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REGULAR ARTICLE

Performance evaluation of aluminum-in-pot evaporative cooler

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Abstract

Cooling applications by refrigeration and air-conditioning require electricity as a source of energy not abundantly available in sub-Saharan African countries. Post-harvest losses of vegetables are caused by poor storage facilities, poor transportation systems, and lack of processing facilities. The current study aimed to evaluate the performance of developed solar-powered Aluminium-in-pot evaporative coolers lined with clay and charcoal blends for the preservation of tomatoes. The evaporative cooler consisted of Aluminium pots inserted into an earthenware mould pot, and the space between the two pots filled with lining media of clay, charcoal, and blends of the two in different ratios. The dry bulb temperature of the ambient air, inner temperatures of the cooling chambers, and relative Humidity were measured using fresh tomatoes as a load for the coolers. The temperature variations of the coolers were recorded for fifteen consecutive days. It was found that the inner temperatures for the five evaporative coolers were significantly different from the dry bulb temperature of the ambient. The temperature of sample E had the lowest temperature range of 19.65 ˚C to 23.65 ˚C for the no-load test, 21.15 ˚C to 25.29 ˚C for the load–load-test (better boy), and 21.1 to 23.25 °C for the load test (Plum). The daily temperature in the coolers dropped significantly to a range of between 3.4 ˚C to 10.46 ˚C with a corresponding daily RH range of 30.93% to 39%. The variations in the efficiency of Sample E were found to be averagely 84% at no load, 72% when loaded with Better Boy and 77% when loaded with Plum tomatoes. The aluminium in pot evaporative cooler could be used for a short-term preservation of tomatoes in remote areas where electricity is not available.

Keywords

Aluminium-in-pot; Evaporative Cooling; Lining; Saturation Efficiency; Thermodynamics.

Introduction

Due to the ever-increasing population, global warming, and increasing standard of living of the world population, there is a continual increase in cooling demands for buildings, food storage, and dissipation of heat from devices (Li et al., 2024). Most of these cooling applications via refrigeration and air-conditioning require electricity as a source of energy, which causes an estimated 15% of all electricity consumption worldwide, and the electricity being generated worldwide produces 10% of greenhouse gases (Li et al., 2024). In the developing countries, apart from access to electricity, which is low, there are frequent power outages and a high cost of electricity (Nduhuura et al., 2021). An alternative to refrigeration and air-conditioning that requires electricity is evaporative cooling (EC).

EC is a process of mass and heat transfer whereby water evaporation cools the air, transferring a significant quantity of heat from the air to the water and lowering the air temperature (Hashim et al., 2022). It is an ancient method that is appropriate for both hot and dry climatic conditions because of the possibility of water vapour evaporation (Raza et al., 2021). It involves feeding water into a porous material, drawing hot, dry air over it, causing the water to evaporate, thereby increasing the moisture content of the air and lowering its temperature simultaneously (Hashim et al., 2023).

According to Defraeye et al., (2023), the temperature of products can be reduced as much as 3°C–10°C and their relative humidity inside the coolers increased up to 70%–100% using evaporative cooling. Thus, Fruits and vegetables can therefore be preserved for much longer thanks to the slower rate of food deterioration at lower temperatures and the decreased moisture loss. Basically, the two types of Evaporative cooling are Direct evaporative cooling (DEC) and Indirect Evaporative cooling (IDEC). Water vapours are released into the atmosphere during DEC, lowering the process air temperature and raising the process air humidity ratio. This cooling process is ideally isenthalpic and its cooling limit is equivalent to the wet bulb temperature at 100% relative humidity (Raza et al., 2021). IDEC involves the chilling of dry air with cool, humid air produced by evaporation. The enclosed chamber is then cooled through a heat exchanger (Patel et al., 2022).

Tomatoes are highly rich in minerals, vitamins, essential amino acids, sugars, dietary fibres, vitamin B and C, iron, and phosphorus (Ouattara & Konate, 2024). According to available statistics, worldwide production of tomatoes reached

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an annual output of 186.1 million tonnes in 2022 (Aksoy & Kaymak, 2024). In line with this, Nigerian total tomato production has reached an annual output of about 4 million tonnes (Ajenifujah-Solebo et al., 2025). Sadly, most fruits and vegetables were rendered unfit for consumption due to spoilage after being harvested. Nigeria's post-harvest losses of fruits and vegetables amount to 35-45% of the annual production (Osabohien, 2024). Globally, between harvesting and retailing of farm produce, about 14% of food is lost, while in households, food services, and retail, it is estimated that 17% of food is wasted (Xu et al., 2022).

According to Kaur & Watson (2024) and Xu et al. (2022), most of these losses were due to a lack of or inadequate storage facilities and electricity outages. This has resulted in huge losses of valuable food, even when the minimum food requirement of the population is yet to be met. The Food and Agriculture Organisation (FAO) has reported that Nigerian vegetables have not been able to meet world standards because of poor post-harvest handling (FAO, 2011). Therefore, it is not only important to grow more but also imperative to preserve properly what has been grown in a better and less costly way. Unlike the convectional earthen pots used traditionally for preservation and cooling, the evaporative cooler pot, is made of clay as the outer materials, and aluminium as the inner material. An outer unglazed clay material is very essential for pot because of its good porosity which enables water to easily evaporate (Ibrahim et al., 2024). However, inner aluminium materials offer a superior heat transfer and remove heat quickly from the tomatoes in the inner chamber and this heat is transferred to the outer wall of the aluminium pot where it is dissipated into the lining material and the heat removed by evaporation.

