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*Full Length Research Paper*

# Development of an evaporative cooling system for the preservation of fresh vegetables

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**An evaporative cooling system for the preservation of fresh vegetables was developed for extending the shelf life of tomatoes and carrots and its performance was evaluated. It consists of a pyramidal shaped with total storage space of 0.075 $m^3$, made of galvanized mild steel, stainless steel and internally insulated with 0.025 m polystyrene foam, a suction fan of 4.3 m/s velocity air flow and 0.5 W (1250 rpm), cooling pad (Jute) of 0.06 m thickness and water pump with discharge capacity of 3.5 l/min as well as a power rating of 0.5 W. A water reservoir of capacity 62.5 $m^3$ is linked to the cooling system at the bottom through a P.V.C. pipe supplying water to keep the cooling pad/mesh continuously wet. Study was conducted to check the freshness of tomatoes and carrots, and data were observed daily. Results of the transient performance tests revealed that the evaporative cooling system chamber temperature and relative humidity depression from ambient air temperature varied over 16-26°C and 33-88% respectively. Ambient air temperatures and relative humidity during the test periods ranged over 26-32°C and 18-31% respectively. The shelf life of the vegetable produce inside the evaporative cooling system was extended by fourteen days relative to ambient storage. Thus, the evaporative cooling system has the prospect of being used for short term preservation of vegetables soon after harvest and it will be very useful in a developing economy like Nigeria.**

**Key words:** Evaporative cooling systems, fresh vegetables, preservation, modeling, temperature, relative humidity, tomatoes and carrots.

## INTRODUCTION

Most of the post-harvest losses incurred on fruits and vegetables in developing countries are due to lack of adequate storage facilities. While refrigerated cool stores are expensive to install and run, they are still the best method of preserving fruits and vegetables.Cooling through evaporation is an ancient but effective method of lowering temperature. The quality of fresh fruits and vegetables depends on post-harvest handling, transportation and storage (Haidar and Demisse, 1999). Compared with several temperate fruits and vegetables, tropical and subtropical vegetables such as tomatoes and carrots, present greater storage and transportation problems because of their perishable nature (Mitra and Baldwin, 1997). Kader (1992) estimated the extent of post-harvest losses in fresh fruit and vegetables at 5 - 25% in developed countries and 20 - 50% in developing countries.

Fresh fruits and vegetables have flavours, aroma and colour that are essential for normal health (Duckworth, 1979). Vegetables are generally regarded as essential herbaceous plant with high moisture content in their freshly forms. They possess considerable quantities of vitamins A, B, C, D, E and K, which help in protecting the body against diseases and contribute in no small measure to good health (Peter, 1997). Hence, they provide maximum vitamins when consumed fresh.

Fruits and vegetables are highly perishable commodities that cannot be kept for long period of time due to their perishable and seasonal nature. It is therefore important that they are preserved in seasons

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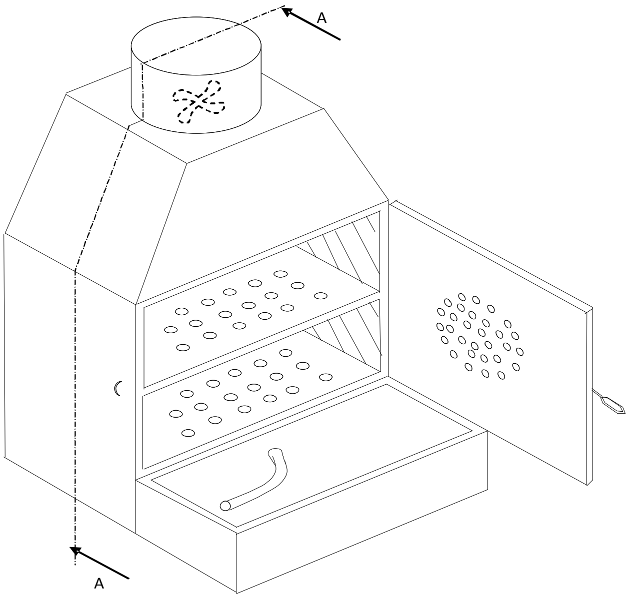


**Figure 1.** A schematic diagram of the evaporative cooling system.

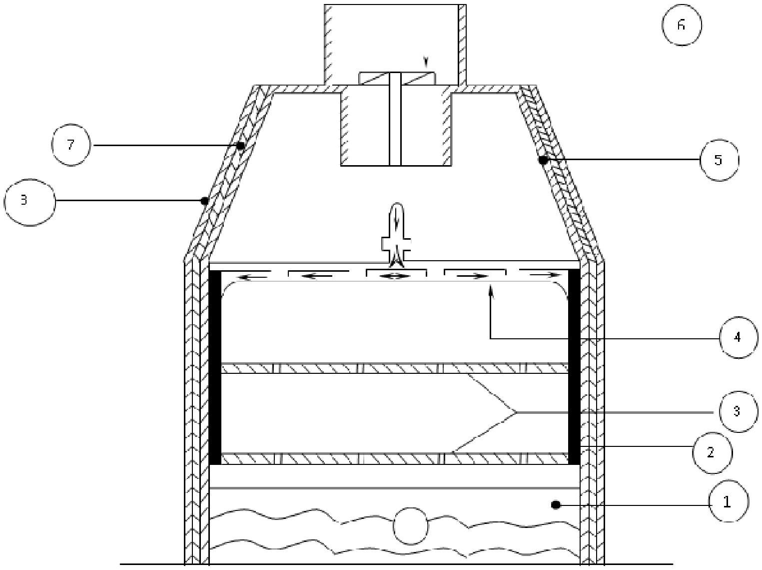
when available in order to ensure their constant supply throughout the year with their nutritional value still retained (CFNEU, 2003). In addition, preservation of fruits and vegetables is of great importance because it makes provision for delayed use and eliminates wastage (Aremu, 1975). Low temperature handling and storage have been described as the most important physical method for post-harvest loss control (Seyoum and Woldetsdik, 2004). Temperature of the surrounding air and produce can be reduced by forced air cooling, hydro cooling, vacuum cooling, and adiabatic cooling (Thompson et al., 1998). In developed countries, methods employed for extending shelf life and minimizing post-harvest losses of perishable produce include mechanical refrigeration, controlled atmospheres, hypobaric storage, and other sophisticated techniques. These techniques are highly capital intensive and for most developing countries, the required manpower is either lacking or inadequate. These cooling methods, except adiabatic cooling, are expensive for small scale peasant farmers, retailers and wholesalers, as they require electric power. Moreover, in the existing mechanical refrigerating systems, proper storage conditions are not often put into consideration as stored items (vegetables) were normally subjected to excessive chilling or freezing. The injurious effects this has on stored vegetable products are often very severe, hence, one of the major reasons for the low efficiency of this system in extending the shelf life of fresh vegetables. Low temperature and high relative humidity can be achieved by using less expensive methods of evaporative cooling (Seyoum and Woldetsadik, 2000; Seyoum and Woldetsadik, 2004). Evaporative cooling has been reported for achieving a favorable environment in greenhouses (Jain and Tiwari, 2002), animations and the storage structure for fruit and vegetables (Helsen and Willmot, 1991; Umbarker et al., 1991). The present study was therefore planned to design and develop an evaporative cooling system that could be utilized to preserve tomatoes and carrots at their minimal storage temperature.

