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EFFECTS OF EVAPORATIVE COOLING STORAGE ON MICROBIOLOGICAL AND NUTRITIONAL QUALITY OF Telfairia occidentalis Hook. F. AND Amaranthus hybridus L.

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ABSTRACT

This study investigated the effect of two evaporative cooling systems (ECS) on the preservation of nutritional qualities and shelf-life of *Amaranthus hybridus* and *Telfairia occidentalis*. Samples were kept in block-in-block (BB) and metal-in-block (MB) ECS structures for up to 7 days and monitored for physicochemical, nutritional, and microbiological changes. The temperature in the ECS structures ranged from 25.8 to 28.5 °C for MB and 25.3 to 28.0 °C for BB with the highest relative humidity of more than 71.2% and 70.0%, respectively. The storage conditions for the control samples were 30.9 °C ± 1.0 °C and relative humidity (RH) of 49.3%. MB and BB extended the shelf-life of the *Amaranthus hybridus* for up to 4 days and *Telfairia occidentalis* for 7 days, while the control samples deteriorated completely by day 3. Weight loss and mineral contents were significantly higher in the control samples. The pH of all samples dropped during storage. MB-preserved samples had higher amounts of moisture, vitamin C, and carbohydrate although a general decline in these nutrients was observed throughout the storage period. The loss of minerals such as potassium, calcium, magnesium, iron, phosphorus, and sodium was observed in the samples stored under the ECS structures. Heterotrophic bacteria, coliforms, and fungal counts declined throughout the storage period, but the control samples had the highest counts, while MB had the least. MB and BB equally extended the shelf-life of the vegetables, but MB preserved the physicochemical and nutritional attributes of the samples better with lower susceptibility to microbial colonization and spoilage. The study concluded that ECS can be used as a low technology agricultural tool to provide short term preservation of vegetables, ultimately contributing to a reduction in postharvest losses.

Keywords: Vegetables, Preservation, *Amaranthus hybridus, Telfairia occidentalis,* Indigenous technology, Evaporator Cooling System.

INTRODUCTION

The global human population is expected to increase to 8 billion by the year 2030 with a concomitant increased demand for food (Barbosa-Cánovas *et al.*, 2003). Consequently, there is a need for improved and sustainable efforts at increasing food production. Despite efforts targeted in this direction, consumption patterns have generally been poor due to unhealthy eating habits in developed countries, coupled with poverty and food insecurity in developing countries (FAO, 2015). It has been estimated that about one billion people are currently undernourished while 2 to 3 billion are malnourished worldwide (Afari-Sefa *et al.*, 2012). This situation is largely attributable to the low consumption of vegetables and fruits which often falls below the daily minimum recommended by the World Health Organisation (WHO, 2003). This is particularly more serious in Africa where excessive consumption of carbohydrate-rich diets has resulted in micronutrient deficiency causing increased mortality, diseases, and poor economic status (Afari-Sefa *et al.*, 2012; Grubben *et al.*, 2014). Vegetables are important sources of micronutrients, vitamins, minerals, and dietary fibre and their consumption is essential for a properly balanced diet (Afari-Sefa *et al.*, 2012).

The volume of vegetables produced in some African countries is unable to meet the minimum required per individual. This shortfall is partly caused by postharvest losses arising from microbial spoilage associated with poor storage facilities and inefficient transportation systems (Ubani and Okonkwo, 2011). Furthermore, the lack of adequate knowledge about postharvest handling and storage among local farmers has resulted in the massive loss of these highly perishable products (Olayemi *et al.*, 2012). In Nigeria, postharvest losses of vegetables and fruits have been estimated as 30-50% (Atanda *et*

al., 2011) at a cost of about 9 billion dollars (Nwaoguji, 2017). These losses can be prevented by the adoption of appropriate preservation technologies that are easily accessible and relevant to local settings (Atanda *et al.*, 2011; Ubani and Okonkwo, 2011).

The high moisture content and the sustained metabolic activities (respiration, transpiration, and ripening) of vegetables, which continue even after harvest, make them highly prone to spoilage (Kitinoja and Kader, 2004; Ben-Yehoshua and Rodov, 2002; Bighaghire *et al.*, 2021). Hence, methods that involve the reduction of moisture loss through temperature reduction have been recommended for the preservation of vegetables (Kitinoja and Kader, 2004). Refrigeration is a good way to achieve this but extended storage in such conditions may cause chilling injury to the products (Olosunde-William *et al.*, 2009). Furthermore, the high energy requirement and costs make refrigeration impractical for poor farmers in rural communities. An evaporative cooling system (ECS) has been advocated as a low-cost alternative for the storage and extension of the shelf-life of vegetables (Kitinoja and Kader, 2004). This system works on the principle that evaporation of water from a medium causes a cooling effect which leads to a decrease in temperature and increased relative humidity relative to the ambient environment (Jahun *et al.*, 2016). ECS has been deployed in some tropical and subtropical climates for fruits, vegetables, and other crops (lal Basediya *et al.*, 2013). It is unique for its simplicity, low setup and operational cost, energy efficiency, and environmental friendliness. These factors make it ideal for use in rural communities in developing countries like Nigeria with a hot tropical climate and energy challenges.

The use of ECS for the preservation of fruits, vegetables, and other crops has been extensively studied in Nigeria (Mogaji and Fapetu, 2011; Okunade and Ibrahim, 2011; Chinenye *et al.*, 2013). The Nigerian Stored Products Research Institute is a governmental body saddled with the mandate to develop technologies for postharvest management and improvement in the quality of Nigerian agricultural commodities (Ubani and Okonkwo, 2011). Using locally sourced materials, NSPRI has developed various model ECS structures such as the cooler basket (Ubani and Okonkwo, 2011), pot-in-pot, metal-in-pot and metal-in-block (Okunade and Ibrahim, 2011), and tin-in-pot ECS (Kamaldeen *et al.*, 2013), (Okunade and Ibrahim, 2011). These structures have been tested on various kinds of agricultural products such as oranges (Babarinsa and Nwangwa, 1986), okra, tomato, garden eggs and pawpaw (Ubani and Okonkwo, 2011), Irish potato (Okunade and Ibrahim, 2011) and (Babarinsa and Nwangwa, 1986) mango (Kamaldeen *et al.*, 2013) (Okunade and Ibrahim, 2011). However, an assessment of the efficacy of the block-in-block (BB) and metal-in-block (MB) types of ECS produced by NSPRI has not been extensively reported in the literature. Furthermore, in many of the studies concerning the preservation of fruits and vegetables with ECS, assessment of the efficacy of the system is usually based on physiological weight loss and/or visual signs of decay only. Very few studies have assessed based on the nutritional (Ndukwu and Manuwa, 2015) and microbiological quality of the products. Considering the role of microorganisms in food spoilage and the importance of wholesomeness and desired food attributes to consumers, any evaluation of ECS should involve microbiological and nutritional assessments in addition to visual examination.

