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Research Article

Effects of Zero Energy Evaporative Cooling Pads on the White Sapote (*Casimiroa edulis* L.) Fruit Quality and Storage Life

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White sapote fruit is one of the underutilized crops in Ethiopia, with a high postharvest loss magnitude (30-70%). Zero energy cooling chamber (ZECC) performance was evaluated with this fruit. The chamber was constructed from locally available materials in a hot and arid area, Dire Dawa. The experiment evaluated the cooling efficiency of ZECC with different cooling pads (sawdust, charcoal, and sand) in CRD with three replications. The cooling efficiency of ZECC was evaluated before and after loading for six weeks. Seventy-five litres of water (25 L for each ZECC) was used thrice daily to keep the cooling pads wet. The environmental air condition of the storage area varied between 24.5 and 32°C, and the average relative humidity (RH) was 47.59%. ZECC storage with different porous materials reduced the temperature by 6.0-10.2°C and raised the RH to 88.2, 85.1, and 87.6% for the cooling pads of sand, sawdust, and charcoal, respectively. Cooling efficiencies of pads resulted in 91.22, 87.95, and 87.82%, respectively, for sand, sawdust, and charcoal with no significant difference. Physiological weight loss of fruit stored in ZECC was 17% on day 18, whereas a similar loss was recorded for control by the 12th day. The shelf life of the fruits was very much prolonged, as expressed in terms of various quality attributes. Hence, smallholder farmers can use ZECC to extend the storage life of fruits in arid and semiarid areas.

1. Introduction

White sapote (*Casimiroa edulis* L.) is a climacteric fruit and is categorized under the *Rutaceae* family. This fruit is well known in Ethiopia with a common name as *amba*, *kasimire*, *or ambuka* [1]. This fruit is a potential source of nutrients and energy. The fruit is rich in minerals like iron, calcium, and phosphorous and contains vitamins A, C, riboflavin, and thiamin [1, 2]. It contains fibers that help to prevent constipation. A larger amount of carbohydrate is reported in white sapote than in all other fruits; this points out that the fruit provides energy [3]. It is also one of the underutilized fruits, and limited attention is paid to it in Ethiopia. Thus, this underutilized fruit needs to be admitted, explored, and used to improve food insecurity [4]. This fruit is very perishable, and research conducted on handling, preservation, and storage of the fruit is very limited.

Fruit and vegetables are highly perishable crops; due to high moisture content and soft texture, they deteriorate easily and are affected by different factors [5]. They produce high ethylene and have a high respiration rate, which leads to rapid senescence and high postharvest losses [6]. The postharvest losses in Ethiopia, Dire Dawa town region, were reported to be 43.35% and 45.32% for mangoes and tomatoes, respectively [7]. The main causes of these losses are poor handling, improper packaging, and high temperature during transportation and storage [7]. In this area, farmers store their fresh fruit and vegetables under big trees' shade, in caves, or buries, temporarily in underground storage [7]. Hence, the utilization of improved postharvest handling and storage life elongation technique play a substantial role in enhancing food security and nutrition. Preserving and promoting this fruit provides a balanced diet and potentially reduces malnutrition in our country [8, 9]. To get this kind

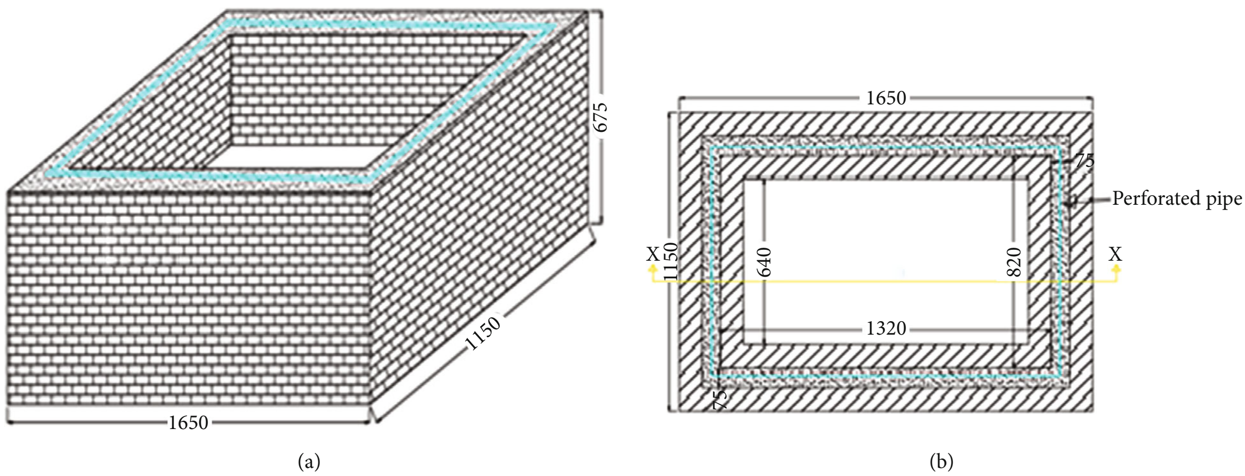

Figure 1: (a) The $L \times W \times H$ design dimensions of ZECC storage (dimensions are in mm). (b) The top view design of ZECC storage (dimensions are in mm).

of benefit from fruits and vegetables, proper handling and storage, such as a zero energy cooling chamber (ZECC), play a key role. Storage life extension of perishable crops plays a significant role in improving food security, specifically in developing countries. That is where ZECC can play its part by preserving fruits and vegetables for short-term period.

