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PERFORMANCE EVALUATION OF AN EVAPORATIVE CHARCOAL COOLER UTILIZING THIN-FILM PHOTOVOLTAIC SYSTEM FOR PRESERVATION OF AVOCADO

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ABSTRACT

Fruits are high moisture agricultural produce rendering them highly perishable hence the danger of postharvest losses is also lurking when there are inadequate storage facilities. The losses result from physical, chemical, and physiological changes that are triggered by the loss in moisture content. Preservation of fruits using available and affordable technologies (such as charcoal coolers) can benefit small-scale farmers in minimizing postharvest losses. An evaporative charcoal cooler 4 m long, 4 m wide, and 2.5 m high providing a 40 m^3 storage capacity was utilized in the study. The cooler with a 150 mm wide cavity filled with charcoal had a perforated pipe connected to a 1000-litrecistern raised at 2.5 m above the ground and connected to a water pump (Pedrollo PKm 60, Italy) that kept the charcoal wet by a drip system. The pump and the three axial fans (REC-21725 A2 W, USA) rated 180 cubic feet per minute (CFM) and 2600 revolutions per minute (RPM) were powered by fast fold thin-film PV (FFMAT-10, Renovagen, UK) system connected to a 10-kWh rated energy hub (FFENERGYHUB-10, Renovagen, UK). Temperature, relative humidity and product quality parameters (weight loss, total soluble solids, vitamin C content and firmness were evaluated).The evaporative cooler temperatures reduced significantly ($P<0.05$) with an average 25.0±0.37 ºC and 32.1±0.99 ºC outdoors temperatures. The cooler relative humidity increased significantly ($P<0.05$) averaging 76.8±1.6% and 43±2.8%

for ambient conditions. The average cooling efficiency in the charcoal cooler was 83.0%.The percentage weight loss of the avocado was 3.9% and 7.5% for the cooler and outdoors respectively. The percentage vitamin C loss was 39.0% for the cooler and 49.6% for those kept outside. The total soluble solids in the cooler rose from 0.5 to 1.6 ^{o}Brix and 0.5 to 2.6 ^{o}Brix in ambient conditions. Firmness decreased from an average 65.0 N to 10.7 N and 65.0 N to 8.0 N after 12 days for samples in the cooler and ambient conditions, respectively. In conclusion, the evaporative charcoal cooler incorporated with thin-film PV system preserved the postharvest quality and extended the shelf life of hass avocado.

Keywords: Evaporative charcoal cooler, Performance, Thin-film PV system

1. INTRODUCTION

The absence of suitable storage facilities in third world countries is responsible for much of the postharvest loss of fruits and vegetables. While refrigeration and cold rooms are the best way to keep fruits and vegetables fresh, they are costly to purchase and operate (Argiriou, 2013). Approximately one-third of the world's total food output is wasted before consumption, including spoilage through the stages of manufacturing and private consumer waste. This indicates that the recovery of just half of the waste could feed the entire world's population. Majority of losses isat the consumer level in developed countries, but postharvest losses, such as improper storage, account for around 40% of waste in developing countries (Gustafsson & Simson, 2016).

Evaporative cooling refers to the process of lowering a substance's temperature through the cooling impact of water evaporation. As water evaporates, sensible heat is converted to latent heat hence the ambient temperature drops, providing effective cooling. Varies from conventional air conditioning and refrigeration in that it can deliver effective cooling without the use of external energy. By simply wetting a surface and allowing the water to evaporate effective cooling is achieved. This impact is most noticeable when the body is cooled by sweat draining from the skin during physical exercise. This basic form of evaporative cooling serves as the foundation for more elaborate and mechanical evaporative cooling systems (Liberty et al., 2013).