Telfairia occidentalis Hook. f. (Ugu) and *Amaranthus hybridus* L. (Tete) are two widely consumed leafy vegetables in Southeast and Southwest Nigeria, respectively. They are grown by both commercial and subsistence farmers in the country. These vegetables are rich in nutrients and minerals (Idoko *et al.*, 2014; Ogbuji *et al.*, 2016). Given the importance of these vegetables in the Nigerian rural and urban diets, and that both are widely planted in many parts of the country, this study was designed to test the efficacy of the BB and MB ECS in preserving their visual/nutritional quality and shelf-life.

MATERIALS AND METHODS

Description of Evaporative Cooling Structures (ECS)

The evaporative cooling structures used in this study were developed by the Nigerian Stored Products Research Institute (NSPRI), Ilorin, Nigeria from 2016 to 2017. The metal-in-block

and the block-in-block ECS types were used and are described below:

i. Metal-in-block (MB): this structure consists of an inner compartment made of a metal cabinet measuring 1.2 m x 1.2 m x 1.2 m and with a door fitted on one side with dimensions of 62 cm x 51 cm x 3 cm. The outer compartment is a cement-plastered block structure with dimensions of 1.8 m x 1.8 m x 1.8 m made with a 23 cm thick block. The metal cabinet was placed neatly into the block and the space between the two compartments was filled with river bed sand (absorbent) (Figure 1). The absorbent material was moistened with 120 L of water on the first day and 70 L on subsequent days. The inner chamber was then cleaned with water and detergent and later disinfected with a hypochlorite solution.

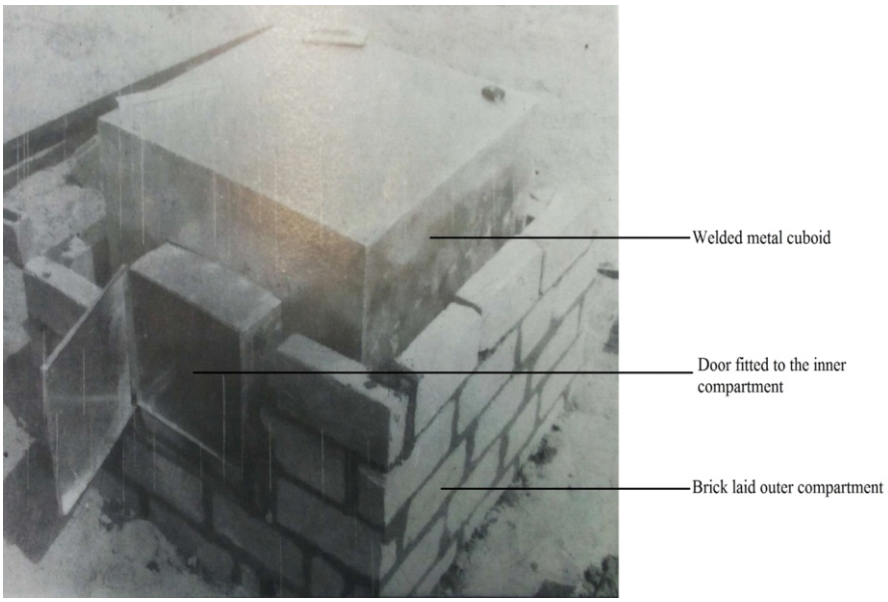

Figure 1: NSPRI's metal-in-block evaporative cooling structure.

i. Block-in-block (BB): The BB was constructed exactly as described for the MB except that the inner compartment was made of a cement-plastered block with the same dimensions as the metal cabinet of MB and the thickness of each block was 23 cm (Figure 2).

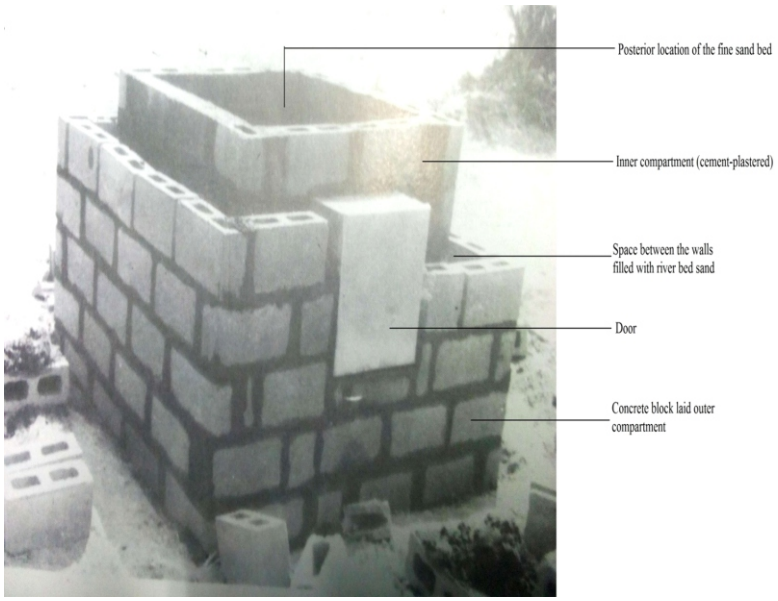

Figure 2: NSPRI's block-in-block evaporative cooling structure.

Collection of vegetable samples

The vegetables used in this study were *Telfairia occidentalis*, known locally as 'Ugu', and *Amaranthus hybridus*, known locally as 'Tete'. Fresh vegetables were obtained from a local market in Ilorin, Nigeria, and were transported immediately to the laboratory. The vegetables were authenticated at the Herbarium of the Department of Plant Biology, University of Ilorin, Nigeria.