ZECC storage is low-cost, affordable, and a simple technology to construct from easily available and cheap materials like bricks, bamboo, grass, and sand with water supply systems to wet the pads [10, 11]. The water from the wet pads evaporates and releases the heat of evaporation with water vapor to the environment and, as a result, cools the pads and the entire inside chamber. Hence, the ZECC storage provides low temperature and high relative humidity without needing electrical energy [12]. This research evaluated white sapote fruit storability and different cooling pad performances under the Dire Dawa climate. Three different porous materials, namely, sand, sawdust, and charcoal, were used and evaluated for their efficiency and quality maintenance of the fruit.

2. Materials and Methods

2.1. Study Area Description. The study was conducted at the Dire Dawa Tony Farm site. Dire Dawa is found in the eastern part of Ethiopia at about 530 km away from Addis Ababa between latitude and longitude of 9° 36'-9.600° N and 41° 52'-41.867° E. Dire Dawa town is one of the driest and hottest areas in Ethiopia. It is characterized by high temperature and low humidity. The mean monthly minimum and maximum temperatures recorded ranged from 22.4 to 27°C and 33.5 to 35.1°C, respectively, with relative humidity (RH) ranging from 31.3 to 49.8%. A brick ZECC was constructed at Dire Dawa Tony Farm. Physical and chemical analyses of the stored fruits were performed in the food science laboratories of Haramaya Institute of Technology, Haramaya University.

2.2. Experimental Design and Treatment. The experiment was carried out from November to December 2021. In this experiment, completely randomized design (CRD) was used. The experiment was conducted with different porous materials (pads) used in ZECC storage filled with sawdust, sand, and charcoal and ambient storage, consisting of four storage levels. White sapote fruit was the experimental material.

2.3. Structure of Zero Energy Cooling Chamber. In this study, three ZECC with different porous materials were constructed to store white sapote fruit at Dire Dawa Tony Farm. Three ZEC chambers were built under different tree shades. The first chamber was filled with sand. The second and third chambers were filled with sawdust and charcoal, respectively. The chambers were rectangular in shape, and each chamber contained three crates. Each ZECC was constructed according to the design of Islam and Morimoto [12]. The walls and floor were constructed using bricks with porous materials: sand, sawdust, and charcoal. ZECC design based on the natural cooling system and the well-ventilated area was selected to harness the maximum evaporative cooling. The dimensions of external and internal walls ($L \times W \times H$) were $1650 \times 1150 \times 675$ mm and $1320 \times 820 \times 640$ mm, respectively (Figures 1(a) and 1(b)). The gap between the external and internal walls was 75 mm and was filled with those cooling pads, and sacks covered the chamber. Watering the porous material was done three times a day with 75 litres of water (morning, midday, and evening; 25 litres for each). The amount of water was selected based on the weather condition and size of the chamber. During watering, the cooling pads were wet enough, and there was no remaining water on the top of the porous materials.

2.4. Experimental Materials. White sapote fruits representing the same maturity, shape, size, and colour were harvested from the home garden in Bate, Haramaya District. The fruit was harvested on the evening of December 9, 2021, with the greatest care because this fruit is vulnerable to mechanical and physical damage during harvesting and postharvest activities. Then, the fruit was transported to Dire Dawa the next day early in the morning. Zero-day physicochemical analysis was done on the harvesting day, and the analysis continued until the end of the experiment. Physical and chemical analyses of stored produce were done at three-day intervals for 18 days (0, 3, 6, 9, 12, 15, and 18 days). The initial quality of white sapote fruit at harvest was a firmness of 89.09 N and pH of 5.0, and it contains 0.44% titratable acidity (TA), 34.21 mg/100 g vitamin C, and total soluble solid (TSS) of 12. 88°brix. They were placed in a perforated plastic crate during transportation and also during the storage period. The fruits that had similar colour, size, and maturity were used for this experiment.

2.5. Sample Preparation. After transporting to the experimental site, fruit selection and sorting were made on the bias of physical quality attributes and maturity. White sapote fruits having similar colour, size, and maturity were sorted. After sorting, the fruit was washed with clean tap water to remove field heat and other dirt like dust and sand to reduce microbial loads. Matured and washed white sapote fruit was divided into four batches. Further, each batch was divided into three subunits, each containing 60 white sapote fruits. Each subunit is put in different plastic crates randomly and labelled out as Sd1, Sd2, and Sd3 stored in ZECC filled with sand; St1, St2, and St3 stored in ZECC filled with sawdust; Ch1, Ch2, and Ch3 stored in ZECC filled with charcoal; and At1, At2, and At3 for samples stored at ambient temperature (control). In this experiment, there were 12 treatments. Each treatment contained 60 white sapote fruits; from each treatment, four fruits were labelled as 1, 2, 3, and 4 randomly and used for weight loss analysis, and three white sapote fruits were taken from each treatment randomly and were used first for firmness measurement, and then, those fruits were used to analyze other destructive parameters TSS, TA, vitamin C, and pH in three-day intervals.

2.6. Physical and Chemical Analyses of Stored Produces

2.6.1. Cooling Efficiency. After the storage structures were ready for work, the dry-bulb and wet-bulb temperatures and humidity data were recorded for both inside and outside atmosphere conditions for a month without stored produce. Data was taken at 6:00 am, 12:00 pm, and 5:00 pm at three-day intervals. The same data collection was continued during the product storage period. Digital hygrometer model 8612 (Alnor) was used to measure the temperature and relative humidity of the atmosphere inside and outside the storage structure.

The cooling efficiency (η) was calculated according to [13]

$$\eta = \frac{Td - Tc}{Td - Tw} \times 100, \quad (1)$$

where Td is the dry-bulb temperature of the ambient air, Tw is the wet-bulb temperature of the ambient air, and Tc is the dry-bulb temperature of the air in the cooling chamber.

