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ORIGINAL RESEARCH ARTICLE

Evaluation of quality and shelf life of fresh tomatoes stored in a pumice padded evaporative cooler with a roof pond

Elias W. Ngotho[1,2], *Urbanus N. Mutwiwa*[1], *Kipchumba Cherono*[1]

[1,] *School of Biosystems and Environmental Engineering, College of Engineering and Technology Jomo Kenyatta University of Agriculture and Technology, Nairobi Kenya.*
[2]*Department of Agricultural and Mechanical Engineering, Rift Valley National Polytechnic, Nakuru, Kenya*

Corresponding author email: ngotho.elias@rvnp.ac.ke

Abstract
The world is faced by myriad challenges like climate change and ever-increasing population making the achievement of global food security a challenge. Although highly perishable, tomatoes are popular food commodity. Farmers have to sell the commodity soon after harvest for fear of deterioration. For longer storage, tomatoes require an environment with low temperature and high relative humidity. Cooling systems such as refrigeration are not accessible to most small-scale farmers because they require connection to the grid. In this study, a solar powered pumice evaporative cooler was developed and evaluated for the storage of ripe tomatoes. The system adopted the principle of evaporative cooling and comprised of walls filled with pumice coupled with a pond filled with water on the roof and below the storage space. This design allowed water to drip from an elevated tank through the pumice walls and drain into the reservoir below the storage space before recirculation using a solar powered pump. Mature tomatoes c.v Ann F1 were harvested at the turning stage and stored both in the cooler (treatment) and under ambient conditions (control). Quality attributes namely pH, total soluble solids (TSS), firmness, colour and shelf life were evaluated on a seven-day interval for 28 days. Results showed a significant ($p \leq 0.05$) difference for pH, TSS, and firmness between samples stored in the cooler and control. However, there was no significant ($p > 0.05$) difference in the colour (hue angle) for the fruits under the treatment and control. Compared to the control, the developed solar powered storage system increased the shelf life of tomatoes from 14 days to 28 days. The results from this study indicate that the solar powered pumice evaporative cooler preserves the quality of tomatoes. This enables the farmers to get better returns as they do not have to sell their harvest at low prices for fear of deterioration.

Key words: Perishability, Latent heat, evaporative cooling, food security

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1.0 Introduction

Tomatoes (*Lycoperscicon esculentum)* are referred to as power house of nutrients as they are rich in minerals and vitamins (Ray et al., 2011; Tipu et al., 2014). Tomatoes have a balanced content of vitamins; K, A, E, B1, and vitamin C (Kaur & Aggarwal, 2015). Tomatoes have been reported to have Chromium which controls blood pressure, in addition beta carotene and lycopene in tomatoes helps in increasing human body immunity (Bhowmik et al., 2012). In addition, consumption of tomatoes reduces risks of diseases like cardiovascular diseases and cancer, this property is because tomatoes contain lycopene.

Tomatoes like other vegetables suffers postharvest loss (PHL). (Korie et al., 2023) recorded a PHL of 45% for fruits and vegetables. These losses may be qualitative or quantitative. Some of the key quality attributes of tomatoes include, sensory qualities, that constitute: flavor, appearance and sense of feel (Gormley & Egan, 1978). Appearance on the other hand comprises of size, colour, shape and defects. Colour and firmness are the quality attributes that consumers assess when choosing or purchasing fruits and vegetables (Gormley & Egan, 1978). In addition, Mutuku et al. (2014) recommended proper use of pesticide. Tomato pH is a measure of the acidity of the fruit. The acidity and sugar concentration determine the taste of tomatoes. The level of maturity of tomatoes affects their pH levels. Low pH level is a desirable characteristic in processing of tomatoes. Green and yellow tomatoes have low pH levels, with ripe ones having values of between 3.4 to 4.8(Wolf et al., 1979) . Therefore, the colour of tomato fruit is correlated with the pH. Fruit pH also varies across different varieties (Sapers et al., 1978). The locality where the tomatoes are grown and the condition during growth has an influence on the pH of tomatoes (Wolf et al., 1979).. Just like firmness of tomatoes, pH is also a factor of the environment where tomatoes are grown. ABIERTAS (2010); (Baumgartner & Grand, 2006) observed a slight difference in the pH of tomatoes grown in a greenhouse (pH 4.48) and field grown tomatoes (pH 4.49).

The sugar content of tomatoes is an important consideration, especially when tomatoes are eaten raw. ^{0}Brix is a measure of tomatoes' total soluble solids (TSS). The soluble solids and the sugar concentration ratio is of importance when it comes to taste. The TSS comprises all solid dissolved in water and they include proteins, free acids and sugars (Menelli et al., 2021). It has been reported by Caliman et al. (2010) that a tomato fruit on average has 5-7.5% dry matter (DM), 48% of the dry matter constitute sugars and 13% malic and citric acid. The level of tomatoes' TSS is dependent on environment with protected tomatoes (grown in green house) having a ^{o}Brix of 3.68% while unprotected tomatoes (field grown tomatoes) had a ^{o}Brix of 5.65%. Tipu et al. (2014) reported that mulching type affects the TSS level. In normal storage, sugars increase and later they are used up in the fruit metabolism (Beckles, 2012). As ripening progresses, the flavour of tomatoes changes due to the changing balance of sugars and acids in the tomatoes (Malundo et al., 1995).