Storage of vegetables in ECS

The vegetable samples were separately washed in sterile distilled water to remove soil debris and were placed on draining racks to remove excess water. Then, they were transferred to special stackable crates developed by NSPRI and placed in the ECS structures. The vegetables were arranged alternately in the ventilated crates for relative aeration while avoiding contact between the vegetables and any extraneous materials. The control samples of the vegetables were stored under ambient conditions in sterilized plastic stackable crates (temperature 30.9 °C ± 1.0; relative humidity 51.25% ±19.95) on the workbench in the laboratory. Samples were taken and analyzed daily from each structure and the controls. The storage of samples in the structures was discontinued at the onset of spoilage as indicated by physical deterioration, apparent rot, or extreme shrinkage.

Measurement of temperature and relative humidity

The temperature and relative humidity of the ECS and ambient were recorded with a thermometer and a digital hygrometer, respectively. Triplicate readings were collected in the morning, afternoon, and evening of each day for the entire period of storage.

Weight loss of ECS-preserved vegetables

The weight loss of the preserved vegetables was determined by weighing the samples on a digital weighing balance (Shimadzu UW620H, Japan). The difference between the final and initial weight of the samples expressed as a percentage of the initial was recorded as the weight loss.

Determination of pH

The vegetable sample (3 g) was macerated and mixed into 27 mL of distilled water to make a 10% solution. The pH of the vegetable solution was measured each day using an electrode pH meter (Searchtech pHS – 3C, United Kingdom).

Determination of Vitamin C

Vitamin C content was determined following the method of Amadi *et al.* (2004). The vegetable sample (10 g) was made into a paste by grinding it with 2 g of acid (2 M HCl)-washed sand using mortar and pestle. To digest the sample, 5 mL of 2 % HCl was added and the whole mixture was transferred into a 100 mL measuring cylinder. The suspension was decanted to remove the sand. This extraction was repeated thrice and the three fractions were combined and made up to 100 mL of distilled water. A 10 mL volume of the extract was titrated with 0.001 M of 2,6 - dichlorophenol indophenol solution until the colour turned pink and persisted for 30 s. Vitamin C concentration was then calculated using the following equation as described previously (Amadi *et al.,* 2004).

$$Vit.C\ (mg/100\ g) = \frac{T \times V_E \times D \times 100}{W}$$

T = titre value (mL), V_E = vitamin C equivalent, D = dilution factor, and W = weight of sample

Proximate analysis of ECS-preserved vegetables

Moisture content, crude protein, crude lipid/fat, crude fibre, carbohydrate, and ash content were determined using the established methods (AOAC, 2005). Moisture content was expressed as the percentage loss in weight of the samples after drying them at 105 ± 2 °C in an oven for 6 h. Crude protein was determined using the micro-Kjeldahl method. The amount of protein was obtained by multiplying the nitrogen content by a conversion factor of 6.25. Crude lipid/fat was determined by heating the sample with petroleum ether in a Soxhlet apparatus at 50 °C for 5 h. The percentage of weight loss of the sample after heating was taken as the amount of fat in the sample. The crude fibre was estimated by sequential hydrolysis of the samples with 1.5% H_2SO_4 and 1.25% NaOH followed by combustion in a muffle furnace at 400 °C for 6 h. The exact

amount of the residual ash expressed as a percentage of the initial sample weight was used as the amount of fibre. The total ash content of the samples was determined by heating in a muffle furnace at 550 °C for 6 h and the percentage weight loss was recorded as ash content. The carbohydrate content was calculated by subtracting the sum of the values obtained for crude protein, fat, fibre, and total ash from 100%.

Determination of the mineral composition of ECS-preserved vegetables

The mineral elements comprising sodium, calcium, potassium, magnesium, iron, zinc, and phosphorus were determined according to the previously described methods (Nahapetian and Bassiri, 1975; Shahidi *et al.* 1999) with some modifications. Two grams of each of the processed samples was placed in a clean porcelain crucible and heated at 550° C for 6 h in a muffle furnace. The resultant ash was dissolved in 5.0 mL of $HNO_3/HCl/H_2O$ (1:2:3) and heated gently on a hot plate until brown fumes disappeared. Exactly 5.0 mL of de-ionized water was then added and heated until a colourless solution was obtained. The mineral solution in each crucible was transferred into a 100 mL volumetric flask by filtration through Whatman No. 1 filter paper and the volume was adjusted to 5 mL with de-ionized water. This solution was used for elemental analysis using an Accusys 211 Atomic Absorption Spectrophotometer (AAS) (Buck Scientific Inc., USA). A 10 cm long cell was used and the concentration of each element in the sample was calculated as a percentage on a dry matter basis (mg/100 g sample). The phosphorus content of the digest was determined using the colorimetric method as described by Nahapetian and Bassiri (1975).

Microbiological analysis of ECS-preserved vegetables

The vegetables stored in the ECS structures and control samples were analyzed for the presence of bacteria and fungi. The vegetable samples were rinsed thoroughly in sterile distilled water and placed on the stackable crates to drain. A ten-fold serial dilution of the rinse solution was prepared and aliquots were plated out on Nutrient Agar medium (Lab M Limited, Lancashire) for bacterial counts, while Potato Dextrose Agar (Sisco Research Lab. Pvt. Ltd., India) was used for the enumeration of fungi. Also, Mac-Conkey agar (BIOMARK Laboratories, India) and Eosin Methylene Blue agar (Lab M Limited, Lancashire) was used for the enumeration of the Enterobacteriaceae and faecal coliforms, respectively. Bacterial plates were incubated at 35 °C for 24 h, while fungal plates were incubated at 25 °C for 3 to 5 days. Distinct isolates obtained after incubation were sub-cultured and maintained on agar slants at 4 °C. Counts were expressed as colony-forming units per gram sample (cfu/g). Molecular identification of bacterial isolates was done using 16S rRNA sequencing at the Bioscience laboratory of the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria. The isolates were identified by alignment of their sequences with those deposited on the NCBI database using the BLAST tool (https://blast.ncbi.nlm.nih.gov/Blast.cgi?_e_pi_=7%2CPAGE_ID10%2C2696348247). Fungal characterization was based on colonial and microscopic observations (Fawole and Oso, 2004). Also, isolates were identified as described previously (Fassatiová, 1986; Ellis *et al.*, 2007).