## MATERIALS AND METHODS

### Design and construction

In this study an evaporative cooling system of 25 kg storage capacity, suitable for the preservation of fresh vegetables was constructed. The evaporative cooling system consists basically of the cabinet, cooling fan and the transmitting medium (cooling pad). It consists of a pyramidal shaped with total storage space of 0.075 $m^3$, made of galvanized mild steel, stainless steel and internally insulated with 0.025 m polystyrene foam, a suction fan of 4.3 m/s velocity air flow and 0.5 W (1250 rpm), cooling pad (Jute) of 0.06 m thickness and water pump with discharge capacity of 3.5 l/min and power rating of 0.5 W. A water reservoir of capacity 62.5 $m^3$ is linked to the cooling system at the bottom through a P.V.C. pipe supplying water to keep the cooling pad/mesh continuously wet. The basic principle relies on cooling by evaporation, when the system is set in operation, the dry air from the suction fan passes over the wet surface (cooling pad) and evaporated away the soaked water away from the cooling pad. When water evaporates, it draws energy from its surroundings (storage chamber) which produce considerable cooling effect in the storage chamber.

The isometric view of the developed evaporative cooling system is shown in Figure 1. Figure 2 shows a sectional view of the system in order to show the section inside the system. The back view is shown in Figure 3 for proper perception of the developed system.



| ITEM | PUMP | NO. OFF | MAIL |
|---|---|---|---|
| 1 | Water Tank | 1 | |
| 2 | Moist Pad | 2 | S.S |
| 3 | Shelves | 2 | Jute Sack |
| 4 | Duct | | |
| 5 | Stainless Steel | | |
| 6 | Fan | | |
| 7 | Polystrene Foam | | |
| 8 | Mild Steel | 1 | |

**Figure 2.** Sectional view across AA.

### Design procedure and machine development

Evaporative cooling systems consist basically of the cabinet, the cooling fan, and transmitting medium (cooling pad).

### The cabinet design

One of the important components of the evaporative cooling system is the cabinet, which houses the insulating materials and their components. The resistance that a wall or a material offers to the flow of heat is inversely proportional to the ability of the wall or material to transmit heat, that is, the overall thermal resistance is inversely proportional to the overall heat transfer coefficient Equation (1). The thermal resistance of the wall is the sum of the thermal resistances of the individual materials in the wall configuration, including air films (Table 1). The summation of these resistances is given in Equation 2 and the nomenclature expressed in Figure 4.

### Determination of temperature gradient across the insulating materials

The section through the cabinet wall is illustrated in Figure 4.

$$U = \frac{1}{\sum R} \tag{1}$$

$$\sum R = R_i + R_1 + R_2 + R_3 + R_0 \tag{2}$$

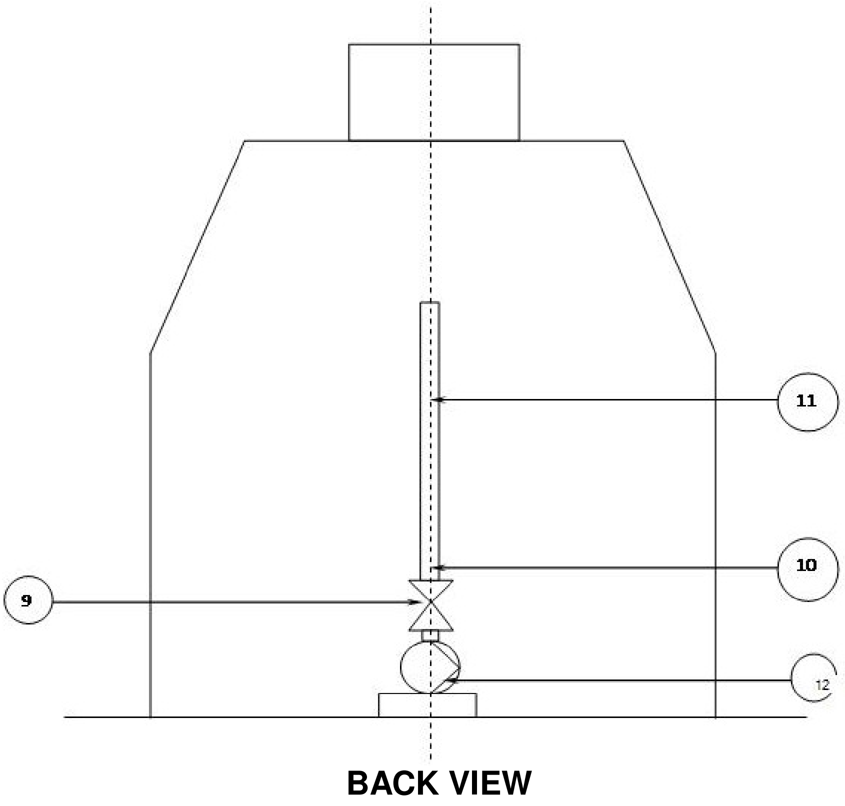
Where:
$\sum R$= Thermal Resistance ($m^2K/W$)
U = Overall heat transfer coefficient ($W/m^2\ K$)
$R_i$ = Inside surface resistance ($m^2\ K/W$)
$R_1$ = Thermal resistance of galvanized mild steel ($m^2\ K/W$)
$R_2$ = Thermal resistance of polystyrene foam ($m^2\ K/W$)
$R_3$ = Thermal resistance of stainless steel ($m^2\ K/W$)
$R_0$ = Outside surface resistance ($m^2\ K/W$)

Using Equations (1) and (2) the U–value is estimated to be 0.45 ($W/m^2\ K$) that is, the coefficient of heat transmission for each of the three walls = 0.45 $W/m^2K$.