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The firmness of tomatoes is another quality attribute commonly considered by consumers, with firm tomatoes being preferable compared to soft ones. For commercial purpose, the firmness of tomatoes should be 1.45 N mm^{-1} (1.48 kgf/cm) and above (Tijskens & Evelo, 1994). Increase in softness of tomatoes increases the susceptibility to damage. In tomatoes, firmness is correlated to its texture, surface appearance and colour (Yang & Chinnan, 1988). Gormley and Egan (1978) studied different varieties of fresh tomatoes and found a tendency of huge variations in firmness. For instance, they found the firmness values of between 2122 g to 3223 g force with variation being also a factor of environment within which the tomatoes were grown (Gormley & Egan, 1978).

Shelf life, which is the duration an agricultural product can be stored before deterioration is of concern to farmers, vendors and wholesalers. Higher profits can be realised with longer shelf life. Evaporative coolers increase shelf life of fruits and vegetables. Jha (2008) reported that evaporative coolers can cause a temperature reduction of 20°C. This finding encourages the use of evaporative coolers on vegetable preservation. Longer shelf life means a reduction in losses and hence an increase in profit from the stored agricultural product. Sow et al. (2020) showed that, raising of relative humidity and reduction of temperature in the cooler chamber increases shelf life. Ronoh et al. (2018) reported an increase in shelf life of spinach and amaranth up to 9 days in a charcoal evaporative cooler. Zakari et al. (2016) also observed an increase in shelf life from 2 days to 6 days, when investigating the shelf life of tomatoes stored in an evaporative cooler.

Tomato consumers evaluate its quality based on fruit colour, therefore, study of the changes in colour of tomatoes during storage is important in assuring consumers of quality (Menelli et al., 2021). Just like other fruits, tomato colour has a significant effect on the quality perception of customers (Choi et al., 1995). The ccolour of tomatoes change with maturity. For instance, Gormley and Egan (1978), using CIELAB Colour space found the ratio a*/b* to be 0.01-0.20 (green yellow), 0.5 (Half red), 0.14 (fully red) and ≥1.90 (dark red). The ratio a*/b* of tomatoes increases with time during storage (Gormley & Egan, 1978). (Gormley & Egan, 1978) reported that the colour value parameters a*, b*, L* and h* refer to redness, yellowness, brightness and hue angle, respectively in addition, the dual while studying grenadier and extase tomato cultivars, concluded that there is a relationship between tomato firmness and colour with a correlation of -0.91 to -0.97. The red colour of tomatoes is directly related to lycopene content. Lycopene is an antioxidant, the higher the ratio a*/b* the higher the lycopene content with R^2 =0.92 (Brandt et al., 2006). Lycopene is affected by fluctuations of temperature during storage Lee and Kader (2000). Total colour difference (ΔE) is an indication of the magnitude by which the colour change. According to (Tiwari et al., 2009) ΔE<1.5 is referred as a small colour change while ΔE of 1.5 to 3.0 represent a significant colour change.

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Besides the destructive method of determining TSS and Firmness, non-destructive methods using Near infrared (NIR) spectroscopy are also common, (Bull, 1991; Kawano et al., 1993; Lammertyn et al., 1998; Osborne et al., 1999; Peiris et al., 1998). The evaporative pad used in the study was pumice that has a porosity of about 85% (Gündüz et al., 1998; Kitis et al., 2005) hence is found to have better cooling efficiency compared to charcoal with a porosity of about 70% (Usta, 2003). Compared with electrical cooling, use of evaporative cooler saves on cost of cooling vegetables by about 55% (El Loubani et al., 2021). Khalid et al. (2022) recorded that passive coolers are environmentally friendly and are a low-cost method of preserving tomatoes.

Evaporative cooling has attracted increased interest recently (Jha, 2008; Sibanda & Workneh, 2020). Eco-friendliness and cost effectiveness are the key points that make evaporative cooling an important technology that can potentially help in mitigating postharvest losses of fresh agricultural commodities in developing countries. Cooling pad material, pumice and roof pond are some of the parameters that have been investigated in an attempt to improve the efficacy of this technology. In this study, a pumice padded evaporative cooler was coupled with a roof pond to improve the cooling efficiency of the system. The general objective of the study was to investigate the effects of the pumice padded evaporative cooler on the quality parameters of fresh tomatoes.

2.0 Materials and methods

2.1 Tomato harvesting

Freshly harvested tomatoes (*Lycoperscicon esculentum cv. Anna F1*) at turning maturity stage were stored in a 100 cm x 100 cm x 200 cm pumice padded/roof pond evaporative cooler. The tomatoes were harvested from a greenhouse at Ng'undu Kamulu (1.252^{0}S, 37.054^{0}E) a distance of 46 km from Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. Harvesting was done at 7 am. The tomatoes were transported to JKUAT using a cooler box. The experiment was carried out at Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya, in the Agricultural and Biosystems Engineering Department (37.05^{o}E, 1.19^{o}S and 1550 m altitude).

2.2 Tomato fruit sample preparation

The harvested tomatoes were sorted on the basis of size uniformity, level of ripeness and elements of defects. The fruits of uniform ripeness, uniform size and those without defects were washed with tap water and wiped with a cotton towel. Tomatoes at turning stage have indications of about 10% to 50% of tomato being pink, tanning yellow or a combination (Cantwell, 2000). The tomatoes were then put into two plastic trays of 50 cm x 20 cm x 10 cm (high). The two trays were randomly assigned to control and experimental group. In each tray 80 tomatoes were put. Each tomato fruit was labeled with a sticker from number 1 to 80 for ease of test. The labeling of tomatoes for the experimental group were assigned the letters EW before the numerical labeling number, for instance letter EW1 symbolized 'experimental group replication number one' while

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the control group had CW before the numerical numbering, for instance CW2 represented the second replication of the control group'. The tomatoes were stored in the cooler and in the ambient condition for 28 days. Using a random table, , four samples for each test (experimental group and control group) were taken after every 7 days (Ayantoyinbo & Adepoju, 2018). In total 8 samples were taken during each sampling. After measuring the quality parameters, the average in each test was determined. The label number and the corresponding quality parameters were recorded.

