# EVALUATION OF A SOLAR-POWERED EVAPORATIVE COOLING SYSTEM FOR SMALLHOLDER PRODUCERS

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**ABSTRACT**

A solar-powered evaporative cooling system was assessed to prolong the shelf-life of farmers' fruits and vegetables in rural areas without electricity. Temperature and relative humidity for both ambient and the cooling device were recorded daily using a wet bulb and dry bulb thermometer and digital humidity - temperature meter**.** Weight loss was measured with a digital weighing balance. The device was evaluated in terms of change in temperature, weight loss, and relative humidity for 14 days using citrus and tomatoes in ambient condition and in the cooler. The average temperature drop and saturation efficiency in the cooler during the no-load test were 7°C and 41%, respectively. Weight losses in citrus and tomatoes in ambient condition were 20.22% and 45.56% respectively, while those stored at cooler temperature were 6.54% and 19.98% for citrus and tomatoes respectively. The cooler's ambient temperature varied from23.0℃ to 26.0℃ and ambient relative humidity from 73.9% to 91.33%. The device is a very simple system intended to serve local farmers to increase their economic returns from their farming activities. The overall cost of this cooling device was forty nine thousand naira (N49, 000).

**Keywords:** Evaporative cooling, humidity, fruits, temperature, solar
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## INTRODUCTION

Fruits are very important in human daily diet because they are ready sources of vitamins and minerals. Due to climatic condition in Nigeria, fruits tend to lose moisture quickly which leads to loss of quality, nutrients and firmness even before it get to the consumers from the farmers. Evaporative cooling is an efficient method of preserving fruits and vegetables since it provides a favourable environment of high relative humidity and low temperature. The rate of water evaporation, thickness and degree of saturation of pad influence the efficiency of an evaporative cooling device was affirmed by Ogbuagu *et al.* [1].

Nigeria post - harvest losses of fruits and vegetables amount to 35-45% of the annual production [2]. The post-harvest losses occur during transportation, storage, and marketing which caused by poor handling and inappropriate storage facilities [3]. Fruits and vegetables shrivel rapidly after harvest if not preserved quickly. They require a high relative humidity and reduced temperature to retain their freshness and qualities. Proper preservation methods will increase shelf lives of fruits and vegetables.

Small-scale vegetable producers still employ their ancient techniques of storage leading to high percentage waste during storage and shipping. Typically, within few days of harvest, fruits and vegetables are kept in temporary bamboo huts built near residential buildings. By this technique, fruits and vegetables can be preserved for the next few days without much harm and producers sell it on the local village weekly exchange according to their economic requirements [4]. Most refrigeration devices consume more energy thus trigger maximum electricity charges; therefore requires alternative power saving devices so that the average expenses of electricity could be reduced [5].

Fruits and vegetables post-harvest losses, particularly in developing countries are due to absence of adequate preservation facilities. The knowledge of storing fruits in cold environment has been in existence for a long time as far back as our forefathers, they used clay pots and assorted devices to retain cold and moisture of the fruits.Being perishable, fruits and vegetables need immediate post-harvest attention to reduce the microorganisms load and boost their shelf life, which can be achieved by storing them at low temperature and high relative humidity conditions [5]. Refrigeration is the best way to preserve fruits and vegetables. However, mechanical cooling is energy-intensive and expensive, involves considerable initial capital investment and requires uninterrupted supplies of electricity that are not always readily available and cannot be installed rapidly and easily [4, 6].The theory defining the evaporative cooling structure is to convert delicate heat to latent heat. The dry and hot indoor air is pushed through the pores of the sheet fabric that is wetted by water released and dispersed by the overhead water tank or warmer reservoir. The air flowing through the wetted pad is taken from the surroundings by a suction pump. In other words, the adjacent air is put in motion by the suction pump and compelled through the wetted pad [7].

Several scientists have been working on evaporative technologies. An active evaporative cooling system for short-term storage of fruits and vegetable in a tropical climate was developed by Ndukwu *et al.* [8]. Similarly, Redulla [9] documented an evaporative drip cooler made of basic components such as burlap and bamboo. However, Roy [10] used burnt bricks to build a double wall evaporative cooling system for fruit and vegetable storage. On the other hand, Ndirika and Asota [11] indicated that the harm in fruits and vegetables is mainly caused by lack of moisture, shift in structure, and pathological assault. In another study, Abdalla and Abdalla [12] examined the suitability of using palm leaves as a wetting medium. A two basic evaporative coolers with jute pouch and rice husk as a cooling pad for vegetable holding and storage was designed by Acedo [13]. The saturation effectiveness and pressure drop across wetted pads of recycled high-density polyethylene (HDPE) and rice husk as a wetted pad in an evaporative cooling scheme was investigated by Santamouris and Asimakopoulos [5]. Although the quality and life cycles of the fruits investigated were enhanced, results of these studies showed loss of between 6 – 28% of such fruits due to mainly moisture, insect and rodent attacks.