In the design, the ambient temperature was measured to be 32°C while the expected storage temperature is to be maintained at 16°C as proposed by Dossat (1997) for carrot, lettuce and tomato. The temperature gradient across the insulating materials was determined using Equation (3):

$$Q_{HL} = \frac{t_0 - t_3}{\sum R} \tag{3}$$

Where $t_0$ = 32°C, $t_3$ = 16°C, $\Sigma R$ = 2.225 ($m^2K/W$)



| ITEM NO. | STEEL | NO. OFF | MAIL |
|---|---|---|---|
| 9 | N.R VALVE | 1 | BRASS |
| 10 | TAP | 1 | BRASS |
| 11 | PIPE | 1 | P.V.C. |
| 12 | PUMP | 1 | M.S |

**Figure 3.** Back view of the evaporative cooling system.

**Table 1.** The thickness and the thermal resistance of the insulating materials.

| Material | Thermal resistance ($m^2K/W$) | Thickness (m) "$x$" |
|---|---|---|
| Surface air film | 0.121 | |
| Galvanized mild steel | 0.188 | 0.025 |
| Polystyrene foam | 1.366 | 0.025 |
| Stainless steel | 0.52 | 0.003 |
| Air films | 0.030 | |

Source: ASHRAE handbook (2002).

$Q_{HL}$= Heat loss per unit area of the system
$t_0$ = Outside temperature
$t_3$ = Inside temperature
$\Sigma R$ = Overall thermal resistance

Thus $Q_{HL} = \frac{(32-16)}{2.225}$ = 7.191 W/$m^2$

Therefore, the temperature gradient across the galvanized mild steel is calculated as follows:

$$Q_{HL} = \frac{t_0 - t_1}{R_1} \tag{4}$$

$$t_1 = 30.6^0 C$$

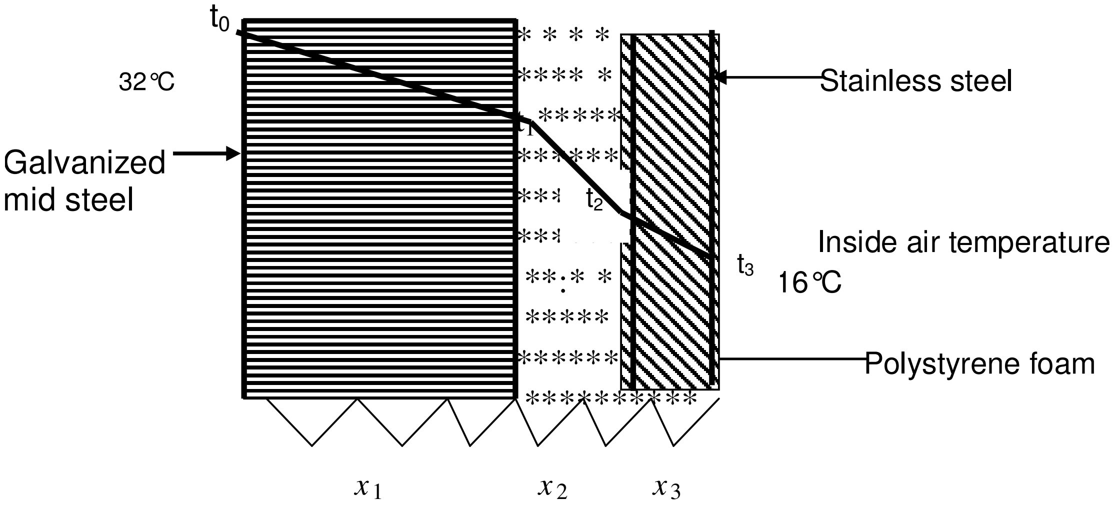


**Figure 4.** Section through the cabinet wall.

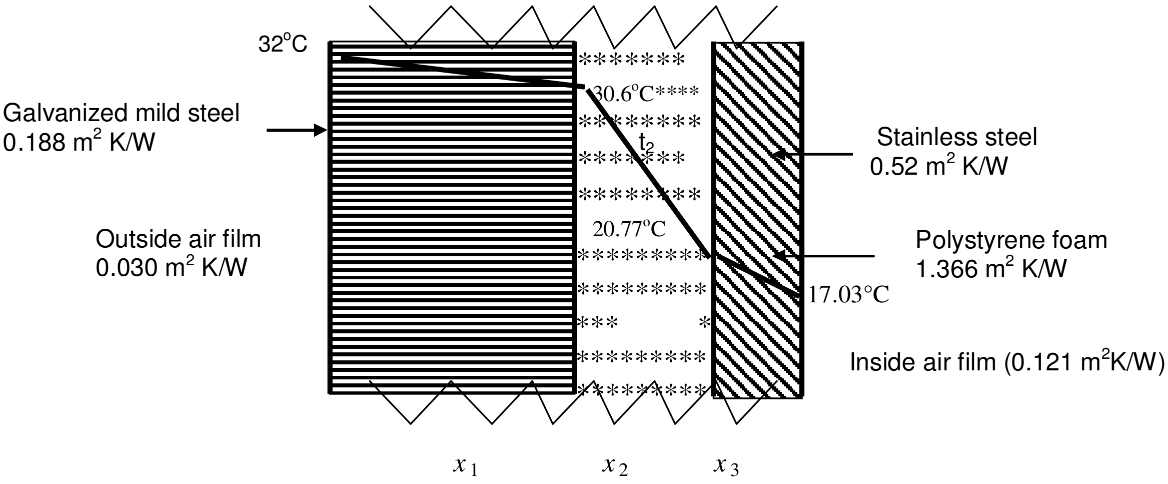


**Figure 5.** Sections of the cabinet together with the temperature gradient across the insulation materials.

The temperature gradient across the polystyrene foam is calculated as follows:

$$Q_{HL} = \frac{(t_1 - t_2)}{R_2} \tag{5}$$

$t_2$ = 20.77°C

The temperature gradient across the stainless steel is calculated as follows:

$$Q_{HL} = \frac{t_2 - t_3}{R_3} \tag{6}$$

$t_3$ = 17.03°C

`Thus, the section of the cabinet together with the temperature gradient across the insulation materials are as shown in Figure 5.