2.3 Description of the cooler and the ambient storage structure

The evaporative cooler (Fig. 1) had a wall thickness of 0.15 m, the thickness was informed by a study conducted by Gunhan et al. (2007) who experimented on three thicknesses; 0.05 m, 0.10 m and 0.15 m, but found the most efficient thickness as 0.15 m.

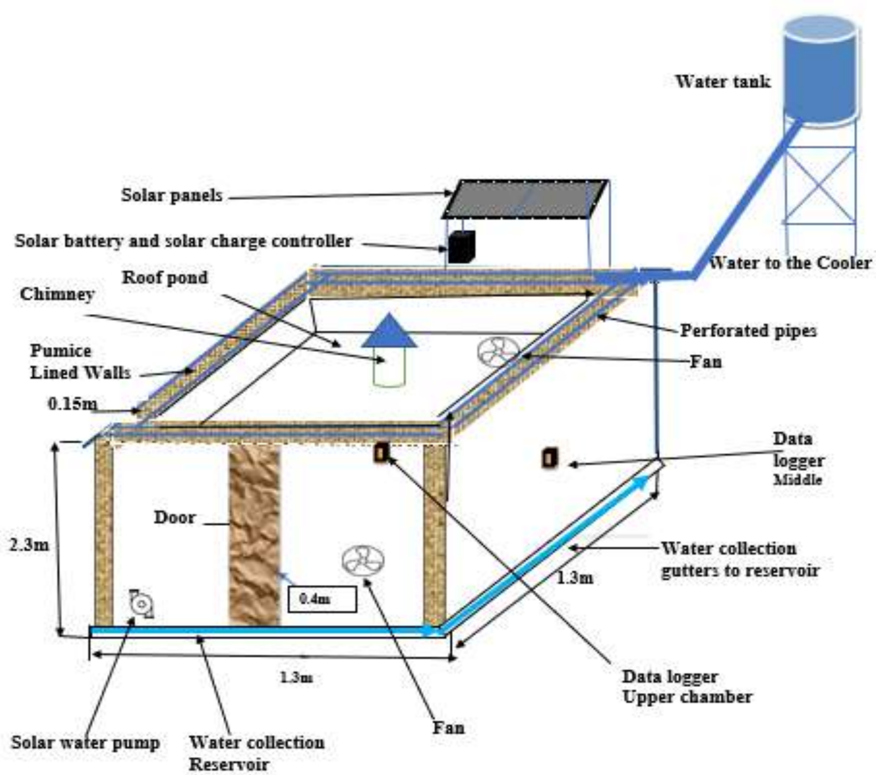

Fig 1: Experimental setup of the designed evaporative pumice/roof-pond cooler

Sow et al. (2020) designed a cooler with 0.15 m thickness, which they termed as having the highest efficiency (93.1%). The internal dimensions were 0.1 m by 0.1 m, these dimensions were informed by maximization of area; by second derivative, the maximum area is found to be a square. (Gunhan

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et al., 2007) also used square based cooler with dimensions 0.5 m and 2.4 m, respectively. The cooler in the current study had a roof pond. The study by Kharrufa and Adil (2008) found out that, roof ponds can reduce cooling load of a building by 29%, in addition Nahar et al. (1999) recorded that 50% of heat come from the roof. The water level at the roof pond was manually maintained between 0.05m-0.15m as recommended by (Runsheng et al., 2003; Sodha et al., 1980; Sodha et al., 1981). 12V fans (620-055, Dorman, USA) were installed, one inside the cooler chamber and at the roof pond. To further increase water evaporation at the roof pond, gunny bags were kept floating. During the experiment, the pumice was kept wet by perforated polypropylene random copolymer (PPR) pipes drawing water from an elevated water tank. The water was circulated using a 12 VDC, 0.22 kW solar pump (DDPS50, Dayliff, China). The cooler was operated on solar energy from two 150 W, 24 VDC crystalline solar panels (TPS-1075-150W, China), a 12 V solar battery and a 24 V, 390 W solar charge controller (Solarmax30AH, Macire, China). The cooler chamber's temperature and relative humidity were captured using HOBO data loggers (MX1104, Onset computer corporation, USA) which provided average values every five minutes, and recorded the environmental conditions every 30 minutes. The ambient storage was an open sided room with iron roof and wooded ceiling. This condition mimicked the common tomato storage environment in the market.

On receiving the four samples of tomatoes from each test, the sampled tomatoes were weighed using a digital balance (Scout Pro SP202, OHAUS GmbH, Switzerland), Colour determination was conducted using a colorimeter (CIElab), then the firmness of the tomatoes was determined using a penetrometer. Finally juice from each tomato was squeezed for pH and TSS determination, and the data was then recorded.

2.4 Experimental design

The experiment was set up using a full factorial design with two storage environments (cooler and ambient), four replications and two environmental conditions were measured (temperature and relative humidity). Two bunches of tomatoes in crates were randomly assigned to ambient and to cooler storage. During testing which were conducted after every 7 days, four samples were randomly selected from each of the two storages.

2.5 Data collection

Tomato fruits, colour, firmness, pH and TSS were measured over a period of 28 days where samples were taken on 0, 7, 14, 21 and 28 days of storage.

2.5.1 Tomatoes pH

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Tomatoes' pH was determined using a pH meter (model 201-TF, Apera instruments, USA). Juice extract from each sample was put into a sterilised flask, the end of the pH meter electrode was dipped into the solution, and the pH value displayed on the pH meter screen was recorded.