Statistical analysis

Statistical analysis was carried out using Minitab software, Version 17.0 (Minitab Inc, USA). Samples were analyzed in triplicates and the analysis of variance (ANOVA) was conducted to determine significant differences ($P< 0.05$). Means were separated using Tukey's HSD post hoc analysis.

RESULTS

Shelf-life of vegetables stored under ECS Conditions

The vegetable samples were stored in the ECS structures and monitored daily for 7 days. Samples were removed from storage at the onset of deterioration. Spoilage was observed after 2 days and 3 days for *Amaranthus hybridus* and *Telfairia occidentalis*, respectively. However, *Amaranthus hybridus* stored under BB and MB lasted up to 4 days before spoilage in both ECS structures, while *Telfairia occidentalis* was preserved for 7 days in the two structures.

Temperature

The changes in temperature in the laboratory where the control samples were kept and ECS structures were observed throughout storage (Figure 1). While the temperature of the laboratory ranged between 29.9 to 31.9 °C, that of BB and MB ranged between 25.8 to 28.5 °C and 25.3 to 28.0 °C, respectively. The two ECS structures had a similar decline in temperature from ambient (2.8 to 6.0 °C for BB and 2.6 to 6.5 °C for MB), with no significant difference (P>0.05) between them, although MB had a slightly lower temperature between days 3 and 5.

Relative humidity

As observed with temperature, there was no significant difference (P>0.05) in the relative humidity (RH) of the two ECS chambers throughout the study (Fig. 2). RH increased from a maximum value of 49.3% for the control samples kept in the laboratory to a maximum of 70% and 71.2% under BB and MB, respectively. Thus, an RH increase of up to 38% and 39.4% was observed.

Weight loss

The weight loss of the samples was recorded daily as percentage weight loss (Table 1). No significant difference (P<0.05) was observed between BB- and MB-preserved samples for both vegetables throughout storage. For *Amaranthus hybridus*, the weight loss between the control and ECS-preserved samples did not differ significantly (P< 0.05) on day 1.

Table 1: Percentage weight loss (%) of vegetables stored in Evaporator Cooling Storage.

Amaranthus hybridus	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Control	35.21 ± 1.77^{a}	62.62 ± 4.48^{a}					
BB	26.71 ± 6.03^{a}	33.53 ± 5.27^{b}	51.25 ± 6.99^{a}	50.53 ± 0.86^{a}			
MB	36.68 ± 4.09^{a}	45.85 ± 5.05^{b}	48.42 ± 1.04^{a}	52.06 ± 4.12^{a}			
Telfairia occidentalis							
Control	17.69 ± 4.83^{a}	66.99 ± 2.64^{a}	71.88 ± 3.11^{a}				
BB	6.88 ± 0.70^{b}	14.16 ± 0.85^{b}	14.31 ± 1.77^{b}	18.20 ± 3.24^{a}	24.77 ± 3.99^{a}	28.36 ± 5.40^{a}	45.83 ± 8.43^{a}
MB	9.01 ± 1.77^{b}	13.39 ± 1.97^{b}	13.70 ± 3.38^{b}	16.02 ± 4.50^{a}	19.37 ± 3.53^{a}	25.27 ± 3.54^{a}	36.73 ± 3.63^{a}

Values represent mean of three replicates ± standard deviation. Subscripts with different letters in the same column are significantly different (P<0.05).

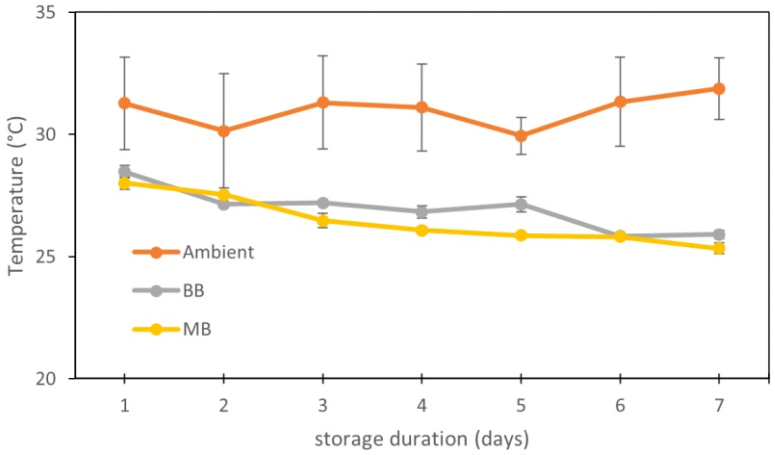

Figure 1: Temperature changes during storage of vegetables under ECS conditions.

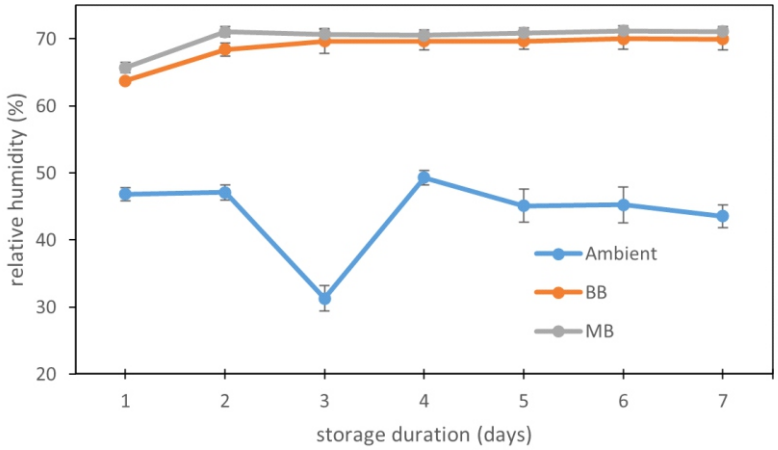

Figure 2: Changes in relative humidity during storage of vegetables in ECS structures.