### Heat transfer analysis

The heat gain by the individual insulating material of the cabinet was estimated using Fourier's law of heat conduction (Equation 7).

$$Q_{hg} = \frac{kA\Delta T}{x} \tag{7}$$

Where,

$Q_{hg}$ = Quantity of heat gained by the material (W/m$^2$)
A = Overall 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 insulating material (m)

The heat gained by the galvanized mild steel is calculated as follows:

$$Q_{hgs} = \frac{k_{gs} A_{gs} \Delta t_{gs}}{x_{gs}} \qquad (8)$$

$Q_{hgs}$ is estimated to be1070 .03 W/m$^2$

Therefore, the heat gained by the polystyrene foam is calculated thus as expressed in Equation (9):

$$Q_{pg} = \frac{k_p A_p \Delta t_p}{x_p} \qquad (9)$$

$Q_{pg}$ is estimated to be 785.02 W/m$^2$

The quantity of heat gained by the stainless steel is calculated thus:

$$Q_{hss} = \frac{k_{ss} A_{ss} \Delta t_{ss}}{x_{ss}} \qquad (10)$$

$Q_{hss}$ is estimated to be 1560.45 W/m$^2$

### Heat balance

The heat flow through the system is represented as shown in Figure 5. Since $Q_{hgs}$, $Q_{hp}$ and $Qh_{ss}$ were estimated to be the heat gains by galvanized mild steel, polystyrene foam and stainless steel respectively.

Therefore, the equation for the heat flow in the system is given by Equation 11:

$$(t_0 - t_1) + (t_1 - t_2) + (t_2 - t_3) = \left[ \frac{Q_{hgs} x_{gs}}{k_{gs} A_{gs}} + \frac{Q_{hp} x_p}{k_p A_p} + \frac{Q_{hss} x_{ss}}{k_{ss} A_{ss}} \right] \qquad (11)$$

Simplifying Equation 11, we have Equation 12 as:

$$(t_0 - t_3) = \left[ \frac{x_{gs}}{k_{gs} A_{gs}} + \frac{x_p}{k_p A_p} + \frac{x_{ss}}{k_{ss} A_{ss}} \right] Q_n \qquad (12)$$

Putting the values into Equation (12):

Then $Q_n = 3415.5 W/m^2$

Therefore the power generated due to the heat flow through the system is estimated using Equation (13):

$$Q_n = \frac{\text{Power Generated}}{\text{A}}$$

where,

A = Total area of the cooling chamber (m$^2$)
$Q_n$ = Heat flow through the system (W/m$^2$)

Power generated is estimated to be = 0.45 W

Thus power generated (0.45 W) was mainly considered as a reference power rating limit in the selection of the other components such as the suction fan and the water pump for the effective performance of the evaporating cooling system.

### 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 (Wiersma, 1983; Thakur and Dhingra, 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, % dry basis, high bulk density reported (Manuwa, 1991). Similar findings have been reported by Igbeka and Olurin (2009).

### Velocity of air (v)

The velocity of air from the suction fan of the evaporative cooling system is determined using Bernoulli's equation as follows:

$$\frac{p_1}{\rho_1} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{\rho_2} + \frac{V_2^2}{2g} + Z_2 + \text{Head loss} \qquad (14)$$

where:

$P_1$ and $P_2$ = Atmospheric pressure (N/m$^2$)
$\rho_1$ and $\rho_2$ = Density (kg/m$^3$)
$Z_1$ and $Z_2$ = Height
$V_1$ and $V_2$ = Velocity (m/s)

Where $\rho_1$ and $\rho_2$ are constant for compressible air flow from the fan:

$P_1 = P_2$ and $\rho_1 = \rho_2$, then:

$$\frac{P_1}{\rho_1} = \frac{P_2}{\rho_2} \qquad (15)$$

$$\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2} = 0$$

(16)

For the fan, $V_1 and Z_2 = 0$

Thus Equation (14) is reduced to Equation (17):

$$Z_1 = \frac{V_2^2}{2g} + \text{Heat loss} \qquad (17)$$

The heat loss at the conical head of the system is determined using Equation (18):

$$H_f = \frac{4fLV^2}{2gd} \qquad (18)$$

Where, f = Frictional factor
g =Gravitational constant m/s$^2$
L = Length of the conical part (m)
d = Diameter of the conical head (m)
V = Velocity (m/s)
f = $16/R_e$
$R_e$ = Reynolds number = 1516.5
f = 0.0106
L= 0.4 m

$$H_f = \frac{4 \ X\, 0.0106 \ X \ 0.4 \ X \ V^2}{2 \ X \ 9.81 \ X \ 0.260}$$

$$H_f = 3.33188 \, X \, 10^{-3} V^2$$

$$Z_1 = \frac{V_2^{\,2}}{2g} + \text{Heat loss}$$

$$Z_1 = V_2^{\,2}\left(1/2g + 3.33188 \, X \, 10^{-3}\right)$$
$$Z_1 = V_2^{\,2}\left(5.097 \, X 10^{-2} + 3.33188 \, X \, 10^{-3}\right)$$
$$Z_1 = V_2^{\,2}\left(5.43019 \, X \, 10^{-2}\right)$$

The datum of the system $Z_1$ =1 m

$$1 = V^2\left(5.43019 \ X \ 10^{-2}\right)$$
$$V_2 = 4.3\, m/s$$

The convective nature of the air flow was determined using Equation (19):

$$R_{ed} = \frac{V_\infty d}{\nu} \quad \text{(Holman, 1997)} \qquad (19)$$

Where, $V_\infty$ = Air velocity (m/s)
$d_{ch}$=Diameter of the chimney head (m)
$\nu$ = Kinematic viscosity (m$^2$/s)
$R_{ed}$ = Reynolds number in tube

From Holman (1997) at 32°C (305 K)

$\nu$ = 16.20 x 10$^{-6}$ m$^2$/s
$V_\infty$ = 4.3 m/s
d = 0.260 m

On substitution, $R_{ed}$ is estimated to be 69025, thus, the air flow through the suction fan is turbulent in nature which justified the required forced convective nature of air flow for an effective evaporative cooling system.

