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# DESIGN AND CONSTRUCTION OF AN EVAPORATIVE COOLING SYSTEM FOR THE STORAGE OF FRESH TOMATO

Zakari M. D, Y. S. Abubakar, Y. B. Muhammad, N. J. Shanono, N. M. Nasidi, M. S. Abubakar, A. I. Muhammad, I. Lawan and R. K. Ahmad
Department of Agricultural Engineering, Faculty of Engineering, Bayero University, Kano –Kano State, Nigeria
E-Mail: mdzakari.age@buk.edu.ng

## ABSTRACT

A solar powered evaporative cooling system of 0.6 $m^3$ capacity was designed and constructed to increase the shelf life of stored vegetables. The evaporative cooler was tested and evaluated using tomato (Roma). The equipment operates on the principle of evaporative cooling and increasing the relative humidity (RH) in the preservation chamber. The storage system was made up of aluminum sheets of 1mm thick while a side of the system is made of jute pad which get moist by water flowing through a series of perforated pipe from the reservoir located at the top of the storage system. The water flows with the influence of gravity. The RH and weight loss of tomato was statistically analyzed using student T – test and the result revealed that there was significant difference in using the evaporative cooling system for storing tomatoes as compared to ambient condition. The average cooling efficiency was found to be 83%. The temperature in the system dropped drastically when compared to the ambient condition which ranges from 6 to 10°C and the relative humidity in the cooling chamber increased considerably to 85%. However, the testing of the evaporative cooling system shows that the tomatoes can be stored for an average of five (5) days with negligible changes in weight, color, firmness and rotting as compared to ambient condition which started rotting after three (3) days. Hence, it is on this note that farmers, house holders and tomatoes processing factories should adopt the use such evaporative cooling system for the storing of fresh tomatoes as this increases the shelf life of tomatoes.

**Keywords:** evaporative cooling, storage, relative humidity, weight loss, tomato.

## INTRODUCTION

Evaporative cooling is the process by which the temperature of a substance is reduced due to the cooling effect from the evaporation of water. The conversion of sensible heat to latent heat causes a decrease in the ambient temperature as water evaporated provide useful cooling. This cooling effect has been used on various scales from small space cooling to large industrial applications (Liberty *et al.,* 2013). Several researches have been done on various forms of design of evaporative coolers (Rusten, 1985; Dzivama, 2000; Olosunde 2006; Sushmita *et al.,* 2008). In developing countries, Storage has been observed to pose a greater threat to fruits and vegetables because information on the storage temperature, humidity requirements and the length of time they can be kept without a decline in market value is either inadequate or unknown to those who need the information (FAO, 2003). Deterioration of fruits and vegetable during storage largely depends on temperature. One way to increase the shelf life of fruits and vegetable is by lowering of the temperature. Too low temperature can cause damage to agricultural produce and as soon as the product leaves the region of controlled temperature, deterioration starts again (Bastrash, 1998). In order to maintain the quality of stored fruits and vegetables, they are normally kept in humid conditions (Sunmonu *et al.,* 2012). For most perishable crops, the higher the humidity the better it is in storage. However if the humidity is too high, water may condense on top of the vegetables thus increasing rotting (Thompson, 1972). Deterioration of fresh tomatoes (*Lycopersicon esculentum*) during storage depends partly on temperature (Ajayi, 2011). One way to slow down deterioration and thus increases the length of time tomatoes can be stored, is by lowering the temperature to an appropriate level. If the storage temperature is too low the product will be damaged and also as soon as the product leaves the cold store, deterioration starts again and often at a faster rate. It is essential that tomatoes are not damaged during harvest and that they are kept clean. Damaged and bruised tomatoes have much shorter storage lives and very poor appearance after storage. (Fabiyi, 2010). Sushmita *et al,* (2008), stated that keeping products at their lowest safe temperature (0°C for temperate crops or 10-12 °C for chilling sensitive crops) will increase storage life by lowering respiration rate, decreasing sensitivity to ethylene gas and reducing water loss. Much of the post-harvest losses of vegetables in developing countries are due to the lack of proper storage facilities. Refrigerated cold stores are the best method of preserving vegetables, but they are expensive. Consequently, in the developing countries such as Nigeria and particularly in northern Nigeria where most vegetable crops are grown there is an interest in simple, low-cost alternatives, many of which depend on evaporative cooling which is simple (Nobel, 2003). As water evaporates, it draws energy from its surroundings which produce cooling effect. Evaporative cooling occurs when air, that is not too humid, passes over a wet surface so that the faster the rate of evaporation the greater the cooling and the efficiency of an evaporative cooler depends on the humidity of the surrounding air (Nobel, 2003). Dry air can absorb moisture faster and no cooling occurs in the extreme case of air that is totally saturated with water (Ajayi, 2011).