The majority of the designs available for conservation of fruits in Nigeria are passive with manual water recirculation setup [14, 15]. Imported evaporative coolers are complicated for local farmers, occupy space, and are run exclusively through the evaporation cycle without fan use. There is therefore a need for further studies into significant techniques to improve the retention of fruits and vegetables in tropics. This has resulted in the development of this solar-powered evaporative cooling system for the storage of citrus fruits for small-scale fruits and vegetable farmers.

In Nigeria and other developing countries, there is now a particular understanding that the fast growth of agriculture largely relies on the effective introduction of contemporary and small-scale agricultural machinery [16]. The aim of this study was to design and evaluate the performance of a solar-poweredevaporative cooler designed purposely to prolong shelf life of stored fruits and vegetables produced by peasant farmers in rural communities without electricity supply. The capacity of the storage system was determined as 0.284 $m^3$.

## MATERIALS AND METHODS

### Design analyses

The device was made of cuboid shape so as to create a wider surface for circulation of air as recommended by Manuwa and Odey [15]. It contains three trays for loading fruits and vegetables and a wider space at the bottom to store larger commodities as shown in the Figure 1.

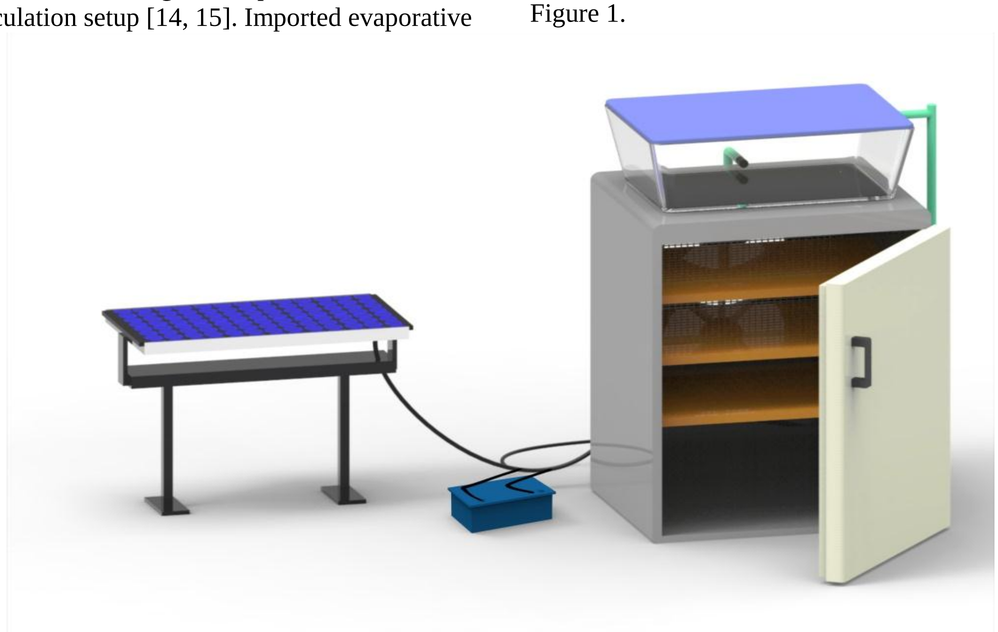


**Figure 1:** Pictorial view of the evaporative cooling system

**Surface area of sides of the cooling device:**
**Front side (door)**
Parameters; Length = 0.9 m, Breadth = 0.5 m
Surface Area of the front side = L x B = 0.9 x 0.5 = 0.45 $m^2$
This area is the same for both front and rear sides.
**Sides of the cooling device**
Parameters;
Length = 0.9 m
Breadth = 0.45 m
Surface area =L x B =0.9 x 0.45 = 0.405 $m^2$
This area is the same for both sides of the device.
**Roof;**
Parameters;
Length = 0.5 m
Breadth = 0.45 m
Surface area = 0.5 x 0.45 =L x B =0.225 $m^2$
**Floor;**
Parameters;
Length = 0.5 m
Breadth = 0.45 m
Surface area = L x B =0.5 x 0.45 = 0.225 $m^2$
**Total area of component parts** = 2.16 $m^2$
**Tray;**
Parameters;
Length = 0.4 m
Breadth = 0.35 m
Surface area = 0.14 $m^2$
Three trays have a surface area of 0.14 $m^2$
**Volume of the storage system:**
The capacity of the storage system was determined using Equation (1);
$Vc = Lc \times Bc \times Hc$ (1)
$Vc = 0.9 \times 0.45 \times 0.7 = 0.284$ $m^3$