## Modeling

A polynomial equation of the form (Equation 20) was used to predict and to validate the efficiency of the developed system at average values over 35 days:

$$t_m = at^3+bt^2+ct+d \qquad (20)$$

The values of the constants a, b, c and d were determined for:

(i) no load.
(ii) when the cabinet was loaded with tomatoes.
(iii) when the cabinet was loaded with carrots.

The results show that the values of “a” is negligible and therefore not included in the expression. The resulting equations respectively for the three aforementioned conditions are given in Equations (21) to (23).

$$t_m = 0.3988t^2-4.5655t+28.929 \qquad (21)$$
$$t_m = 0.1269t^2-2.5019t+28.425 \qquad (22)$$
$$t_m = 0.1458t^2-2.7405t+29 \qquad (23)$$

## Apparatus and experimental observation

The following parameters stated in (i), (ii) and (iii) were measured daily at intervals of one hour from 10:00 am and 7:00 pm:

i) ambient and the cabinet temperature (using digital thermometer).
ii) relative humidity (using digital humidity –temperature meter).
iii) Products weight (preserved and unpreserved) (using digital weight balance).

The evaporative cooling system was tested over a period of 35 days at The Federal University of Technology Mechanical Engineering Workshop, Akure, Nigeria, using 25 kg of fresh red tomatoes and 25 kg of carrots as specimens respectively. The chamber was tested for its ability to reduce the temperature while maintaining the increased relative humidity. The experiment was carried out using the developed evaporating cooling system at no load condition for 7 days.

The system was also used at loaded condition to preserve tomatoes and carrots for the other 14 days respectively. During the testing period, the thermometer was suspended in the chamber through a small hole in the cabinet to ascertain the variation of temperature in the chamber, while a control sample of 25 kg of fresh red tomatoes and carrots spread on a tray were expose to the open air.

## Experimental data analysis

A regression analysis of the data for no-load and each of the products obtained during the experiment was determined using the least square method relations in Equation 24:

$$t_{ca}=a+b\,\Delta t \qquad (24)$$

Where ,$t_{ca}$ = Calculated temperature
$\partial t$ = Change of time
a and b = Parameters of the regression equation.

Table 2 shows the values of ‘a’ and ‘b’ obtained from the regression, as well as ‘ $R^{2'}$ the coefficient of correlation.
This gives an ‘$R^{2}$’ value of 0.98 for no–load, 0.95 and 0.96 for tomatoes and carrots respectively.

The following trend equations were obtained:

**Table 2.** Results of regression analysis.

| Agricultural product | a | b | $R^2$ |
|---|---|---|---|
| No–load | 24.14 | -1.38 | 0.98 |
| Tomatoes | 26.9 | -1.21 | 0.95 |
| Carrots | 25.4 | -1.09 | 0.96 |

**Table 3.** Ambient and cabinet hourly temperature and relative humidity variation for the system at no–load condition for 7 days.

| Time (Hour) | $t_{ca}$ (°C) | Average ambient temperature (°C) | Relative humidity ambient (%) | Average cabinet temperature (°C) | Relative humidity cabinet (%) |
|---|---|---|---|---|---|
| 10:00 | 22.8 | 26 | 29 | 25 | 32 |
| 11:00 | 21.4 | 27.5 | 26 | 21.5 | 45 |
| 12:00 | 20 | 29.5 | 21.5 | 18 | 58 |
| 13:00 | 18.6 | 31 | 19.5 | 17 | 66 |
| 14:00 | 17.2 | 32 | 18 | 16.5 | 84 |
| 15:00 | 15.9 | 32.5 | 17.5 | 16.5 | 84 |
| 16:00 | 14.5 | 28 | 25 | 16 | 88 |

**Table 4.** Ambient and cabinet hourly temperature and relative humidity variation for the system at loaded condition with tomatoes for 14 days.

| Time (Hour) | $t_{ca}$ (°C) | Average ambient temperature (°C) | Relative humidity ambient (%) | Average cabinet temperature (°C) | Relative humidity cabinet (%) |
|---|---|---|---|---|---|
| 10:00 | 25.7 | 27 | 31 | 26 | 33 |
| 11:00 | 24.5 | 27.5 | 26 | 24.5 | 36 |
| 12:00 | 23.3 | 29 | 22 | 23.5 | 43 |
| 13:00 | 22.1 | 31.5 | 20 | 23 | 49 |
| 14:00 | 20.9 | 32 | 18 | 20 | 54 |
| 15:00 | 19.6 | 33 | 17.5 | 19 | 66 |
| 16:00 | 18.4 | 30 | 20.5 | 17 | 75 |
| 17:00 | 16.9 | 29 | 22 | 16.5 | 84 |
| 18:00 | 16.01 | 27 | 31 | 16.5 | 84 |
| 19:00 | 14.8 | 26 | 30 | 16 | 88 |

$$t_{ca} = 24.14 - 1.38\partial t \text{ (No–load)} \quad (25)$$

$$t_{ca} = 26.9 - 1.21\partial t \text{ (Tomatoes)} \quad (26)$$

$$t_{ca} = 25.4 - 1.09\partial t \text{ (Carrots)} \quad (27)$$

These equations were used to calculate the new cabinet temperatures and results obtained are presented alongside their corresponding mean experimental values for both ambient and cabinet hourly temperature and relative humidity variation for the system on no–load and loaded condition for tomatoes and carrots respectively in Tables 3, 4 and 5.

