International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 13, No. 2, p. 114-127, 2018

INNSPUB

RESEARCH PAPER

OPEN ACCESS

Effectiveness of evaporative cooling technologies to preserve the postharvest quality of tomato

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Article published on August 23, 2018

Key words: Cool chain, Pot-in-Pot, Season, shelf-life, ZEBC.

Abstract

A research was conducted during dry and rainy seasons to assess the effectiveness of evaporative cooling technologies (ECT) namely; Evaporative Charcoal Cooler (ECC), Zero Energy Brick Cooler (ZEBC) and Pot-in-Pot cooler to preserve postharvest quality and extend shelf-life of tomato under storage in Malawi. A homogenous sample of freshly harvested tomato fruits were divided into four similar batches and stored in ECC, ZEBC, Pot-in-Pot and ambient conditions (control) for 24 days. Changes in Temperature, Relative humidity, Physiological Weight loss(PWL), Firmness, wilting, color, vitamin Cand total cost of producing the evaporative cooling technologies were determined for 24 days in both seasons. Shelf-life was determined bycounting number of days taken to reach the last stage of ripening up to the stage when they remained marketable. A 2°C -16°Ctemperature reduction and 24%-42.59% increase in relative humidity were observed between ambient and ECT storage in both seasons. After 24 days, ambient stored tomato lost 25.2% and 18.85% of their initial weight in season 1and 2 respectively, lowest losses were recorded in Pot-in-Pot (5.2%) and ZEBC (5.15%)in season 1 and 2. EC technologies significantly reduced losses in firmness, wilting and color compared to ambient storage in both seasons. The shelf-life of ambient stored tomato was 10 and 12 days in season 1and 2 respectively, compared to 24 days for Pot-in-Pot stored tomato, the highest in both seasons. ECC recorded high construction costs. In conclusion, evaporative cooling technologies preserved postharvest quality and increased shelf-life of tomato under storage.

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Introduction

Tomato *(Lycopesicon esculentum)* is one horticulture crop gaining importance in Malawi as an alternative to tobacco farming and is the most prevalent vegetable (Mapemba *et al.,* 2013). Malawi is ranked 92 out of 142 tomato producing countries (FAOSTAT, 2014) which is an indication of how important tomato is to Malawi in terms of its nutritional and economic contributions to food security and the economy of the country. Tomato farmers in Malawi are faced with many challenges including postharvest losses which is at 40-50% (Obura *et al.,* 2015; Woldemariam and Abera, 2014; Pila *et al.,*2010)due to among others, lack of access to cheap cold storage technologies leading to poor management of the cool chain which includes exposure to high temperatures and low relative humidity after harvest (Kakwesa, 2015:Ndukwu, 2011: Getinet, 2011).

These challenges contribute to increased postharvest losses of tomato, forcing the farmers to sell their tomato at a give-away price to avoid losing due to its perishable nature. Management of these postharvest losses is key to realization of profitability of tomato production. Postharvest losses of tomato is determined by the loss in physical quality of the fruits which include; texture, firmness, color and physiological weight loss due to loss of water to the surrounding environment (Ndukwu *et al.,* 2015).Maintenance of the cold/cool chain is keyto maintaining the fresh form of tomato hence reducing postharvest losses (Kitinoja, 2013).

Mechanical refrigeration is one of the techniques used to achieve high relative humidity and low storage temperatures in the developed countries (Woldemariam and Abera, 2014). However, such technologies require uninterrupted electricity and high initial capital for procurement and installation which prohibits the use of cold rooms for storage by small holder farmers resulting in increased losses. Evaporative cooling, which is premised on cooling by evaporation is a cheaper option for resource poor farmers in countries such as Malawi to achieve low temperature and high relative humidity storage hence reducing postharvest losses.

As dry air from the surrounding passes through the wetted pad or sand, it absorbs water from the pads and therefore become cooled and saturated, in turn cools the inside environment of the cooling structure and the produce under storage (Ndukwu *et al.*, 2015; Woldemariam and Abera 2014).

Previous studies conducted on Evaporative cooling (EC) storage of fruits and vegetables have shown that EC can maintain temperature 10-15^{o}C below the normal outside temperature and increase relative humidity up to 90%, which are conditions that can double the shelf-life of fruits and vegetables (Kitinoja, 2013). A shelf life of 5, 19, 21days was recorded for tomato stored under ambient, pot-in-pot and bamboo jute cooler respectively (Woldemariam and Abera, 2014).

Islam and Morimoto, (2012) reported an increase in shelf life of tomato and eggplant stored in a Zero Energy Brick Cooler (ZEBC) from 7 day and 4 days respectively under ambient storage to 16 days for tomato and 9 days for eggplant. Rayaguru *et al.*, (2010) revealed a 5–8°C lower than surrounding temperature in a ZEBC and maintained above 90% relative humidity. Advantages of the evaporative cooling include; low cost of production (USD 200 to 300 for an EC with 200Kg capacity), less or no energy consumption, easy to install and operate and uses locally available materials for construction such as burnt bricks, sand, charcoal, bamboo etc. (Ambuko *et al.,*2017; Ndukwu *et al.,* 2014).

Despite their potential benefits, there is little utilization of the evaporative cooling technologies in Malawi due to lack of knowledge on their effectiveness in reducing postharvest losses of fruits and vegetables at a cheaper price. And there is little research conducted on evaporative cooling in Malawi. Hence this research was conducted to test the efficacy of three evaporative cooling technologies (Zero Energy Brick Cooler, Pot-in-pot evaporative cooler and Evaporative charcoal cooler) in preserving the postharvest quality and extending shelf life of tomato in Malawi.