Hussain et al. (2022) developed a method to evaluate the parameters affecting the direct and indirect evaporative cooling systems. The method developed involved coupling Gaussian process regression algorithm for hyperparameter optimisation with a deep neural network. Results of the study showed that the system depends on meteorological parameters such as dry and wet bulb temperature, dew point temperature relative humidity and enthalpy. It was also found that parameters such as area and inlet velocity have no noticeable effect on the system.

Abaranji et al. (2025) investigated experimentally the direct evaporative cooling in vermicompost which is water storage medium that was used to replace conventional air coolers, the pump and the electric motor. The investigation compares three dissimilar types of masses and the two methods of water supply. The results of the study showed that the masses of 500g and 1000g produced an effectiveness of 82% with continuous water supply, while 1500g produced an effectiveness of vermicompost of 85% with initial water supply. The result also showed that the lower mass of continuous supply of water is better for cooling in spaces that are small, while a large mass of initial water supply is better for cooling in large spaces. It concluded that 69.43% of energy savings was achieved by neglecting the use of pumps and motors.

Rashwan et al. (2025) studied experimentally the performance of a volcanic stone pad used for an evaporative cooling system. The parameters employed in the experiments were different pad thicknesses, different water addition rates, and different air speeds. Results from the study showed that the 10 cm thick pad gave better performance in comparison to the 15 cm across all the different air speed and water addition rates considered. The 10 cm thick pad was able to achieve a higher cooling efficiency rate of 82% at a water addition rate of 2.4 litres/m /m (min) and an air speed of 1.75 m/s, while the cooling efficiency for the 15cm thick pad was 64% for the same condition.

However, the 10 cm thick pad was found to consume more water than the 15 cm pad. The work concluded that volcanic stone pads can provide similar cooling performance equivalent to that of commercial cellulosic pads but have additional advantages of resilience, less maintenance, and resistance to biological degradation. Ndukwu et al., (2025) evaluated the hygrothermal effects on the evaporative cooling of fruits with waste palm fruit fibre pads. The experimental direct evaporative cooling (EVC) was conducted at an air delivery velocity of 4 m/s, air delivery temperature that ranged between 25.8 °C and 20.2 °C, and air relative humidity of between 85.6% and 96.8 %. Results of the study showed that the EVC system reduced the inlet temperature by 10 °C and the cooling efficiency and cooling capacity obtained ranged from 77% to 98.8 % and 0.73 and 2.52 kW, respectively.

Little attention has been paid to the utilisation of metals such as aluminium as the inner pot material in evaporative coolers in literatures. This material is lighter, more hygienic, more durable and a better heat transfer material than the traditional clay pot that has been employed as inner material in the past. The current research aims to evaluate the performance of an Aluminium in pot evaporative cooler which utilises clay, charcoal, and their blends as lining materials.

Materials and Methods

Place of Study

The experimental rig was set up outdoors, in a dry, ventilated space at the back of the Department of Mechanical Engineering, Faculty of Engineering and Technology, University of Ilorin, Ilorin. Ilorin is the capital city of Kwara State, Nigeria. It is located on latitude 8.4799°N and longitude 4.5418°E, marking a divide between the southern forest Zone and the Northern grassland of Nigeria.

The climate of Ilorin is categorised by both wet and dry seasons. The experiment was conducted between November and January, with ambient temperatures ranging from 33 °C to 34 °C, while ambient temperature varied between 34 °C and 53 °C from February to April (Ayanshola et al., 2024; Ifabiyi et al., 2019). The month of November to February is generally categorised as the harmattan seasons with very low relative humidity typically around 15%-40% (Sufiyan et al., 2020).

The climate characteristics is of dry air with cooler mornings and evenings as a result of north-easterly winds from the Sahara Desert reducing the moisture in the air. The mean monthly temperatures are very high, varying from 25 °C to 28.9 °C. The mean monthly temperature ranges from 25 °C to 28.9 °C, with an average of five hours of daily sunshine. The total annual rainfall in the area is approximately 1200 mm (Ayanshola et al., 2024; Yahaya et al., 2018). Figure 1 depicts a map of Nigeria showing Kwara state and the study area.

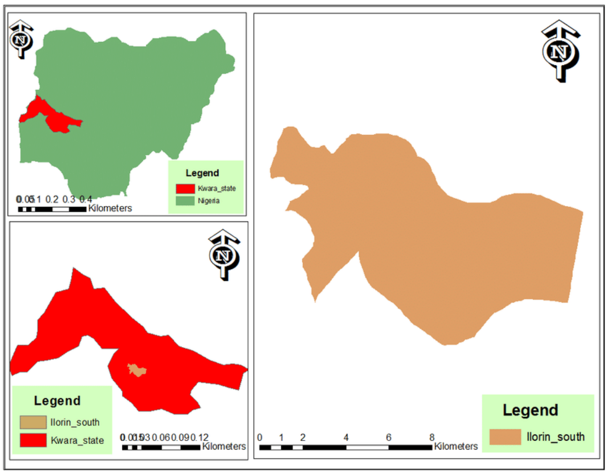

Figure 1. Map of Nigeria showing Kwara state and the study area (Ifabiyi et al., 2019).

