Design, construction and evaluation of an evaporative cooler for sweet potatoes storage

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Abstract: A 14.4 × 86.0 × 70.0 cm mud evaporative cooler was designed and constructed for the storage of sweet potato roots to evaluate its performance in storing orange fleshed sweet potato variety (Apomuden) roots. The investigation lasted for 14 weeks, from November 2014 to February, 2015. The dry bulb (Tdb) and wet bulb temperatures (Twb) for the ambient storage ranged between 27.600C to 26.900C and 22.500C to 20.100C respectively with their corresponding RH of 64.00%, 77.00% respectively, while Tdb and Twb within the cooler ranged between 25.940C to 24.860C and 21.940C to 20.610C with corresponding R.H of 89.00% to 92.00% respectively. The efficiency of the constructed evaporative cooler was 87.17%. From an initial weight of 2000 g, roots weight decreased to 1298.3 g during the storage period, while the weight loss within the cooler was from 2000 g to 1570.65 g over the same period. Also, the moisture content of the roots stored under ambient conditions declined from 68.9% to 48.35%. Roots stored in the evaporative cooler declined from 68.9% to 60.80%. As mc decreased from 68.9% to 48.35%, energy content increased from an initial of 501 to 858.677 kJ/100g under ambient storage while in the evaporative cooler, as mc declined, from 68.9% to 60.8%, energy content increased from an initial of 501.518 to 642.296 kJ/100g. The evaporative cooler maintained the quality of the sweet potato roots by fourteen weeks while those stored in the ambient storage lasted for eight weeks.

Keywords: evaporative cooler, storage weight loss, wet bulb temperature, dry bulb temperature, moisture content, energy content.

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1 Introduction

Sweet potato (Ipomoea batatas L.) is a native of tropical America and was domesticated at least 5000 years ago. The crop was brought to Spain by Columbus and subsequently introduced to Africa and Asia. Sweet potato is the only economic important plant of the family Convolvulaceae (Purseglove, 1968). The edible portion of the crop is known as tuberous root though young leaves and shoots are sometimes eaten as greens. The edible tuberous root is long and tapered with smooth skin. The root color ranges between red, purple, brown and white and the root flesh color ranges from white through yellow, orange and purple (Purseglove, 1991; Woolfe, 1992).

In Africa, sweet potato has recently gained importance because of its numerous potentials of alleviating poverty, reducing night blindness, and improving the diet of the rural poor. In terms of area under cultivation, Nigeria is the leading producer in Africa followed by Uganda, (FAO, 2004) and majority comes from Southern and Eastern Africa (Roots, 1994). Improved sweet potato yields recorded in Africa by IITA is between 21-41 t/ha in 140 d without fertilizer application while unimproved varieties average only 14

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t/ha when harvested in 180 to 240 d after planting (IITA, 1985).

In Ghana, sweet potato is grown by peasant and small-holder farmers scattered in Upper East and Central Regions. These two regions in Ghana produce about 93603 metric tons (SRID, 2007). During the period of glut in the market, unsold agricultural products especially fresh produce are allowed to rot away and some eaten or fed to animals. Most of the farmers in the developing countries cannot afford the high cost of storage facility available in the market. Also, power outage is very regular due to the rising cost of energy for power generation. This has greatly affected income generation since most products produced cannot be properly preserved, resulting in huge waste especially of fruits, vegetables, roots and tubers. The Food and Agriculture Organization (FAO) of the United Nation has envisaged this crisis and its impact in the global food production since 1983. Therefore the FAO advocated for a low cost and energy saving storage system based on the principle of evaporative cooling for the storage of fresh agricultural produce during the favourable weather conditions. The World Bank also in 1999 recognized the benefits of evaporative cooling which includes reduction in the energy cost, low carbon emission if any, no usage of hydrocarbon gases, improving indoor air quality and humidity and regional energy independence.

In most tropical developing countries including Ghana, sweet potato roots have shelf-life for only 1 to 2 weeks (Rees et al., 2003). Storage of these fresh roots presents the most serious constraint to the production of sweet potato. Fungal and viral diseases, insect pests, mites, nematodes and rodents combine in different ways under varying environmental conditions to cause high deterioration of the roots after harvest. Mariga (2000) indicated that post-harvest losses due to pest and diseases account for as much as 60% of the crop output. However, under controlled conditions the roots can be stored for extended periods where lower temperatures of 13^0C to 15^0C are maintained. Optimum conditions required for storing sweet potato roots are temperature of 12^0C to 15^0C and relative humidity of 85% to 90% (Picha, 1986; Woolfe, 1992) and under such conditions sweet potato roots can be stored for up to a year. Temperature and relative humidity management are the most important tools that can be used to extend the shelf life of the fresh roots; this is because relative humidity and temperature affect water loss, decay and disease development. However in the tropics, during harvesting bruising and cutting of the fresh roots occur which serve as entry points to diseases and microorganisms. So to minimize these effects, the roots must be cured in order to promote rapid healing of the wounds and increase the toughness of the skin (periderm).