Materials and methods

Site description and materials

The study was conducted on station at Mzimba North District Agriculture demonstration site in Mzuzu (the Northern region of Malawi). Tomato fruits (Tengero variety) were harvested from one selected farmer who was constantly supervised by agricultural extension workers in the course of production, within the area of experiment. The fruits were harvested in the morning at the pink stage with reference to the USDA color chart. The fruits were transported to the research site in a cooler box and washed with tap water to remove sand and field heat and then air-dried at ambient room conditions. A homogenous sample of tomatoes was divided into four batches and packed in plastic crates before putting in the evaporative coolers in both seasons.

Description of evaporative coolers

The Evaporative charcoal cooler (ECC) was made from an open timber frame 50mm x 25mm with the door made by hanging one side of the frame. The frame was covered with chicken wire mesh both inside and out leaving a space of 25mm in between the cavity where charcoal pieces were filled in (Alhassan and Halidu, 2014:Jadhav *et al.,* 2010).The charcoal was drenched with water three times a day bydrip pipes connected to a 45litre water tank.

The Zero Energy Brick Cooler (ZEBC), was made by constructing a floor 165cm long and 115cm wide followed by construction of two walls with burnt bricks to a height of 67.5 cm leaving a 7.5cm space in between the walls which was field with river sand (*Rayaguru et al., 2010:Ndukwu, 2011).* The cover (165cm by 115cm) was constructed using bamboos. The sand was wetted thrice daily to maintain the temperature and relative humidity as in the charcoal cooler.

The Pot-in-pot evaporative cooler was made by molding two clay pots with one larger (50cm diameter) and 1 smaller (45cm diameter) molded using locally collected clay. The smaller one was made in a way to be able to fit inside the bigger pot leaving 2.5cm space in-between the pots that was filled with sand and a hessian sack socked in water was used to cover the pots, (Hears,2014:Ndukwu and Manuwa, 2014).

Data Collection

Color changes, physiological weight loss, firmness, wilting and vitamin C were analyzed from three randomly picked tomato fruits from each batch which were collected for analysis every 2 days.

Temperature and relative humidity were recorded 6 times daily (8am, 10am 12 noon, 2pm, 4pm and 6pm) using digital thermo hygrometer (HTC-2 model, Griffchem).

Physiological weight loss (PWL) was determined by weighing three tomato fruits which were randomly sampled and labeled 1 to 3 to be used to measure PWL throughout the storage period, using a digital weighing scale (Constant 14192-1F model, China), and expressed as percentage weight loss using the following formula (Gambo *et al.,* 2013).; Percentage Weight Loss (PWL) = $\frac{(W1-W2)}{W1} * 100$ Where; W1 = Initial weight of sample (Kg), W2 = Weight of sample after storage (Kg).

Firmness was measured using a fruit hardness tester (FTH-05 model, Guangzhou, China) fitted with a 3.5mm probe. Three tomato fruits were sampled for a destructive analysis, the probe was allowed to penetrate a depth of 1.5cm on the equatorial zone of each tomato on both sides, the penetration force was recorded and the measurements were converted to Newton (N) (Abiso *et al.,* 2015: Mitcham and Kader, 1996).

Wilting magnitude was evaluated using 7-Point Hedonic scale where 1=Extreme wilting, 2=Very severe wilting, 3= Severe wilting, 4= Moderate wilting, 5=Slight Wilting, 6=Very slight wilting, 7=No wilting.

Color change was assessed using a colorimeter (Model WR 10, Laizhou, China), color coordinates L*, b* and a* were recorded with b* and a* converted to hue angle (H°) (Arias *et al.,* 2000: Mclellan *et al.,* 1995).

Vitamin C was determined by 2, 6-Dichlorophenol indophenol method, (AOAC 967.21). 50g of the sample was blended with 50ml HPO_3/CH_3COOH mixture and quantitatively transferred into 100 ml volumetric flask and topped up to the mark, 5g of animal charcoal activated powder was added to the mixture and rested for 5 minutes to remove tomato colour. The mixture was then filtered with what man No.1 filter paper. 10ml of the fruit juice extract was then pipetted into a 100ml conical flask and titrated with standardised solution of 2, 6-dichlophenolindophenol (DCPIP). Ascorbic acid content was then expressed in mg/100g.

Shelf life

The shelf life of the tomato fruits was determined by counting number of days taken to reach the last stage of ripening up to the stage when they remained acceptable for marketing (Pila *et al.,* 2010). Total cost of producing the evaporative coolers was determined by recording the cost of all the materials used for construction including labor costs and compared those (Jadhav *et al.,* 2010).

Experimental design

The experiment was laid in a Completely Randomized Design (CRD), with 4 storage treatments (Zero Energy Brick cooler, Evaporative Charcoal cooler, Pot-in-Pot and ambient storage (control) and was replicated three times. The experiment was conducted in two seasons with the same treatments. The first experiment was conducted from October to November 2017 which was the dry season (Season 1) and second experiment was conducted in January 2018 (rainy season) (Season 2).

Data analysis

Data collected was analyzed using Analysis of Variance (ANOVA) using Gen Stat software 15th edition, means were separated using Fisher's Protected Least Significant Difference (LSD) test at 5% level of significance.

Results

The changes in temperature between ambient storage and the three evaporative cooling technologies were significantly different (P<0.001) in both seasons. Figure 1 (A and B) show higher temperature under ambient storage compared to ZEBC, ECC and Pot-in-Pot storage in both seasons. High temperatures were observed between 14 and 16:00hrs in all storage forms.

Table 1. Average Relative Humidity (%) in Zero Energy Brick Cooler (ZEBC), Evaporative Charcoal Cooler (ECC), Pot-in-Pot, and Ambient storage during the 24 day Storage Period for Season 1 and 2.