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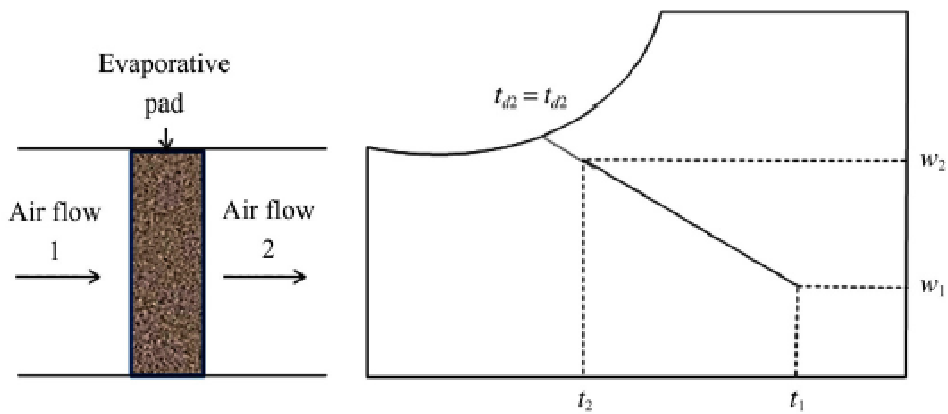

Figure 1: Illustration of evaporative cooling (Akton Associates, 2009).

Evaporative cooling is also attractive because of its low energy consumption, and easy maintenance. Because of the utilization of a total airflow renewal, evaporative cooling eliminates the re-circulation flow and multiplication of microorganisms, an incessant problem in customary cooling frameworks.). Figure 1 illustrates the process of evaporative cooling where t_1 and t_2 are initial and final ambient temperatures and w_1 and w_2 initial and final moisture contents of the air. The process occurs along the constant wet bulb temperature line (Xichun et al., 2008).

Water absorbs or loses heat as it transitions from one condition to the next. For example, 2260 kJ/kg of water is equal to latent heat of vaporization is required to convert water from liquid to vapor (Ambuko et al., 2017). For the storage of fresh fruit, charcoal cooling is used to create an atmosphere that is both cooler than ambient temperature and has a greater relative humidity. Because of the high relative humidity, the produce loses less water (Shitanda et al., 2011). Avocado just like any other agricultural produce is perishable and its preservation is imminent immediately after harvest. The main indicator of ripeness is firmness which decreases gradually at first, then accelerates till it reaches less than 5 N resistance to penetration at full ripening (Flitsanov et al., 2000).

Evaporative charcoal cooler employs Direct Evaporative Cooling principle. Direct evaporative coolers are a cost-effective and energy-efficient way to meet the cooling requirement for space conditioning. They are generally utilized in dry and hot regions because their potential is highly dependent on air hygrothermal conditions, though they can be used in a wide range of applications and climates (Velasco-Gómez et al., 2020)

The best ways for preserving and extending the shelf life of fruits and vegetables have been found to be refrigerated storage methods. Storage in a ventilated shed and at low temperatures are two of these methods. However, these systems are costly to purchase and operate, especially for smallholder farmers, the majority of whom live in impoverished developing countries.

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Despite the fact that the evaporative cooler may not be as effective as a refrigerator, it is envisaged that it would be useful in the storage of avocados and other agricultural produce in rural areas due to their socioeconomic position. The humidity of the surrounding air affects the efficiency of an evaporative cooler. Because very dry air can absorb a lot of moisture, it cools down faster. In the extreme situation of completely saturated air, no evaporation occurs, and therefore no cooling takes place. In countries with a hot and dry climate, evaporative cooling devices are often used. Several studies, particularly in India and the United States, have been reported to use evaporative cooling principles in preservation fruit and vegetable. (Kenghe et al., 2015).

The stacked charcoal in the existing charcoal cooler had crumbled rendering a lot of spaces in it. The drip pipe failed due to blockage and therefore the charcoal cooler system was unusable in its state. As a result, the goal of this research was to evaluate the performance of an evaporative charcoal cooler utilizing thin-film PV system for preservation of avocados.

2. MATERIALS AND METHODS

2.1 Charcoal cooler and site description

The charcoal cooler used in the study (Figure 2) is located in Kimicha, Kirinyaga County. The coordinates of the actual location are 37.294^o E longitude, 0.594^o S latitude and altitude of 1258 m above sea level. The dimensions of the cooler are 4 m long, 4 m wide, and 2.5 m high providing a 40 m^3 storage capacity. The 150 mm thick charcoal with thermal conductivity of 0.084 W/mK were held in place by a wire mesh and chicken net supported by intermediary metal. The cooler had a charcoal-filled door that gave access to 20m^2 preparation room and 12m^2 records office (Kanali et al., 2017).

Figure 2: Evaporative charcoal cooler (Ronoh et al., 2020).