Material Selection

The materials used in this study include clay and Aluminium for chamber materials, clay and charcoal for lining materials, glass fibre for lagging materials and other materials. The clay was collected from the Okelele pottery area, Ilorin East local government area of Kwara State. Clay is a naturally occurring mixture made up primarily of clay minerals and a few other substances. It is flexible when moist but hard when dried or burnt (Mukherjee, 2013). Their stable thermal, mechanical, and fire resistance properties make them excellent choices for large-scale devices (Lan et al., 2021). However, its thermal conductivity and the temperature it can withstand varies depending on many factors such as porosity. Research have shown that clay from this same location has mainly concentration of alumina-silica and alumina of concentrations 47.30-58.50% and 32.75-34.30% respectively (Shuaib-Babata et al., 2019). It is also having a moisture content that is between 21.00-33.00%, apparent porosity of 21.00-37.00% and bulk density of 1.99 - 2.87 g/cm^3.

Charcoal material is a key component of the lining that can affect the cooling rate of the evaporative coolers because of its microporosity. The charcoal was sourced commercially from Ilorin area and has a grade size of between 15mm-80mm. Depending on the origin of the charcoal, it has a thermal conductivity of 0.07 W/mK, bulk porosity of about 61% and bulk density of 184 kg m^{-3}(Defraeye et al., 2024). Aluminium sheet material was procured at a local Aluminium market in Ilorin. For the current study, aluminium sheet metal of 1mm thickness was utilised for the construction of the inner storage chamber. It was chosen due to its high thermal conductivity and ability to retain the freshness of stored products like tomatoes. It has a thermal conductivity of 237 W/mK and a density of 2.7 g/cm^3 which is corresponding to a third of the densities of steel (Zhang & Li, 2023). The lagging materials are utilised to reduce the effect of radiative heat transfer that could be gained from direct sunlight. For the current work, the thermal insulator used was fibreglass based on the low thermal conductivity it possesses (0.04 W/m°C).

Methodology

Each of the five cooling chambers were made from clay into an outer porous earthenware pot, and inner container of square shapes made of Aluminium. The five Aluminium containers were separately inserted inside each of the larger clay pots, and the inter-spaces between them were filled with either clay, charcoal, or a clay-charcoal blend of lining material with a 50 mm gap, and a piping system was connected to ensure the supply of water to the lining media in the evaporative cooler. The cooler volumetric capacity is 0.008m^3. The interspace between Aluminium and the clay pot was filled with varying percentages of lining material as shown in Table 1. The control tomatoes samples were kept under normal ambient temperature and humidity to establish a baseline for comparison for tomatoes kept in evaporative coolers.

Table 1. Percentage mix ratios of lining media samples

	Materials (%)	
Sample	**Clay**	**Charcoal**
A	100	0
B	72	28
C	50	50
D	28	72
E	0	100

A shed was constructed to cover the rig as shown in Figure 2. Figure 3 shows the schematic diagram of the Aluminium in-pot evaporative cooler. The shed was built under the *Butea monosperma* (Flame of the Forest) tree to provide additional shade. The lining media of Aluminium in-pot evaporative cooler were constantly wetted with an equal volume of water two times daily in the morning and evening. A solar panel supplies power to suction fans on top of each sample. This helps to remove air from each of the pots so as to control the level of humidity in the coolers and also to help in increasing the drying rate of water which increase the rate of cooling. Too high humidity prevents moisture loss in the tomato samples but it also creates condensation on tomatoes skin samples which accelerates growth of moulds and microbes (Umeohia & Olapade, 2024). This is undesirable because it leads to spoilage of the tomatoes. While passive cooling can easily lead to too high humidity, active cooling through the use of extractor tend to addresses this lapses.

Figure 2. Photograph of the experimental rig.

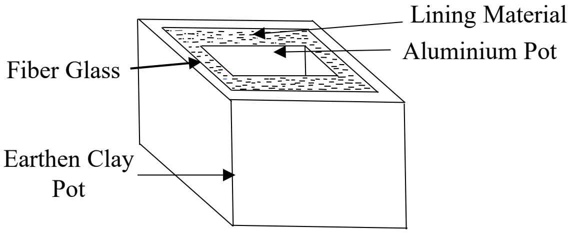

Figure 3. Schematic Diagram of the Aluminium in Pot Evaporative Cooler.

Theory and basic principle of evaporative cooling system

It has been established that vaporisation is an endothermic process which points to water needing thermal energy to change its state from liquid to vapour (Chemin et al., 2018). However, this energy must be extracted from somewhere.