## RESULTS AND DISCUSSION

### Temperature and relative humidity variation

The performance of the evaporative cooling system without any load to be cooled was evaluated daily at intervals of one hour from 10:00 am and 7:00 pm for 7 days as shown in Table 3. Within these period of evaluating the performance of the cooling system, the ambient temperature kept on increasing with time changing, the cabinet experienced drop in temperature and thereafter maintained an appreciable constant low temperature value of about 16°C with time for the remaining testing period. However the average temperature inside the cool chamber varied from 16 to 25°C while in the ambient air temperature varied from 26 to 32.5°C, when it is unloaded, with fan speed velocities in the order of 4.3 m/s. Thus, the evaporative cooling system temperatures were consistently lower than the ambient air temperatures during the hottest time of the day when insulation was appreciable and cooling most needed also inside the evaporative cooling chamber

**Table 5.** Ambient and cabinet hourly temperature and relative humidity variation for the system at loaded condition with carrots for 14 days.

| Time (Hour) | $t_{ca}$ (°C) | Average ambient temperature (°C) | Relative humidity ambient (%) | Average cabinet temperature (°C) | Relative humidity cabinet (%) |
|---|---|---|---|---|---|
| 10:00 | 24.3 | 26 | 32 | 25.5 | 32 |
| 11:00 | 23.2 | 27 | 26 | 24.5 | 39 |
| 12:00 | 22.1 | 29 | 22 | 22 | 43 |
| 13:00 | 21.3 | 30 | 20.5 | 20 | 48 |
| 14:00 | 20 | 32 | 18 | 19 | 65 |
| 15:00 | 18.9 | 32.5 | 17 | 17.5 | 71 |
| 16:00 | 17.8 | 30 | 20.5 | 17 | 75 |
| 17:00 | 16.7 | 28 | 24 | 16.5 | 84 |
| 18:00 | 15.6 | 27.5 | 26 | 16.5 | 84 |
| 19:00 | 14.5 | 26 | 32 | 16 | 88 |

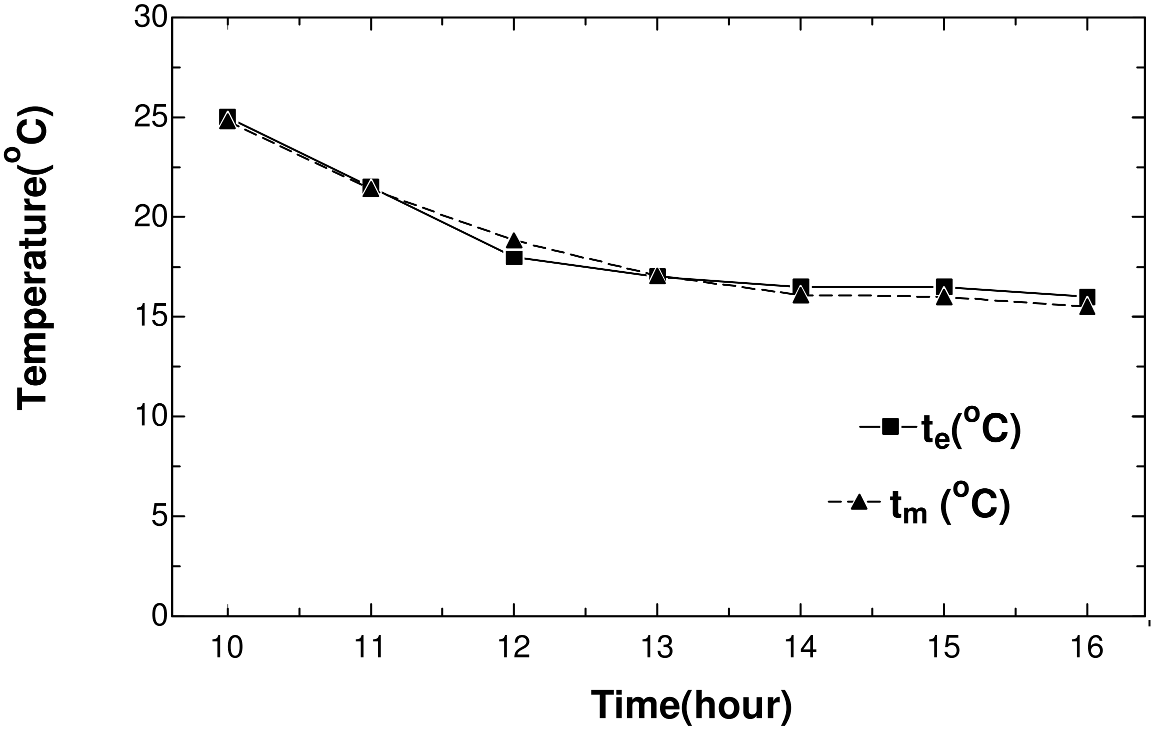


**Figure 6.** Experimental and model results at temperature range between (16 and 26)°C on no-load.

relative humidity is 32-88% while at outside it was recorded 18-29%.

The transient responses of the evaporative cooling system loaded for 14 days with fresh tomatoes and carrots respectively during the testing period are presented in Tables 4 and 5, and it shows the relative humidity and the average temperature. Low temperatures are necessary to maintain the products in fresh conditions for a significantly longer period. These results clearly demonstrate that the evaporative cooling system may be useful in our climate for short term preservation of farm products, especially during the hottest times of the day when cooling is most needed, in addition to double checking the efficiency of the evaporative cooling system developed. A model was developed to predict and validate the efficiency of the developed system at average values over 35 days of the system evaluation, the variations in temperature obtained for the test temperature "$t_e$" and model temperature "$t_m$" experiments relative to the different stored products are shown in Figures 6 to 8.

