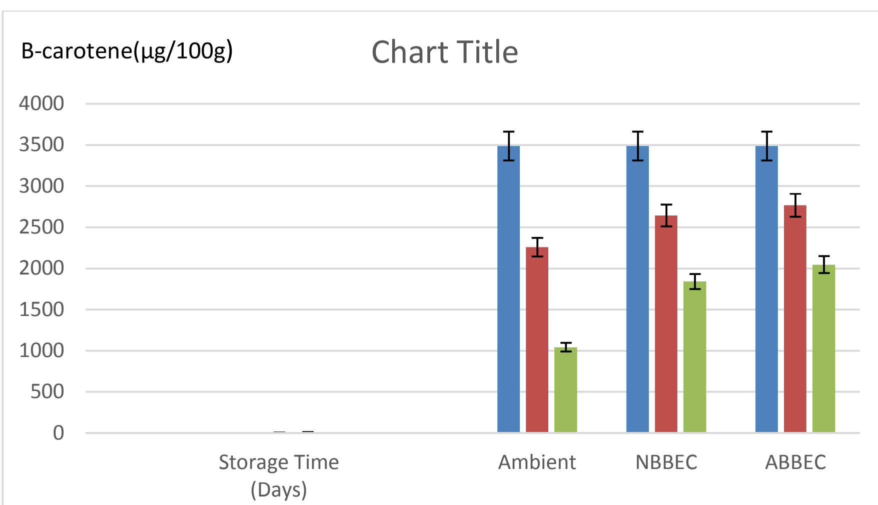

Fig. 2. Effect of storage conditions on the beta carotene content of papaya

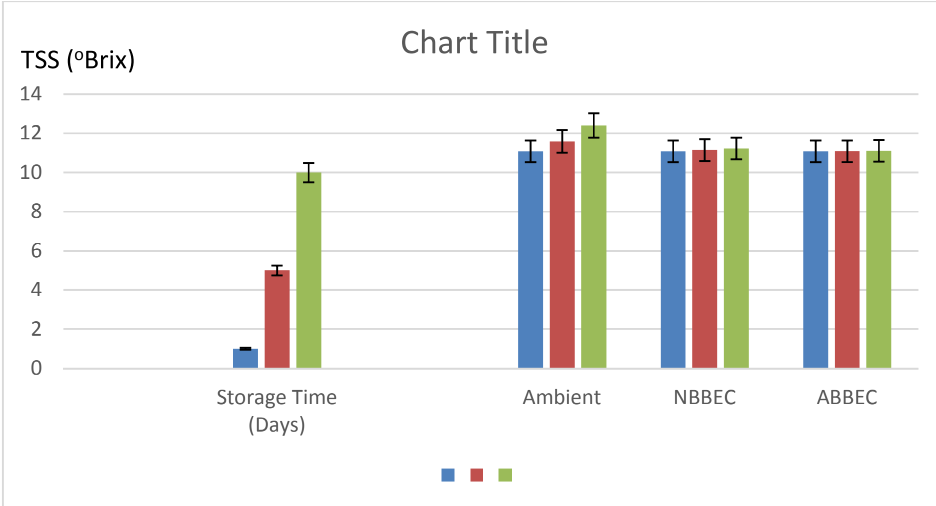

Fig. 3. Effect of storage conditions on the TSS of papaya

3.2.3 pH and total titratable acidity

The result of pH and titratable acidity are presented in Table 2. The pH of papaya fruit was not significantly (p>0.05) different as it varied from 5.23 to 5.40 at the different storage conditions. These results were similar to those of [33] who reported pH value of 5.03 and [34] with pH value of 5.5. However, Bello et al. [35] reported a lower value of 3.90. Higher increase in pH was observed at ambient storage conditions. Changes in pH may be due to metabolic activities of fresh papaya. pH of fruit is also associated with ripening. During storage, as the fruit respires the ripening process increases and hence, pH of the fruit pulp increases.

A decrease in titratable acidity was observed in papaya fruit during storage. Total titratable acidity varied from 0.81% to 1.38% in the evaporative coolers and from 0.81% to 1.38% 0.70% under ambient storage conditions respectively. Azene et al. [4] reported slightly lower titratable acidity values with a range varying from 0.3 to 0.48% in evaporative cooler and 0.36-0.54% in ambient storage. This trend is in agreement with Camara et al. [36] who reported values ranging from 0.2 to 1.0%. The higher loss of TTA at ambient could be due to the depletion of organic acids as a result of relatively faster respiration and ripening rate of fruits at ambient storage [37]. Generally, the TTA value of papaya fruits was maintained at relatively lower level in the evaporative coolers than ambient storage. Furthermore, slow respiration as well as transpiration rate may contribute to higher retention of water in fruits. Therefore, the concentration effect caused by water loss may be reflected on TTA values of fruits [4]. The decrease of acidity during storage demonstrated fruit senescence.