Where; $Vc$= Volume of the cooling system, $Lc$= Length of the cooling system, $Bc$= Breadth of the cooling system, $Hc$= Height of the cooling system
**Volume of Reservoir:** The volume of the reservoir was determined using Equation (2);
$Vr = \pi r^2 H$ (2)
Where; $V$ = volume of reservoir, $r$= radius of reservoir, $H$ = height of reservoir
$V = 3.14 \times 0.17 \times 0.5 = 0.027$ $m^3$=27 litres
**Design of suction fan**
The capacity of the suction fan was determined in accordance with [16] as given in Equation (3):
Fan Capacity:
8cfm/sqft × floor area in squared foot
Floor area:
$Af = Lf \times Bf$ (3)
$Af = 1.47 \times 1.63 = 2.4 sqft$
Fan Capacity = 8cfm / sqft×2.4sqft =19.2Cfm

**Design considerations of the evaporative cooling device**
The following design factors were considered:
i) Cooling requirements. Cooling of distinct products requires distinct temperatures;
ii) Average relative humidity of the region where cooling is required. If the relative humidity is constantly large, evaporative cooling is not a feasible alternative and therefore another scheme requires to be considered. If the relative humidity is small, evaporative cooling may be efficient;
iii) A decent supply of water for the cooling unit. If this is easily accessible, evaporative cooling can be possible;
iv) The surface area of the evaporative refrigerator is uniform;
v) Water recirculation device has been integrated to guarantee minimal attention;
vi) The flow rate of water was continuous from the top tank;
vii) Water was automatically recirculated to guarantee minimal attention;
viii) For ease of movement, the evaporative cooler was comparatively light weight.

**Description of the device**
The device consists of a lead acid battery, a suction fan, solar panel (solar collectors), storage tank, a storage cabin, control system and water distribution network which comprises of a pump, pipes, and two water containers. The transfer medium was installed at the top left corner of the cooling device with the suction fan attached directly at the rear. Water drips from a container fixed on top of device through the charcoal medium. Charcoal was used as transfer medium for this experiment due to its moisture retention capacity. Another container was fixed below the device to collect excess water from the transfer medium. The device uses power from the solar panel directly during the day and the power stored in the battery at night. Figure 2shows the isometric view of the device while Figure 3 shows the exploded diagram of the cooling device.