Statistical analysis shows that the correlation coefficient

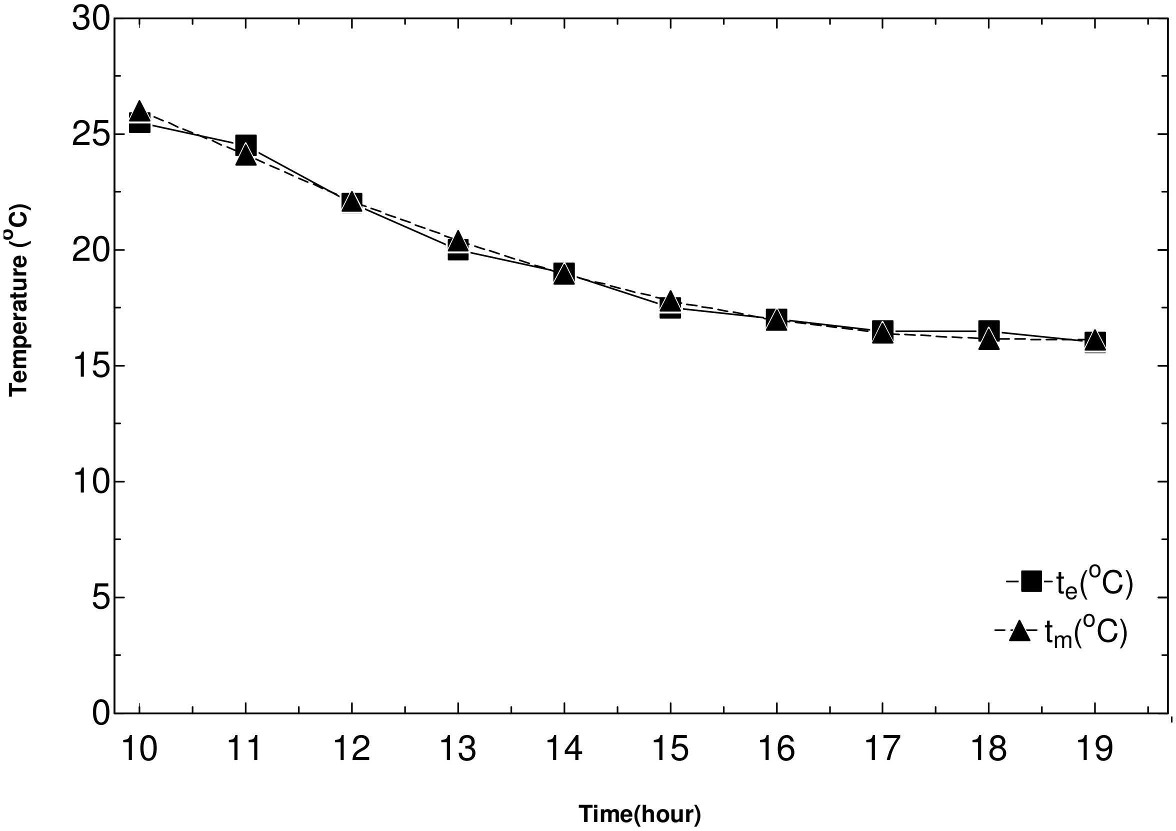


**Figure 7.** Experimental and model results at temperature range between (16 and 26)°C for tomatoes.

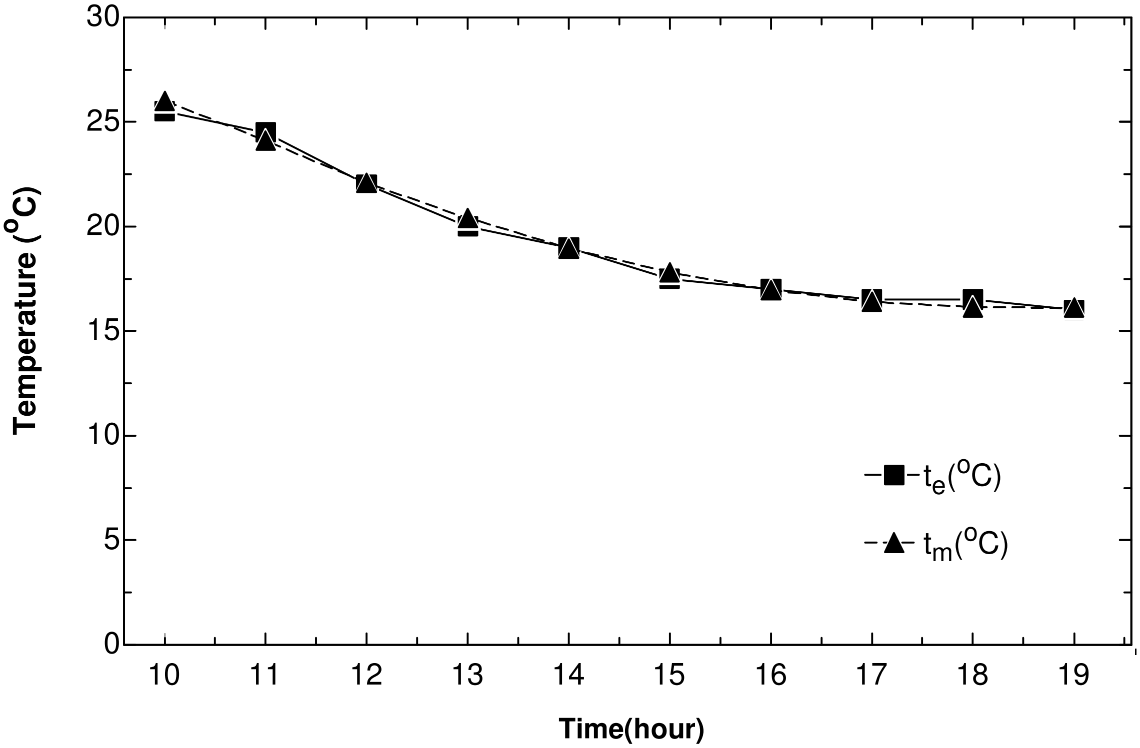


**Figure 8.** Experiment and model results at temperature range between (16 and 26)°C for carrots.

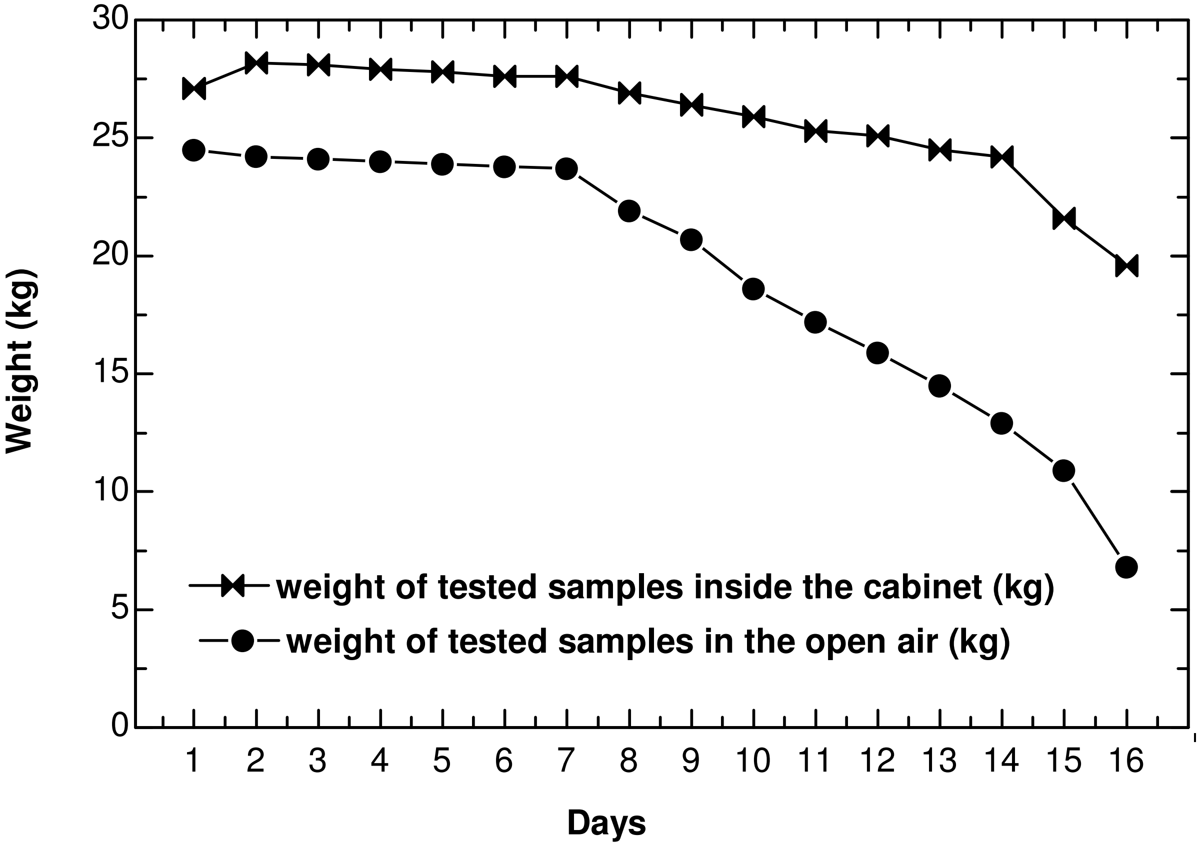


**Figure 9.** Physiological weight loss of the tested samples (Tomatoes).

for the three conditions of the collected data compared with the data generated through the model are 0.977, 0.9919 and 0.9682 respectively. The correlation coefficient values generated with the model were observed to be very close to those calculated manually using the least square method as presented in Table 2.

In general, as shown in Figures 6 to 8, the experimental temperature measured in this study agreed reasonably well with those obtained with the model results which validate the efficiency of the evaporative cooling system developed.

## Physiological weight loss during storage

It was observed that the weight loss of tomatoes and carrots was minimum when the commodities were stored in the evaporative cooling system chamber while it was maximum in ambient storage as presented in Figures 9 and 10. The physiological weight loss obtained for the tested samples that is, tomatoes and carrots are plotted in Figures 9 and 10 respectively. The weight of tomatoes and carrots stored in open air was maintained for only 7 days after which there was a sharp decline in weight from approximately 25 to 6 and 10 kg for the tested samples respectively after 2 weeks of storage, resulting into a loss in weight of about 18 and 14 kg for the samples respectively. Contrary to this observation, tomatoes and carrots kept in the evaporative cooling cabinet had their weight relatively maintained at 25 kg within 2 weeks of storage with only an approximate 5 and 3 kg loss in weight for the tested samples respectively after 2 weeks of storage.