2.5.2 Total soluble solids

In the determination of the sucrose content, total soluble solids (TSS, % Brix) of tomatoes using a refractometer (3810 PAL-1, Atago, Japan), a drop of juice extracted from tomatoes was placed on the clean prisms of a calibrated refractometer. The TSS level was read on the scale of the refractometer. In each sampling, four readings from four samples were made and the average recorded. After TSS was determined, the prism was cleaned and wiped with a soft cloth before storage.

2.5.3 Colour

In measuring tomato colour, a calorimeter (BCM 200, Biobase group, China) was used, starting with determining the standard reading and them measuring the tomato colour from the 8 tomatoes sampled in each test. The colour of eight sampled fruits (four from ambient and four from the cooler environment) was taken. The readings were measured after standardising the instrument using its white tile. According to international commission of illumination, colour can be determined using CIELAB colour space, also referred as L*, a*, b* and h where a* is the redness, b* is the yellowness, L* is the perceived colour brightness while h is hue angle which describes the relative amounts of yellowness and redness of colour (Cherono et al., 2018a; Polenta et al., 2015) The L*, a*, b* and h values were recorded from the eight sample (four samples from the experimental group and two samples from control group). The colour was taken at the equatorial axis of the fruit (Cherono et al., 2018a, 2018b; Polenta et al., 2015).

2.5.4 Firmness

The firmness of the tomatoes was determined using a penetrometer (GY-3, Laboratory instruments, China) with a range of 1-24 kg/cm^2. The penetrometer hand two probes (8 mm and 11 mm) for measuring different fruit hardness. The firmness of the fruit was conducted on each of the eight samples, the firmness of the tomatoes was tested by pressing the indenter vertically and evenly at the equatorial axis of the tomato as described by Polenta et al. (2015).

2.5.5 Shelf life

The subjective quality assessment was carried out following the method by (Cherono et al., 2018b) where tomatoes conditions observed and assessed were; level of decay and shrinkage. The shelf life was determined by the level of marketability of the tomatoes according to Workneh et al. (2012), marketability of tomatoes is determined by the percentage of sellable tomatoes in relation to all tomatoes in storage. Shelf life of the tomatoes is the number of storage days when the crop

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is within commercial viability levels. The nature of tomatoes was assessed and the maximum number of days the crop was kept in the storage while it had commercial value was recorded as the shelf life. For tomatoes, the determinants of the commercial viability observed were; the surface texture, level of rotting and skin rapture.

2.5.6 Data analysis

The experimental design in this study was full factorial design. Multivariate Analysis of variables (MANOVA) was carried out to establish the effects of the conditions on the storage of tomatoes. The data collected was analyzed using Statistical Packages for Social Scientists (SPSS) version 25 (IBM, USA). Separation of means was done using LSD (least significant difference) tests. The experimental design in this study was full factorial design. MANOVA was carried out to establish the effects of conditions on the storage of tomatoes.

3. Results and discussion

3.1 Environmental conditions

Figs. 2 and 3 show the mean temperatures and the relative humidity in the evaporative cooler and the ambient environment for 24-hours averaged over a 28-day storage period. In Fig. 2, ambient temperature conditions are generally higher than the temperatures in the evaporative cooler, with the temperature in ambient conditions being approximately 10^{o}C higher than the temperature in the cooler environment at 1400hrs, while the maximum temperature in the ambient condition was about 31^{o}C. The temperature depression of 10^{o}C in this study was lower than the temperature depression recorded by Jha (2008) which was 20^{o}C. This difference can be explained by the likely different environmental conditions where the two studies were conducted. The study by Jha (2008) was conducted at Delhi, India where the average temperature is higher than average temperature at JKUAT, the location where the present study was undertaken. The lowest ambient temperature during storage was 16^{o}C. The temperatures and relative humidity in the cooler are within the optimum conditions for storage of tomatoes and ranged from 18^{o}C to 21^{o}C and 90 to 95% relative humidity. Hobson (1987) recorded that temperature lower than 9^{o}C causes chilling injury in tomatoes. Therefore, the cooler temperatures offer a conducive environment for storage of tomatoes.

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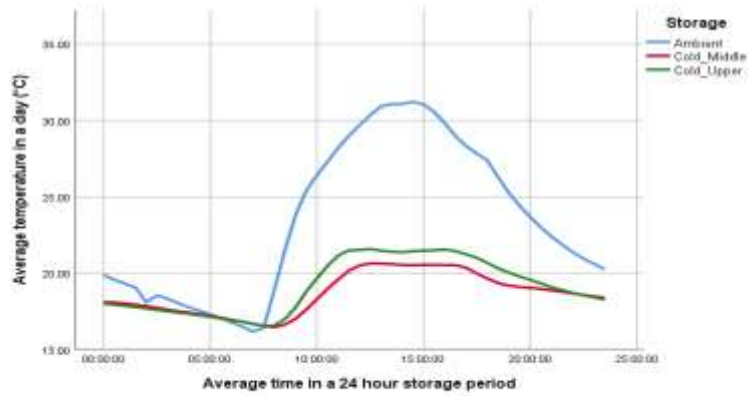

Fig 2: Mean daily temperatures averaged over the 24-hour storage period over the entire storage period