There are several methods of sweet potato storage that only require simple and cheap building materials. The most commonly used are pit storage, clamp storage and indoor storage. These techniques are used only sporadically as most farmers practice sequential harvesting in which tubers are left in-ground until needed.

Sweet potatoes have numerous benefits; storage in the tropics is still a challenge due to the high temperatures recorded throughout the year. Under the natural ambient environment, the roots last for only 1 to 2 weeks with no temperature control (Rees et al., 2003). However under controlled conditions, the roots can be stored for up to a year (Picha, 1986; Woolfe, 1992). The perishable nature of the crop is mainly due to its high moisture content, thin delicate skin, which encourages excessive respiration and easy damage during handling. However, problems are encountered during storage in the tropics and these include sprouting, shrinkage, decay and weight loss.

Mechanical refrigeration is energy intensive and expensive, involves considerable initial capital investment, and requires uninterrupted supplies of electricity which are not always readily available, and cannot be quickly and easily installed in rural areas.

Appropriate cool storage technology is therefore required for on farm storage of freshly harvested perishable produce in remote and inaccessible areas, to reduce losses. This study is therefore conducted to develop a low-cost, low-energy, environmentally friendly zero energy cooler made from locally available materials, and which utilized the principles of evaporative cooling for storing sweet potato roots in the dry savannah regions of Ghana. This cooler is capable of maintaining the temperatures at 10^0C to 15^0C below ambient conditions, as well as at a relative humidity of 90%, depending on the season.

1.1 Principle of evaporative cooling system

Evaporative cooling is a physical phenomenon in which the evaporation of liquid into surrounding air cools a body in contact with it. The principle underlying evaporative cooling is the conversion of sensible heat to latent heat. The warm and dry outdoor air moves through a porous wall or wetted pad that is replenished with water from a reservoir. Due to the low humidity of the incoming air, some of the water evaporates. Some of the sensible heat of the air is transferred to the water and becomes latent heat by evaporating some of the water. The latent heat follows the water vapour and diffuses into the air (Watt, 1986). Evaporation causes a drop in the dry-bulb temperature and raises the relative humidity of the air. The greater the difference, between the dry bulb temperature and wet bulb temperature is, the greater the evaporative cooling effect could be (Datta S. et al., (1987). The process is adiabatic because sensible heat of the air is converted to latent heat in the added vapour (El-Refaie and Kaseb, 2009). The process is adiabatic because sensible heat of the air is converted to latent heat in the added vapour (El-Refaie and Kaseb, 2009). The surface of the body becomes much cooler when water evaporates from it because it requires heat to change the liquid into vapour (Das et al., 2001). The transfer of coolness is accomplished with the help of a heat exchanger (Singh and Naranyahgkeda 1999).

2 Materials and method

2.1 Experimental procedure and evaluation

The orange flesh variety of sweet potatoes, Apomuden was procured from the International Potato Centre (CIP), Navrongo, Ghana for the test. The experiment was conducted between November 2014 and February 2015. This is the period the crop is harvested and if poorly handled, results in huge losses. The roots were cured at a temperature of 35^0C and RH of 90% for 7 days before the storage began. This ensured that wounds were healed and skin toughens enough to withstand handling bruises. The experimental evaporative cooler was located under a shed below a tree. This has the advantage of reducing considerably the effects of direct solar radiation on the test facility and exposing it to open air flow. The cooler was positioned facing the direction of the wind. The cooling pad was wetted by means of a perforated water hose connected to an overhead tank containing water which drained by gravity. This eliminated the need for regular manual pad watering.