This emphasise the core idea behind evaporative cooling which is that water absorbs heat from air and the environment, causing it to change from liquid to vapour thereby converting sensible heat into latent heat of vaporisation (Hashim et al., 2022). The implication is that the energy that has been extracted from a particular location will lead to a reduced level of such energy at that location.

Other researchers such as Kalsia et al., (2023), explained evaporative cooling to be based on heat and mass transfer method that employs the principle of evaporation of water thereby transferring heat from air to water and resulting in the reduction of the air temperature. However, during this process, the moisture content of air is increased. Evaporative cooling is also said to occurs when hot dry air is forced over a wet pad with the water in the pad evaporating through removal of heat from the air while adding moisture to the air (Jahun et al., 2016).

In evaporative coolers, warm and dry external air from the atmosphere is driven through the pores of the materials which had been moistened with water that is released through overhead water tank. A suction fan is employed in drawing air from the pots which aids the movement of air through the wetted pad as shown in Figure 4a. Evaporation causes the chamber to cool through the conversion of sensible heat from warm and dried air from the surrounding environment, into latent heat as it passes through the wet pad (Babaremu et al., 2018a).

The dry bulb temperature and the wet bulb temperature of the ambient air determine the cooling effects. The greater the difference between them, the greater the effect (Kalsia et al., 2023). However, when the air temperature falls to that of the wet bulb temperature, the air is saturated and the maximum cooling that can be attained as been reached. Therefore, to optimise the pot-in-Aluminium cooler, it requires a combined high latent heat of vaporisation and high evaporation rate of the water. This is generally provided by the thermal energy received from the environment where the water is located and the forced dry air from the ambient (Chemin et al., 2018). The thermal process of the direct evaporative cooling on the psychometric chart is schematically depicted in Figure 4(b).

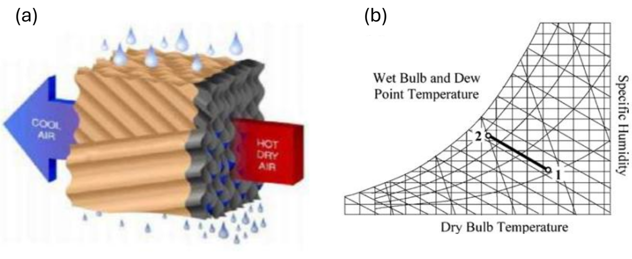

Figure 4. Pictorial representation of Evaporative Cooling Process (Babaremu et al., 2018b) (a) and The Psychrometric Chart of Direct Evaporative cooling (Heidarinejad et al., 2008) (b).

Collection of produce

The tomato variety employed in the experiment was *Lycopersicon esculentum Va.* The tomato fruits were collected from the Mandate market in Ilorin, Kwara State, Nigeria. Figure 5 (a) and (b) show the pictorial representation of Plum and Better Boy tomatoes.

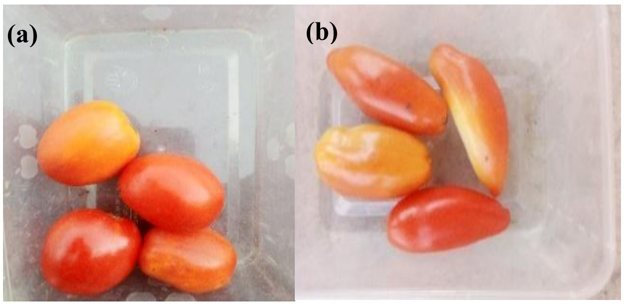

Figure 5. Pictorial Representation of the Tomatoes used in Loading (a) Plum and (b) Better Boy tomatoes.

Test Procedure

Additional analyses were carried out to determine if there was significant difference between the temperatures of the ambient and the temperature inside the pot based on the various types of lagging materials. The null hypotheses are as follows:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$$

where μ_2, μ_3, μ_4, μ_5, μ_6 are the mean temperatures for the samples A, B, C, D and E)

$$H_1: \mu_1 \neq \mu_i$$

for at least one *i*, with *i*=2,3,4,5,6

where μ_1 represents the mean ambient temperature and μ_i represents the mean temperature inside pot i and i stands for each pot sample. SPSS Analysis of Variance (ANOVA) was utilised in testing the hypotheses stated above (Yahaya et al., 2018). If the significant P-value obtained from the ANOVA is less than 0.05, then the null hypothesis is rejected, which means there is a significant difference. However, if the P-value obtained is greater than 0.05, then the null hypothesis fails to be rejected, which means there is no significant difference.

Evaluation of the efficiency of the evaporative cooler

A load test and a no-load test of the evaporative coolers were conducted to evaluate the effect of the evaporation that is expected to take place whether the process is effective or not. This determines its efficiency before being loaded with the vegetables and after being loaded with vegetables for fifteen consecutive days. This was achieved by taking the dry bulb temperature of the ambient, the wet bulb temperature of the ambient, temperature of the each of the cooler and also the relative humidity of the ambient and the coolers at the same time with the use of six digital thermo-hygrometers "HTC-2'' (with accuracy: Temperature ±1°C (1.8°F), humidity ± 5% Relative humidity) attached to each of the evaporative coolers. The readings were taken from 9:00 to 17:00 hours at an interval of two hours daily, for fifteen consecutive days. The wet-bulb temperature was obtained from the psychometric chart using both the dry-bulb temperature and the Relative humidity readings earlier obtained.