## Conclusions

The newly developed system performed up to expectation as tested samples maintained their fresh condition for the 14 days within which they were tested. The required storage temperature for the preservation of the selected vegetable samples was achieved at 16°C for the cabinet temperature at an ambient temperature of about 32°C.

With respect to the quality of the stored items (vegetable samples) results obtained show that there is a tremendous improvement over the mechanical multipurpose refrigerating system. The system developed maintained a higher quality of preservation when compared to the mechanical multipurpose refrigerating system. Hence, the excessive chilling or freezing effects normally experienced with vegetables stored using the

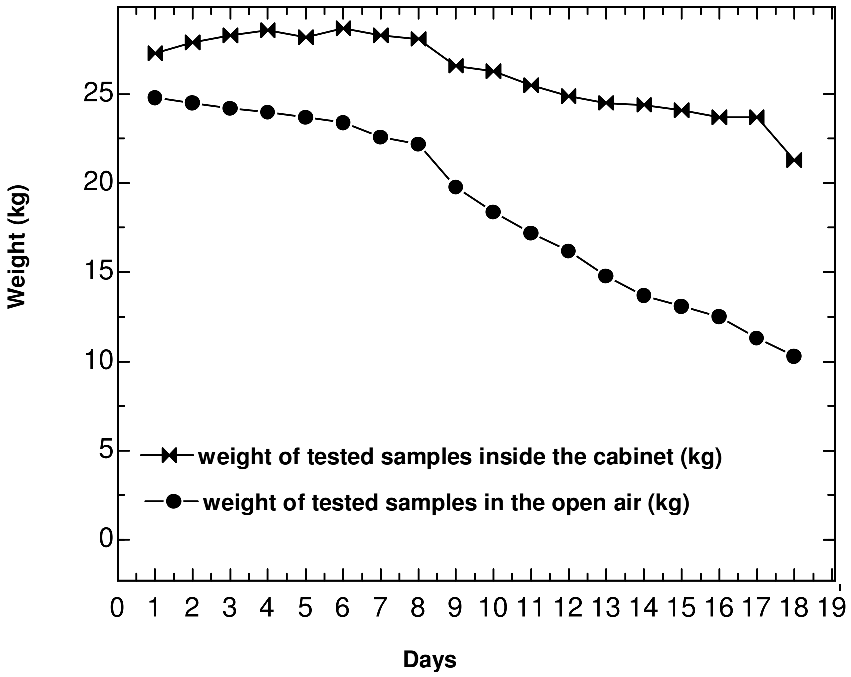


**Figure 10.** Physiological weight loss of the tested samples (Carrots).

latter method were naturally eliminated by the operating conditions of the newly developed evaporative cooling system, as the stored products were only exposed to their required storage temperatures. Hence this system can be used for preservation of fresh vegetables with their quality still maintained for at least fourteen (14) days.

The developed evaporative cooling system is easy to operate, efficient and affordable most especially for peasant farmers in developing countries who may find other methods of preservation quite expensive and unaffordable. This work has elucidated a cost effective means of preserving fresh vegetables, which if adopted will reduce post harvest losses, hence increase in income generated from agricultural produce.

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