2.6.2. Fruit Storage Period. The storage period was determined according to Tabassum et al. [14], the days in which the fruit stayed in good condition. Days for attaining a loss of 25% weight were considered to calculate storage life.

2.6.3. Weight Loss. Weight loss measurement percentage of white sapote fruit was performed at 0, 3, 6, 9, 12, 15, and 18 days, according to Kaur [15]. Each fruit's mass was measured using a digital balance model (YP-10002, China).

$$WL\,(\%) = \left(\frac{initial\,weight - final\,weight}{initial\,weight}\right) \times 100. \quad (2)$$

2.6.4. Firmness. The degree of firmness was determined following the procedures described by Kitinoja and Kader [16]. The FT-327 model penetrometer was used to measure firmness.

2.6.5. Total Soluble Solids and pH. The total soluble solid (TSS) was determined using a hand refractometer, according to Waskar et al. [17], and the pH value of white sapote juice was determined with a portable digital pH meter (model, pH-016, China).

2.6.6. Total Titratable Acidity. The titratable acidity (TA) of white sapote fruit was measured as Khan et al. [18] described by titrating the juice against 0.1 N NaOH and calculated using

$$\mathrm{TA}\,(\%) = \frac{d \times 0.1\,\mathrm{N\,NaOH} \times 0.64 \times c}{a \times b} \times 100, \quad (3)$$

where $\mathrm{TA}\,(\%)$ is the titratable acidity, d is the average burette reading for sample, a is the weight of sample, b is the volume of aliquot taken for examination, and c is the volume made with distilled water.

2.6.7. Ascorbic Acid. The ascorbic acid concentration of white sapote fruit was titrated according to Meaza et al. [19] and calculated using

$$Ascorbic\,acid\,\left(mg\,100\,g^{-1}\right) = \frac{titre \times dye\,factor \times volume\,made\,up}{volume\,\mathrm{of}\,sample} \times 100\%. \quad (4)$$

2.7. Statistical Analysis. The data were analyzed by a factorial test with a two-way analysis of variance (ANOVA) using a Statistical Analysis System (SAS version 9.0) tool.

3. Results and Discussion

3.1. Temperature and Relative Humidity. The experimental area's ambient air condition varied from 24.5 to 32°C and 23 to 54.6% for temperature and RH, respectively. The air velocity of this area is 16.3 km/h. Dire Dawa is one of the hottest areas in Ethiopia. So the high temperature of the area can enhance the evaporation of water and can hold more water vapor. Figures 2(a) and 2(b) explain the changes in dry bulb temperature within and outside of the ZECC. Sensible heat changes to latent heat and causes the evaporation of water while cooling inside the chamber; due to the evaporation of water, the surrounding RH becomes high [20].

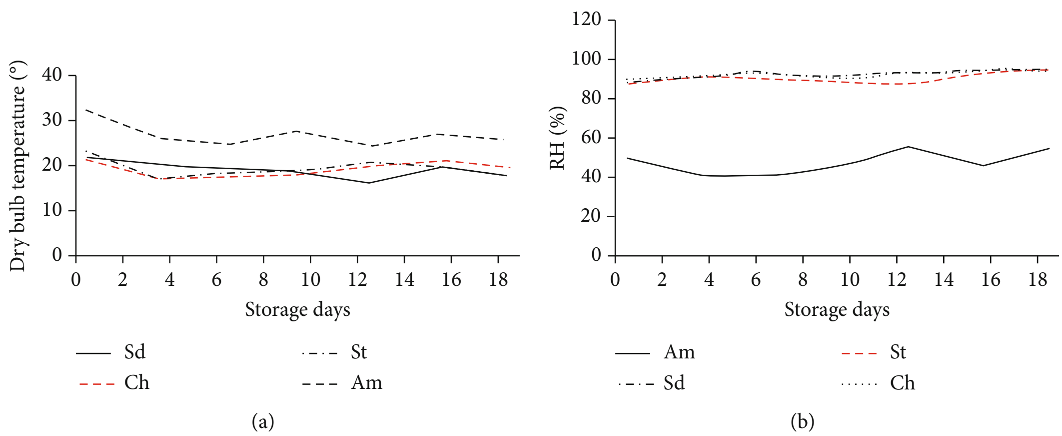

FIGURE 2: (a) Dry bulb temperature of the ambient air (Am) and ZECC storage with different porous materials (Sd = sand, St = sawdust, and Ch =charcoal). (b) The RH of the ambient air (Am) and ZECC storage with different porous materials (Sd = sand, St = sawdust, and Ch =charcoal).