However, the difference became significant (P>0.05) on day 2 with the control samples recording 62.62% weight loss compared to BB (33.5%) and MB (45.9%). However, weight loss values differed significantly (P<0.05) between the control- and ECS-preserved samples from day 1 to day 3 before the complete deterioration of the control samples. Generally, higher weight loss was observed in *Amaranthus hybridus* than in *Telfairia occidentalis* under ECS storage.

pH

Generally, pH values of all the samples remained in the acidic range (< 7.0) throughout the study, but a reduction in pH was observed as storage continued (Table 2). The control samples had higher pH values (6.23-6.47 for *Amaranthus hybridus* and 5.70-6.63 for *Telfairia occidentalis*) than those stored in the ECS structures (5.57-6.23 for *Amaranthus hybridus* and 4.50-5.90 for *Telfairia occidentalis*). Samples stored in BB had slightly higher pH values than those stored in MB. Also, lower pH values were recorded with *Telfairia occidentalis*.

Table 2: Changes in pH of vegetables stored in ECS storage.

Amaranthus hybridus							
Days	1	2	3	4	5	6	7
Control	6.47 ± 0.15^{a}	6.23 ± 0.06^{a}	ND	ND	ND	ND	ND
BB	6.23 ± 0.06^{ab}	5.90 ± 0.10^{ab}	5.67 ± 0.06^{b}	5.67 ± 0.06^{b}	ND	ND	ND
MB	6.17 ± 0.06^{ac}	5.80 ± 0.17^{ac}	5.77 ± 0.15^{c}	5.57 ± 0.06^{c}	ND	ND	ND
Telfairia occidentalis							
Control	6.63 ± 0.06^{a}	6.33 ± 0.15^{a}	5.70 ± 0.17^{a}	ND	ND	ND	ND
BB	5.90 ± 0.10^{ab}	5.77 ± 0.21^{ab}	5.23 ± 0.15^{ab}	5.13 ± 0.06^{a}	4.97 ± 0.06^{a}	4.77 ± 0.06^{a}	4.77 ± 0.06^{b}
MB	5.73 ± 0.06^{ac}	5.53 ± 0.06^{ab}	5.20 ± 0.10^{ac}	4.77 ± 0.06^{a}	4.73 ± 0.12^{a}	4.60 ± 0.10^{b}	4.50± 0.04^{b}

Values represent mean of three replicates ± standard deviation. Subscripts with different letters in the same column are significantly different (P<0.05). ND – not determined (due to spoilage)

Vitamin C

A general decrease in vitamin C content was observed with all the vegetable samples throughout the storage period (Table 3). *Telfairia occidentalis* had a significantly higher content of vitamin C (19.97 to 72.37 mg/100 g) than *Amaranthus hybridus* (9.54 to 33.17 mg/100 g) under all the storage conditions. The control samples had lower vitamin C content (maximum of 30.83 mg/100 g for *Amaranthus hybridus*, and 66.22 mg/100 g for *Telfairia occidentalis*) than those in the ECS structures (maximum of 33.17 mg/100 g for *Amaranthus hybridus*, and 72.37 mg/100 g for *Telfairia occidentalis*). It was also observed that MB-preserved samples had a higher amount of vitamin C than BB-preserved ones,

with maximum values of BB and MB of 33.17 and 32.13 mg/100 g for *Amaranthus hybridus*, and 66.4 and 72.37 mg/100 g for *Telfairia occidentalis*, respectively.

Table 3: Changes in vitamin C content of vegetables stored under ECS conditions.

Amaranthus hybridus (mg/100 g)							
Days	1	2	3	4	5	6	7
Control	30.83 ± 0.69[a]	22.43 ± 1.61[a]	ND	ND	ND	ND	ND
BB	33.17 ± 3.18[b]	25.51 ± 3.03[ab]	20.51 ± 2.06[a]	9.54 ± 0.70[a]	ND	ND	ND
MB	32.13 ± 2.21[c]	26.37 ± 0.75[ac]	22.26 ± 0.70[b]	17.51 ± 1.70[a]	ND	ND	ND
Telfairia occidentalis (mg/100 g)							
Control	66.22 ± 6.57[a]	48.48 ± 7.76[a]	30.50 ± 0.53[a]	ND	ND	ND	ND
BB	66.40 ± 6.88[b]	57.39 ± 6.35[ab]	47.81 ± 4.00[ab]	40.36 ± 2.37[a]	33.23 ± 4.40 [a]	32.04 ± 3.83 [a]	19.97 ± 1.68 [a]
MB	72.37 ± 3.51[c]	65.01 ± 2.77[ab]	62.28 ± 1.01[ab]	55.21 ± 3.49 [a]	51.13 ± 3.10 [a]	44.72 ± 3.76 [a]	34.76 ± 5.15 [a]

Values represent mean of three replicates ± standard deviation. Subscripts with different letters in the same column are significantly different ($P < 0.05$). ND – not determined due to the on-set of deterioration.

Nutritional Composition (Proximate Analysis)

The results of the proximate analysis of the samples stored in MB recorded the highest amounts of moisture *Amaranthus hybridus* - 86.5% - (Table 4) and *Telfairia occidentalis* - 71.2% - (Table 5). These were higher than samples in BB with a maximum moisture content of 67.23% and 66.43% in *Amaranthus hybridus* and *Telfairia occidentalis*, respectively. The least moisture was found in the control samples. It was observed that the control samples had wilted due to the loss of moisture.

Table 4: Proximate composition of *Amaranthus hybridus* under ECS storage.