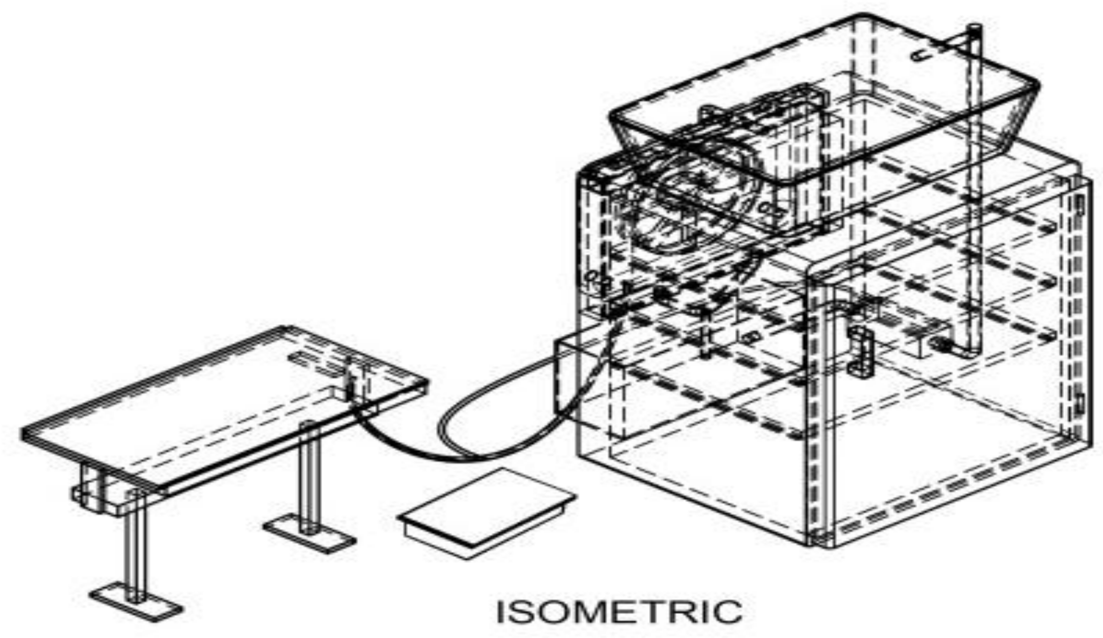
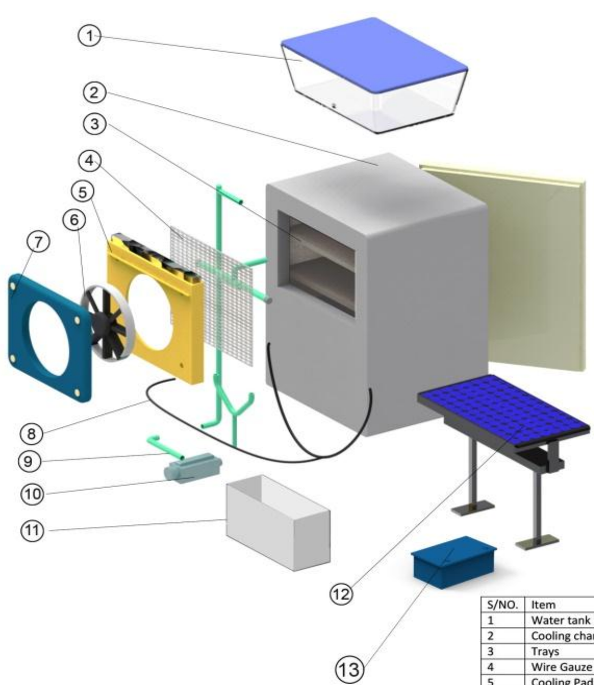



**Figure 2:** Isometric and orthographic representation




| S/NO. | Item | Material | Quantity |
|---|---|---|---|
| 1 | Water tank | Plastic | 1 |
| 2 | Cooling chamber | | 1 |
| 3 | Trays | Mild Steel | 4 |
| 4 | Wire Gauze | Mild Steel | 1 |
| 5 | Cooling Pad/Transfer medium | Mild Steel/Charcoal | 1 |
| 6 | Fan | Plastic | 1 |
| 7 | Screws | Mild Steel | 4 |
| 8 | Wiring | | |
| 9 | Water piping | PVC | |
| 10 | Pump | | 1 |
| 11 | Water collector | Mild Steel | 1 |
| 12 | Solar Panel | | 1 |
| 13 | Battery | | 1 |

**Figure 3**: Exploded diagram of the cooling device

## Material selection

### Operational principle and components of the solar cooling device

The evaporative cooling system operates on the principle of cooling and humidifying warm dry air through a jute bag. It works with solar energy as the energy source when cool air is stored in the storage chamber. The high efficiency collectors available on the market today (such as dual-glazed flat-plates collectors or evacuated pipe pickers), have become the majority used in solar cooling systems to date.

**Solar panel**: Solar panel was selected based on the rated power of the cooler. The rated power of cooler is184 W. Assuming 6 hours of operation per day, would require about 1104 or 1200 Watt hours per day. Considering the losses and the availability of panels, 220 Wp, 12V solar panel was selected.

**Battery**: 100 Amp-hour12V battery available in market can store 1.2 kW of electricity. Hence this battery was selected for the purpose.

**Pad**: Choice of charcoal for the transfer medium was based on its porosity, water absorption (and evaporation), availability, and cost. The medium was framed from steel and covered by a wire mesh.

**Suction fan:** A 33 cm swept depth diameter fan was selected. Its major work was to suck air from the environment and force the dry warm air through the wetted charcoal to cause cooling effect inside the chamber.

## Experimental procedures

Evaluation of the fabricated solar powered evaporative cooling was carried out at Soil and Water Laboratory of Agricultural and Biosystems Engineering Department, Landmark University. Citrus and tomatoes obtained from market were used for evaluation. Evaluation was conducted in two parts. In the first part, the device was operated under no -load condition without crops to ascertain its conditions. Temperature readings of the device and the ambient were recorded using a thermometer. Relative Humidity (RH) readings of the cooler and the ambient relative humidity were taken using a hygrometer (PCE-WB 20SD) and a data logger (OM-HL-SP) which has readings for both relative humidity and temperature). The readings were taken 3 times in a day (8 am – 3 pm and 9 pm) for 2 weeks.