2.1.1 No load test

The ‘No-load’ test was done to establish its transient response to variations in prevailing weather conditions in terms of temperature reduction between the ambient and the cooler storage chamber and change in relative humidity before storage of sweet potatoes began. The wet and dry bulb temperatures inside the cooler were monitored with two thermometers (one with a wick for measuring wet bulb temperature) fixed permanently in the cooler chamber. Ambient wet and dry bulb temperatures were measured with similar set of thermometers. The temperature of the cooling chamber was measured daily and compared with the ambient air. The readings were recorded every 2 h from 08.00 to 18.00 h for 2 consecutive days under ‘No-load’ condition. The average cooler and ambient temperatures were calculated from 2 days data. The relative humidity was then determined from a standard psychrometric chart. These measurements provided the general trend of the prevailing conditions within the cooler. The cooling efficiency (η) of the cooler, indicating the extent to which the dry bulb temperature of the cooled air approaches the wet bulb temperature of the ambient air was calculated using Equation1 (Olosunde et al., 2009; Lertsatitthanakorn et al. 2006).

$$\eta = \left(\frac{Tadb - Tedb}{Tadb - Tawb}\right) \times 100 \quad (1)$$

Where,

Tadb: Ambient air dry bulb temperature, ^{0}C

Tawb: Ambient air wet bulb temperature, ^{0}C

Tedb: Cooled air dry bulb temperature, ^{0}C

2.1. 2 Load test

Tests were undertaken with cooler loaded with produce in place. This was done to determine how long tubers in the cooler last before they became unwholesome for consumption.

2.2 Measured parameters

Three baskets of cured bulk sweet potato roots each weighing 2000 g were stored in the evaporative cooler. A control experiment in which the same quantity of roots as those inside the evaporative cooler was exposed to open air conditions was used to evaluate the cooler's effectiveness in preserving the roots. Data on physiological weight loss, shrinkage, unwholesomeness, moisture content and energy content of roots were collected every fortnightly.

2.2.1 Determination of weight loss

Bulk weight loss was determined by weighing 20 randomly selected roots from each basket at the start of the experiment and at 2 weeks interval. Where roots were discarded due to decay, the remaining roots were considered when calculating the mean weight loss. Percentage weight loss was determined by weighing the roots 2 weeks' intervals during storage, and calculating with Equation 2 used by Mule et al., (2009) and Teye et al., (2011).

$$Weight\ Loss = \frac{W1 - W2}{W1} \times 100 \quad (2)$$

Where,

W1: Weight of sample before storage

W2: Weight of sample after storage

2.2.2 Determination of unwholesomeness

The roots in each of the storage systems were observed fortnightly for signs of any decay, dryness, sprout, and softness. Decay was scored on the extent of rot on the surface of the root using the following scale by Rees et al.: 1= 0%, 2=1% to 25%, 3=26% to 50%, 4=51% to 75% and 5=76% to 100%. After each assessment, roots that scored 4-5 were discarded. In subsequent weeks, the previous discarded roots were still included with a score of 5 when the overall mean score was calculated. The unwholesome samples were removed from the rest. The percentage unwholesomeness was calculated at the end of the storage period using Equation 3.

$$\%\ Unwholesomeness = \left(1 - \frac{N2}{N1}\right) \times \quad (3)$$

Where,

N_1: Number of tubers before storage

N_2: Number of tubers after left after storage

2.2.3 Determination of shrinkage

Shrinkage of the roots was determined by a method used by Abano et al., (2011) in which the diameters of the roots were measured with a digital caliper at the start of the research and also at every 2 weeks interval. The diameter measuring point at the start was marked with a permanent marker and this served as reference point for subsequent measurements. The differences in the initial and final diameter were used to calculate for shrinkage. The percentage shrinkage was calculated using Equation 4:

$$\%\ Shrinkage = \left(1 - \frac{D2}{D1}\right) \times 100 \quad (4)$$

Where,

D_1: Diameter of tubers before storage

D_2: Diameter of tubers after storage

2.2.4 Determination of moisture content

The standard method of moisture determination was used to determine the moisture content of the kernel. In this method, sweet potato tubers were selected at random from each storage system and chopped into slices. 10 g was taken and dried in an oven (DIN EN 60529-IP 20 Shchutzart, Germany) at 105^0C until constant weight. The ratio of the difference between the initial weight and final weight to the initial weight was determined as the moisture content by AOAC (1995) recommended method and using the following Equation 5:

$$\mathrm{MCwb} = \left(1 - \frac{\mathrm{Wd}}{\mathrm{Ww}}\right) \times 100 \qquad (5)$$

Where,

MCwb: Moisture content (wet basis)

Wd: Weight of material after oven drying

Ww: Weight of materials before oven drying

2.2.5 Determination of energy content

Energy content was calculated by using Equation 6. Bradbury (1986); Woolfe (1992) have also used this equation to determine energy content of sweet potato

$$\mathrm{EC} = -17.38\mathrm{MC}+1699 \qquad (6)$$

Where,

EC: Energy content in KJ per unit weight (100g).

MC: Moisture content

2.3 Design consideration

The following were design considerations:

1. The evaporative cooler was designed with locally available material to reduce cost.
2. The shape of the cooler is a cuboid placed under a shade, to reduce the ambient heat.