Generally, an evaporative cooler is made of a porous material that is fed with water. Hot, dry air is drawn over the material. The water evaporates into the air raising its humidity and at the same time reducing the temperature of the air. For fresh market produce, any method of increasing the relative humidity of the storage environment (or decreasing the vapor pressure deficit (VPD) between the commodity and its environment) will slow the rate of water loss. The best method of increasing relative humidity is to reduce temperature (Nobel, 2003). However, the problem of inadequate storage facilities for fresh vegetables after being harvested in Nigeria, result to the reduction in the quantity that gets to the market; this also has a direct effect on the economic distribution and consumption of the needed quantity for human sustainability. Hence, the purpose of this work is to Design and Construct an Evaporative Cooling System that will temporarily store fresh vegetables to increase the shelf life before economical distribution, consumption and for processing.

## MATERIALS AND METHOD

### Design Criteria of the Cooling System

The storage system is rectangular in shape, and the design specifications for the system as well as the reservoir seat were done in accordance with Adeniran *et al.*, (2011) as follows;

### Design of Front and Rear Sides of the Storage System

The design of the rear side of the system was achieved using Equation (1);

$$A_r = H_r \times L_r \quad (1)$$

$A_r = 0.8 \times 0.4 = 0.32\text{m}^2$

Where; $A_r$ = Area of rear side, $L_r$ = Length of rear side, $H_r$ = Height of rear side

**Design of Left and Right Hand Sides of the Storage System (Pad Area)** The design for the left side of the storage system was done using Equation (2);

$$A_l = H_l \times B_l \quad (2)$$

$A_l = 0.8 \times 0.5 = 0.4\text{m}^2$

Where; $A_l$ = Area of left side of the storage system, $H_l$ = Length of left side of the storage system, $B_l$ = Breadth of left side of the storage system.

Similarly, the right hand side of the system has the same design with the left side of the system, with three well-spaced circular openings for insertion of the suction fans. Each having an area as shown in Equation (3);

$$A = \pi r^2 \quad (3)$$

$A = 3.14 \times 0.12^2 = 0.045\text{m}^2$

Where; $A$ = Area, $r$ = Radius

**Design of Top of the Storage System** The design for the top of the storage system was done using Equation (4);

$$A_t = L_t \times B_t \quad (4)$$

$A_t = 0.5 \times 0.4 = 0.2\text{m}^2$

Where; $A_t$ = Area of top of the storage system, $L_t$ = Length of top of the storage system

$B_t$ = Breadth of top of the storage system,

**Design of Reservoir Seat:** The design for the reservoir seat was also done using Equation (5);

$$A_s = L_s \times B_s \quad (5)$$

$A_s = 0.5 \times 0.3 = 0.15\text{m}^2$

Where; $A_s$ = Area of reservoir seat, $L_s$ = Length of reservoir seat, $B_s$ = Breadth of reservoir seat

**Volume of the Storage System:** The capacity of the storage system was determined using Equation (6);

$$V_c = L_c \times B_c \times H_c \quad (6)$$

$V_c = 0.4 \times 0.5 \times 0.8 = 0.16\text{m}^3$

Where; $V_c$ = Volume of the storage system, $L_c$ = Length of the storage system, $B_c$ = Breadth of the storage system, $H_c$ = Height of the storage system

**Volume of Reservoir:** The volume of the reservoir was determined using Equation (7);

$$V_r = \pi r^2 H \quad (7)$$

$V_r = 3.14 \times 0.16^2 \times 0.3 = 0.024\text{m}^3 = 24\,litres$

Where; $V_r$ = volume of reservoir, $\pi = 3.14$, $r$ = radius of reservoir, $H_r$ = height of reservoir

The aluminum frames that make up the storage cabin were extended upward by 0.1m to serve as reservoir stand while reservoir seat was constructed above it, as shown Figure 1 – 4. The water distribution network consists of pipes, an overhead tank and a bottom pipe network to collect the excess water that drips from the jute. The pipe network also consists of a control valve which will be used to regulate the flow rate.