Concrete was used for the cooler floor, providing easy cleaning and drainage. The water was supplied by two a 1000-litre cistern one erected 2.5m above the ground and the other as a reservoir on the ground (Figure 3). Three axial fans (REC-21725 A2 W, USA) rated 180 cubic feet per minute (CFM) and 2600 revolutions per minute (RPM), a 0.37kW water pump (Pedrollo PKm 60, Italy), and the data logger with four digital temperature-humidity sensors (DHT22, China) were powered by fast fold thin-film PV (FFMAT-10, Renovagen, UK)system connected to a 10-kWh rated energy hub (FFENERGYHUB-10, Renovagen, UK)which also provided power for the operations in the records office. The integration of thin-film PV system in place served as the source of power for the water pump and axial fans as well as the data logger. Introduction of the water pump ensured that the charcoal is wet within the shortest duration while the fans extract warm air from the cooler and therefore the conditions are stabilized and maintained within the required levels within the shortest time. The energy consumption was obtained through a digital energy meter (TS-836B, China).

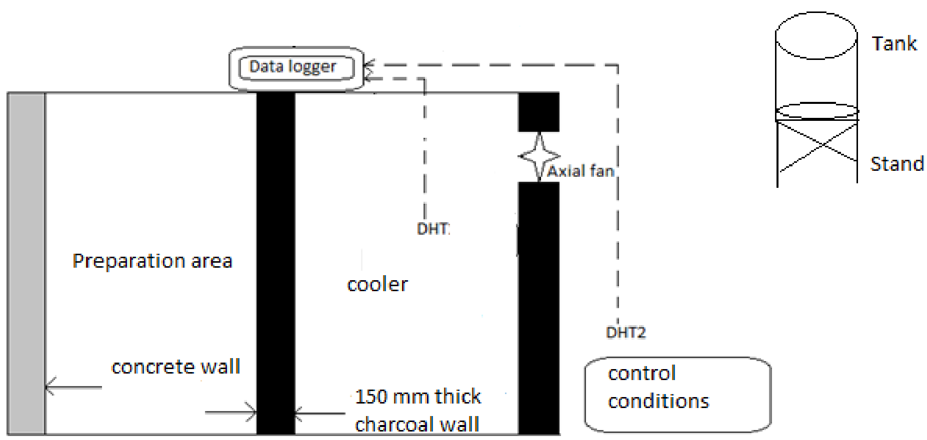

Figure 3: Charcoal cooler setup.

2.2 Data collection

Temperature and relative humidity were measured using three digital temperature and humidity (DHT 22) sensors which were hanged at different positions in the charcoal cooler and one outside for ambient conditions (Figure 2). Temperature and relative humidity values were recorded in a data logger which was locally fabricated using Arduino uno microcontroller (R3, Italy), SD card module and a real time clock (RTC) at half-hour intervals between 8:00 am and 5:00 pm. The cooler's cooling efficiency (η), which indicates how close the cooled air's dry bulb temperature approaches the ambient air's wet bulb temperature, was determined using Equation 1(Olosunde et al., 2009). In the equation, T_a is the dry bulb temperature of the ambient conditions (°C), T_i is the cooled air dry bulb temperature (°C) and T_{wb} is the ambient air wet bulb temperature (°C), which was determined by use of a psychrometric chart by American Society of

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Heating, Refrigeration and Air conditioning (ASHRAE) and confirmed by ASHRAE calculator (Herrmann et al., 2009) by applying the known inputs (ambient relative humidity, RH_a and T_a).

$$\eta = \frac{T_a - T_i}{T_a - T_{wb}} \times 100\% \qquad (1)$$

Firmness, total soluble solids (TSS), physiological weight loss, vitamin C content and colour changes were measured in three randomly selected avocados from the cooler and ambient conditions.

Physiological weight loss was determined by weighing three avocado samples labeled s1,s2 and s3 three times a day (morning, noon and evening) both from the cooler and the ambient conditions using a digital weighing scale (A&D Gulf, India), with a precision of ±0.01 g. Weight loss was expressed as the percentage of the initial weight using Equation (2) (Jahun et al., 2016). In the equation, w1 is the initial weight at day zero and w2 is the final weight.

$$\text{Weight loss (\%)} = \frac{\text{w1} - \text{w2}}{\text{w1}} \times 100 \qquad (2)$$

Firmness was measured after every four days using a rheometer (compac-100, Japan) using a 7mm probe. The force required to penetrate the avocado sample at the equatorial zone was recorded in kilogram force (kgf) and later converted to Newton (N). This was repeated three times and an average value calculated.