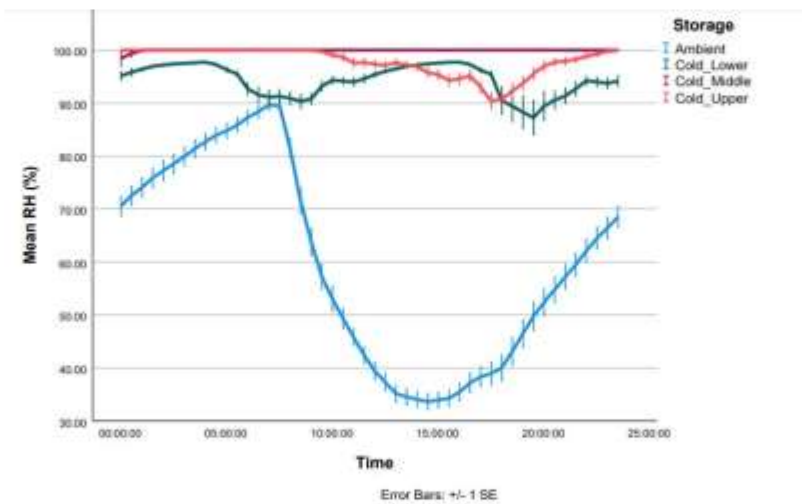

Fig. 3: Daily mean relative humidity in the evaporative cooler and ambient environment.

In Fig. 3, the relative humidity in the evaporative cooler was generally higher than the ambient environment. The lowest relative humidity was attained between 1200hrs and 1400hrs, this is the range of the solar noon (Jones Jr & Burkhart, 1981) and is an expected phenomenon at the equatorial region. Relative humidity at the evaporative cooler was between 90% and 100% during the storage period and the lowest relative humidity was attained between 1200hrs and 1400hrs (solar noon).

Figs. 4 & 5 show the mean daily temperatures and humidity averaged over the 24-hour storage period for the entire storage period. It was observed from Fig. 4 that the cooler's temperatures ranged from 16°C to 21°C during the 28 days of storage. The temperatures reported in the cooler are suitable for tomato storage and in agreement with those established by Cantwell (2000), where it has been demonstrated that a mean temperature of 17.5°C is optimal not only for ripening and colour development, but also for tomato storage because they result in good red colour and firm tomatoes. The temperature in the ambient environment ranged between 21°C and 25°C (average of 22.5°C).

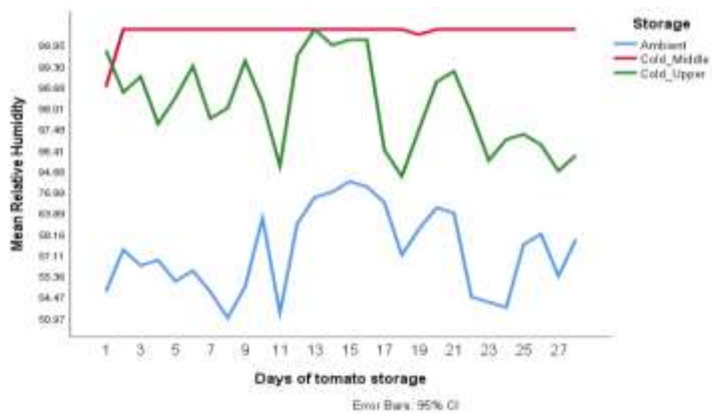

Fig 4: Mean daily relative humidity averaged over the 24-hour storage period for the entire storage period

The maximum temperature depression (10°C) was recorded on the 11th day. For the ambient conditions, the lowest temperatures occurred on 14th, 15th and 16th day. The maximum ambient temperature was on 11th day. Additionally, a temperature below 10°C causes chilling to tomatoes (Cantwell, 2000), a phenomenon that was not observed in the evaporative cooler. This is an indication that the developed pumice evaporative cooler is the suitable for storage of tomatoes. The average temperature in the ambient condition is detrimental to the storage of tomatoes, as Cantwell (2000) reported that temperatures at and above 25°C result into poor ripening, where tomatoes are soft and poorly coloured. In addition, such high temperatures hinder ethylene production, a bio-hormone required for synthesis and accumulation of lycopene in fresh tomatoes. The cooler developed in this study established a colder temperature compared to that reported by Jha (2008), who, using river sand as the evaporative media got an average temperature of 23°C. This variation may be due to difference in environmental condition or the evaporative material used.

In Fig. 5, it is apparent that the relative humidity of the evaporative cooler was higher than the relative humidity at the ambient conditions. The relative humidity in the cooler ranged between 90% and 100%.

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The relative humidity is within the range of optimum storage relative humidity for tomatoes which is above 92% according to Chilson et al. (2011b).. Chilson et al. (2011a) in their study found out that relative humidity of 92% and above was best for overall quality of tomato colour, freshness, firmness, decay and shrivelling, hue angle of relative humidity above 88% tend to be lower red compared to those above 88%. (Nunes et al., 2012) additionally recorded that firmness of pepper (Cv. Revolution) decreased as the pepper was subjected to a relative humidity of 40% to 95%. The coherence in the findings with the optimum tomatoes storage condition is an indication that the cooler has both ideal temperature and humidity conditions for tomato storage based on the prevailing experimental conditions. Jha (2008) in the study using river sand found the relative humidity of the cooler to be 85%. The difference in relative humidity in this study (are the finding by Jha (2008) might be attributed to the evaporative material used and the incorporation of a roof pond in the current evaporative cooler. The evaporative cooler hence seems to be the ideal for storage of tomatoes.