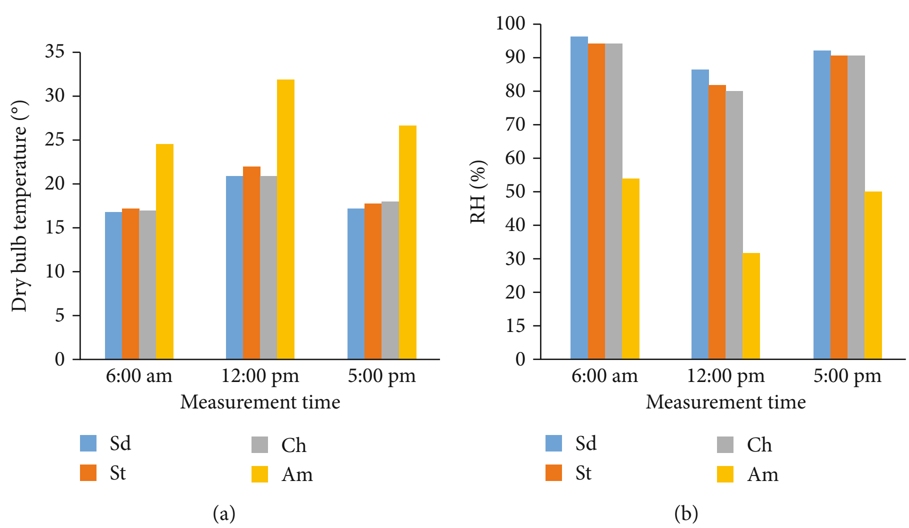

FIGURE 3: (a) Daytime effect on dry-bulb temperature and ZECC with different porous materials (Sd = sand, St = sawdust, and Ch = charcoal). (b) Daytime effect on relative humidity (RH) of ambient (Am) and ZECC with different porous materials (Sd = sand, St = sawdust, and Ch = charcoal).

Continuously watering ZECC is important to keep it cool and increase the ZECC efficiency.

The lowest temperature inside ZECC was observed in ZECC filled with sand, and the highest dry bulb recorded for ZECC filled with sawdust was 16.4 and 22.9°C, respectively (Figure 2(a)). The maximum temperature differences between ZECC and ambient temperature were 10.2°C. This value was recorded for ZECC filled with sand, whereas the minimum difference was 6°C and recorded for ZECC filled with charcoal and sawdust. Temperature reduction and increment in relative humidity are different among the three cooling pads due to the thickness of the cooling pad contributing to its water-holding capacity and surface evaporation. According to Singh and Satapathy [21], partial wood with 7 mm thickness provides the highest surface water evaporation per minute. Heat and mass transfer increase in the evaporative cooling chamber with cooling pad thickness due to the high contact area between air velocity and water and also high residence time between them. According to [22], large pad thickness resulted in a larger water evaporation rate and temperature drop.

Daytime has its own influence on dry bulb and RH, as shown in Figures 3(a) and 3(b), respectively; the highest dry bulb was recorded at 6 pm while lower dry bulbs were measured during morning and evening. The same applies to RH; the lowest was measured at 6 pm. Dirpan et al. [10] describe daylight's effect on ZECC efficiency; the outside temperature is higher than the inside, particularly in the daytime. According to Workneh [23] and Khalid et al. [24], ZECC can lower the daily maximum dry bulb.

The recorded average temperature difference between inside and outside ZECC is corroborated with the report of Khalid et al. [24], who reported that the average temperature difference between ZECC and outside was 9°C. As a result, it shows us that the reduction in temperature inside the chamber plays a great role in postharvest loss reduction.

Temperature is the most important factor influencing fruit's storability because temperature accelerates ethylene production and respiration [17]. White sapote fruit is climacteric and produces high ethylene, shortening the fruit life. Creating and maintaining optimum storage temperature is key to reducing these internal activities of white sapote fruit. So, using ZECC storage provides low temperature, keeping the fruit well and lessening the activities.

This research is in line with the work of Basediya et al. [22], who demonstrate that ZECC made from bricks can reduce the temperature by 10-15°C when the ambient temperature is above 35°C. The ambient relative humidity is below 40%. Another study by MIT D-Lab and the World Vegetable Center in Mali indicated that when ambient relative humidity is below 40%, brick ZECC can reduce average and peak daily temperatures by 5-7°C. Temperature variations in the ZECC chamber were 3.1 to 6.5°C during the fruit storage period, strengthening the current finding. One advantage of ZECC is a low-temperature variation inside the chamber. High temperature variation around the storage increases and enhances the activities of some enzyme like polygalactose and polymethyleasterase, which affect fruit firmness. This made ZECC appropriate storage for perishable products [8, 10, 24–27].

In the first week, the RH of ZECC filled with sand, sawdust, and charcoal was 62.0, 60.0, and 57.6%, respectively (Figure 3(b)). The cooling improved as watering continued, and fluctuation of temperature and RH decreased during testing time. The average RH of the ZECC with different absorbent materials was 88.2, 85.1, and 87.6% for sand, sawdust, and charcoal, respectively (Figure 2(b)). During storage, fruit loss water at low RH causes wilting on the fruit, and high RH around the storage reduces such quality losses. Thus, the quality of white sapote fruit was maintained due to high RH and low dry bulb inside ZECC. These results agreed with the report of Mitra et al. [28], who stated that the relative humidity inside ZECC remained between 73 and 92%. Also, Workneh [23] reported that the evaporative cooler chamber air temperature decreased from 36.0 to 16.4°C, while RH increased from 25.4 to 91.1%.

3.2. The Cooling Efficiency of Zero Energy Cooling Chambers. The performance evaluation of ZECC with different porous materials was carried out in terms of temperature drop (Table 1) and change in the RH depending on the atmospheric condition. The decrease in temperature and increase in RH inside ZECC, concerning ambient temperature conditions, were due to evaporation through porous materials. This evaporation depended on the thickness of the porous materials and was used to calculate the cooling efficiency of ZECC with different absorbent materials. The calculated cooling efficiency of ZECC with sand, sawdust, and charcoal is presented in Figure 4. As we can see from the figure, in the first week, the cooling efficiency of ZECC with different porous materials was low and increased in progress; in the fourth week, it reached its peak and declined after the produce was stored. The average cooling efficiencies of ZECC filled with sand, sawdust, and charcoal were 91.22, 87.95, and 87.82%, respectively. This result agreed with the work of Khalid et al. [24], who demonstrated that the cooling efficiency of the cool chamber remained between 84 and 97% with an average value of 90%. Ahmed et al. [2] studied three different cooling pads' performance and reported that the sliced wood pad gave a lower temperature with 90% cooling efficiency compared to the celdek and straw pad.