Total soluble solids concentration (^{o}Brix) was determined after every four days using a handheld refractometer (Atago 2360 N-8, Japan). Avocado slices were cut and crushed using a mortar and a pestle, and the juice squeezed through a soft cloth. A drop of the sample juice was placed on the glass measuring surface and readings taken through the eyepiece while holding the refractometer up to natural light (Misco, 2014).

Samples of avocado were taken to the laboratory for vitamin C content analysis. The amount of vitamin C content (mg/100g) was determined using a method described by the vitamin C testing procedure (AOAC, 2010),where titration was performed and the titre result converted into vitamin C level in mg/100 g (Equation 3). In the equation, *c* is the standardization value, *v* is the volume prepared, *l* is the aliquot made and *s* is the sample weight.

$$Vitamin\ C = \frac{titre - (blank \times c \times v)}{l \times s} \times 100 \qquad (3)$$

2.3 Data Analysis

Analysis of variance (ANOVA) was conducted using R 4.1.2 for Windows (Vienna, Austria) to ascertain whether the PV powered charcoal cooler system had any significance influence on cooler's microclimate conditions at 5% level.

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3. RESULTS AND DISCUSSION

3.1 Temperature

A variation of air temperature of both the charcoal cooler and the ambient environment is shown in Figure 4. The evaporative cooler temperatures recorded for the 12 days were reduced significantly (P<0.05) prolonging the shelf-life of avocados as compared to avocados stored outdoors. The average temperature of the cooler was 25.0±0.37°Cwhile ambient one was 32.1±0.99°C.

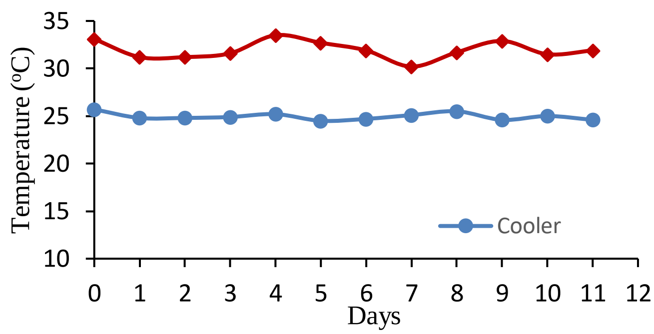

Figure 4: Daily average temperature variation.

3.2 Relative humidity

The cooler's ability to maintain high uniform relative humidity was demonstrated by the reduction in relative humidity fluctuation over time inside the cooler compared to ambient conditions as illustrated in Figure 5. The evaporative cooling system's relative humidity increased significantly (P<0.05), extending the shelf life of avocados as compared to the ambient. The average relative humidity of the cooler was 76.8±1.6% while the average ambient relative humidity was 43.3±2.8%.The maximum difference between the charcoal cooler and ambient relative humidity was 37.7%, while the minimum difference was31.2%.These results are in agreement with (Xuan et al., 2012) which asserted that 100% efficiency cannot be achieved in the evaporative charcoal cooler because of the loosely packed nature of the pads and insufficient contact with water.

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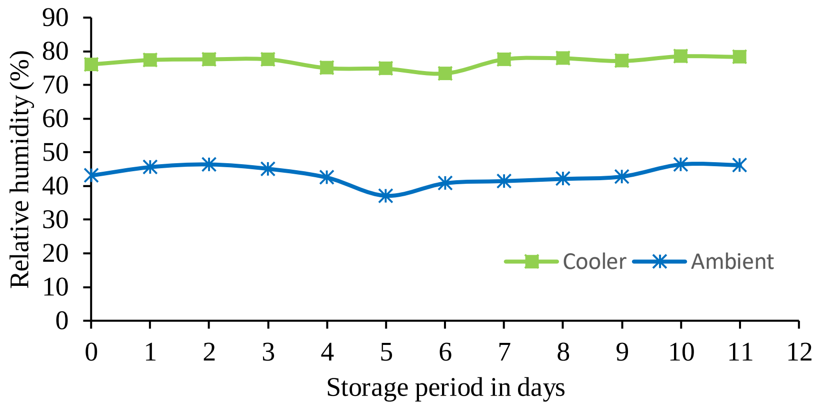

Figure 5: Average daily relative humidity variation.