	Season 1	Season 2
Storage Option	Average Relative Humidity (%)	Average Relative Humidity (%)
Pot-in-Pot	96.78 ± 0.399^c	98.96 ± 0.0248^c
ZEBC	96.06 ± 0.541^c	98.85 ± 0.103^c
ECC	91.00 ± 0.515^b	95.91 ± 0.569^b
Ambient	54.19 ± 0.923^a	71.09 ± 0.374^a
LSD (P<0.05)	1.712	2.365
CV%	8.7	4.7

Means with different letters within each column are significantly different at p<0.05.

There was a significant difference (P<0.05) between ECC storage compared to ZEBC and Pot-in-Pot storage in season 1 but no significant difference was observed between ZEBC and Pot-in-Pot storage (Fig 1(A)). In Season 2, no significant difference on temperature was observed between ZEBC, ECC and Pot-in-Pot storage (Figure 1(B)).

During the 24 day storage period, Ambient storage in season 1 recorded a temperature range of 19.9°C to 37.7°C, Pot in Pot 17.1°C to 27.7°C, ZEBC17.8°C to 23.2°C with minimal fluctuations while Evaporative charcoal cooler (ECC) recorded a range16.4°Cto24.6°C depending on time of the day.

In season 2, ambient storage recorded a temperature range of 20.0°C to 24.6°C, Pot in Pot 17.4°C to 22.5°C, brick cooler 18.1°C to 21.5°C with ECC storage recording 16.5°C to24.6°C.

The Relative Humidity under ambient storage showed a significant difference ($P<0.001$) compared to the three evaporative coolers in both season 1 and 2 (Table 1). There was also a significant difference between the Evaporative Charcoal Cooler (ECC) which showed a significant lower relative humidity compared to ZEBC and Pot-in-Pot storage but no significant difference was observed between ZEBC and Pot-in-Pot storage technologies in both season 1 and 2. In season 1 on average, ECC increased relative humidity by 36.81% while ZEBC storage increased relative humidity by 41.87% with Pot-in-Pot increasing by 42.59% relative humidity from that of ambient storage. In season 2, ECC storage increased relative humidity on average by 24.82%, ZEBC storage increased by 27.76% and 27.87% increase by Pot-in-Pot storage from the relative humidity recorded under ambient storage.

Table 2. Wilting index of Tomato stored under ZEBC, ECC, Pot in Pot and Ambient Storage on a 7-Point Hedonic scale for 24 day storage for Season 1 and 2, where 1=Extreme wilting, 2=Very severe wilting, 3= Severe wilting, 4= Moderate wilting, 5=Slight Wilting, 6=Very slight wilting, 7=No wilting.

	Season 1	Season 2
Storage Option	Wilting (Hedonic Scale)	Wilting (Hedonic Scale)
Pot-in-Pot	$6.713^{c}\pm0.0559$	$6.815^{b}\pm0.0545$
ZEBC	$6.583^{b}\pm0.0769$	$6.787^{b}\pm0.0709$
ECC	$6.546^{b}\pm0.0794$	$6.778^{b}\pm0.0635$
Ambient	$5.157^{a}\pm0.172$	$5.361^{a}\pm0.165$
LSD ($P<0.05$)	0.0995	0.1294
CV%	6.0	7.5

Means with different letters within each column are significantly different at $p<0.05$.

Changes in Physiological weight loss (PWL) (%) showed a significant ($P<0.001$)weight loss on tomato stored under ambient conditions compared to those stored in Pot-in-Pot, ECC and ZEBC in both season 1 and 2 (Figure 2). There was no significant difference in PWL between tomato stored under ECC, ZEBC and Pot-in-Pot in both seasons. On day 24 which was the final day of the experiment in season 1, ambient stored tomato lost 25.2% of the initial weight, ECC stored fruits lost 10.4%, ZEBC stored tomato lost 6.5% while those stored under Pot-in-Pot evaporative cooling storage lost 5.2%. In Season 2 on the last day (Day 24), ambient stored tomato lost 18.18% of the initial weight, 5.98% for ECC stored tomato, 5.23% for Pot in Pot stored tomato, and 5.15% for ZEBC stored tomato. Significantly higher ($P<0.05$) losses were observed in season 1 compared to season 2.

Table 3. Average Changes in Hue angle (Color) (H°) of Tomato stored under ZEBC, ECC, Pot-in-Pot and Ambient Storage during Season 1 and 2.

	Season 1	Season 2
Storage Option	Color (H°)	Color (H°)
Pot-in-Pot	$47.77^{ab}\pm1.443$	$53.22^{b}\pm2.055$
ZEBC	$49.98^{b}\pm1.702$	$51.99^{b}\pm2.547$
ECC	$49.91^{b}\pm2.329$	$53.19^{b}\pm2.496$
Ambient	$46.64^{a}\pm1.855$	$45.46^{a}\pm1.490$
LSD ($P<0.05$)	2.798	2.576
CV%	12.3	10.8

Means with different letters within each column are significantly different at $p<0.05$.

Changes in firmness

All the four forms of storage showed loss in firmness as the number of days under storage increased in both Seasons (Figure 3). Tomato stored under ambient conditions showed a significant decrease ($P<0.001$) in firmness compared to tomato under evaporative cooling storage in both seasons. In season 1, there was a significant difference ($P<0.05$) on loss in firmness between Pot in Pot stored tomato compared to ZEBC and ECC stored tomato which were not significantly different from each other (Figure 3 (A)).

Table 4. Shelf life (Days) of Tomato stored under Zero Energy Brick Cooler (ZEBC), Evaporative Charcoal Cooler (ECC), Pot-in-Pot and Ambient Storage.