### Design and Selection of Suction Fan

The determination of fan capacity was in accordance with (Bartok, 2013) as given in Equation (8):

Fan Capacity:

8cfm/sqft × floor area in squared foot

Floor area:

$$A_f = L_f \times B_f \quad (8)$$

$$A_f = 1.67 \times 1.33 = 2.22 sqft$$

$$\therefore FanCapacity = 8cfm / sqft \times 2.22 sqft = 17.8 cfm$$

Factor of safety is 10% of fan capacity given as:

$F_s = \frac{10}{100} \times 17.8 = 1.78\text{cfm}$

Required fan capacity =fan capacity +factor of safety

Required fan capacity =17.8 +1.78= 19.6cfm $\cong 20cfm$

Where: $A_f$ = Area of floor, $L_f$ = Length of floor in ft, $B_f$ = Breadth of floor in ft, $F_s$= factor of safety

**Selection of Cooling Pad**

As part of the general requirements, the efficiency of an active evaporative cooler depends on the rate and amount of evaporation of water from the cooling pad. This is dependent upon the air velocity through the fan, pad thickness and the degree of saturation of the pad, which is a function of the water flow rate wetting the cooling pad (Thakur and Dhingra, 1983; Wiersma, 1983). In this work, Jute type of cooling pad of 0.06 m thickness was selected for an efficient performance of the evaporative cooling system as it has good water holding capacity, high moisture content, and percentage dry basis, high bulk density reported (Manuwa, 1991; Igbeka and Olurin, 2009).

**Heat Transfer Analysis of the System**

The heat gain by the aluminum material used for the cabinet construction was estimated using Fourier's law of heat conduction

$$Q_{hg} = \frac{-KA\Delta T}{x} \tag{9}$$

$$Q_{hg} = \frac{-204\times1.418\times10}{0.001} = 2892720\text{w}$$

Where; $Q_{hg}$ = Quantity of heat gained by the material (W), A = Area of the material (m), k = Thermal conductivity of the material (W/m K), $\Delta$T = Temperature difference of thermal (°C), x = Thickness of the material (m)

**Selection of Solar Power Supply System**

The installed suction fans on the evaporative cooling system have the following specifications: 12V (voltage ratings), 0.15A (Current), 1.8W (power ratings) and these specifications were considered in selection of the solar power source that will ensure the continuous functioning of the fans. The solar panel selected has the following specification: Voltage = 18v, Current = 0.36A

**Design of Battery Charger**

The battery charger was designed so that it can step down the voltage rating from the solar panel from 18V to 15V in order to charge the battery adequately.

The battery charger was designed in accordance with Tharaja, (1995) as shown in Equation (10).

RT= R1+R2+R3+R4= 0 (10)
RT= 120+2+2+1= 125
I= V/R = 18/125 = 0.12A
V= IR =0.12*125= 15V

**Determination of Battery Capacity and Selection of Battery**

The battery capacity was determined with reference to the suction fans specifications and this is in accordance with Linden, (2002) as given in equation (11)

$$C = H_n \times A \tag{11}$$

C = 12 × 0.3= 3.6AH

Where; C = battery capacity, $H_n$ = Hours from sunset-sunrise, A = Fan current

Based on the above findings, the appropriate battery thatwas selected has the following specifications: Voltage = 12V, Capacity = 6AH.

**Construction of the Evaporative Cooler**

Hollow rectangular aluminum pipes and sheets were measured, cut and assembled to form a rectangular storage chamber with the left hand side left open for the insertion of jute pad and mesh wire according to specifications of the design. The pipes and sheets were assembled with the aid of screws as shown in Figure-1. Three circular openings of radius 60mm were made in the side opposite to the jute pad where suction fans were fitted (Figure-4). The storage chamber was divided into two shelve using mesh wire (Figure-4). An opening of 10mm radius was made near the bottom of the reservoir tank which has a volume of 24 liters; a PVC pipe of 20mm diameter was inserted in opening, T-joint, and elbow joint was used to connect the pipe networks together using gum to hold the pipe in position and a stopper was also used at the end of the pipe network to stop water flow (Figure-2). The pipes were assembled so that a single pipe runs over the jute pad area, a sharp object was used to perforate the pipe at certain intervals creating opening so the water flows over the jute pad when the control valve is opened as shown in Figure-2. A 40mm diameter PVC pipe was divided into two halves with a half connected at the bottom of the storage system at the side were the jute pad is inserted so it collects the excess water that drips off from the jute pad as indicated on Figure-3.