3.3 Cooling efficiency

The average cooling efficiency of the evaporative charcoal cooler was 83.0% and a minimum of 62.6%.The maximum and minimum values were realized at the maximum and minimum temperature difference between the cooler and ambient environment, respectively. This relationship was also reported by Basediya et al. (2013).

3.4 Weight loss

The evaporative cooler system had higher air humidity and was cooler than the ambient storage conditions, preventing the fruit from losing too much moisture. The physiological weight loss of the avocado samples is plotted in Figure 6. The percentage weight loss of the avocado samples stored in the cooler was 3.9% and 7.5% for the samples in ambient conditions. The mean effect of the number of days on the weight loss for avocados in the charcoal cooler and the ambient was significantly different ($P<0.05$). The higher percentage weight loss observed in ambient environment samples compared to those in the cooler was attributed to high humidity in the cooler which reduced the excessive moisture loss from the samples (Jahun et al., 2016). One of the most commonly employed criteria for export of avocado is weight, which is regarded the most important quality element given by trade organizations around the world (Ramírez-Gil et al., 2019).

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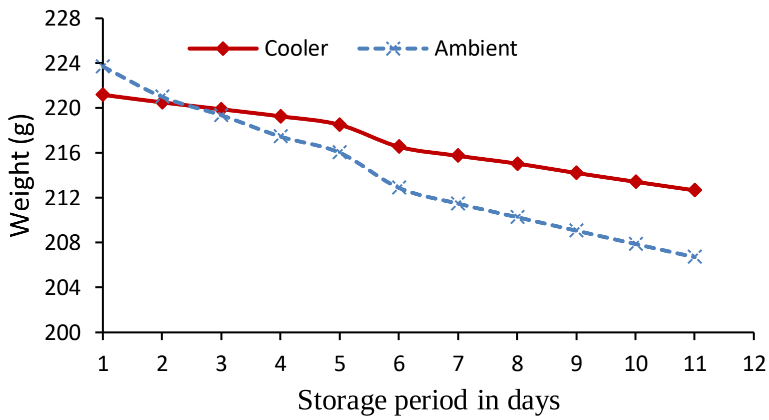

Figure 6: Physiological weight loss.

3.5 Vitamin C

The loss of vitamin C was higher for the avocado samples in the ambient as compared to those inside the cooler as shown in Figure 7. The percentage vitamin C loss was 39.0% and 49.6% for the samples in the cooler and ambient environment, respectively. The high vitamin C loss in the ambient conditions is attributed to high temperatures (Moneruzzaman et al., 2009). When compared to the evaporatively cooled avocados, the high temperature and low relative humidity reported in ambient storage caused water loss, which resulted to a faster wilting rate and hence quicker vitamin C loss.

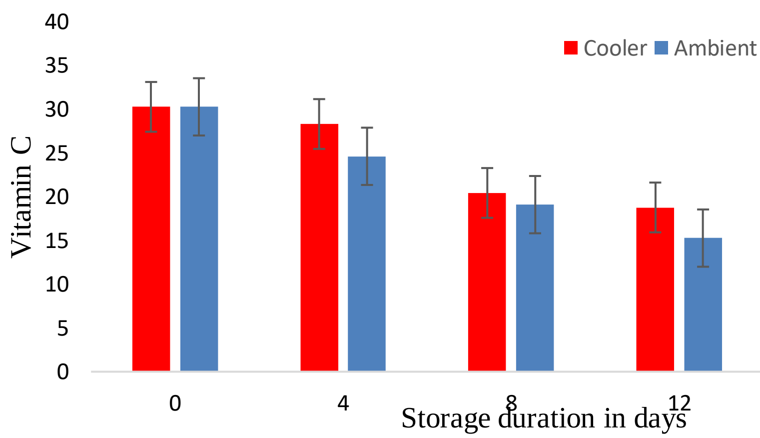

Figure 7: Vitamin C change in charcoal cooler and ambient conditions.