Storage Option	Shelf life (Days) Season 1	Shelf life (Days) Season 2
ECC	20	22
ZEBC	22	24
Pot in Pot	24	24
Ambient Condition	10	12

In season 2, ECC stored tomato showed significantly higher loss in firmness compared to ZEBC and Pot-in-Pot stored tomato but the two showed no significant difference (Figure 3(B)). After 24 days of storage, ambient stored tomato in season 1 lost 55% of the initial firmness, while ECC stored tomato lost 21.14%, ZEBC stored tomato lost 14.91% and only 7.12% for tomato under Pot-in-Pot storage. In Season 2, on day 24 of the storage, ambient stored tomato lost 52.5% of the initial firmness, while ECC stored tomato lost 17.3%, ZEBC stored tomato lost 6.01% and only 5.28% for tomato under Pot-in-Pot storage.

Table 5. Construction Cost of a 1.25m*0.6m*0.85m Charcoal Cooler for storage of tomato.

Item	Unit Cost (US$)	Quantity	Amount (US$)
Fabrication	55.62	1	55.62
Charcoal 50kg bags	4.87	3	14.61
Timber	3.48	10	34.8
Pipes			4.17
Wire Mesh	1.39	10	13.90
			123.1

Wilting was observed in tomato stored in the three evaporative coolers as well as the Ambient (control) stored fruits in both seasons. A significantly ($P<0.001$) increasing rate of wilting was observed in ambient stored tomato compared to tomato stored in the three evaporative cooling technologies which showed a slow rate of wilting (Table 2). In season 1, Pot-in-Pot stored tomato showed a significantly low rate of wilting compared to ECC and ZEBC stored tomato, but the two showed no significant difference on the rate of wilting. In season 2, all the evaporative cooling technologies showed no significant difference on the rate of wilting of the tomato under storage (Table 2).

The Color Change on tomato stored under ECC, ZEBC, Pot-in-Pot and ambient conditions during season 1 showed a significant difference ($P<0.05$) between ambient stored tomato and ECC, ZEBC but there was no significant difference between ambient and Pot-in-Pot stored tomato on color change. Tomato stored under the three evaporative cooling technologies showed no significant difference on color change (Table 3). In season 2 there was a significant difference ($P<0.001$) between ambient stored tomato and tomato stored under ZEBC, ECC and Pot-in-Pot but the three evaporative cooling technologies showed no significant difference. In both seasons, the change in hue angle was rapid in ambient stored tomato.

Table 7. Cost of producing 2 pot diameters 0.5m and 0.45m for a Pot-in-Pot Evaporative Cooler.

Item	Unit Cost (US$)	Quantity	Amount (US$)
Fabrication	7.58	2	15.16

The changes in Vitamin C on tomato stored in Pot-in-Pot and Ambient conditions in season 1showed no significant difference on loss of Vitamin C but the two were significantly different (P<0.05) from tomato under storage in ZEBC and ECC (Fig 4). After 10 days of storage, ambient stored tomato in season 1 lost 80% of the initial vitamin C while ECC stored tomato lost 59.3%, ZEBC stored tomato lost 56.7% with Pot-in-Pot stored tomato losing 46.7%. In season 2, there was a significant difference (P<0.05) in loss of vitamin C on ambient stored tomato compared to the evaporative cooled tomato.

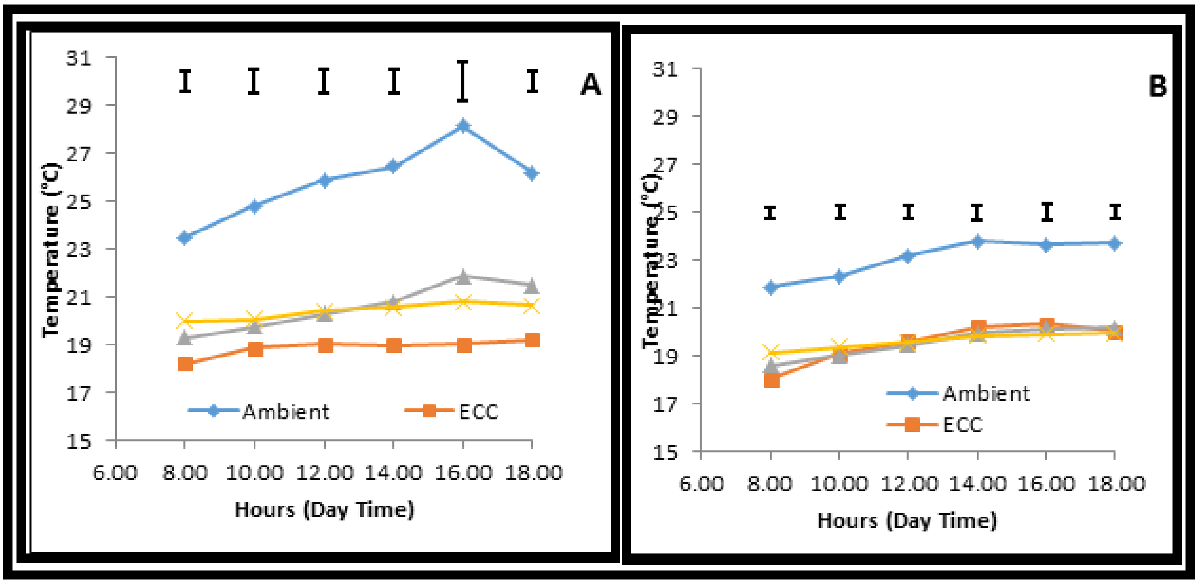

Fig. 1. Change in Temperature (°C) from morning to afternoon hours in Zero Energy Brick Cooler (ZEBC), Evaporative Charcoal Cooler (ECC), Pot-in-Pot, and ambient storage for Season 1 (A) and 2 (B). Top Bars represent LSD of means (P≤0.05).