The saturation efficiency (also called Effectiveness), which is a measure of how close the cooling of the coolers are in comparison to the theoretical maximum. This depends on the rate of evaporation of water from the lining media. This was calculated using the relation below in equation (1) (Abaranji et al., 2025; Al-Ismaili & Al-Azri, 2016; Yahaya et al., 2018).

$$SE = (\frac{TAmb(db) - (Tc)}{TAmb(db) - TAmb(wb)} \qquad (1)$$

where; SE = Saturation Efficiency (%), $TAmb(db)$ = Ambient dry bulb Temperature (°C), Tc(db) = dry-bulb cooler temperature (°C) and T(wb) = ambient wet-bulb temperature (°C).

Results and discussion

The solar-powered aluminium-in-pot evaporative coolers developed were subjected to both No-load and load tests. Two cultivars of tomato variety; Better-boy (*UTC*) and Plum (*Kerewa*) were selected in carrying out these experiments. The following graphs are results obtained during the evaluation of the evaporative coolers.

Temperature and Relative Humidity Mesurement

Figure 6 shows the graph of ambient relative humidity against time. It was observed from the graph that the ambient Relative humidity decreases as the time-of-day increases during the season under consideration.

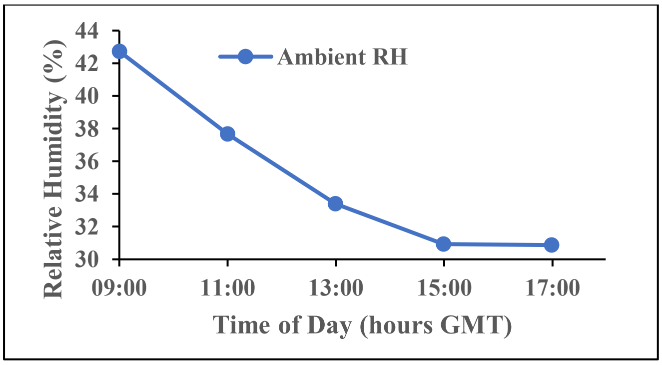

Figure 6. Graph showing Mean Ambient Relative Humidity against Time.

From the thermodynamics view of the results obtained in the developed coolers, the different lining materials were soaked with water while air is extracted from each cooler. The conversion of the water to vapour as a result of sensible heat obtained from the air provided the latent heat of vaporisation for the water. The air then becomes saturated with increased moisture content but reduced temperature. The suction fan serves two purposes. Apart from aiding faster evaporation rate of water to vapour from the lining material, it also removes saturated moisture air from the coolers and assist in the recirculation of air back into the coolers. This aids the evaporative cooling process as lower temperature air enters the coolers.

Figure 7 shows the plot of mean dry bulb ambient temperature, the wet bulb temperature of the ambient, and the mean dry bulb inner temperature of the five coolers with different lining materials under no-load conditions against time of day. From SPSS ANOVA analysis done, P-value for each of the cases has a value of 0.001. This was less than 0.005 ($p<0.005$) which implies that there was a significant difference in each of the cases between the ambient temperature and the observed temperature inside the coolers. But, among experimental groups, there was significant difference between T_E and T_A ($p = 0.032$). And the null hypothesis (H_0) is rejected and H_1 is accepted. These are the two diverse materials in the experimental group. T_A being all clay lining and T_E being all charcoal lining, the other materials lie in between the two materials.

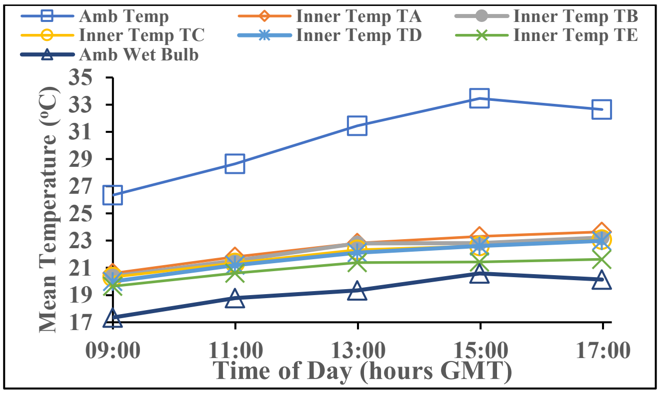

Figure 7. Variation of Mean dry Bulb Temp, Ambient Wet-Bulb Temp, Inner Temperature of the coolers with time of day for different lining media under No-Load.