3.6 Total soluble solids (TSS)

Throughout the storage time, the avocados exposed to the various treatments showed a general increase in TSS (Figure 8). When compared to evaporative storage conditions, the increase in

TSS occurred at a higher rate in ambient conditions. The TSS level in the cooler increased from 0.5 to 1.6 °Brix compared to 0.5 to 2.6 °Brix in the ambient conditions. Higher hydrolysis of carbohydrates contained within the avocado fruit into soluble sugars may have been caused by increased temperature and reduced RH under ambient conditions (Kassim & Workneh, 2020).

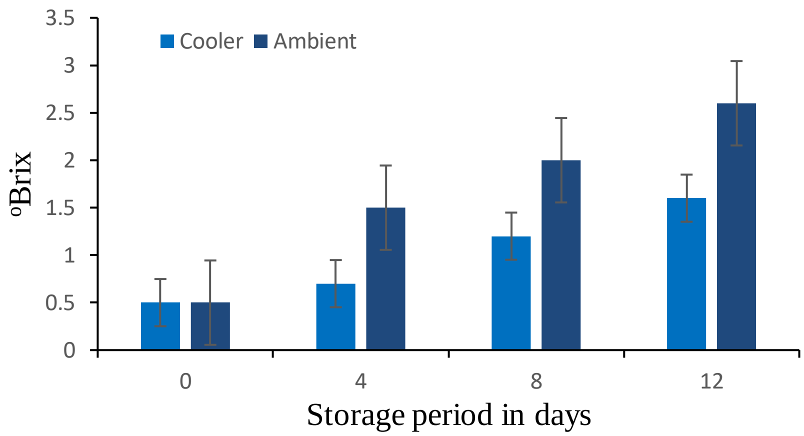

Figure 8: Total soluble solids change.

3.7 Firmness

The fruit hardness decreased continuously, as shown in Figure 8, both for the samples inside the cooler and those in the ambient conditions. The highest penetration value was realized on the first day at an average of 65 N with 10.7 N and 8 N after 12 days for samples in the cooler and ambient conditions, respectively. Decrease in the avocado firmness can be attributed to hydrolysis of peptic compounds contained in cell wall and the loss of water holding capacity in the plant cell membrane. As the temperature rises, this process of structural compound degradation accelerates, resulting in a loss in fruit firmness (Defilippi et al., 2018; Ochoa-Ascencio et al., 2009).

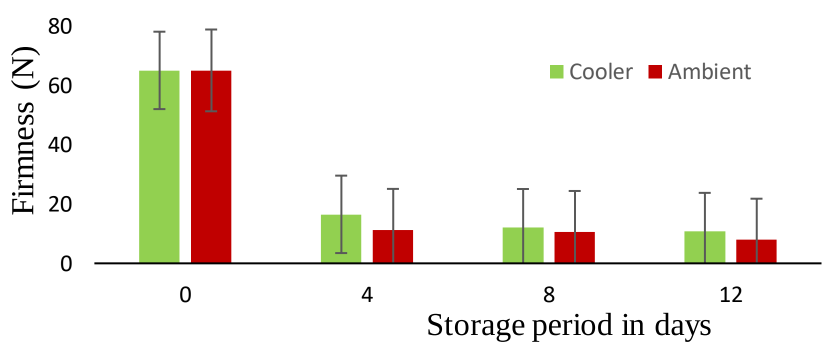

Figure 9: Firmness change with time.

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4. CONCLUSIONS

The study discovered that as compared to ambient storage, evaporative cooler incorporated with a thin-film PV system was able to considerably reduce physiological weight loss, loss of firmness, vitamin C and total soluble solids. From the study it can be deduced that the charcoal cooler can preserve the avocados for 12 days without spoilage and past that duration, the charcoal cooler cannot support. The evaporative charcoal cooler not only reduced the air temperature around the produce, but also raised the moisture content. The findings also revealed that keeping hass avocado fruit at a lower temperature and higher relative humidity during storage helped to preserve fruit quality and prevented loss. The use of cheap and efficient technologies such as evaporative charcoal coolers in the preservation of fresh produce such as avocados can be a viable alternative to smallholder farmers and therefore, they should be empowered to adopt in order to boost food security and enhance sustainability.

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