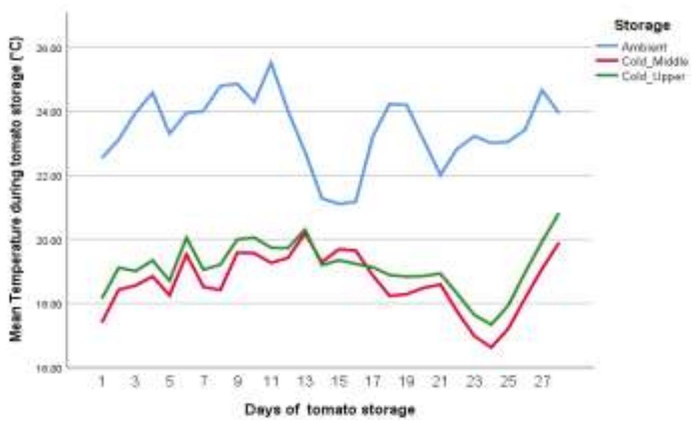

Fig 5: Mean daily temperature averaged over the 24-hour storage period for the entire storage period.

A MANOVA of the data showed that the relative humidity in the cooler was significantly ($p \leq 0.05$) higher than the relative humidity at the ambient conditions. Similarly, the temperatures in the evaporative cooler were significantly ($p \leq 0.05$) lower than the ambient temperature conditions. This is due to the low temperature created in the cooler as a result of the latent heat of vaporization absorbed as the air entered the chamber. The conditions in the evaporative cooler were similar to the study by (Ronoh et al., 2010), that reported a relative humidity in a charcoal cooler to be 38.07% more compared to the ambient RH. Liberty et al. (2013) in their study

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recorded a drop in temperature from 33 °C to 16.75 °C and increased relative humidity from 47.5% to 76.2%.

There was a significant ($p \leq 0.05$) two-way interaction between the storage environment and days of storage. This means that as storage days proceeded the storage environment was changing also. Separation of means using LSD tests, showed that, the relative humidity within the cooler chamber differed significantly ($p \leq 0.05$) in relation to vertical levels, a similar relationship was noted for temperatures recorded by sensors at the middle and upper part of the cooler. The present study also revealed that the temperature at the middle (100cm from the cooler floor) of the cooler chamber was significantly ($p \leq 0.05$) lower than the temperature at the upper part of the cooler chamber. Similarly, the relative humidity at the middle of the cooler was significantly ($p \leq 0.05$) lower than the relative humidity at the upper part of the cooler. The reason why the middle temperature was lower than the upper chamber temperature may be due to the high air turbulence at the floor of the cooler where the fan was placed. Although scientifically, warm air is lighter than cold air, and hence the upper chamber is expected to be at a higher temperature than the lower part of the cooler, the turbulent air caused more evaporation at the lower part of the cooler compared to the upper part of the cooler. There was no significant ($p > 0.05$) change in ambient environmental conditions (temperature and relative humidity) over the storage period. This was expected because the experiments were conducted on the same period with no much deviation in weather conditions.

From the statistical analysis, the cooler had significant ($p < 0.05$) effect on temperature and relative humidity. As expected, the temperature in the cooler was generally lower that the temperature in the ambient conditions while the relative humidity inside the cooler was higher than the relative humidity of the ambient conditions. This may be due to the cold environment caused by the cooling effect of the latent heat of evaporation as the ambient air passed through the wetted pumice. These results agree with Sow et al. (2020) who reported that evaporative coolers significantly increases relative humidity and reduces temperature of the cooler chambers. The results of the current study show the roof-pond incorporated cooler seem to be ideal for storage of tomatoes a low temperature

3.2 Changes in tomato fruit quality attributes during storage

3.2.1 pH

Fig. 6 shows the mean pH for tomatoes stored for 28 days in the cooler and in the ambient environment. From Fig. 6, the pH in the ambient storage was generally higher than the pH in the evaporative cooler. The pH decreased in the first 7 days and then increased to the 21st day, after which the pH in the cooler decreased while the pH of the tomatoes in the ambient condition increased further to a pH of about 4.4.

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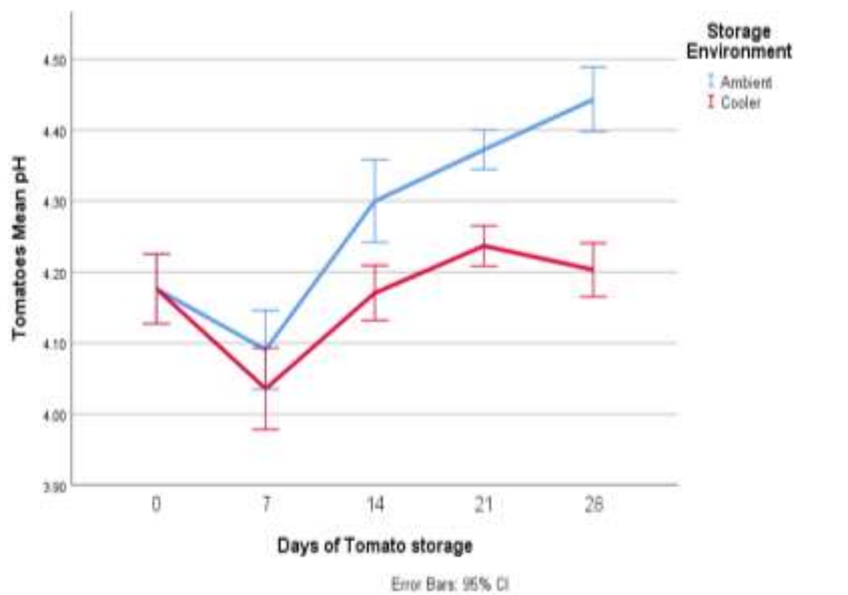

Fig 6: The mean pH values for tomatoes stored in the cooler and in the ambient environment

The tomatoes in the cooler maintained a lower pH compared to the tomatoes in the ambient condition. Lower pH in tomatoes is highly preferred during processing of tomatoes. Mundt and Norman (1982) recorded that a pH higher than 4.4 encourages microbial growth in processed tomatoes. The pH in the present study was maintained at a level lower than 4.3 and hence it may be considered as an ideal storage for tomatoes to be processed.