2.4 Description of the evaporative cooling systems

The evaporative cooler is made up of double jacket walls to reduce the heat transfer by conduction. The inside wall is a cuboid (78 x 50 x 70 cm) shaped clay (mud) storage structure for storage of roots. The outside wall is also a cuboid (14.4 x 86 x 70 cm) with an 8 cm gap separating it from the inside wall. The mud was excavated from a nearby stream and before the casting of the structure; it was mixed thoroughly with water to increase its plasticity. Mud was chosen because of its low conductivity of heat and its abundance. It is also very cheap. The top of the structure is covered with a wooden frame cover (16 x 88 x 2 cm) and covered with a transparent polyethylene sheet because of its low heat conductivity. Inside the storage chamber, the air picks up heat from tubers and the temperature rises due to respiration of the product. A tiny opening is made to serve as exit for air. The conditioned air passes in a vertical flow direction and exits back to the environment. A water reservoir (Green 50 L plastic tank) linked to the cooler at the top through a perforated pipe (holes 3 mm diameter, 10 cm apart) maintained the pad's uniform wetness by water being properly distributed along the upper edge of the walls through a drip system as shown in Figure. 1. Detailed drawings are found in Figure 2 and Figure 3.

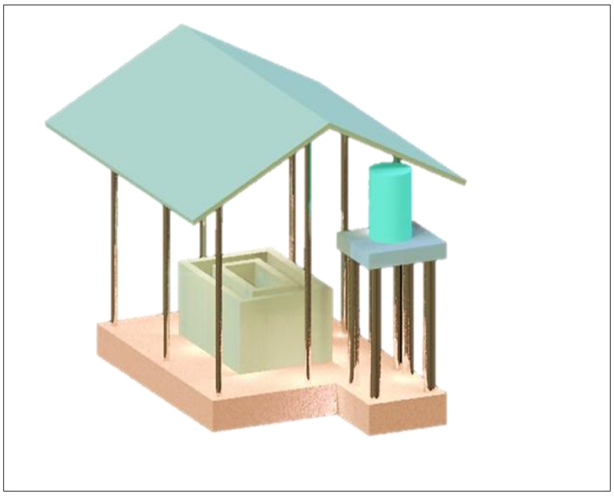

Figure 1 AutoCAD sketch of evaporative cooler

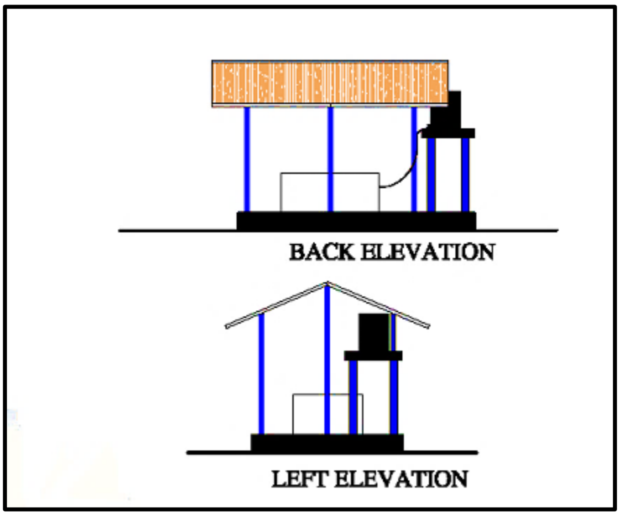

Figure 2 Back and left elevation of evaporative cooler

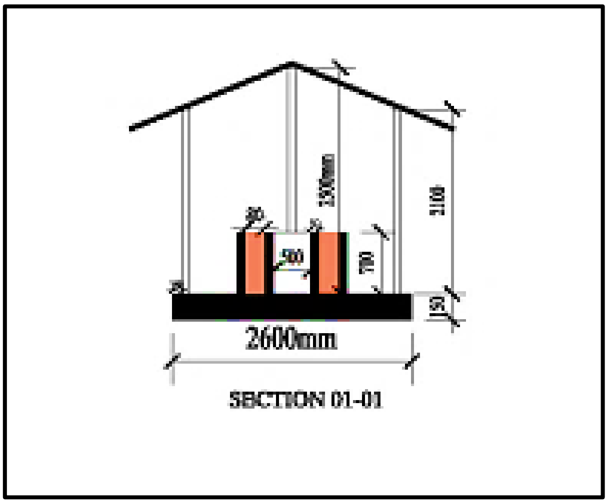

Figure 3 Side view of evaporative cooler

3 Results and discussion

3.1 Cooler efficiency

The average cooler efficiencies for a 12 h period are shown in Table 1. From this Table, the cooler efficiency ranged between 72.22% and 97.73%. At 8.00 h, the efficiency was 94.74%. This increased marginally to 97.14% and declined sharply to 85.48% and further to 75.73% at 10.00 h, 12.00 h and 14.00 h respectively. The drastic decline in the efficiency is probably due to the increase in the ambient Tdb as the intensity of the sun increased during this period. At 16.00h, the efficiency rose again to the highest of 97.73%. This coincided to the period cooling of fresh produce is much needed. The efficiency reduced to 72.22% at 18.00 h. The average cooler efficiency was 87.17%.