Parameter (%)	Storage condition	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Moisture	Control	81.07 ± 1.23	34.70 ± 3.48	ND	ND	ND	ND	ND
	BB	83.77 ± 0.40	67.23 ± 0.74	66.20 ± 3.12	51.00 ± 0.66	ND	ND	ND
	MB	86.50 ± 0.20	69.30 ± 1.10	61.70 ± 0.30	65.80 ± 0.20	53.90 ± 1.10	ND	ND
Protein	Control	3.40 ± 0.89	19.20 ± 0.85	ND	ND	ND	ND	ND
	BB	3.57 ± 0.21	9.10 ± 0.57	10.03 ± 2.06	15.57 ± 0.25	ND	ND	ND
	MB	3.10 ± 0.00	7.60 ± 0.40	13.80 ± 0.40	15.10 ± 0.10	15.10 ± 0.10	ND	ND
Fiber	Control	3.20 ± 0.95	2.70 ± 0.46	ND	ND	ND	ND	ND
	BB	1.97 ± 0.12	2.80 ± 0.40	4.50 ± 0.66	5.70 ± 0.79	ND	ND	ND
	MB	1.87 ± 0.55	2.60 ± 1.14	5.70 ± 0.40	4.20 ± 0.00	5.30 ± 0.30	ND	ND
Fat	Control	1.60 ± 0.89	8.77 ± 1.20	ND	ND	ND	ND	ND
	BB	1.80 ± 0.20	3.43 ± 0.47	2.83 ± 0.15	6.40 ± 0.70	ND	ND	ND
	MB	1.60 ± 0.10	2.50 ± 0.10	4.10 ± 0.10	2.90 ± 0.20	3.20 ± 0.10	ND	ND
Ash	Control	4.87 ± 0.65	27.33 ± 1.46	ND	ND	ND	ND	ND
	BB	0.57 ± 1.57	4.80 ± 0.70	4.83 ± 1.46	9.37 ± 0.25	ND	ND	ND
	MB	0.63 ± 0.42	1.90 ± 0.10	2.90 ± 0.40	2.30 ± 0.00	2.30 ± 0.10	ND	ND
CHO	Control	5.57 ± 0.35	5.93 ± 0.15	ND	ND	ND	ND	ND
	BB	8.30 ± 0.36	11.60 ± 0.70	11.60 ± 0.79	11.97 ± 0.71	ND	ND	ND
	MB	6.23 ± 0.12	15.30 ± 1.20	11.80 ± 0.20	10.50 ± 0.30	23.90 ± 1.30	ND	ND

ND – not determined due to the on-set of spoilage; CHO – carbohydrate; Values are means of three replicates; ± standard deviation.

Table 5: Proximate composition of *Telfairia occidentalis* under ECS storage.

Parameter (%)	Storage condition	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Moisture	Control	71.70 ± 0.40^{a}	44.73 ± 3.27^{c}	32.47 ± 3.72^{e}	ND	ND	ND	ND
	BB	66.43 ± 0.^{74ab}	59.40 ± 1.39^{b}	56.17 ± 0.91^{b}	51.73 ± 0.35^{bc}	46.87 ± 0.85^{c}	44.90 ± 1.14^{c}	40.47 ± 0.15^{cd}
	MB	71.20 ± 1.00^{a}	69.80 ± 0.30^{ab}	66.83 ± 2.22^{ab}	61.40 ± 1.18^{b}	53.87 ± 0.67^{bc}	51.83 ± 0.61^{bc}	42.00 ± 0.26^{cd}
Protein	Control	3.97 ± 1.00^{de}	25.13 ± 1.34^{a}	27.13 ± 1.88^{a}	ND	ND	ND	ND
	BB	4.67 ± 1.31^{d}	8.00 ± 0.26^{cd}	8.47 ± 0.93^{cd}	10.57 ± 0.60^{c}	15.00 ± 0.78^{b}	12.10 ± 0.70^{bc}	16.20 ± 0.17^{b}
	MB	3.70 ± 0.10^{de}	4.97 ± 0.35^{d}	7.60 ± 0.26^{cd}	11.03 ± 0.51^{bc}	13.27 ± 0.31^{bc}	15.17 ± 0.90^{b}	17.33 ± 1.55^{b}
Fiber	Control	7.10 ± 0.20^{ab}	6.20 ± 0.53^{b}	6.20 ± 1.76^{b}	ND	ND	ND	ND
	BB	3.57 ± 0.35^{cd}	3.80 ± 0.56^{cd}	6.00 ± 0.66^{b}	6.97 ± 0.78^{b}	7.37 ± 1.01^{ab}	6.43 ± 1.89^{b}	9.27 ± 0.32^{a}
	MB	2.83 0.25^{d}	2.77 ± 0.12^{d}	3.07 ± 0.25^{d}	3.50 ± 0.10^{cd}	4.77 ± 0.47^{c}	3.13 ± 0.85^{cd}	3.30 ± 0.72^{cd}
Fat	Control	1.13 ± 0.31^{e}	8.77 ± 0.57^{b}	12.67 ± 2.21^{a}	ND	ND	ND	ND
	BB	1.80 ± 0.20^{e}	3.43 ± 0.47^{c}	2.83 ± 0.15^{de}	9.37 ± 0.25^{b}	7.03 ± 0.15^{bc}	6.90 ± 0.26^{bc}	6.47 ± 0.42^{bc}
	MB	2.70 ± 0.10^{de}	3.10 ± 0.40^{d}	4.30 ± 0.82^{cd}	5.10 ± 0.44^{c}	4.73 ± 0.60^{c}	3.77 ± 0.40^{d}	3.70 ± 0.10^{d}
Ash	Control	5.23 ± 0.40^{cd}	7.17 ± 1.27^{c}	16.43 ± 3.50^{a}	ND	ND	ND	ND
	BB	6.43 ± 1.59^{c}	9.90 ± 1.15^{bc}	10.47 ± 1.07^{b}	11.23 ± 1.17^{b}	11.07 ± 1.27^{b}	17.50 ± 3.24^{a}	17.30 ± 0.89^{a}
	MB	6.10 ± 0.40^{c}	4.10 ± 0.82^{d}	2.93 ± 0.95^{de}	2.70 ± 0.70^{de}	3.07 ± 0.55^{de}	5.27 ± 0.68^{cd}	13.27 ± 2.76^{ab}
CHO	Control	10.90 ± 0.46	8.20 ± 1.59	5.03 ± 0.80	ND	ND	ND	ND
	BB	15.60 ± 0.62^{b}	13.83 ± 0.25^{bc}	14.07 ± 1.00^{b}	13.00 ± 0.70^{bc}	12.67 ± 0.35^{bc}	12.17 ± 0.38^{bc}	10.30 ± 0.26^{c}
	MB	13.07 ± 1.15^{bc}	15.20 ± 1.11^{b}	15.27 ± 0.80^{b}	16.23 ± 1.22^{ab}	20.37 ± 0.42^{a}	20.87 ± 0.51^{a}	20.67 ± 0.67^{a}

ND – not determined due to the on-set of spoilage; CHO – carbohydrate; Values are means of three replicates ± standard deviation.