Table 1: The average drop in temperature.

S. no.	Type of pads	Drop in temperature (°C) Maximum	Minimum
1	Sand	10	6.0
2	Sawdust	9.1	6.0
3	Charcoal	10.2	6.3

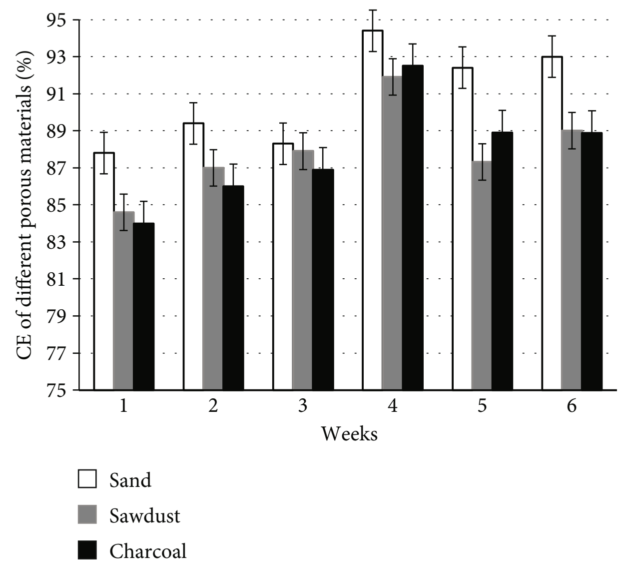

Figure 4: The cooling efficiency of ZECC storage as affected by the type of different absorbent materials.

3.3. Storage Period (Days). Table 2 describes the effect of different types of porous materials on the storage period of white sapote fruit. The result shows that keeping white sapote fruit in ZECC maintains the quality of the fruit. Temperature is a driving factor that regulates respiration rate and metabolic activity inside the fruit cell; when storage temperature becomes higher, ethylene production increases; thus, respiration rate is accelerated. The transpiration rate is also higher at high temperatures, and this leads the fruit to quality loss and deterioration of the fruit. Temperature management is one way to lessen the change and to length the fruit life. A low transpiration rate slows down the water loss, shrivelling, and wilting of the fruit, leading to quality and quantity losses. The shortest shelf life was recorded in a sample stored at ambient temperature. According to Hassan et al. [29], keeping this fruit between 19-21°C and 85-90% RH prolonged the storability of the fruit for up to 2-3 weeks. This research finding partially agreed with the discovery of Hassan et al. [29], who reported that the storability of white sapote was five days at room temperature and 15 days at

Table 2: Storage period of white sapote fruit stored under ZECC as influenced by different porous materials and ambient temperature.

S. no.	Treatments	Storage periods (days)
1	ZECC with sand	18
2	ZECC with sawdust	18
3	ZECC with charcoal	18
4	Ambient temperature storage	12

10°C. According to Dirpan et al. [10], metabolic activity is reduced, and the ripening process is delayed, extending the fruit's shelf life because of the conditions provided by ZECC. This researcher also indicates that the life of mango fruit is well kept in ZECC.

3.4. Physiological Weight Loss (PWL). Respiration and transpiration are the fundamental factors which drive weight loss in fruit. The process of respiration resulted in the evaporation of H_2O and CO_2 generation [10, 30]. The data presented in Table 3 indicated that a significant difference was observed due to storage conditions. Storage temperature and weight loss are closely related. The weight of fruit stored at low temperatures was better maintained due to low respiration and transpiration rate. Temperature and RH are the two main factors affecting fruit quality. There was a gradual weight loss in all fruits stored inside ZECC with different porous materials and at ambient, but the loss was significantly ($P \leq 0.05$) higher for fruit stored at ambient temperature. Similar observation was stated by Mishra et al. [30] with his findings; mango fruit stored inside ZECC showed lower PLW than those stored at ambient temperature. Fruit stored at ambient temperature lost 12.05% of the initial weight on the sixth day of the storage period compared to the 3.91 and 4.43% of the fruits stored in ZECC with different porous materials. The 12% weight loss was recorded by fruits in ZECC on day twelve, on average, six days later (Table 3). This result is in line with [12, 26], who describe that tomato fruit stored at ambient temperature showed 5.4% weight loss after seven days of storage period while tomatoes stored inside ZECC showed 5.35% after 16 days of storage period. These findings agree with those obtained by Perez-Gago et al. [31] and Fagundes et al. [32], who noted that the storage temperature and weight loss of fruit have a direct relationship. Dirpan et al. [33] also reported that mango fruit stored at ambient temperature showed the highest weight loss (20.3%). Another researcher, Singh et al. [34], indicated that combining ZECC treatment with other treatments like $CaCl_2$ is the most effective treatment for retaining fruit weight.