There was also a significant difference between ZEBC stored tomato which showed fewer losses compared to Pot-in-Pot and ECC stored tomato but the two showed no significant difference. Ambient stored tomato in season 2 lost 83% of the initial vitamin C on day 10 while ECC stored tomato lost 78.9%, ZEBC tomato lost 78.2% while Pot-in-Pot stored tomato lost 71.5%. Losses were rapid in ambient stored fruits compared to the evaporative cooled tomato in both seasons (Fig. 4).

Tomato Shelf-life

In season 1, Ambient stored tomato fruits lost marketability after 10 days while ECC stored tomato remained marketable for 20 days, ZEBC stored tomato took 22 days to loss marketability while Pot-in-Pot stored tomato had a shelf life of 24 days. In season 2, ambient stored tomato lost shelf life after 12 days, 22 days for tomato stored under ECC, while tomato stored under Pot-in-Pot and ZEBC had a shelf life of 24 days (Table4)

The total cost of fabricating the evaporative coolers

After recording all the materials and their costs including labor, it was found that Evaporative Charcoal cooler which stored about 0.188 tons of tomato costUSD123.01(Table 5) while the Zero Energy Brick Cooler (ZEBC) holding about 0.14tons of tomato cost USD 63.09 (Table 6) and the Pot-in-Pot storing 0.02tons of tomato fruits costs USD15.16 (Table 7).

Discussion

Tomato are living climacteric fruits which continue to respire even after harvesting making them liable for postharvest losses due to loss of water to the environment in which they are stored. Maintenance of the cool chain after harvest is critical for maintenance of freshness of the perishable produce. Evaporative cooling technologies offer smallholder farmers a low-cost alternative to the expensive cold room in their effort to maintain the cool chain.

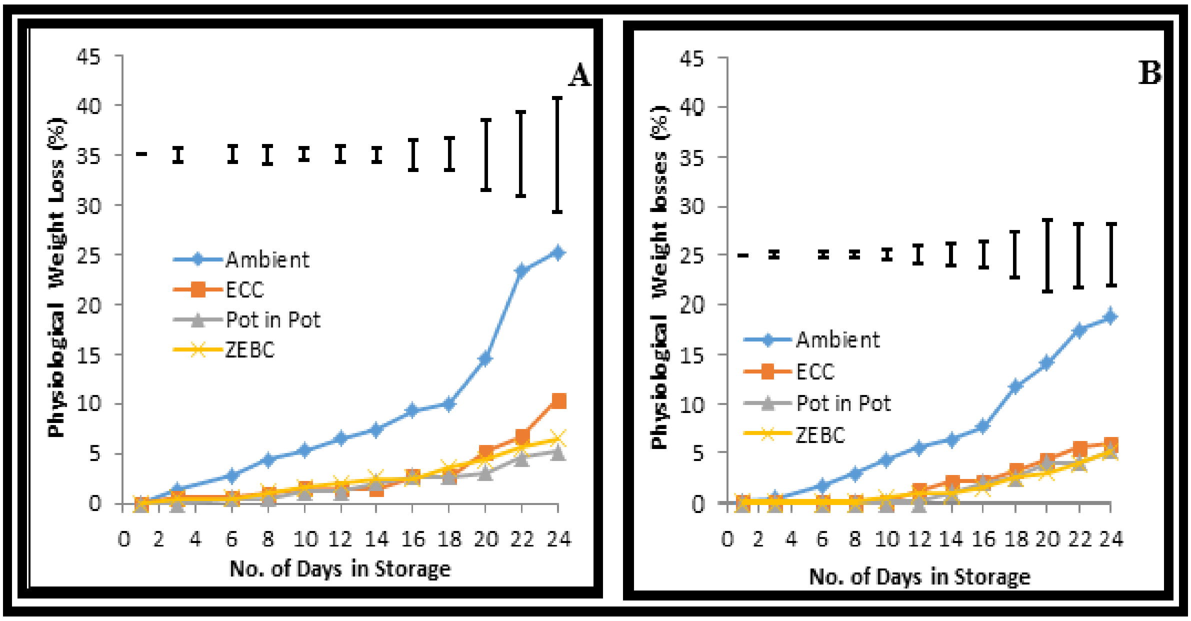

Fig. 2. Physiological Weight Loss (%) of tomato stored under ECC, ZEBC, Pot in Pot Cooler and Ambient (room conditions) storage for Season 1 (A) and 2 (B). Top Bars represent LSD of means (P≤0.05).

This research was conducted to assess the effectiveness of evaporative cooling technologies namely; Evaporative Charcoal Cooler (ECC), Pot-in-Pot and Zero Energy Brick Cooler (ZEBC) in preserving postharvest quality and increasing shelf-life of tomato under different seasons of Malawi.

Results on maximum temperature recorded by the individual evaporative coolers compared to ambient showed that in Season 1 (Dry season); Pot-in-Pot decreased temperature by10°C than ambient storage, ZEBC reduced temperature by 14.5°C while ECC decreased by 16°Ccompared to that recorded under ambient storage. In season 2 (wet season); Pot-in-Pot storage reduced temperature by 4.4°C compared to ambient storage, 5.4°C difference recorded by ZEBC while ECC reduced temperature by 2.3°C.

The high temperature differences recorded in season 1compared to season 2 are as a result of the differences in weather within which the two experiments were conducted.