The air passing through the jute pad was designed to remove the heat load from the evaporative cooler. There are three major ways to determine the heat load from the evaporative cooling device as recommended by Babaremu [3].

(a) Heat gained by conductance through the walls, roofs, floor and cooler. The wall, roofs, floor and cooler contribute to the heat load by conduction in the cooler. The heat transfer was calculated by multiplying the area of each component of the cooler such as the roof, floor, and walls by their appropriate conductivity value, reciprocal of insulation thickness and the temperature difference between the external and internal temperature. The total heat load was then calculated from equation 4:

$$Q = KA\frac{dT}{dt} \qquad (4)$$

Where: Q = heat transfer by conduction, W

A = Total area of the various components

dT = Temperature difference between internal and external temperature

dt = insulation thickness

(b) Respiration heat load from the produce - The heat generated from the produce is directly proportional to the mass of the produce and the storage temperature which is represented by:

$$Qr = Mp \times Pr \qquad (5)$$

Where;

Qr = respiration heat, V/hr

Mp = mass of produce, g

Pr = rate of respiration heat production, W/kghr

(c) Field heat of the produce - The heat picked up by the produce on the field and it is directly proportional to the mass of the produce and the storage temperature which is expressed by;

$$Qf = (MpCp) \infty T/tc \qquad (6)$$

Where:

Qf = Field heat picked by produce, W

Cp =Specific heat capacity of produce, KJ/Kg °C

tc = cooling time in seconds, for fruits to equal 12 hrs [17]

T = infiltration of air (Heat transfer from cracks and door opening during cooling). Heat is estimated from 10 to 20% of the total heat load from other sources and thus from an average of 15% we have;

$$QL = (Qc + QT + Qr) \times 0.15 \qquad (7)$$

Where QL = heat transfer through cracks and opening of cooler doors.

Second part of evaluation was load test to ascertain efficiency (evaporative cooling efficiency) of the cooler when loaded was with fruits. The quality assessment of the produce was estimated, and the fruits selected were based on their low shelf life. The weight of the produce after some days was also estimated and compared to the initial weight as suggested by Babaremu [3].

**Physiological weight loss**
The variance in the weightiness was assessed by storage both in the cooler and in the ambient. This was done for some period to determine the effectiveness by means of the evaporative cooler as suggested by Babaremu [3].

**Colour changes**
The alteration in the colour of the fruit was also noted both in the cooler and in the ambient. The colour changes revealed was grounded essentially on the bodily appearance of the fruits as suggested by Babaremu [3].

**Fruit firmness**
The bodily quality of the fruit was observed and was noted. The change in the firmness was noted after storage of the fruit in the cooler and the ambient as suggested by Babaremu [3].

**Cooling efficiency**
Cooling efficiency of the evaporative cooler was evaluated by using Equation (8)

$$S.E = \frac{\{T1_{(db)} - T2_{(db)}\}}{\{T1_{(db)} - T2_{(wb)}\}} \quad (8)$$

where;