3.5. Changes in Firmness. Based on the result presented in Table 4, storage duration strongly affected the firmness of white sapote fruit. During fruit storage, firmness declined progressively, but it was sharp for the control sample when compared to ZECC samples; Sharma et al. [35] reported similar observations. Significant ($P \leq 0.05$) differences were noted in the firmness values of samples stored in ZECC with the three different pad materials, on days 3 and 6, with sand performing better than the other two. On day three, the values were 79.39, 76.14, 72.67, and 65.68 N for samples stored in ZECC with sand, sawdust, and charcoal pad materials, respectively. On day six, the values decreased to 74.32, 65.90, 66.71, and 44.06 N, respectively. After that, the values showed no difference ($P > 0.05$) among them despite the reduction as the storage days increased. It can be said that the three pad materials performed well equally for the longer storage times. The differences in the early days can be explained by the differences in cooling efficiencies of the porous materials exhibited during those periods, which depended on their water-holding capacities. The finding is similar to Baloch et al.'s [36] report. According to this researcher, mango fruit experiences loss of firmness due to cell wall degradation by pectinesterase and polygalacturonase during ripening. Fruit softness increases with the progression in ripening due to cell wall breakdown and loss of water [37]. This loss is reduced for samples stored inside ZECC due to low temperature. Low temperature reduces the transpiration process. Thus, the loss of firmness was reduced. This finding is similar to the result of Sarkar et al. [38], who stated that the higher firmness maintained in fruit stored under ZECC is due to the cooling effect of ZECC with low temperature and high relative humidity.

3.6. Change in Total Soluble Solid. As indicated in Table 5, the total soluble solid (TSS) value increased gradually throughout the storage periods, regardless of storage conditions. Hoa et al. [39] reported that the TSS values of three mango varieties increased from 9.0 to 17.5% during the storage period. Significantly, lower TSS values were observed due to ZECC storage compared to samples stored at ambient temperature. During the ripening stage, fruit TSS becomes higher due to the conversion of starch into disaccharide and simple sugar. This conversion is accelerated highly at high temperature [40]. Different absorbent materials used in ZECC (sand, sawdust, and charcoal) did not cause significant ($P > 0.05$) differences in TSS of white sapote fruit during the storage period of eighteen days. However, ZECC storage had caused an important ($P \leq 0.05$) difference in total soluble solids compared to the sample stored at ambient temperature. Storage period and storage temperature have a direct relationship with an increment of TSS, and low temperature can restrict enzymatic activities. TSS of white sapote fruit stored at room temperature increased from 12.88 at 0 days to 19.07% on the last storage period (day 12). This value was equivalent to those measured five days later for white sapote fruit stored inside ZECC, with values of 19.15, 18.95, and 19.17% for sand, sawdust, and charcoal pad materials, respectively. This result agreed with Dirpan et al. [10], who indicated that during the ripening stage of mango fruit, there is a rise in reducing sugar and a decline in acidity; the process is slower in ZECC storage. The low temperature in ZECC delayed the TSS value by five days. At the end of the storage time, the TSS values of samples stored inside ZECC with absorbent materials of sand, sawdust, and charcoal were 20.41, 20.70, and 20.71%, respectively. This research is similar to the finding of Ishaque et al. [41] and Tefera et al. [42].

Table 3: Effect of type of different porous materials on weight loss (%) of white sapote fruit.

Porous materials	Storage period (days) 3rd	6th	9th	12th	15th	18th
Sand	1.93 ± 0.60^b	3.91 ± 0.76^b	5.45 ± 0.60^b	12.20 ± 1.28^b	13.52 ± 1.76^a	16.91 ± 0.95^a
Sawdust	1.84 ± 0.70^b	3.91 ± 0.43^b	4.93 ± 0.71^b	12.24 ± 0.63^b	13.23 ± 1.69^a	17.02 ± 0.86^a
Charcoal	2.11 ± 0.13^b	4.43 ± 0.77^b	6.09 ± 0.73^b	12.25 ± 1.07^b	14.07 ± 3.07^a	17.21 ± 2.40^a
Ambient	3.24 ± 0.12^a	12.05 ± 0.66^a	17.10 ± 1.91^a	19.33 ± 0.26^a	—	—
LSD	0.87	4.12	1.88	3.69	1.98	2.04
CV	15.64	13.86	15.63	9.30	14.85	9.23

CV = coefficient of variation; LSD = least significance difference. Similar superscript letters letter have no significant difference.

Table 4: Effect of type of porous material used in ZECC on firmness (N) of white sapote fruit.

Porous materials	Storage period (days) 3rd	6th	9th	12th	15th	18th
Sand	79.39 ± 1.49^a	74.32 ± 1.40^a	59.41 ± 1.13^a	47.17 ± 0.85^a	30.26 ± 0.84^a	13.08 ± 0.28^a
Sawdust	76.14 ± 0.87^b	65.90 ± 1.99^b	58.07 ± 1.01^a	46.99 ± 0.85^a	31.77 ± 0.95^a	11.97 ± 0.86^a
Charcoal	72.67 ± 0.73^c	66.71 ± 1.07^b	58.07 ± 1.08^a	47.08 ± 0.85^a	30.35 ± 0.89^a	12.46 ± 0.29^a
Ambient	65.68 ± 1.22^d	44.06 ± 2.64^c	40.85 ± 3.21^b	33.02 ± 0.50^b	—	—
LSD	2.84	5.47	5.20	3.92	5.10	3.11
CV	4.01	9.06	9.99	11.55	8.15	19.89

CV = coefficient of variation; LSD = least significance difference. Similar superscript letters letter have no significant difference.

Table 5: Effect of type of porous materials used in ZECC on TSS% of white sapote fruit.