In both *Amaranthus hybridus* and *Telfairia occidentalis*, protein content was found to increase as storage progressed. For *Amaranthus hybridus* (Table 4), the observed increase was from 3.40% to 19.2% for control samples 3.57% to 15.57% for BB, and 3.10% to 15.10% for MB. In the case of *Telfairia occidentalis* (Table 5), the observed increase was from 3.97% to 27.13% for ambient, 4.67% to 16.2% for BB and 3.70% to 17.33% for MB. A much larger increase was observed in the samples kept under ambient storage. The same pattern was observed for *Amaranthus hybridus* under all the storage conditions for fibre, fat, and carbohydrates (Table 4). However, in the *Telfairia occidentalis*, a general decline in carbohydrate content was observed in the control samples and BB storage (Table 5). The concentration of the other nutrients showed a general increase as the storage progressed.

Mineral Content

The mineral content of vegetable samples preserved in the ECS structures were examined after 4 days of storage. In both samples, a reduction in the amount of the minerals under BB/MB storage was observed (Table 6). In particular, reduction in potassium and magnesium was highest in all the samples with 161.72, 62.41, and 72.19 mg/100 g in *Amaranthus hybridus*, and 102.37, 55.81, and 63.70 mg/100 mg in control, BB and MB samples, respectively. The mineral content of the control samples was significantly higher ($P<0.05$) that the samples stored in BB and MB ECS, and correlated with their moisture content.

Table 6: Mineral composition of vegetable samples stored under ECS conditions.

	Amaranthus hybridus			*Telfairia occidentalis*		
	Control (mg/100 g)	BB (mg/100 g)	MB (mg/100 g)	Control (mg/100 g)	BB (mg/100 g)	MB (mg/100 g)
Potassium	161.72	62.41	72.19	102.37	55.81	63.70
Calcium	56.01	51.60	29.82	72.51	49.28	46.62
Magnesium	221.08	93.54	124.28	198.74	73.04	91.26
Iron	28.84	20.51	18.25	24.10	10.11	9.26
Phosphorus	31.01	6.28	19.71	28.16	15.70	13.21
Sodium	18.62	11.21	6.06	51.29	20.04	31.65

Microbiological Analysis

Microbial counts from the samples stored under ECS conditions are presented in Tables 7 and 8. For *Amaranthus hybridus*, the control samples had higher counts of heterotrophic bacteria (6.22 log CFU/g), coliforms (3.48 log CFU/g), and fungi (5.95 log CFU/g) than those stored in BB (6.11 log CFU/g bacteria, 3.25 log CFU/g coliforms, 5.8 log CFU/g fungi) and MB (6.0 log CFU/g bacteria, 2.99 log CFU/g coliforms, 5.68 log CFU/g fungi). For *Telfairia occidentalis* (Table 8), the control sample counts were heterotrophic bacteria (6.7 log CFU/g), coliforms (3.04 log CFU/g), and fungi (5.75 log CFU/g), which were higher than counts from BB (6.49 log CFU/g bacteria, 3.04 log CFU/g coliforms, 5.71 log CFU/g fungi) and MB (6.37 log CFU/g bacteria, 3.03 log CFU/g coliforms, 5.70 log CFU/g fungi). MB samples had the least microbial counts.

Table 7: Microbial counts of *Amaranthus hybridus* stored under ECS conditions.

	Control (log CFU/g)							BB (log CFU/g)							MB (log CFU/g)						
	Days																				
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Bacteria	6.22 ± 0.03	6.09 ± 0.04	-	-	-	-	-	6.11 ± 0.03	5.83 ± 0.05	5.17 ± 0.13	4.75 ± 0.10	-	-	-	6.00 ± 0.04	5.77 ± 0.03	5.54 ± 0.32	4.67 ± 0.16	-	-	-
Coliforms	3.48 ± 0.04	3.14 ± 0.06	-	-	-	-	-	3.25 ± 0.07	2.88 ± 0.09	2.56 ± 0.21	2.37 ± 0.10	-	-	-	2.99 ± 0.07	2.64 ± 0.21	2.30 ± 0.24	1.82 ± 0.00	-	-	-
Fungi	5.95 ± 0.06	5.81 ± 0.13	-	-	-	-	-	5.80 ± 0.04	5.62 ± 0.08	5.38 ± 0.12	5.14 ± 0.15	-	-	-	5.68 ± 0.11	5.48 ± 0.10	5.24 ± 0.23	4.77 ± 0.13	-	-	-

Table 8: Microbial counts of *Telfairia occidentalis* stored under ECS conditions.

	Control (log CFUg)							BB (log CFU/g)							MB (log CFU/g)						
	Days																				
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Bacteria	6.70 ± 0.07	6.73 ± 0.05	6.74 ± 0.06	6.64 ± 0.03	-	-	-	6.49 ± 0.03	6.54 ± 0.06	6.38 ± 0.09	6.25 ± 0.11	5.87 ± 0.77	5.85 ± 0.03	5.78 ± 0.13	6.37 ± 0.07	6.36 ± 0.16	6.17 ± 0.06	6.05 ± 0.11	5.79 ± 0.03	5.74 ± 0.15	5.58 ± 0.19
Coliforms	3.04 ± 0.21	3.09 ± 0.23	3.01 ± 0.39	2.87 ± 0.34	-	-	-	3.04 ± 0.08	2.87 ± 0.29	2.82 ± 0.11	2.75 ± 0.05	2.60 ± 0.24	2.37 ± 0.10	2.22 ± 0.28	3.03 ± 0.20	2.92 ± 0.03	2.78 ± 0.14	2.67 ± 0.10	2.30 ± 0.24	2.12 ± 0.17	2.00 ± 0.00
Fungi	5.75 ± 0.05	5.91 ± 0.13	5.99 ± 0.06	5.78 ± 0.09	-	-	-	5.71 ± 0.05	5.68 ± 0.10	5.56 ± 0.31	5.07 ± 0.68	5.32 ± 0.29	5.20 ± 0.18	5.18 ± 0.25	5.70 ± 0.10	5.38 ± 0.08	5.36 ± 0.09	5.29 ± 0.12	5.21 ± 0.14	4.99 ± 0.13	4.69 ± 0.07