Table 1 Average bi-hourly variations of evaporative cooler efficiencies for 12 h

Time	Ambient air		Air inside evaporative cooler		Cooler efficiency
h	Tdb ^{0}C	Twb ^{0}C	Tdb ^{0}C	Twb ^{0}C)	H, %
8.00	22.70	20.80	20.90	18.60	94.74
10.00	25.90	22.40	22.50	19.80	97.14
12.00	29.90	23.70	24.60	24.40	85.48
14.00	35.20	24.90	27.40	25.20	75.73
16.00	29.00	24.60	24.70	21.00	97.73
18.00	24.80	23.00	23.50	19.10	72.22
Mean	27.92	23.23	23.93	21.35	87.17

3.2 Ambient and cooler air properties

Summary of mean monthly psychrometric variables of ambient-air and the cooler-air are presented in Table 2. It is realized that the mean air properties in the evaporative cooler are more suitable for storage than the mean ambient air properties. The system improved the air properties for storage close to Chouksey's (1985), whose structure storing potato maintained a temperature of 21^{0}C to 25^{0}C with 80% to 90% RH for a zero cooler and outside temperature and RH were 40^{0}C to 42^{0}C and 30% to 35%, respectively. The mean dry bulb temperature (Tdb), wet bulb temperature (Twb), enthalpy (h), specific volume (V) decreased by 11.5%, 0.90%, 0.79% and 0.58% respectively within the first eight weeks of storage. The mean dew point temperature (Tdp), relative humidity (RH), humidity ratio (W), density (ρ), and vapour pressure (Pw) increased by 4.5%, 21.23%, 11.11%, 2.5% and 11.80% respectively within the same period of storage. Decreasing the Tdb by 11.50% and Twb 0.90% significantly reduced respiration rate of roots. These values agreed with works done by Jain (2007) and Teye (2010). The respiration rate of produce doubled at every 10^{0}C increase in temperature. The vapour pressure decreased by 11.80%, suggesting that, the potential of the cooler air to hold more water is decreased as compared to the ambient air. This means that stored produce in the cooler will lose less water and thereby maintain their freshness and weight as opposed to those stored under ambient conditions. As vapour pressure (Pw) increased, humidity ratio (W) and relative humidity both increased. Increasing the relative humidity of the storage environment (or decreasing the vapour pressure deficit (VPD) between the commodity and its environment for freshly harvested produce will slow the rate of water loss and other metabolic activities (Katsoulas et al., 2001). The condition within the system reduced transpiration and improved storage. Enthalpy (h) also decreased by 0.79%. The respiration rate within the cooler was lower than those stored under ambient conditions in which accelerated shrinkage, weight loss and decay were recorded. After the end of the eighth week of storage, all sweet potato roots under ambient storage shrunk, dried and became unwholesome for consumption. However, storage in the cooler continued for further three and half months before they became unwholesome in the 14th week. The temperature depression for cooling application is in the range of 2^0C to 120^0C as reported by Anyanwu (2004).

Table 2 Mean monthly psychrometric properties of ambient and evaporative cooler air

Month	*Tdb*	*Twb*	*Tdp*	*R.H*	*W*	*h*	*ρ*	*V*	*Pw*
Ambient air									
Nov.	26.90	23.70	22.50	77.00	0.017	70.90	1.16	0.87	2724
Dec.	27.60	22.30	20.10	64.00	0.015	65.40	1.16	0.87	2447
Mean	27.25	23.00	21.30	70.50	0.016	68.15	1.16	0.87	2586
Air inside evaporative cooler									
Nov.	21.94	20.61	20.0	89.00	0.015	59/00	1.19	0.86	3242
Dec.	22.40	21.28	20.8	91.00	0.016	61.90	1.18	0.86	2462
Jan.	25.94	24.86	24.6	92.00	0.020	75.82	1.17	0.87	3085
Feb.	26.20	24.40	23.8	86.00	0.019	73.70	1.20	0.87	2940
Mean	24.12	22.79	22.3	89.50	0.018	67.61	1.19	0.865	2932

Note: Tdb- Dry bulb temperature in ^{0}C, Twb- Wet bulb temperature in ^{0}C, Tdp- Dew point temperature in ^{0}C, R.H- Relative humidity in %, W- Humidity ratio/ moisture content in kgH$_2$O/kg d.a., h- Enthalpy in KJ/Kg d.a., ρ- Density in kg/m^3, V- Specific volume in m^3/kg d. a. and Pw- water vapour pressure in Pa.