Porous materials	Storage period (days) 3rd	6th	9th	12th	15th	18th
Sand	13.82 ± 0.64^b	13.96 ± 0.71^b	16.26 ± 0.64^b	17.60 ± 0.71^b	19.15 ± 0.82^a	20.41 ± 0.40^a
Sawdust	13.96 ± 0.76^b	14.31 ± 0.60^b	16.56 ± 0.83^b	17.93 ± 0.64^b	18.95 ± 0.99^a	20.70 ± 0.68^a
Charcoal	13.71 ± 0.58^b	13.77 ± 0.62^b	16.04 ± 1.07^b	17.99 ± 0.72^b	19.17 ± 0.95^a	20.71 ± 0.56^a
Ambient	14.95 ± 0.51^a	16.65 ± 1.60^a	18.39 ± 1.29^a	19.07 ± 0.49^a	—	—
LSD	0.50	0.74	0.90	0.73	0.60	0.71
CV	3.71	5.20	5.55	3.65	3.23	2.77

CV = coefficient of variation; LSD = least significance difference. Similar superscript letters letter have no significant difference.

3.7. Change on pH. The pH data of the stored fruits are presented in Table 6 to show the effect of the type of porous materials on the pH. The initial pH value of white sapote fruit recorded on day one was 5.0. This result followed the discovery of Yahia and Gutierrez-Orozco [43], who reported that the pH value of white sapote fruit at harvest was 5.1. On days 3 and 6, significant ($P \leq 0.05$) differences were observed due to storage conditions and due to different absorbent materials used in the ZECC. This result is corroborated by the result of Sarkar et al. [38]. The values ranged from 5.05 to 5.41 for the two storage periods. The pH values increased (5.36 to 5.57) on day 9 with 5.37, 5.36, and 5.41 with no statistical difference ($P > 0.05$) for samples stored under ZECC with sand, sawdust, and charcoal pad material, respectively, and 5.57 for those stored under ambient conditions. This is due to fruit acids' ripening as respiration substrates [10]. The pH values continued to increase in the rest of the storage period until day 18, showing no statistical difference ($P > 0.05$) among samples stored under ZECC with different pad materials. The pH increased as the storage period advanced, but the rate of change was sharp in the case of control (ambient) samples rather than samples stored inside ZECC. The same observation was reported by Baloch et al. [36], who indicates that ZECC slower respiration and metabolic activities, thereby delaying the ripening process and consequently lengthening the fruit life due to low temperature and high RH conditions inside ZECC.

3.8. Total Titratable Acidity. The data of total titratable acidity (TTA) as influenced by storage condition is presented in Table 7. The initial total titratable acidity of white sapote was 0.44%. This result is corroborated by the finding of [26], who indicated that the titratable acidity of white sapote fruit was 0.34 and 0.39% in two successive seasons. Significant ($P \leq 0.05$) differences were observed in ZECC due to a different cooling pad. 0.26% was observed for white sapote samples stored at ambient temperature on the third day of the storage period. The values continued to decline until it was

Table 6: Effect of type of porous materials used in ZECC on pH of white sapote fruit.

Porous materials	Storage period (days)					
	3rd	6th	9th	12th	15th	18th
Sand	5.05 ± 0.19^{c}	5.20 ± 0.14^{b}	5.37 ± 0.12^{b}	5.50 ± 0.11^{b}	5.62 ± 0.137^{a}	5.78 ± 0.06^{a}
Sawdust	5.15 ± 0.15^{b}	5.19 ± 0.33^{b}	5.36 ± 0.23^{b}	5.44 ± 0.14^{b}	5.60 ± 0.09^{a}	5.73 ± 0.09^{a}
Charcoal	5.23 ± 0.16^{bc}	5.29 ± 0.20^{a}	5.41 ± 0.15^{b}	5.45 ± 0.09^{b}	5.67 ± 0.173^{a}	5.83 ± 0.16^{a}
Ambient	5.33 ± 0.09^{a}	5.41 ± 0.17^{a}	5.57 ± 0.18^{a}	5.66 ± 0.07^{a}	—	—
LSD	0.10	0.15	0.13	0.13	0.11	0.15
CV	1.98	2.87	2.38	2.0	1.97	1.92

CV = coefficient of variation; LSD = least significance difference. Similar superscript letters letter have no significant difference.

Table 7: Effect of type of porous material used in ZECC on TA (%) of white sapote fruit.

Porous materials	Storage period (days)					
	3rd	6th	9th	12th	15th	18th
Sand	0.30 ± 0.04^{ab}	0.23 ± 0.06^{a}	0.22 ± 0.04^{ab}	0.21 ± 0.03^{a}	0.22 ± 0.02^{a}	0.21 ± 0.02^{a}
Sawdust	0.32 ± 0.06^{a}	0.31 ± 0.04^{b}	0.24 ± 0.06^{a}	0.22 ± 0.02^{a}	0.22 ± 0.01^{a}	0.21 ± 0.01^{a}
Charcoal	0.31 ± 0.05^{a}	0.23 ± 0.01^{a}	0.20 ± 0.02^{b}	0.21 ± 0.03^{a}	0.22 ± 0.01^{a}	0.21 ± 0.01^{a}
Ambient	0.26 ± 0.04^{b}	0.22 ± 0.02^{c}	0.17 ± 0.02^{c}	0.15 ± 0.02^{b}	—	—
LSD	0.04	0.08	0.03	0.03	0.04	0.01
CV	12.32	11.16	16.16	11.45	5.36	4.91

CV = coefficient of variation; LSD = least significance difference. Similar superscript letters letter have no significant difference.

Table 8: Effect of type of porous material used in ZECC on ascorbic acid (mg/100 g).