$T_{1(db)}$ = dry bulb outdoor temperature

$T_{2(db)}$ = dry bulb cooler temperature

$T_{1(wb)}$ = wet bulb outdoor temperature

**RESULTS AND DISCUSSION**

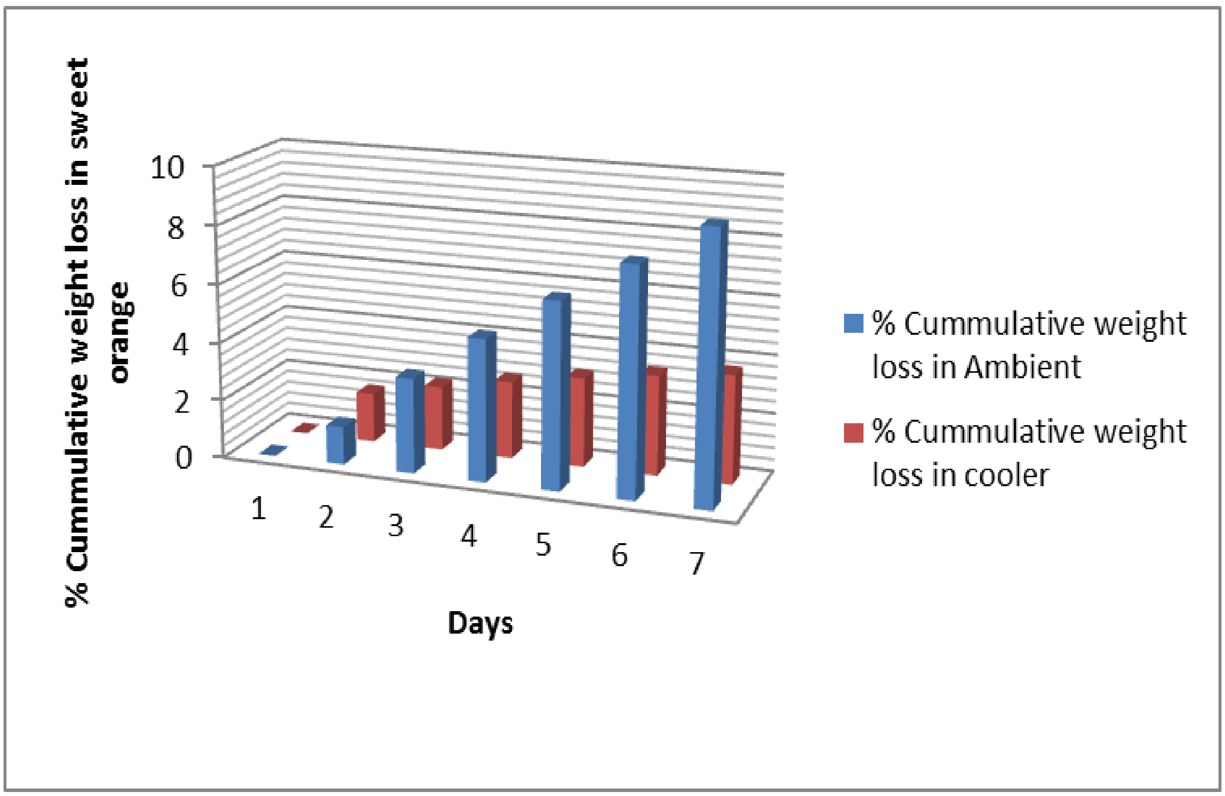



**Figure 4:** Percentage weight loss in sweet orange

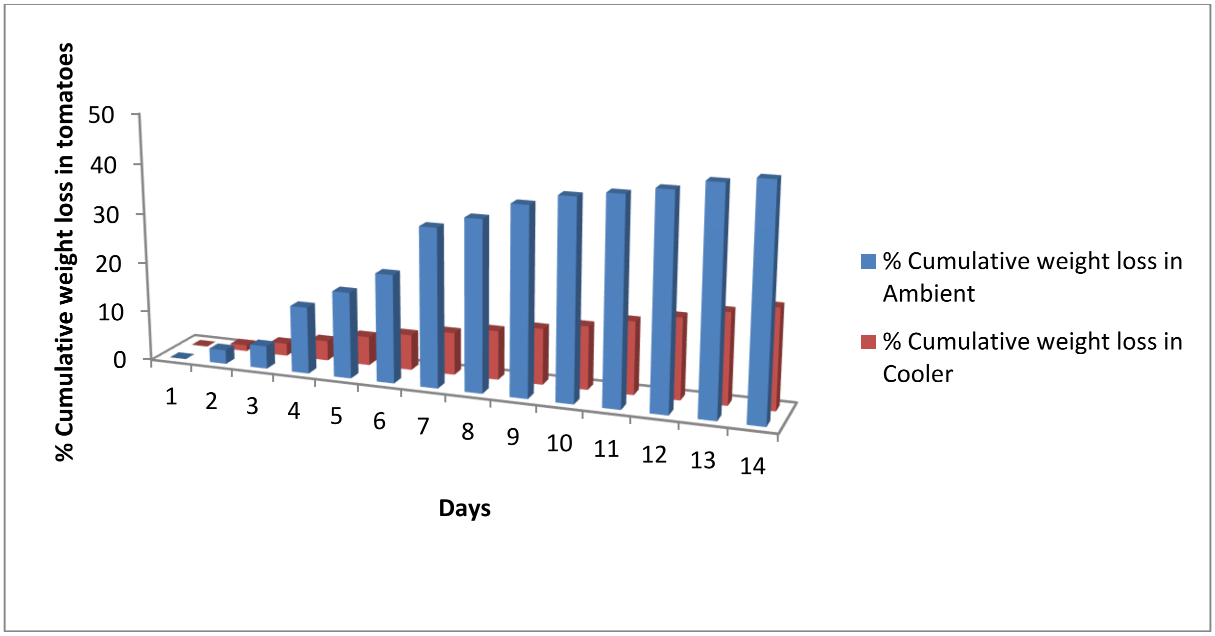



**Figure 5:** Percentage weight loss in tomatoes

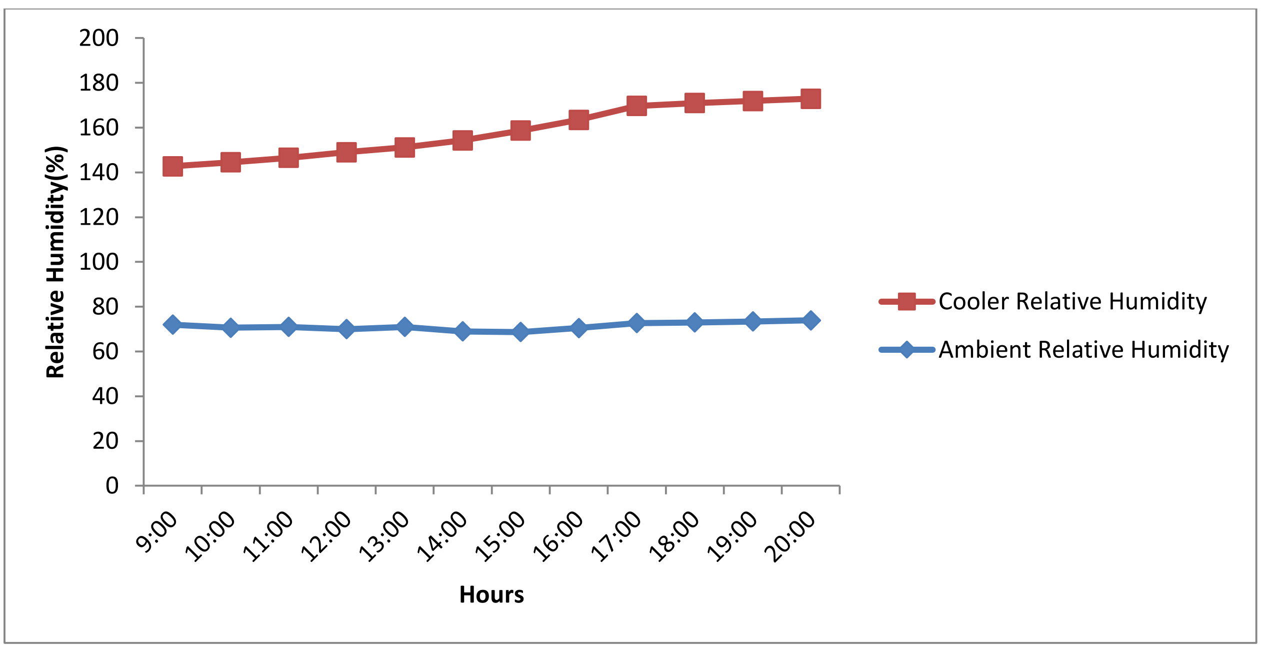



**Figure 6:** Ambient and cooler relative humidity

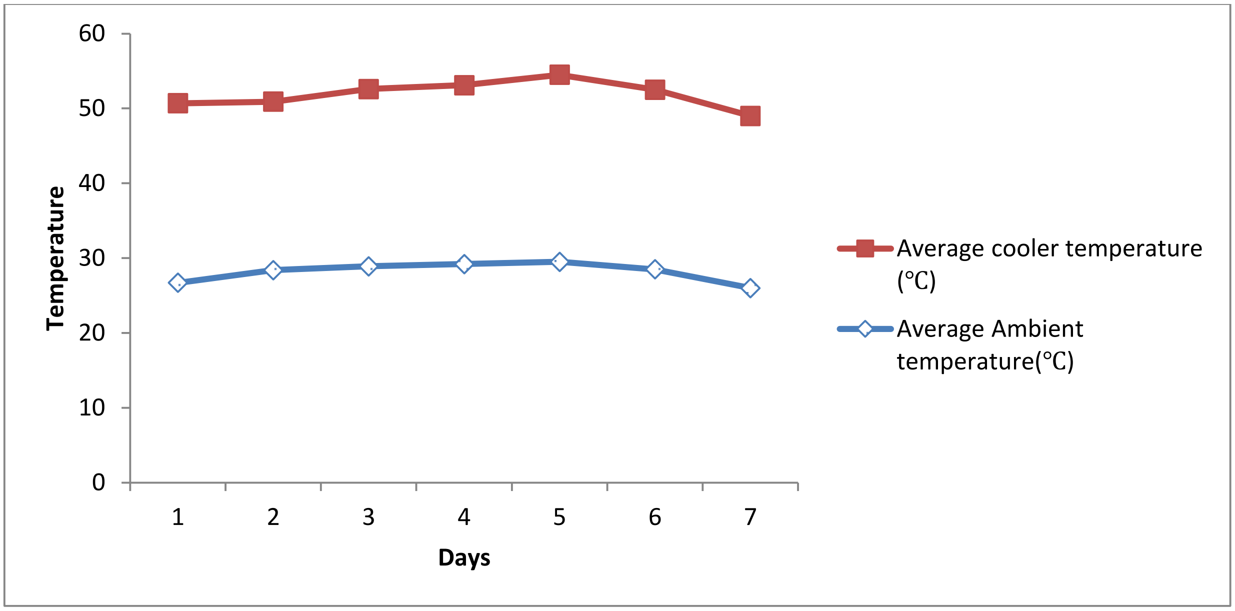



**Figure 7:** Ambient and cooler relative temperature

**Weight loss**

Weight losses that occurred during storage of the biological materials were determined. This was done through percentage loss estimate. Percentage cumulative weight loss in sweet orange and tomatoes are shown in Figures 4 and 5. It was observed that the weight loss of sweet orange (18.94%) and tomatoes (38.61%) in ambient condition were greater than that of weight loss of sweet orange (5.13%) and tomatoes (14.25%) recorded inside the cooler. This is as a result of the reduction in temperature and increase in relative humidity of the cooler, and also to the evaporation of water which depend on the temperature and the relative humidity of the surrounding.

In a similar study by Rastvoski [17], it was observed that weight of tomatoes dropped from 40.00 to 15.45 kg after 8 days in open air. But tomatoes in the evaporative cooling cabinet had their weight relatively maintained at 39 kg within one week of storage with only an approximate 2.95 kg loss in weight. However, Timothy and Olaoye [18] observed that mango, tomatoes, banana and carrot stored