3.3 Physiological weight loss of roots during storage

The variations in physiological weight loss of stored tubers during the storage in both storage methods are presented in Figure 4. From an initial weight of 2000 g, weight loss from the 2nd, 4th, 6th and 8th week in the ambient storage were, 1647.00, 1532.40, 1413.80, and 1298.30 g respectively. The corresponding percentage weight losses were 17.65%, 23.38%, 29.31% and 35.09%. The weekly mean weight loss in the ambient storage was 13.19%. From an initial weight of 2000g, the weight and percentage weight losses from the 2nd, 4th, 6th, 8th, 10th, 12th and 14th week in the cooler storage were, 1781.10, 1652.80, 1633.20, 1624.95, 1610.65, 1590.65, 1570.65g and 10.95%, 17.37%, 18.34%, 18.75%, 19.81%, 20.47% and 21.47% respectively. Rees et al., (2003) reported that loss in weight of sweet potato in storage is inevitable though it can be reduced. The weekly mean weight loss in the evaporative cooler was 9.01%. Weight loss of fresh tomato has been reported to be primarily due to transportation and respiration, and limited shelf-life and losses in quality have been identified as the major problems faced in the marketing of fresh tomatoes (Bhowmic and Pan 1992). The experiment resulted in a percentage decrease in weight loss of 5.75%, translating into 115 g of weight retained by roots stored in the evaporative cooler which was lost when stored in ambient condition. It was also observed that, there was a logarithmic increase in weight loss in both storage methods, but after the 4th week, while the weight loss in the cooler was increasing marginally, same increased widely in the ambient storage. Room storage lasted for 8 weeks while cooler storage extended to the 14th week.

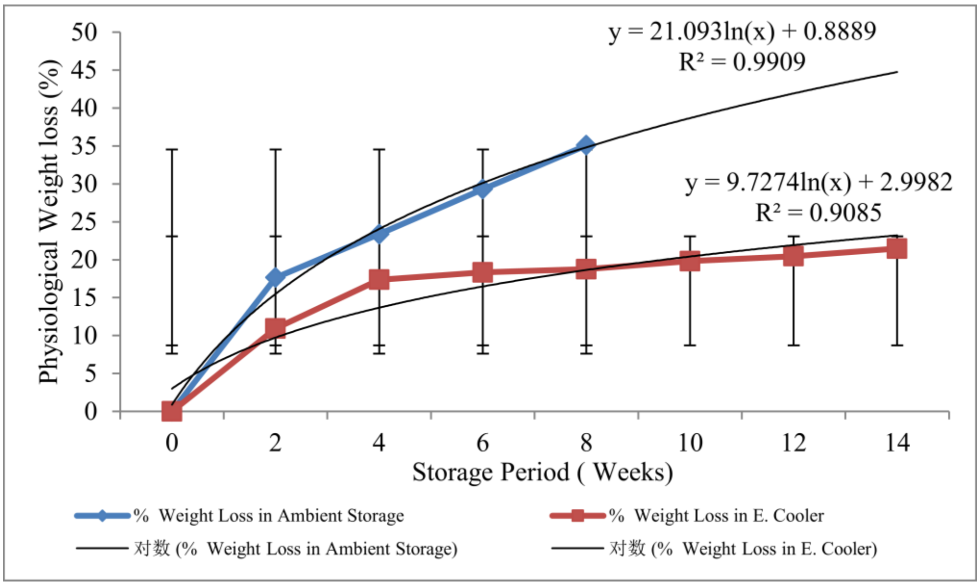

Figure 4 Variation in physiological weight loss of roots during storage. Bars represent standard deviation

3.4 Percentage root shrinkage during storage

The variations in shrinkage of stored roots during the storage in both storage methods are presented in Figure 5. The average diameter and percentage shrinkage of roots from the 2nd, 4th, 6th and 8th week in the ambient storage were, 34.92, 31.73, 26.45 and 4.00 mm and 6.52%, 15.06%, 29.19%, 75.48% respectively. The weekly mean shrinkage in the ambient storage was 31.78%. The average diameter and percentage shrinkage of roots from the 2nd, 4th, 6th, 8th, 10th, 12th and 14th week in the evaporative cooler storage were, 61.92, 61.89, 61.88, 61.89, 66.87, 61.87, 61.86 mm and 4.73%, 6.27%, 7.44%, 22.03%, 22.22%, 27.95%, 40.31% respectively. The weekly mean shrinkage in the ambient storage and the evaporative cooler storage was 3.95% and 1.34% respectively. It was observed that, there was an exponential increase in shrinkage in the ambient storage method while the percentage shrinkage in the cooler increased linearly.