**Figure-1.** The cooling system under construction.

**Figure-2.** Assembly of the pipe network in progress.

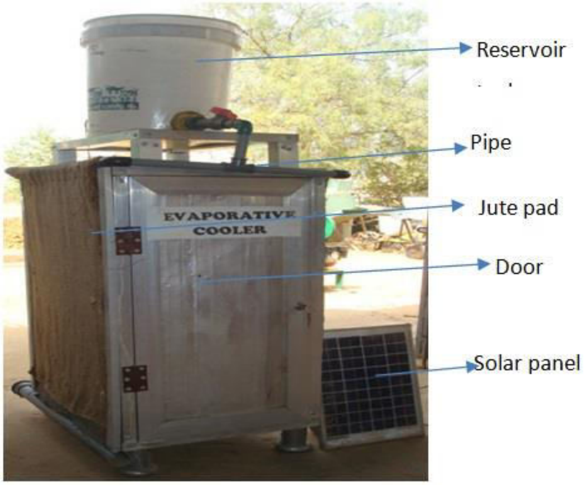


**Figure-3.** General over view of evaporative cooling.

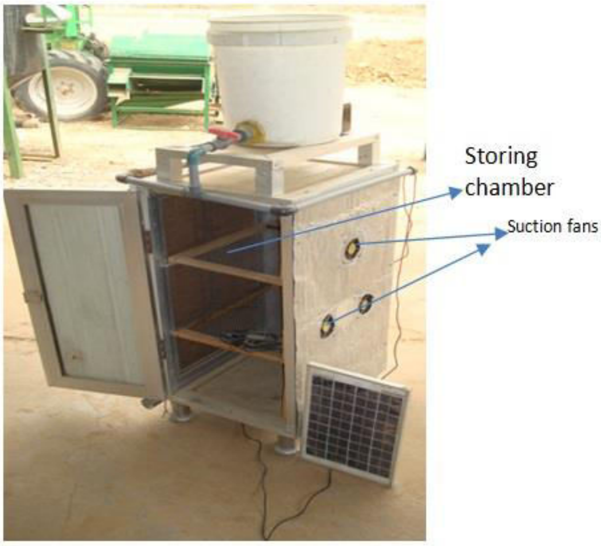


**Figure-4.** System's interior and installed suction fans.

**Principles of Operation**

The design of the evaporative system was based on the principle of evaporation being always accompanied by a cooling effect to its surrounding. It is an enclosed system which comprises of four (4) sides, such that one (1) side was made of mesh wire and pad (jute material), while the remaining three sides were made of aluminum sheets in which the side opposite to the jute pad section is equipped with three suction fans well-spaced. Air is allowed to pass through the pad into the system with the help of suction fans. Water drips into the jute pad at a constant rate through a water distribution system. As the water drips into the pad the suction fan draws warm air from the system and passes it out. During this process the warm air which is the sensible heat passes through the wetted pad which is now changed to latent heat due to the evaporation that has occurred as a result of the water being evaporated which causes the cooling within the enclosure to achieve a temperature difference of about 10°C., as a result of this, the shelf life of the vegetable is expected to increase. (Rusten, 1985).

**Testing of the Evaporative Cooler**

**No Load Test of the Evaporative Cooling System**

A no-load test of the system was conducted to see the effect of the evaporation that is expected to take place whether the process is effective or not in order to determine its efficiency before being loaded with the vegetables that will be stored. This was achieved by taken temperature difference and the relative humidity of the system relative to the ambient condition.

**i. Saturation Efficiency (SE)**

The effectiveness of the jute pad was based on the cooling efficiency. The saturation efficiency (SE) of the cooler for the jute bag used was calculated using Equation (12), (Harris, 1987)

$$S_E = \frac{T_1(db) - T_2(db)}{T_1(db) - T_1(wb)} \tag{12}$$

Where; $T_1(db)$ = dry –bulb outdoor temperature, °C,
$T_2(db)$ = dry- bulb cooler temperature, °C
$T_1(wb)$ = wet-bulb outdoor temperature, °C

**ii. Flow Rate**

The flow rate of water from the reservoir was determined through the use of a stop watch to monitor the time it takes to collect a certain volume of water by the water collector at the bottom of the cooling system.