3.3 Microbiology of Papaya

The effect of the storage conditions on the microbial load of papaya is presented in Table 3 indicated that the total plate count and total fungal count ranged from 0.61 to 3.48Log$_{10}$cfu/g and 0.39 to 2.77Log$_{10}$cfu/g respectively. Bello et al. [35] reported the mean total plate count in papaya juice as 4.81Log$_{10}$cfu/g and total fungal count as 4.43 Log$_{10}$cfu/g. Jolaoso et al. [38] reported the total plate count in papaya within the range of 4.56 to 4.86 Log$_{10}$cfu/g and fungal count within the range of 5.30 to 5.60 Log$_{10}$cfu/g. Lower plate count and fungal count within the range of 4.08 to 4.15 Log$_{10}$cfu/g and 1.78 to 2.20 Log$_{10}$cfu/g respectively were reported by Odebisi-Omokanye et al. [39]. These microbial loads were generally higher than those obtained in this study. Higher microbial counts for ambient storage in this study may be due to relatively higher temperatures and exposure to contamination from the environment. However, the growth of mesophilic microorganisms is retarded at lower temperatures and higher sensory attribute for produce stored under ABBEC condition relative to NBBEC and ambient. Low temperatures slowed down plant metabolic processes such as respiration, ethylene production and enzyme activity. Aluminum cladding further improved microbial quality and shelf life of papaya fruits because it is a good thermal and electrical conductor thereby reducing the temperature of storage space.

Table 2. Effect of storage conditions on pH and TTA of papaya

Parameter	Storage time (Days)	Ambient	NBBEC	ABBEC	LSD
pH	1	5.23[a]	5.23[a]	5.23[a]	0.18
	5	5.29[a]	5.26[a]	5.24[a]	
	10	5.40[a]	5.29[a]	5.26[a]	
TTA (%)	1	1.38[a]	1.38[a]	1.38[a]	0.27
	5	0.92[ab]	0.98[ab]	1.31[a]	
	10	0.70[c]	0.81[b]	0.84[b]	

Table 3. Effect of storage conditions on microbial load of pawpaw

Microbial parameter	Storage Time (Days)	Storage conditions ambient	Storage conditions NBBEC	Storage conditions ABBEC
Total Plate Count (Log_{10} cfu/g)	1	0.61[c]	0.61[c]	0.61[c]
	5	1.93[b]	1.82[b]	1.63[b]
	10	3.48[a]	2.92[a]	1.78[a]
Yeast & Mould Count (Log_{10} cfu/g)	1	0.39[c]	0.39[c]	0.39[c]
	5	1.55[b]	0.57[c]	0.43[c]
	10	2.44[d]	2.32[d]	0.46[c]

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

Table 4. Effect of storage conditions on sensory scores of papaya

Sensory attribute	Storage Time (Days)	Storage conditions ambient	Storage conditions NBBEC	Storage conditions ABBEC
Appearance	1	6.69[a]	6.69[a]	6.69[a]
	510	5.25[b]	6.08[b]	6.34[a]
		4.38[c]	5.00[b]	5.08[b]
Texture	1	6.08[a]	6.08[a]	6.08[a]
	5	5.46[ac]	5.94[a]	5.98[a]
	10	3.38[d]	5.35[c]	5.46[ac]
Overall Acceptability	1	6.62[a]	6.62[a]	6.62[a]
	5	5.45[b]	5.64[ab]	5.67[ab]
	10	3.32[c]	5.15[d]	5.12[d]

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

3.4 Sensory Evaluation of Pawpaw Fruit

Table 4 presents the organoleptic scores of papaya fruit in this study. Pawpaw fruits under ABBEC storage looked shiny and had an attractive colour compared to those stored under ambient condition. This might be attributed to reduced rate of respiration and transpiration of fruits due to relatively lower temperature and higher relative humidity inside the evaporative cooler. In terms of degree of shriveling, papaya fruit inside the ABBEC showed no signs of shriveling, wilting or dryness compared to those in ambient environment. Azene et al. [4] reported that pawpaw fruit stored in the evaporative coolers remained fresh and firm for a reasonable period of time. In the present study, pawpaw fruits lost their firmness and became soft after 4 days under ambient storage, 3 days under NBBEC storage and 10 days under ABBEC storage. Several authors [40,41] reported that during storage, the texture of fruit is likely to soften due to several factors such as loss in cell turgidity pressure, loss of extracellular and vascular air and the degradation of the cell wall and consequent loss of water by the cell breakdown. Lazan et al. [42] reported similar result of the rapid loss of firmness of pawpaw at ambient temperature which is associated closely with increase in activity of polygalacturonase, pectin methyl esterase and beta galactosidase as well as with depolymerisation of cell wall. Lazan et al. [43] also reported that the differences in decrease of firmness of papaya fruits at the different storage conditions could be due to the differences in the rate of respiration that affected solubility and depolymerisation of pectins during ripening. Riviera-Lopez et al. [44] observed that weight loss was affected significantly ($p \leq 0.05$) by temperature and storage. They also confirmed that storage temperature affected significantly ($p < 0.05$) the firmness loss of fresh-cut pawpaw cv "Maradol". They observed that overall quality index was highly correlated with firmness and weight loss.

4. CONCLUSION

Storage environments had significant ($p < 0.05$) effect on the physicochemical, microbiological and organoleptic qualities of papaya fruits. Generally, ABBEC storage showed better retention of firmness, exhibited lower biochemical and physiological reaction rates hence tissue breakdown, colour changes, pH and TTA were lower than in NBBEC and ambient. The best way to maintain the quality of fresh fruits and vegetables is by maintaining an adequate temperature and relative humidity throughout the postharvest handling chain. ABBEC can be used for short term, on-farm storage of fresh produce.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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