3.2.2 TSS

Fig. 7 shows the total soluble solids (TSS) content of tomatoes stored in the evaporative cooler and in the ambient conditions. Generally, the TSS of the tomatoes in the ambient condition was higher that the TSS of the tomatoes stored in the cooler.

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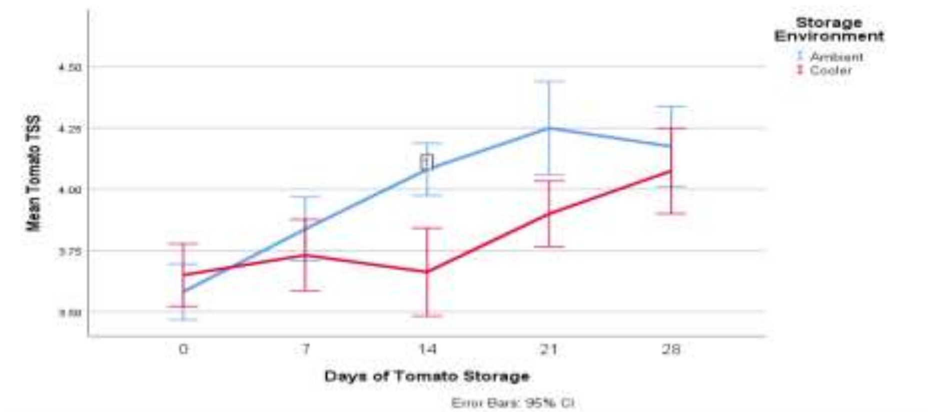

Fig 7. The mean Total Soluble Solid (TSS) for tomatoes stored in the cooler and at the ambient condition. Error bars designate mean±SEM.

The TSS of the tomatoes in the ambient storage condition increased continuously up to the 21st day where it registered a slight drop up to the 28th day of storage, while the TSS of the tomatoes stored in the cooler showed a slight increase up to the 7th day from where it registered a slight decrease up to the 14th day, after the 14th day the TSS in the tomatoes stored in the cooler increased sharply up to the 28th day.

The greatest difference (about 0.42 ^{o}Brix) in TSS was experienced on the 14th day. It is reported by Beckles (2012) that the trend of TSS tomatoes under storage depict increase in TSS as the fruit ripens, then later during storage, the sugars (TSS) developed are used up in tomatoes' metabolism. The trend in the current study is in agreement with the reported trend because the tomatoes in the ambient condition ripened faster than the tomatoes in the evaporative cooler. This is because the temperature in the ambient condition was higher than in the temperature in the cooler condition. The study found that the TSS maintained an increasing trend up to the end of the storage period. Therefore, the cooler maintained the tomatoes at higher TSS compared with the ambient condition. The delayed ripening of tomatoes in the cooler is beneficial for tomato storage because it means a prolonged shelf life.

3.2.3 Firmness

Fig. 8 shows the changes in firmness of tomatoes stored in the evaporative cooler and in the ambient environment.

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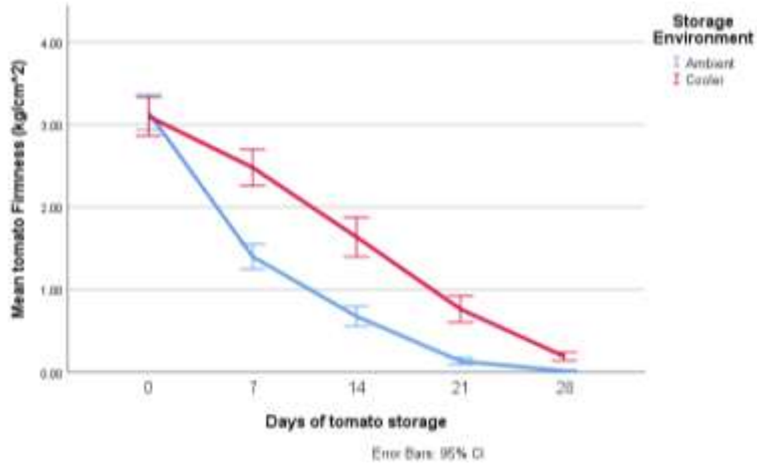

Fig 8. The mean firmness of tomatoes stored in the ambient environment and evaporative in the evaporative cooler. Error bars designate mean+-SEM

Generally, throughout the study period, the tomatoes stored in the cooler remained firmer than the tomatoes stored in the ambient condition. In addition, both categories of tomatoes registered a continuous decrease in firmness as storage period progressed. During the study, the mean firmness of tomatoes in the ambient condition reduced from 3.20 kg/cm^2 to near 0 kg/cm^2, while the mean firmness of tomatoes in the cooler decreased from 3.20 kg/cm^2 to about 0.2 kg/cm^2.

The largest difference in firmness was registered on the 7th day of about 1.1 kg/cm^2. Since consumers check freshness of tomatoes by touching and pressing, it means that the tomatoes stored in the evaporative cooler will comparatively be more appealing to the consumers over a long period of time compared to the tomatoes stored in the ambient environment resulting into higher profits to tomato vendors (Gormley & Egan, 1978). The results of the study are in agreement with (Chilson et al., 2011b) who recorded that tomatoes stored in higher humidity (88% to 92%) maintained higher acidity (low pH) compared with tomatoes stored in lower relative humidity.