**Load Test of the Evaporative Cooling System**

The load test of the evaporative cooling system was subjected to the following:

**i. Temperature and Relative Humidity Measurement**

The temperature and relative humidity were determined. Both the temperature of the evaporative cooling system and that of ambient were determined. The temperature readings were taken using the dry and wet bulb thermometer. The relative humidity was then obtained using the psychometric chart which has reading for both the dry and wet bulb temperature. The readings were taken from 8am to 8pm at an intervals of four hours for five consecutive days.

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**ii. Physiological Weight Loss**

The differences in weight of the tomatoes stored in both the ambient and in the cooler condition for five days were estimated and this was done for five days. The percentage weight loss was estimated using Equation (13) as given by Fabiyi, (2010).

Percentage Weight loss =

$$\frac{OriginalWeight - NewWeight}{OriginalWeight} \times 100 \qquad (13)$$

**iii. Color Changes and Firmness**

The changes in color of the tomatoes were noted both in the cooler and in the ambient condition in conjunction with the physiological weight loss. The color changes observed was based on the physical appearance of the vegetable Fabiyi, (2010). The physical texture of the tomatoes was examined and noted. The difference in the firmness was also noted after storing the vegetables in the evaporative cooling system and in ambient condition.

**Statistical Analysis**

Data collected from both ambient and evaporative cooler were computed and statistically analyzed (using t – test) to fully evaluate and ascertain the efficiency of the system.

## RESULTS AND DISCUSSIONS

**Cooling Efficiency**

The cooling efficiency of the evaporative cooling system was calculated when loaded with tomatoes and Table-1 shows the result of the cooling efficiency of the preservation chamber with the tomatoes. The result showed that the average cooling efficiency of the system was 83.0%, this shows that the evaporative cooling system was very effective and hence it will increase the shelf life of fresh tomatoes.

**Table-1.** Cooling efficiency of cooler for five days.

| Days | Cooling efficiency (%) |
|---|---|
| 1 | 82.0 |
| 2 | 90.6 |
| 3 | 83.9 |
| 4 | 71.0 |
| 5 | 87.5 |
| Average | 83.0 |

**Reservoir Discharge Rate**

The discharge rate was determined by measuring the volume of water collected at the bottom of the cooling system after one (1) hour. The volume was made to be two (2) liters, therefore the discharge of the system is two liters per hour.

**Testing of Evaporative Cooler**

The evaporative cooler was subjected to both no load and load tests and tomato (Roma variety) was selected in carrying out these experiments.

**No Load Test of Evaporative Cooler**

The test was achieved by testing the system without uploading tomatoes in order to ascertain whether there is temperature drop and increase in relative humidity as compared to that of ambient environment.

**Load Test of the Evaporative Cooling System**

The evaporative cooling system was loaded with 3.1kg of Roma variety of tomatoes with the same quantity kept under ambient condition. The temperature and relative humidity of both the system and ambient condition were monitored throughout the experiment and assessment of the physiological weight loss, color change and firmness of tomatoes were carried out. The load test result (daily temperature and relative humidity) of the system were shown in Table-2 and the result was then averaged and presented in Table-3. It was observed that the temperature difference between the ambient and cooling system ranges from 6 °C to 10 °C which was in conformity with that reported by Rusten (1985) who gave ranges of temperature difference as 5 to 10 °C. It was observed that there is increase in the system relative humidity in relation to that of the ambient and this increase ranges from 13% to 55% as presented in Table-2. It has been reported by ASHRAE (1982), that the required storage relative humidity of vegetables ranges from 85 to 90%, hence the system relative humidity achieved ranges from 70.0 to 90.0% which closely agrees with that reported by ASHRAE (1982) and Mogaji and Fapetu (2011) who reported 32 to 88% and this is moderately acceptable, but however, the result of the relative humidity of the ambient system which ranges from 31 to 69% was below that recommended by ASHRAE (1982) and hence this will reduce the shelf life of fresh vegetable storage. The result of the average storage temperature of tomatoes achieved in the system ranges from 13.75 to 14.75 °C which virtually agrees with that reported by ASHRAE (1982) and Mogaji and Fapetu (2011) whose gave tomatoes storage temperature as 13 to 21 °C and 16 to 25oC respectively; meanwhile, the temperature of the ambient ranges from 17 to 28 °C which was above the storing temperature of fresh vegetable recommended by ASHRAE (1982) who gave storing temperature of fresh vegetable as 13 to 21 °C. Figure-5 shows the graph of daily average relative humidity per day throughout the experiment. The result of statistical analysis revealed that the calculated t-value (5.26) of the relative humidity was greater than the table t-value at degree of freedom (DF) equal to 4 and 5% level of significance (2.78) and even at 1% level of significance (4.60). This implies that the