The Ambient dry bulb temperature increases with the time of the day from 9:00 to 15:00 hours before there was a slight decrease up to 17 hours. For each of the 5 specimens, their inner temperatures, T_A, T_B, T_C, T_D and T_E, were found to increase from 9.00 to 17 hours. In all cases, the maximum temperature was attained at 15 hours. The inner temperatures were noticeably lower than the ambient dry bulb temperature but are greater than the wet bulb temperature. The reduction is as a result of hotter ambient air being drawn into the soaked porous lining materials by the suction fan. This causes the water to extract the sensible heat from the air which it utilised for latent heat of vaporisation to convert to vapour. This manifest into reduction in temperature of the air but increase in its water content and relative humidity. The difference in the inner temperature of each specimen is as a result of different grades of lining materials utilised. Charcoal lining materials have very good microporosity with tiny holes that give large surface area and absorb large quantity of water (Defraeye et al., 2024). When water is pumped into the lining materials, I got soaked by the tiny pores of the charcoal more than hybrid of charcoal and clay or clay alone. Clay is also porous but of larger sizes but the water holding capacity of it is far lower than that of charcoal. This is in line with the findings of (Yahaya et al., 2018) that charcoal is the best lining material. The higher the charcoal content of the lining materials, the better is the temperature drop as shown by the Figure 7.

Figures 8 and 9 on the other hand show the plot of mean daily ambient temperature and inner temperature of the five coolers under the loaded condition of tomatoes Better Boy and Plum against time respectively. Just like in the unloaded case, the ambient temperature followed the same trend in both figures with it increasing with time of the day from 9:00 to 15:00 hours before there was a slight decrease in temperature up to 17 hours. For the inner temperature of the five coolers A, B, C, D and E, the inner temperature is also found to increase from 9.00 to 17 hours. The coolers' temperatures range from 19.65 to 23.65 ºC for No-load test, 21.15 to 25.29 ºC for load test involving UTC specie and 21.10 to 25.20 ºC for Load test involving *Kerewa*. This is slightly above the storage temperature of fresh tomatoes recommended by (ASHRAE, 2018), which is within 13 to 21 °C. However, the result agreed with what was reported by (Mogaji & Fapetu, 2011), which is between 16 to 25 ºC. The mean ambient temperature of the dry bulb ranged from 26.35 to 33.46 ºC, 26.51 to 32.95ºC and 25.45 to 33ºC for the No-load test, Load–test of *UTC* and Load–test of *Kerewa* respectively. The mean ambient wet-bulb temperatures were respectively 17.35 to 20.13 ºC, 17.66 to 20.11ºC, 18.52 to 20.15ºC for the No-load test, Load–test of *UTC* and Load–test of *Kerewa* which were slightly higher than that of Zakari et al., (2016) which was 15 to 18.75°C. It was observed in Figures 8, 9 and 10 that the temperature differences at No-load and load test, between the ambient and coolers range from 3.4 to 10.46 ºC which closely agree with what was reported by Zakari et al., (2016) which is 4 to 7 °C.

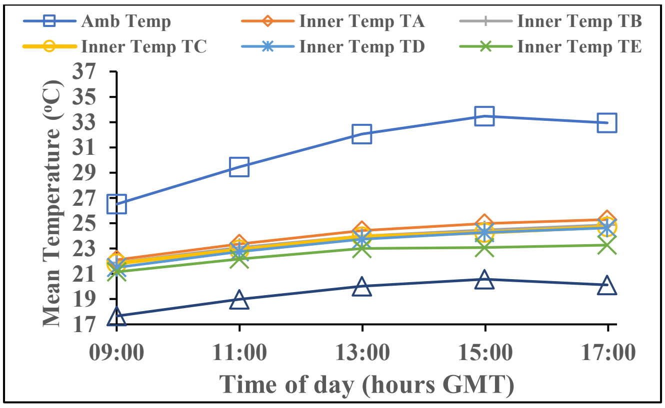

Figure 8. Variation of Mean dry Bulb Temp, Ambient Wet-Bulb Temp, Inner Temperature of the coolers with time of day for different lining media when loaded with Better Boy tomatoes.

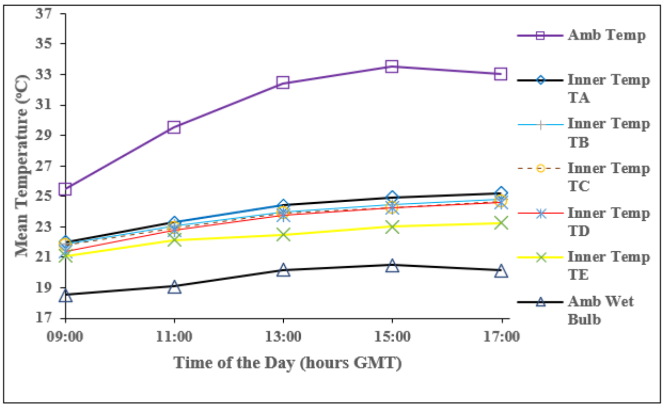

Figure 9. Variation of Mean dry Bulb Temp, Ambient Wet-Bulb Temp, Inner Temperature of the coolers with time of day for different lining media when loaded with Plum Tomatoes.