Season 1 was conducted during the hot dry season of Malawi which experiences very high temperatures and low relative humidity while season 2 was conducted at the start of the rainy season with low temperature and relative humidity.

Pot-in-Pot increased Relative humidity by 42.59% compared to ambient storage and was the highest increase recorded in season 1, while in season 2 the highest difference of 27.87% was also recorded by Pot-in-Pot storage.

The difference in relative humidity for the two seasons was due to the same reasons as in temperature above. Although temperatures were a bit higher in Pot-in-Pot storage, it was the best technology in increasing relative humidity compared to the other two technologies. Temperature under ambient storage was lower during morning hours and continued to increase and reached maximum at 16:00hrs then started decreasing in both seasons.

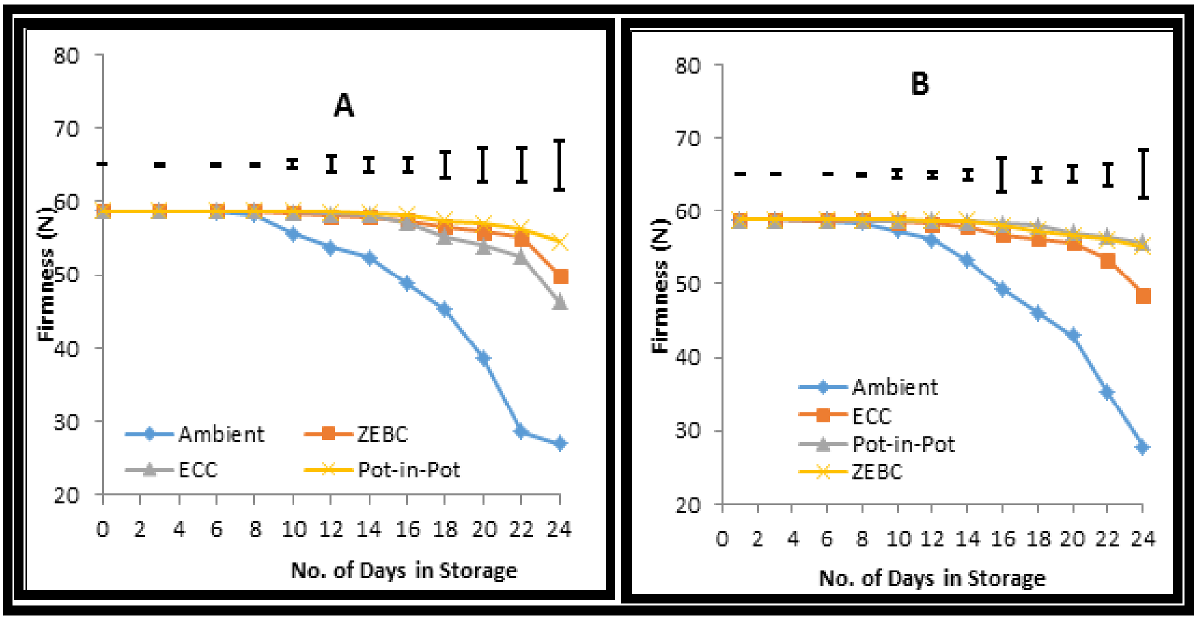

Fig. 3. Changes in fruit firmness (N) for Tomato stored in Zero Energy Brick Cooler (ZEBC), Evaporative Charcoal Cooler (ECC), Pot in Pot and ambient condition for Season 1 (A) and 2 (B). Top Bars represent LSD of means (P≤0.05).

The same trend was observed in Pot-in-Pot storage in season 1 and ECC in season 2 but minimal variation in temperature was observed in ZEBC storage in both seasons. Relative humidity portrayed an opposite picture following the same trend. Under ambient storage, relative humidity was highest at 8:00am but started decreasing with the lowest recorded between 14:00hrs and 16:00hrs then started increasing. In the evaporative coolers as the temperature was decreasing, relative humidity was increasing with minimal variations observed in ZEBC and Pot-in-Pot storage. These findings are in line with Kitinoja (2013) who reported a high performance of evaporative cooling technologies when the temperatures are high and relative humidity is low as was the case with season 1. Rayaguru *et al.,* (2010) reported an average decrease in temperature of 5-8°C from the surrounding environment and maintenance of relative humidity of about 90% in turn increasing the shelf-life of tomato from 3 days to about 15 days compared to ambient storage. These findings also agree with Obura *et al.,* (2015) who reported a 36.6% increase in relative humidity and a reduction of 8.2°C for tomato under storage in a Pot-in-Pot evaporative cooler. Abiso *et al.,* (2015) also found Pot-in-Pot storage as the best in reducing relative humidity and temperature compared to ZECC and desert storage cooler, which resulted in maintenance of postharvest quality of tomato under storage. Not only does the increase in relative humidity and decrease in temperature increase shelf life but the stored fruits exhibit less wilting and low physiological weight loss and a good appearance than those stored under ambient conditions just as reported by Chandhari *et al.,* (2015).Therefore the evaporative cooling storage technologies were effective in preserving the postharvest quality and extending shelf life of tomato under Malawi conditions.