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difference between the ambient and evaporative cooling system was highly significance and therefore the use of evaporative cooling system for preservation of tomatoes cannot be neglected. However, high relative humidity increases the shelf life of fresh vegetable as reported by ASHRAE (1982) and therefore, the evaporative cooling system with mean 83% gave the higher relative humidity than that of ambient condition with mean 56.6%. Hence, the evaporative cooling system should be used in preservation fresh tomatoes.

**Table-2.** Daily temperature and relative humidity for five days.

| Day 1 | | | | | |
|---|---|---|---|---|---|
| Time | Ambient condition | | | Cooler condition | |
| | DB(°C) | WB(°C) | RH (%) | DB(°C) | RH(%) |
| 8:00am | 19 | 12 | 43 | 13 | 70 |
| 12:00pm | 22 | 17 | 61 | 15 | 80 |
| 4:00pm | 26 | 26 | 58 | 19 | 73 |
| 8:00pm | 20 | 20 | 52 | 12 | 89 |
| **Day 2** | | | | | |
| Time | Ambient condition | | | Cooler condition | |
| | DB(°C) | WB(°C) | RH (%) | DB(°C) | RH (%) |
| 8:00am | 18 | 10 | 34 | 11 | 89 |
| 12:00pm | 24 | 18 | 56 | 14 | 80 |
| 4:00pm | 28 | 20 | 46 | 20 | 83 |
| 8:00pm | 19 | 12 | 48 | 12 | 90 |
| **Day 3** | | | | | |
| Time | Ambient condition | | | Cooler condition | |
| | DB(°C) | WB(°C) | RH (%) | DB(°C) | RH (%) |
| 8:00am | 18 | 11 | 41 | 12 | 78 |
| 12:00pm | 23 | 16 | 45 | 15 | 80 |
| 4:00pm | 25 | 19 | 57 | 16 | 90 |
| 8:00pm | 20 | 14 | 52 | 12 | 89 |
| **Day 4** | | | | | |
| Time | Ambient condition | | | Cooler condition | |
| | DB(°C) | WB(°C) | RH (%) | DB(°C) | RH (%) |
| 8:00am | 19 | 13 | 50 | 11 | 89 |
| 12:00pm | 23 | 18 | 62 | 16 | 90 |
| 4:00pm | 26 | 21 | 69 | 18 | 82 |
| 8:00pm | 21 | 15 | 53 | 13 | 79 |
| **Day 5** | | | | | |
| Time | Ambient condition | | | Cooler condition | |
| | DB(°C) | WB(°C) | RH (%) | DB(°C) | RH (%) |
| 8:00am | 17 | 10 | 40 | 9 | 88 |
| 12:00pm | 24 | 18 | 56 | 16 | 81 |
| 4:00pm | 27 | 21 | 53 | 19 | 82 |
| 8:00pm | 20 | 11 | 31 | 12 | 78 |

**Table-3.** Average temperature and relative humidity readings for both ambient condition and the evaporative cooling system.

| Days | Ambient temperature Readings | | | Cooler temperature readings | |
|---|---|---|---|---|---|
| | DB(°C) | WB(°C) | RH% | DB(°C) | RH% |
| 1 | 21.75 | 18.75 | 53.5 | 14.75 | 78.00 |
| 2 | 22.25 | 15.00 | 46.00 | 14.25 | 85.50 |
| 3 | 21.50 | 15.00 | 48.75 | 13.75 | 84.25 |
| 4 | 22.25 | 16.75 | 58.50 | 14.50 | 85.00 |
| 5 | 22.00 | 15.00 | 45.00 | 14.00 | 82.25 |