3.2.4 Fruit hue angle

Fig. 9 shows changes in the hue angle of tomatoes stored in the ambient environment and in the evaporative cooler. The tomato hue angle (h) was measured according to Pinheiro et al. (2015). hue angle measures colour of agricultural products where angle of 270^0 is associated with blue colour, 180^o is for green, 90^o is assigned to yellow and 0o is assigned to red. This shows the process of ripening from greento red. This is in relation to the colour change as described by Carrillo-López

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and Yahia (2014) that colour of tomatoes change according to six stages: green, breaker, turning, pink, light red and deep red).

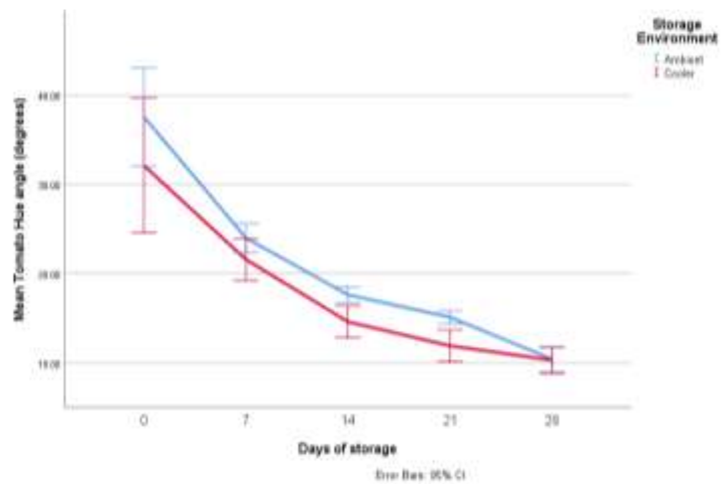

Fig 9. The mean hue angle of tomatoes stored in the ambient environment and evaporative cooler. Error bars designate mean±SEM.

Throughout the experimental period, the hue angle decreased to 100 in both tomato categories. The largest difference in hue angle (about 30) was experienced between the 7th day and the 14th day. There was no significant ($p>0.05$) change in colour (hue values) in the two storages. The slight difference in h value change between the ambient and cooler condition can be associated with the high temperature in ambient environment which in a catalyst for increased bioreaction in the stored tomatoes Cherono et al. (2018a); (Cherono et al., 2018b). The results are in agreement with (Chilson et al., 2011a) who found out that hue angle (h) was not significant among the relative humidity ranging from 41% to 88% at a constant temperature of 15^{0}C.

3.2.5 Shelf life

From Table 1, the number of shrank tomatoes, decayed tomatoes and overripe tomatoes duration the storage of tomatoes. The total number of tomatoes in each group at the start of storage was 80.

Table 1: The progressive subjective quality of tomatoes during storage

Subjective quality parameters	Day 0		Day 7		Day 14		Day 21		Day 28	
	Cooler	Ambient	Cooler	Ambient	Cooler	Ambient	Cooler	Ambient	Cooler	Ambient

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Decayed samples (n)	0±0.00	0±0.00	0±0.00	0±0.00	‘99	4.25±0.25	4.25±0.48	14.25±0.47	7.25±0.25	11±1.08
Shrunk samples (n)	0±0.00	0±0.00	0±0.00	2±0.41	8±1.47	12±0.41	6.25±0.25	13±0.41	7.75±0.75	13±0.41
Overripe samples (n)	0±0.00	0±0.00	0±0.00	4.5±0.50	2±3.56	5.75±0.85	12±0.41	17.5±1.19	30.25±0.25	15.75±1.60
Marketability (%)	1000.0±0	100.00±0.0	100.0±0.0	91.45±0.84	85.07±3.56	69.44±0.77	66.91±0.40	34.19±0.93	41.80±2.03	6.9±2.12

The percentage marketability was determined by calculating the percentage of the marketable tomatoes (ones which are not shrunk, not decayed and not overripe) in relation to the quality tomatoes. The calculation of percentage marketability was determined in relation to the remaining tomatoes during any sampling day. The subjective quality determination was determined before sampling. The tomatoes in the ambient condition started showing shrinkage on the 7th day while the tomatoes in the cooler started shrinking on the 14th day. The quality deterioration increased further on the 21st and 28th day. On the 28th day, the average marketability was 41.8% and 6.9% for the tomatoes stored in the cooler and ambient conditions, respectively. The results show that the cooler maintains the tomatoes in marketable quality longer compared with the ambient condition storage. The cooler increased the shelf life of tomatoes from 14 days to 28 days. The shelf life is determined by the duration when 40% of the fruits are in marketable condition. These results agree with those reported by (Ronoh et al., 2010) who studied the effect of evaporative cooler on amaranths and found that shelf life is increased from 3 to 9 days.

4.0 Conclusion

The tomatoes stored in the cooler condition maintained a significant lower pH, higher firmness and lower TSS compared with the ambient conditions. Low pH means high level of acidity, which is desirable in tomatoes for processing because the high acidity hinders development of microorganism in processed tomatoes. Higher firmness of the tomatoes stored in the cooler is an indication of marketability because consumers prefer firm tomatoes compared to soft ones. The cooler's condition maintained a lower TSS compared with the ambient condition. The Hue angle of the tomatoes in the cooler showed no significant difference compared with the tomatoes in the ambient conditions. This is an indication of delayed ripening. The tomatoes' shelf-life was 28 days compared with 14 days at the ambient condition. The low temperature at the cooler helps in delaying ripening and hence increase the shelf-life of the tomatoes. Increased shelf-life is an indication of longer period of sale and reduced post-harvest losses. Longer shelf-life is also an indication of higher profits for vendors and wholesalers.

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