DISCUSSION

This study evaluated the effectiveness of the block-in-block and metal-in-block evaporative structures in preserving the shelf-life and the nutritional and microbiological qualities of *Amaranthus hybridus* and *Telfairia occidentalis* vegetables. The shorter shelf-life of *Amaranthus hybridus* in all the storage conditions as compared to *Telfairia occidentalis* reflects the innate higher perishability of the former. This may be related to the higher content of nutrients and moisture in *Amaranthus hybridus* (Ambuko *et al*., 2017; Gwamba *et al*., 2020). The consistently lower temperature in the ECS resulted in the extension of the shelf-life of the vegetables. The higher ambient temperatures recorded higher standard deviations than the ECS values. This is an indication of the effectiveness of the ECS structures in cooling the air of the chambers and keeping the temperature relatively stable. This is another reason for the preservation of the vegetables because subjecting vegetables to high and fluctuating temperatures as obtained under ambient storage could promote the onset of conditions that could facilitate spoilage (Nunes and Emond, 1999). Storing vegetables under reduced temperatures suppresses the physiological activities of both the vegetables and the microorganisms which could have caused spoilage (Nunes and Emond, 2002). This is further supported by the results of the relative humidity, which was fairly stable in both ECS structures. These observations further justify the similarity in the shelf-life of vegetables stored in the MB and BB ECS. Similar observations have been reported with various types of ECS structures (Dadhich *et al*., 2008; Ndukwu, 2011).

The observed trend in weight loss can be attributed to the relative humidity of the storage structures. The weight loss results are consistent with the RH data where it was observed that no significant difference in RH was observed between both ECS structures while that of ambient was significantly lower. Low RH causes loss of moisture which leads to eventual loss of weight in vegetables and fruits (Medina *et al*., 2012). Therefore, the higher RH prevalent in the ECS structures reduced the amount of moisture loss which resulted in the lower percentage of weight loss recorded in the samples preserved with BB and MB. Falayi and Jongbo (2011) reported similar considerable differences in

weight loss between ambient and a metal-in-block ECS structure during the preservation of tomato fruits and *Amaranthus hybridus* leaves. The Vitamin C content of the stored vegetables generally declined during storage, with a sharp decline under ambient conditions. It was also observed that MB-preserved samples had a higher amount of vitamin C than BB-preserved ones. These observed variations could be attributed to the effect of temperature as this is known to lead to loss of vitamin C (Ndukwu and Manuwa, 2015). Hence, samples in ambient storage which had higher temperatures than the ECS structures contained lower amounts of vitamin C than those stored under ECS. Similarly, due to the slightly higher temperature recorded under the BB storage (especially between days 3 and 5), BB-preserved samples had lower vitamin C content than the MB-preserved ones. The degradation of vitamin C can also be due to the action of oxidative enzymes, polyphenol oxidase, and peroxidase, which contribute to the loss of the vitamin (Barrett and Lloyd, 2012). These observations are in agreement with the findings of Ndukwu and Manuwa (2015).

Nutrients in the stored vegetables generally increased as their moisture content reduced. Vegetables are still physiologically active at harvest (Ambuko *et al.,* 2017) and moisture loss through transpiration can lead to the concentration of the nutrients in the vegetables. However, the observed decrease in carbohydrate content under ambient and BB for *Telfairia occidentalis* could be a result of the higher temperatures recorded in those storage conditions which likely promoted oxidation of the carbohydrates as substrates during the respiration of the vegetables. In addition, carbohydrates are utilized as an energy source by spoilage microorganisms. The reduction in mineral content in the ECS-stored vegetables can be attributed to the lower temperature in these structures and the higher relative humidity (Ambuko *et al.,* 2017). According to (Okoli, 2009), drying under low temperatures and high moisture content can cause leaching out of soluble vitamins and minerals along with water.

Both *Amaranthus hybridus* and *Telfairia occidentalis* samples stored under ambient conditions had higher counts of heterotrophic bacteria, coliforms, and fungi than those in BB and MB. MB samples had the least microbial counts. This is due to the unrestricted exposure of the samples to air which is laden with spores and cells of numerous spoilage microorganisms. This is partly responsible for the rapid decay and short shelf-life of samples stored in ambient conditions. Heterotrophic bacteria were significantly higher in population than fungi while coliform bacteria had the least occurrence in both samples. Similar high bacterial counts have been reported for various vegetables from Nigeria (Eni *et al.*, 2010). The sources of these bacteria could include natural resident flora, irrigation water, unhygienic transportation means, or poor handling (Ewekeye *et al.*, 2013). A general decline in the microbial counts was observed for all the samples as storage progressed. This can be attributed to the concentration of the antimicrobial substances in the vegetables following the loss of moisture during storage. *Amaranthus hybridus* and *Telfairia occidentalis* have been reported to contain various antimicrobial compounds (Oboh *et al.*, 2006; Amabye, 2015) which may have caused the reduction in microbial counts. *Aeromonas hydrophila* was predominant in the vegetables with a percentage occurrence of 27%. Other bacteria found in the samples are *Comamonas testosterone* (24%), *Pseudomonas plecoglossicida* (18%), *Pseudomonas putida* (18%) and *Aeromonas rivuli* (12.1%). The fungi were *Rhizopus stolonifer* (18%), *Mucor micheli* (15%), *Alternaria alternata* (13%), *Aspergillus fumigatus* (10%), *Aspergillus niger* (10%), *Madurella mycetomatis* (10%), *Aspergillus flavus* (9%), *Aureobasidium pullulans* (8%) and *Verticillium nees* (6%). Some of these microorganisms have been implicated in the spoilage of various vegetables (Tournas, 2005).

CONCLUSION

MB and BB extended the shelf-life of the vegetables longer than the ambient storage. This was due to the lower temperature and higher relative humidity recorded in the former. Although a general decline in some nutritional parameters was observed, MB-preserved samples showed better retention of vitamin C and carbohydrate. The loss of minerals was observed in the ECS-preserved samples. MB-preserved samples were the least susceptible to microbial colonization and spoilage. The ECS structures

studied can be easily adopted by rural farmers for the reduction of postharvest losses of vegetables.

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