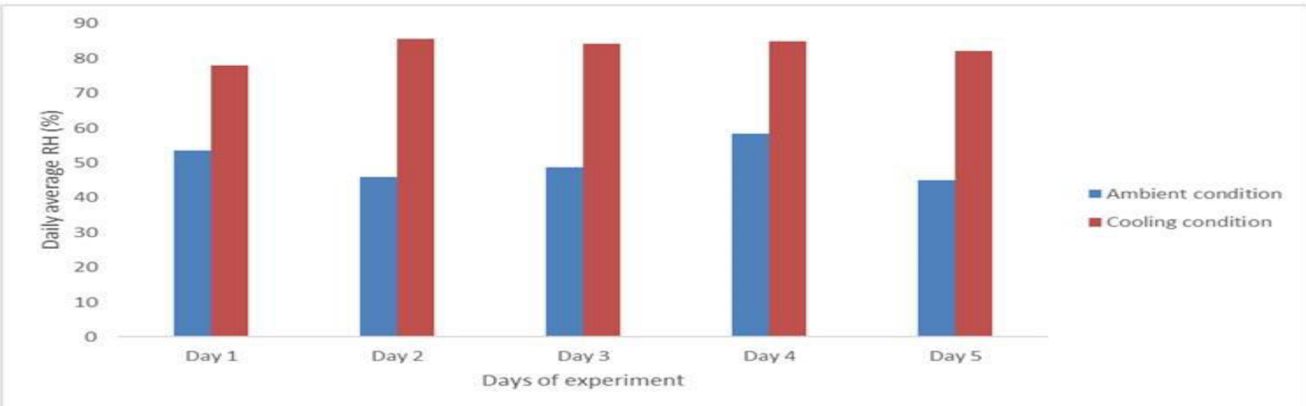


**Figure-5.** Daily average relative humidity for both ambient and cooling system.

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**Physiological Weight Loss of Tomatoes**

Table-4 and 5 showed the results of physiological weight loss and percentage of weight loss of tomatoes while Figure-6 shows the daily weight loss during the experiment. These results revealed that the weight loss of tomatoes in the evaporative cooling system ranged from 1.7 to 5.7g per day while that of ambient system ranges from 9.3 to 18.6g per day while and the percentage of weight loss of tomatoes in evaporative cooling system and ambient ranged from 0.05 to 0.18% and 0.30 to 0.60% per day respectively. The physiological weight loss of the tomatoes both in ambient and evaporative cooling system were subjected to statistical analysis and the results of the analysis also revealed that the computed t-value (7.50) of the weight loss was greater than the table t-value at degree of freedom of 4 and at both 5% (2.78) and 1% (4.60) level of significance. This means that the difference between the ambient and evaporative cooling system was highly significant and therefore the use of evaporative cooling system for preserving and improving the shelf life of tomatoes cannot be avoided. FAO, (1989) as reported that water is an important constituent of most fruits and vegetables and its adds up to the total weight and losses of water will definitely reduce the weight and begin to wilt and soon becomes unusable, hence it is on this note that it is paramount to maintain the weight of fresh tomatoes in order to maximize profit. However, the evaporative cooling system with mean 3.98g gave the less loss of weight as compared to the ambient condition with mean 13.95g gave the highest loss of weight. Hence, the evaporative cooling system should be used in preserving fresh tomatoes.

**Table-4.** Physiological weight measurement of tomatoes.

| Days after storage | Weight loss of tomatoes in evaporative cooling system (g) | Weight loss of tomatoes in ambient condition (g) |
|---|---|---|
| 1 | 1.7 | 9.3 |
| 2 | 3.05 | 13.95 |
| 3 | 4.4 | 18.6 |
| 4 | 5.05 | 15.5 |
| 5 | 5.7 | 12.4 |