Table 3 Mathematical model of effect of storage period of roots on percentage weight loss

Storage method	Model	Coefficient of correlation
Ambient storage	*%WL=21.093ln(SP) +0.8889*	0.9909
evaporative cooler storage	*%WL=9.9274ln(sp) +2.9982*	0.9085

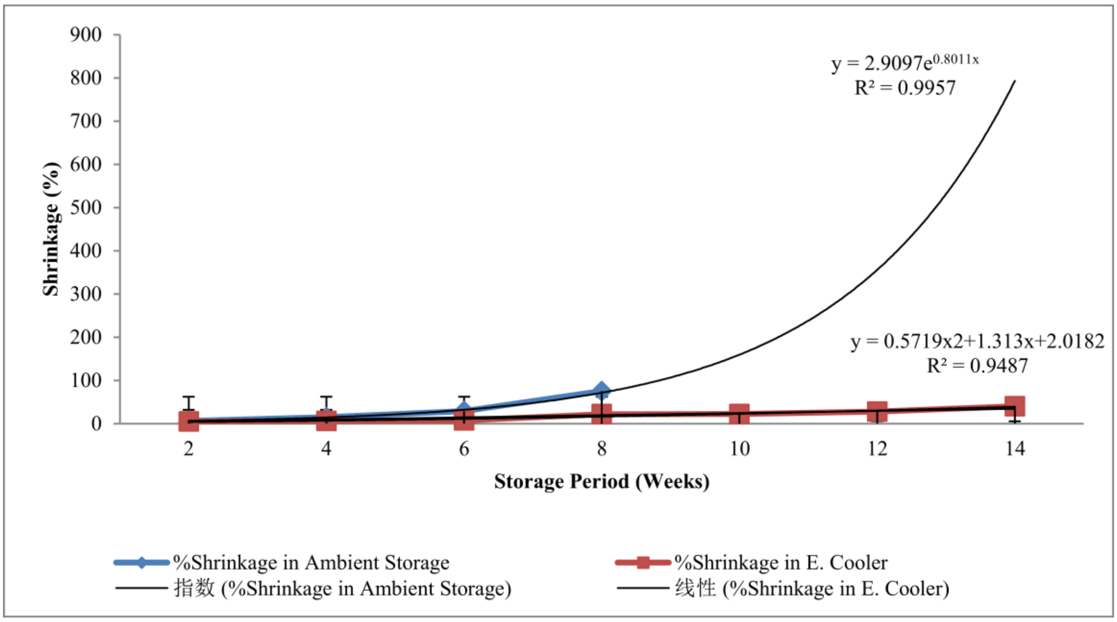

Figure 5 Variation in shrinkage of roots during storage. Bars represent standard deviation

The models developed for the relationship between the effect of storage period (SP) on shrinkage of roots stored in the two storage methods are given in Table 4.

Table 4 Mathematical model of effect of storage period of roots on percentage shrinkage

Storage method	Model	Coefficient of correlation
Ambient storage	$\%Shk=2.9097e^{0.8011SP}$	0.9957
Evaporative cooler storage	$\%Shk=0.5719\ (SP)^2+1.313(SP)+2.0182$	0.9487

3.5 Percentage unwholesomeness during storage

There was no decay or dryness observed until the 4th week of storage in the ambient storage. 4(20%), 7(35%) and 9(45%) of roots showed that 50% of surface area decayed from the *2nd*, 4th, 6th and 8th week of storage respectively. As at the end of the 8th week, all the sweet potato roots became unwholesome for consumption. In the evaporative cooler, decay was first observed at the 6th week. 1(5%), 3(15%), 5(25%), 5(25%) and 6(30%) of roots showed signs of unwholesomeness from the 2nd, 4th, 6th, 8th, 10th, 12th and 14th week respectively. The weekly mean percentage unwholesomeness in the ambient storage the evaporative cooler storage was 6.47% and 5.12% respectively. Critically comparing these results, it is seen that, though roots stored in the ambient conditions started to decay and dried by the 14th week, the percentage unwholesomeness was 4 times higher than the percentage unwholesomeness of roots stored in the evaporative cooler which begun at the *6th* week, 2 weeks after the first sign of unwholesomeness in the ambient storage. In addition, the evaporative cooler extended the wholesomeness of the sweet potato roots by 6 weeks, (see Figure 6). Wasker et al., (1999) reported slower rate of change of physico-chemical constituents in fruits stored in cool chamber. Sandooja et al., (1987) reported least deterioration in quality parameters of tomato when stored in a zero energy cool chamber. A regression analysis was used to establish the relationship between percentage unwholesomeness (%U) and storage period (SP) and presented in Table 5.