These variations strongly depend on the prevailing weather conditions. However, inner temperature T_E was found to have the lowest temperature range of the five media considered with a temperature of 19.65 ºC to 21.63 ºC. While under loading conditions UTC and Plum tomatoes, the inner temperature T_E is found to have the lowest temperature of the five media considered with the temperature T_E varying from a temperature range of 21.15 ºC to 23.27 ºC and 21.11 ºC to 23.25 ºC, respectively. This is analogous to the findings of (Jahun et al., 2016) which was at a temperature range of 20.00 ºC to 23.5 ºC when loaded with tomatoes. The difference between the wet bulb temperature and the dry bulb temperature determines the level of the lower temperature that can be attained in the evaporative cooler (Lal Basediya et al., 2013). However, the theoretical maximum relative humidity of 100% which could have given the lowest temperature in the evaporative cooler could not be attained (Ndukwu et al., 2025).

The implication of the experimental findings is that T_E shows superior thermal performance over T_D, T_C, T_B, T_A. Also looking from material point of view, T_E has better lining materials with better water distribution. This shows that at arid climates where the difference between ambient temperature and wet bulb temperatures is huge, T_E will be able to provide substantial cooling.

Mean Daily Temperature Drop Measurement

Figures 10, 11 and 12 respectively show the variation of temperature drop with time of day for no-load, loaded with Better Boy and loaded with Plum. The Temperature drop increases as the Time of day goes from 9:00 to 14:00 hours with a little drop to 17 hrs. From the Figures presented, the highest mean daily drop in temperature was obtained from evaporative cooler T_E which varied between 6.7 ºC and 12.0 ºC for no-load, 5.4 ºC and 10.4 ºC for Betterboy and 4.3 ºC and 10.46 ºC for plum tomatoes.

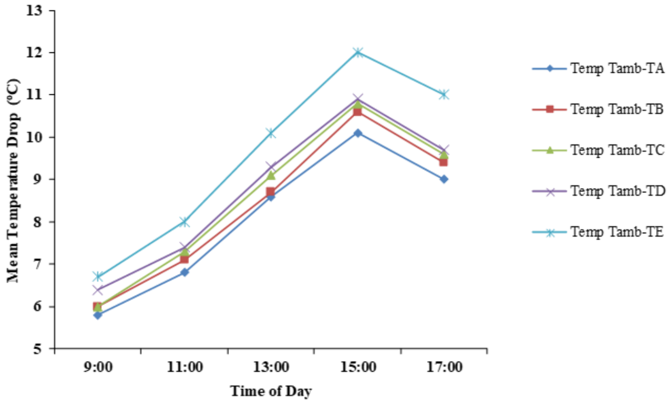

Figure 10. Variation of Mean dry Bulb Temp, Ambient Wet-Bulb Temp, Inner Temperature of the coolers with time of day for different lining media when loaded with Plum Tomatoes.

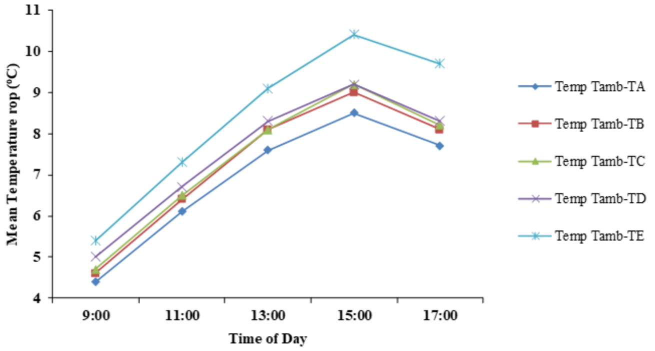

Figure 11. Graph of Mean Daily Temperature drop of the coolers during Load test with Better-boy tomatoes.

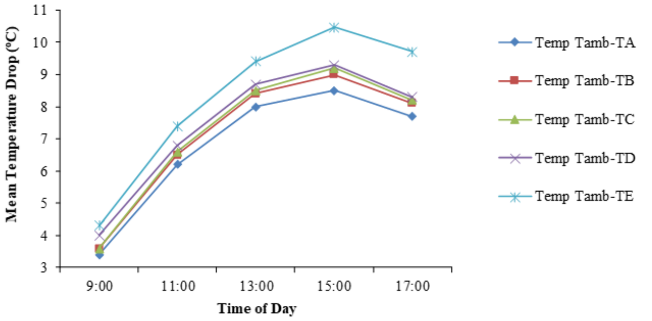

Figure 12. Graph showing Mean Daily Temperature drop during Load test with Plum tomatoes.

Saturation Efficiency

Many researchers (Abaranji et al., 2025; Awafo et al., 2020; Chaomuang et al., 2024; Yahaya et al., 2018; Zakari et al., 2016) have evaluated the saturation efficiency of evaporative coolers. The saturation efficiency is evaluated from equation 1. Figure 13 compares the saturation efficiency of the five samples of cooling chambers with the time of the day under no load conditions. While Figures 14 and 15 depict the plot of saturation efficiency against Time of day for the five sample cooling chambers under loading conditions of better boy and plum respectively.

In each of the cases investigated, the coolers' saturation efficiency increases as the time of the day increases and reaches a maximum at 15 hours. In each of the cases of no-load and loading considered, Sample E was found to have the greatest efficiency followed by Samples D, C, B and A in that descending order. This difference in efficiency is as a result of the water retaining capacity of the different lining materials. Which translate into better cooling as the water evaporate from the lining after extracting thermal energy from the incoming air, while the air itself becomes more saturated with water vapour due to the vaporisation.