Porous materials	Storage period (days)					
	3rd	6th	9th	12th	15th	18th
Sand	33.54 ± 1.31^{a}	30.79 ± 1.35^{a}	30.87 ± 1.74^{a}	29.82 ± 0.48^{a}	28.42 ± 1.01^{a}	26.78 ± 0.63^{a}
Sawdust	33.54 ± 1.05^{a}	31.36 ± 1.18^{a}	30.14 ± 0.87^{a}	29.74 ± 0.38^{a}	28.05 ± 1.14^{a}	27.36 ± 0.59^{a}
Charcoal	33.44 ± 1.18^{a}	30.75 ± 1.03^{a}	30.40 ± 1.47^{a}	29.69 ± 0.40^{a}	28.22 ± 1.10^{a}	27.30 ± 0.72^{a}
Ambient	32.29 ± 0.56^{b}	29.52 ± 1.17^{b}	28.65 ± 0.43^{b}	27.46 ± 0.29^{b}	—	—
LSD	0.87	0.88	0.75	0.47	0.85	0.83
CV	2.54	4.54	4.13	1.25	3.09	8.45

CV = coefficient of variation; LSD = least significance difference. Similar superscript letters letter have no significant difference.

completely wasted by day 15. Baloch et al. [36] reported a similar result. Reduction in acidity during the storage period is due to the consumption of organic acid in pyruvate decarboxylation at the repining stage; the TTA of white sapote fruit declined through the storage time. This result follows the report of Mohan et al. [44]. The values for the stored samples were 0.30, 0.32, and 0.31% citric acid for storage with sand, sawdust, and charcoal, respectively, with no statistical difference ($P > 0.05$). The values decreased the following day and continued to do so until the storage period's end, whereas all the values were 0.21%. The majority of these data did not show statistical differences ($P > 0.05$) attributed to the different absorbent materials but were statistically ($P \leq 0.05$) higher than values of samples stored at ambient conditions. This result is following other researchers' work. Hassan et al. [29] stated that total titratable acidity significantly decreased during the last time of the storage period. White sapote samples kept at ambient temperatures showed high decreases in total acidity. This is due to malic acid's degradation while malic acid glyoxylase increased during ripening. Generally, acidity levels lowered when the ripening process advanced [45]. This is due to the catabolic effect of the natural acid in fruit.

3.9. Changes in Ascorbic Acids (AsA). White sapote fruit's initial ascorbic acid content was 34.21 mg per 100 g, while ascorbic acid leached out as the storage period advanced. Initially, the loss of ascorbic acid content was slow. It increased with the storage period due to phenoloxidase and ascorbic acid oxidase enzymes during storage (Table 8), showing a change in ascorbic acid. The values of fruit samples kept at ambient temperature were significantly ($P \leq 0.05$) lower than those stored under ZECC, with values ranging from 32.29 on day 3 to 27.46 mg/100 g on day 12. This finding is strengthened by Dirpan et al. [10], who stated that the mango fruit stored inside ZECC showed a higher value of ascorbic acid. This might be due to low temperature and high relative humidity lessening the respiration rate and undesirable metabolic activities; as a result, the process of ageing is reduced; the finding is also similar with lal Basediya et al. [22]. The reduction of ascorbic acid responsible for quality change occurred during the storage of foods [46]. Ascorbic acid is degraded at high storage temperatures [22, 45]. The values of samples stored under ZECC ranged from 33.54 on day 3 to 26.78 mg/100 g on day 18, with no statistical difference ($P > 0.05$) attributed to the different absorbent materials. According to Mohan et al. [44], low temperatures reduce oxidation by slowing internal activities during the storage period. This is in agreement with this finding. As described by Yaman and Bayoındırlı [47], pH value increased during storage and adversely affected vitamin C due to the oxidation process.

4. Conclusions

White sapote (*Casimiroa edulis* L.) fruit is very perishable, has a short storage life due to a high respiration rate, and is highly perishable after harvest. The fruit is underutilized; it needs research and attention regarding improving food and nutrition security in Ethiopia and beyond. Hence, technologies, such as zero energy cooling chamber (ZECC), to extend the storage life of the fruit are critical. In this study, the performance of ZECC was tested using white sapote fruit, and a significant result was observed due to a reduction in temperature inside the ZECC chamber. The performance of three different cooling pads, viz., sand, sawdust, and charcoal, was tested. The average temperature reduction inside ZECC was 8.1°C. This slows down the respiration rate and lengthens the life of the fruit to 18 days with acceptable physiological quality. The temperature differences between ambient and ZECC with different cooling pads varied between 6.0 and 10.2°C. The average relative humidity (RH) of the ZECC with different absorbent materials was 88.2, 85.1, and 87.6% for sand, sawdust, and charcoal, respectively. This reduced the transpiration process, and the quality of white sapote fruit was maintained due to the high RH and low dry bulb. Cooling efficiency is governed by a drop in temperature and a change in RH. The tested ZECC showed good temperature reduction and gave high RH. The average cooling efficiencies of ZECC with different cooling pads, viz., sand, sawdust, and charcoal, were 91.22, 87.95, and 87.82%, respectively. Sand gave the highest CE due to high water-holding capacity, which increased evaporation rate while high cooling efficiency. All three cooling pads had good cooling efficiency, while sand was the highest. So, from the result, it can be concluded that it is possible to use one of the three cooling pads for evaporative coolers for smallholder farmers in arid and semiarid climates, such as Dire Dawa town and the region of Ethiopia.

Data Availability

All the derived data supporting the findings of this study are used in this manuscript.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Authors' Contributions

Hawi Tolera was responsible for the original draft, data generation, investigation, formal analysis, and writing of the draft manuscript. Solomon Abera was responsible for the project management, advising, data generation, formal analysis, and editing of the draft manuscript. Getachew Neme Tolesa was responsible for the project management, advising, data generation, formal analysis, drafting, and editing of the draft manuscript. Tigistu Belachew was responsible for the project facilitation, data generation, formal analysis, drafting, and editing of the draft manuscript.

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