Ambient stored tomato fruits started losing weight from day 3 of storage and by day 10, they had already lost an average of 5.31% weight in Season 1 and 4.28% in Season 2, which was contrary to the evaporative cooling technologies which at the same time lost an average of 1%. There is a connection between the high ambient temperatures and low relative humidity to the rate of Physiological weight loss observed in the present study. Abiso *et al.,* (2015) reported that the rate of loss in physiological weight depends on the rate of transpiration and respiration. The high temperatures and low relative humidity observed at 4pm caused an increased loss of moisture in ambient stored tomato since the surrounding air was less saturated resulting in water being drawn from the fruits while the cool and humid conditions inside the evaporative coolers were able to reduce the rate of transpiration and respiration hence low water loss from the stored tomato resulting in reduced weight loss (Abiso *et al.,* 2015:Tilahuni, 2010).These results portray Pot-in-Pot as the best technology in reducing weight loss which is in agreement with the highest relative humidity observed in Pot-in-Pot compared to the other evaporative coolers in the present study. Jadhav *et al.,* (2010) also found that physiological weight loss was higher in tomato stored under room temperature compared to evaporative cooling storage. Islam and Morimoto (2014) reported that low temperature reduces ethylene production which results in reduction of physiological weight loss and other metabolic activities. These findings also agree with Rayaguru *et al.,* (2010) who found higher weight losses in summer season in both the cool chamber and ambient storage compared to weight losses during the winter season. The present findings positively answer the question on whether the evaporative cooling technologies can be used to preserve the postharvest quality of tomato under storage.

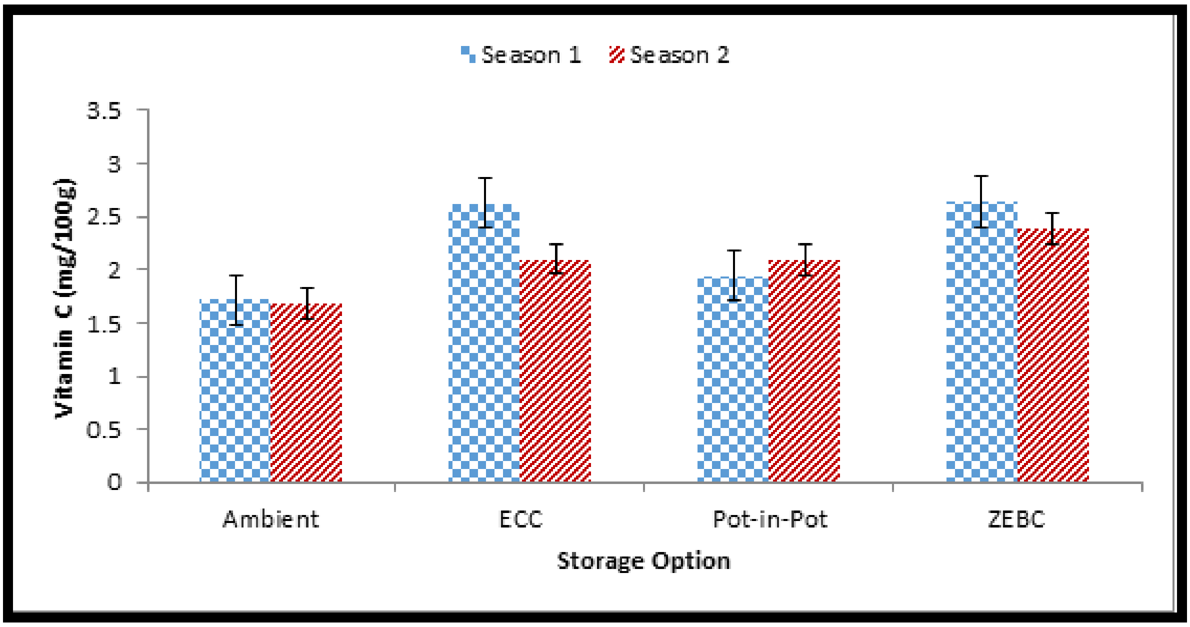

Fig. 4. Changes in Vitamin C (mg/100g) in tomato stored in Zero Energy Brick Cooler (ZEBC), Evaporative Charcoal Cooler (ECC), Pot in Pot and ambient condition in Season 1 and 2. Top Bars represent S.E of means ($P \leq 0.05$).

An increasing rate in wilting was also observed in ambient stored tomato in both seasons but high in season 1 while a slow rate of wilting was observed in the evaporative cooled tomato. Pot-in-Pot stored tomato showed less wilting compared to the other technologies in season 1 but no significant difference was observed in season 2. The high temperature and low relative humidity recorded in ambient stored fruits resulted in increased rate of respiration and transpiration which in turn increased moisture losses resulting in loss of turgidity whose direct impact is wilting and softening of the fruits (Mogaji and Fapetu, 2011).

Firmness is a determinant quality for tomato buyers at the market, the softer and shriveled the tomato, the lesser the chances of being bought. The results showed an increasing rate of loss in firmness for ambient stored tomato compared to evaporative cooled tomato in both seasons with a higher rate observed in season 1 compared to season 2.Among the evaporative cooling technologies in both seasons, ECC stored tomato recorded more losses compared to ZEBC and Pot-in-Pot stored tomato which also reflects the differences recorded on relative humidity during the present study, which was unstable and lower in ECC storage than Pot-in-Pot and ZEBC.

The low temperature recorded in the evaporative coolers reduced enzymatic activities of the tomato under storage, which in turn reduced the loss in firmness of tomato under storage (Islam and Morimoto, 2014)

Results on change in color (hue angle) showed significant difference between ambient stored tomato and evaporative cooled tomato but there was no significant difference between ambient and Pot-in-Pot stored tomato in season 1. This can be attributed to the high temperature recorded in Pot-in-Pot storage which may have facilitated the ripening process hence the rapid color change, but because of the high relative humidity in Pot-in-Pot, the tomato still remained firm regardless of the color change. In season 2, tomato stored under ambient conditions showed significant difference in color change compared to evaporative cooled tomato but no statistical difference was recorded between the evaporative cooled tomatoes. Color development is increased with high temperatures. Zakari *et al.,*(2016) reported color change in ambient stored tomato after 3 days of storage while tomato stored under evaporative cooling technologies took 6 days to start changing color.