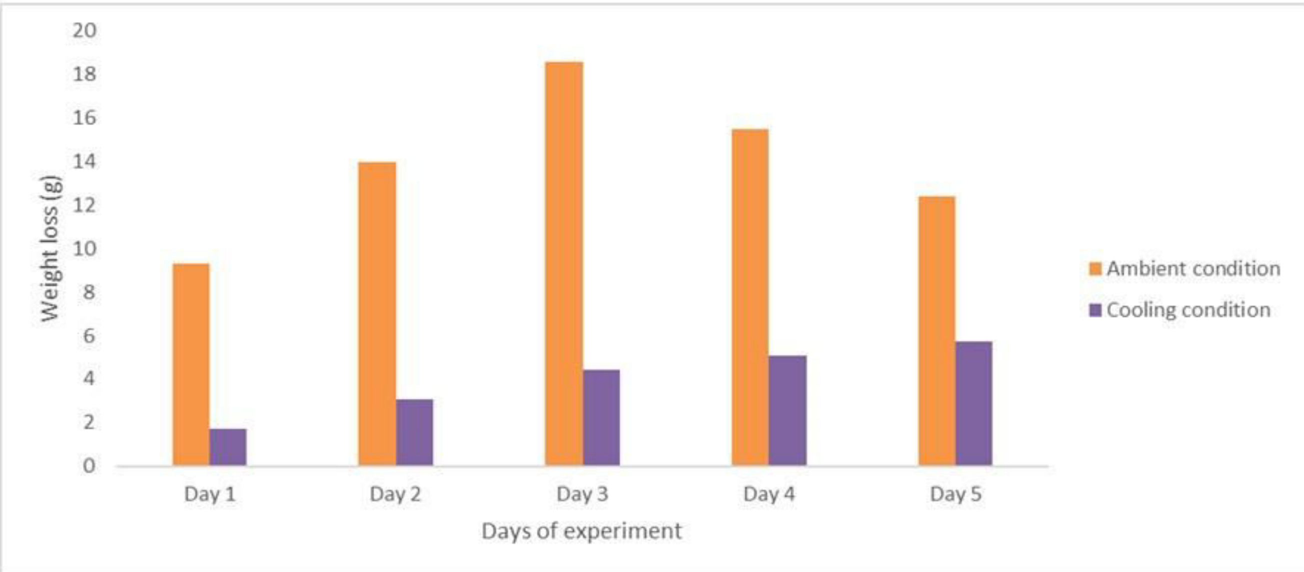


**Figure-6.** Daily weight loss of tomatoes kept in both ambient and cooling system.

**Color Change**

During The testing period, the color changes of the tomatoes were monitored for both samples kept under ambient and evaporative cooling system. The color changes of tomatoes stored under ambient condition was very obvious from the third day of storage. By the sixth day, the tomatoes color changed from yellowish red (Figure-7) to a deep red color while some turned reddish black (Figure-8). It was also observed that the tomatoes stored in the evaporative cooling system still retained their color after six (6) days (Figure-9) with no color changes noticed in most of the tomatoes.

**Figure-7.** Fresh tomatoes (roma) before storage.

**Figure-8.** Tomatoes after 6 days under ambient condition.

**Figure-9.** Tomatoes after 6 days in the cooling system.

**Firmness**

The change in the firmness was much noticed in the tomatoes because of their spherical shape. The tomatoes stored in the evaporative cooler still retained its firmness but those stored in the ambient have started losing their firmness after the third day and after the sixth day most of the tomatoes have started rotting (Figures-8 and 9). It is based on this background that the use of evaporative cooling system for storing fresh tomatoes is significant and cannot be over emphasized.

## CONCLUSIONS

An evaporative cooling system was designed and constructed for preservation of fresh vegetables and tested using tomatoes (Roma variety). The evaporative cooling system works on the principle such that warm dry air is cooled and humidified by passing through a jute bag. The evaporative cooling system operate by the means of solar energy as the power source in which cool air passes through the storage chamber were the tomatoes are stored. The evaluation of the system was carried out to ascertain the average drop in the temperature during the no-load test where the temperature recorded ranged from 13.75 to 14.75 °C. The cooling efficiency of the cooler was estimated both on load and a no-load condition and ranged from 71 to 90.6% with an average of 83%. The tomatoes were stored both in cooling system and in ambient condition in order to deduce the effectiveness of the system, taking the physical phenomenon such as the system relative humidity, weight loss, color and firmness of tomatoes into consideration and evaluating them using student T-test. The percentage weight loss of the tomatoes was much in the ambient (0.30 to 0.60%) compared to those stored in the cooler (0.05 to 0.18%). The color changes observed in the tomatoes stored in the ambient (deep red to reddish black) was greater compared to the ones stored in the evaporate cooler (yellowish red to red). The loss of firmness was also very obvious in the tomatoes stored under ambient as compared to evaporative cooling system. Statistical analysis revealed that the use of evaporative cooling system in preserving fresh tomatoes was highly significant. However, the testing of the evaporative cooling system shows that the tomatoes could be stored for an average of five (5) days without rotting compared to that of ambient which started rotting after three (3) days. Hence, it ws concluded that farmers, house holders and tomatoes processing factories should adopt the use of an evaporative cooling system for the preserving of fresh tomatoes as this increases the shelf life of tomatoes.

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