in the ambient air lost more weight than produce stored in the cooler. Similarly, Jahun [19] also noted that the release of ethylene which is a ripening hormone was very rapid in the tomatoes stored in ambient condition but ethylene production of the produce in the cooler was low. Therefore, weight loss increases rapidly in ambient condition due to the respiratory activities that occur, as fruits and vegetables are biological materials, the low relative humidity outside the cooler increased the ripening process causing deterioration in the produce.

**Relative humidity difference**

Figure 6 shows the effectiveness of the cooler through the obvious difference between the relative humidity of the ambient which was 73.9% and the cooler 93.25%. This was an indication that the cooler is effective as it reduces temperature and increases relative humidity causing reduction in deterioration rate that is an increase in shelf life. The main characteristic of an evaporative cooler is low temperature and high relative humidity [20].

**Temperature difference**

Figure 7 shows the relation between the ambient temperature and the temperature of the controlled environment which is the cooling system in a no-load test. During the no-load test the relative humidity of the cooler was high and the temperature was low but when the cooler was loaded with fruits and vegetable, the relative humidity dropped and the temperature rose because the produce are biological materials that respire. The device was evaluated for temperature variations from morning to afternoon at an interval of 1hourfor 8hours. The results are as shown in Figure 6. The ambient temperature was observed to be increasing with time while the cabinet experienced drop in temperature. Average temperature inside the cooling device varied from 23ºC to 26ºC while the ambient air temperature varied from 28ºC to 30ºC for tomatoes. For sweet oranges, temperature increased from 22.8ºC to 24.5ºC inside the device while ambient air temperature increased from 28ºC to 30.5ºC. These results show that the evaporative cooling system can prolong shelf lives fruits and vegetables for a short time.

### Colour changes

The initial colour of the orange was light green before storage but during the evaluation process the colour of the orange began to change to yellow, while the one in the cooler had a change in colour that could almost go unnoticed. The initial colour of the tomatoes was bright red before storage but during the evaluation process the tomatoes changed from bright red to brownish red with white patches.

## CONCLUSION

A solar-powered evaporative cooling device for small farm holders was fabricated and evaluated with tomatoes and sweet orange. Evaluation results revealed a temperature reduction from 26ºC to 23ºC and increased relative humidity of 73.9% to 91.33% was achieved. This shows that the device can reduce deterioration rates of fruits. Saturation efficiency was increased by powering with solar power. This evaporative cooler would be useful for small-scale fruits and vegetable farmers in preserving their crops and thereby increasing their economic returns from their farming activities.

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