Loss of vitamin C was observed in all storage forms from day 4 of storage which was significantly rapid in ambient stored tomato compared to evaporative cooled tomato in both seasons. Pot-in-Pot stored tomato showed high losses in both seasons compared to the other evaporative cooling technologies with ZEBC stored tomato showing few losses. The performance of the evaporative cooling technologies in reducing loss of vitamin C was significantly higher in season 1 (Dry season) compared to season 2 (Wet season) except for Pot-in-Pot storage. ECC reduced losses by 53.26% in season 1 while in season 2 it reduced by 25.33% compared to that of ambient stored tomato. ZEBC reduced the losses by 53.73% in season 1 and 42.1% in season 2. Pot-in-Pot reduced losses by 13.57% in season 1 and by 24.79% in season 2. Loss of vitamin C in Pot-in-Pot tomato and ambient stored tomato were not different which is in line with the high temperatures recorded under Pot-in-Pot storage. According to Moneruzzaman *et al.,* (2009) vitamin C is affected by high temperature which is the trend in the present findings. The high temperature and low relative humidity recorded under ambient storage influenced water loss resulting in a higher rate of wilting and in the process leading to rapid losses in vitamin C compared to the evaporative cooled tomato.

The high relative humidity and low temperature recorded under evaporative cooling technologies in the present study offered favorable conditions to reduce metabolic processes taking place inside the tomato which reduced the deteriorative processes hence the increase in shelf life of tomato observed in the present study (Kitinoja, 2013).

The shelf life of tomato in season 1 under ambient storage in the present study was 10 days, which was 10 days shorter than that of ECC stored tomato, 12 days and 14 days shorter for ZEBC and Pot-in-Pot stored tomato respectively. In season 2, the shelf life of ambient stored tomato was 12 days which was 10 days shorter than that of ECC stored tomato and 12 days shorter for ZEBC and Pot-in-Pot stored tomato. ECC had low shelf life compared to the other technologies because the temperature and relative humidity recorded under ECC varied with the surrounding temperature which was contrary to ZEBC and Pot-in-Pot storage technologies. Shitanda *et al.,* (2015) reported that as water dries up in the charcoal cooler the temperatures also tend to increase. From the present findings it is shown that the shelf-life of tomato in season 1 (dry season) was shorter than that in season 2 (wet season) which shows that the relatively high humidity in season 2 also had an influence on shelf-life. The present findings are in line with Rayaguru *et al.,* (2010) who reported an increase in shelf life of 3 to 15days depending on the product and season of the year. Babarinsa *et al.,* (2016) also reported a 13 day shelf-life of tomato under ZEBC compared to 5 days under ambient storage.

Evaporative Charcoal Cooler (ECC) with the storage capacity of 0.188 tons cost USD 123.01 which was almost twice the cost of constructing a ZEBC holding 0.14tons which was USD63.09 and the cheapest was the Pot-in-Pot evaporative cooler which stored 0.02ton tomato and only required USD15.16 during the present study. Comparing the same storage capacity of 0.188 tons, Pot-in-Pot would cost USD142.5,ECC would cost USD123.01 while ZEBC would cost USD84.72 which would mean that ZEBC was the cheapest based on the same storage capacity with Pot-in-Pot being the most expensive and less applicable technology to use on large scale because of its nature (own Opinion). The results in the present study are close to report by Ambuko *et al.,* (2017) who quoted the cost of a 0.2ton capacity evaporative cooler costing between USD 200 and 300.Jadhav *et al.,* (2010) also found charcoal cooler as the most expensive compared to drip cooling chamber with gunny bag walls and cooling chamber with vetiver mat walls.

Conclusion

The present study found a 16°C temperature decrease as the highest by the ECC in season 1and 5.4°C by ZEBC in season 2 with an average day decrease of 8.9°C by the evaporative coolers in season 1 and 5.52°C in season 2. An average increase of 40.42% relative humidity in season 1 and 26.82% in season 2 by evaporative cooling storage compared to ambient storage conditions. The study also found that the evaporative cooling technologies were able to reduce Physiological weight loss, wilting, loss in firmness, color change and vitamin C significantly compared to ambient storage in both seasons. The present study also found an increase in shelf-life from 10 days in ambient stored tomato to 20 day in Evaporative Charcoal Cooler (ECC) stored tomato and 22 days in Zero Energy Brick Cooler (ZEBC) stored tomato and 24 days in Pot-in-Pot cooler, a difference in shelf life of at least 10 days in season 1. In season 2 the shelf-life was 12 days for ambient stored tomato, 22 days for ECC store tomato and 24 days for ZEBC and Pot-in-Pot stored tomato. The present study also found that ECC storage was more expensive in construction with Pot-in-Pot recording the least cost. This study therefore concludes that evaporative cooling technologies are effective in preserving postharvest quality and extending shelf-life of tomato under storage in Malawi. The evaporative cooling technologies were able to maintain postharvest quality of tomato under storage more during the dry season compared to wet season. Pot-in-Pot storage which was the best in extending shelf-life and preserving most of the postharvest qualities assessed in the present study was recommended for use in local kitchen because of the storage capacity and is less applicable technology to use on large scale because of its nature while ZEBC should be recommended for use by smallholder farmers during the dry season.

Disclosure

The funding source had no involvement in the study design, data collection; analysis, and interpretation of data; in the writing of the report, and in the decision to submit the article for publication

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgement

This material is based upon work supported by the United States Agency for International Development, as part of the Feed the Future initiative, under the CGIAR fund, award number BFS-G-11-00002, and the predecessor fund the Food Security and Crisis Mitigation II grant, award number EEM-G-00-04-00013.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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