The variations in the efficiency of Sample E were found to be averagely 84% at No-load, 72% when loaded with better boy and 77% when loaded with Plum tomatoes. The maximum saturation efficiency of sample E which is 93% as given by Figure 13, occurred at 15:00 which aligned with highest ambient temperature. The drop in efficiency after 15.00 might be as a result of increased humidity which reduces the likelihood of evaporative cooling. When comparing Figures 13, 14, and 15, the efficiency at no-load is higher than that of when loaded. This is because the unloaded coolers only have its structure and the air within it to cool, but the loaded cooler must not only cool the structures but the tomatoes and also manage the heat being released by the tomatoes.

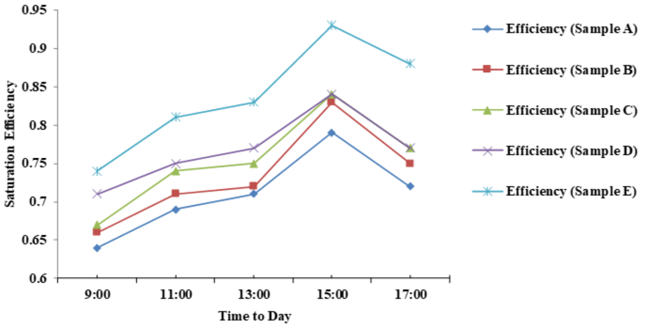

Figure 13. Graph of Saturation Efficiency against Time of day for the coolers with different lining media at No-Load.

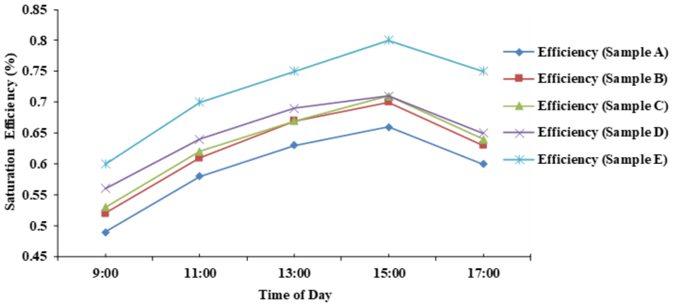

Figure 14. Graph of Saturation Efficiency Time of day for the coolers of different lining media when loaded with Better boy Tomatoes.

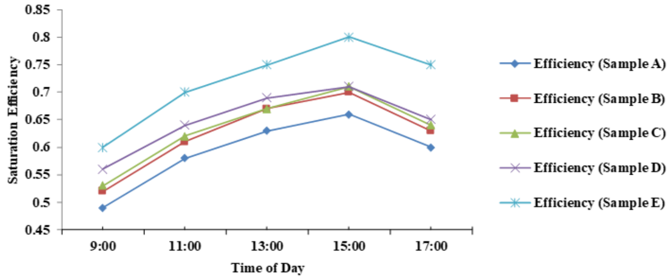

Figure 15. Graph showing Mean Efficiency against Time of day for the coolers of different al lining media when loaded with Plum.

Table 2 presents the maximum efficiency of various evaporative coolers when the coolers were not loaded and their respective relative humidity. T_E shows very good saturation which implies good contact between air and water while T_A shows poorer saturation. Figure 6 shows ambient relative humidity that varied from 30.87-42.73% which is a moderately dry air which is encourages for evaporative cooling.

Table 2. Saturation Efficiency of Coolers when unloaded at 15:00 hours.

Time of Day	Cooler	Inner Temperature (°C)	Saturation Efficiency (%)	Internal RH (%)
15:00	T_A	23.32	78.5	80.7
15:00	T_B	22.82	82.3	83.5
15:00	T_C	22.62	83.7	84.6
15:00	T_D	22.61	83.8	84.7
15:00	T_E	21.44	93.1	92.2

Limitation of the study and Future direction

The study failed to address the issue of the flow rate of the forced air movement measurement in the evaporative cooler. This would have assisted in evaluating the water consumption rate in each of the cooler when unloaded and loaded. Future work will serve to address this. Also, temperature measurement time in future work will be reduced from the current work's two hours to seconds to capture real time temperature variation in the coolers.

Conclusions

An analysis concerning the performance of Aluminium pot-in-pot cooling device has been performed. The lining material was examined to assess the efficiency of the aluminum-in-pot cooling process. The variations in the mean efficiency of sample E were found to be averagely 84% at no load, 72% when loaded with Better Boy and 77% when loaded with Plum tomatoes. The order of performance of the five lining media sample was discovered to be E (100% Charcoal), D Clay-charcoal (28:72) mix ratio, C clay: charcoal (50:50) mix ratio, B Clay: Charcoal (72:28) mix ratio and A clay (100%). This has shown that charcoal is having great potential in extending shelf life of stored product. The developed pot-in-Aluminium evaporative coolers can be used for a short-term preservation of fresh tomatoes depending on the climatic condition.

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