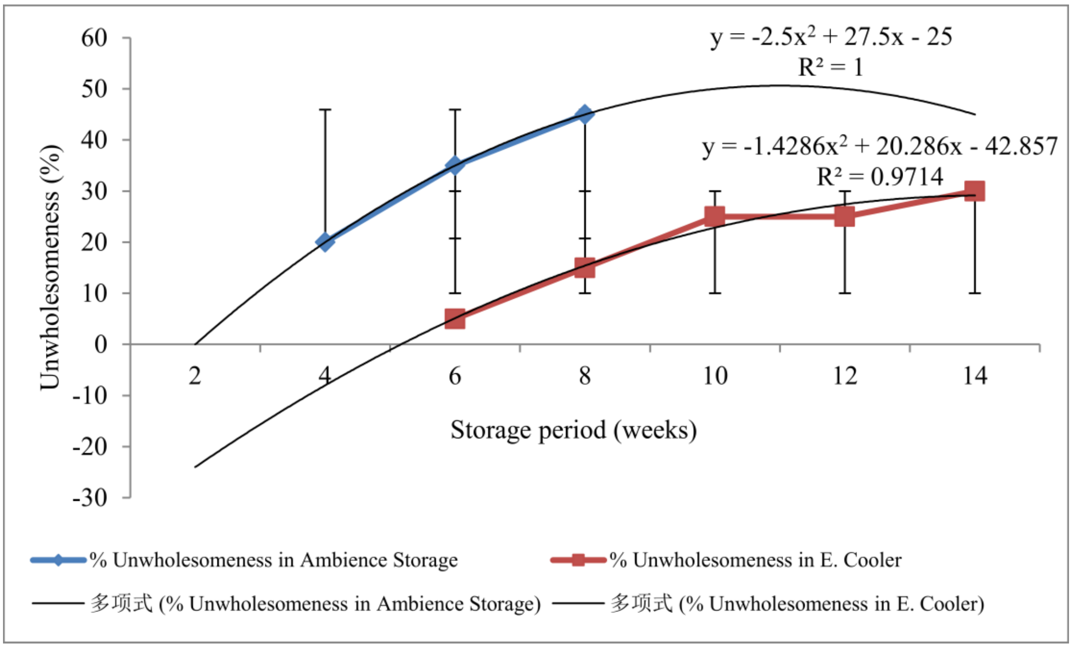

Figure 6 Variation in unwholesomeness of roots during storage. Bars represent standard deviation

A regression analysis was used to establish the relationship between percentage unwholesomeness (%U) and storage period (SP) and presented in Table 5.

Table 5 Mathematical model of effect of storage period of roots on percentage unwholesomeness

Storage method	Model	Co-officient of correlation
Ambient storage	$\%U = -2.5(SP)^2+27.5(SP)-25$	1.000
evaporative cooler storage	$\%U = -1.4286(SP)^2+20.286(SP)-42.857$	0.9714

3.6 Moisture content of roots during storage

A variation in moisture content of roots during storage is presented in Figure 7. From an initial moisture content of 68.90%, roots stored under ambient conditions declined to 60.24%, 56.16%, 50.40% and 48.35% from the *2nd*, *4th*, *6th* and *8th* week respectively with a weekly mean mc of 26.89% while from an initial mc of 68.90%, roots stored in the evaporative cooler declined to 64.60%, 63.14%, 62.40%, 61.90%, 61.50%, 61.10% and 60.80% from the *2nd*, *4th*, *6th*, *8th*, *10th*, *12th* and *14th* week respectively with a mean weekly mc of 31.05%. From the graph, there was a logarithmic declined in mc of the roots stored under ambient conditions while in the evaporative cooler, the trend of decline was a power. Clearly the evaporative cooler maintained the mc of the sweet potato roots within the storage period. This probably explains why percentage weight loss was lower in the evaporative cooler as compared to those stored under ambient conditions. Additionally, the water vapour pressure (pw) in the evaporative cooler was higher and this reduced the potential of the air to hold water, resulting in reduced transpiration. The mc at the end of the storage period in the ambient condition was 48.35% as compared to 60.80% for storage in the evaporative cooler, a difference of 12.45% which lasted until the *14th* week.

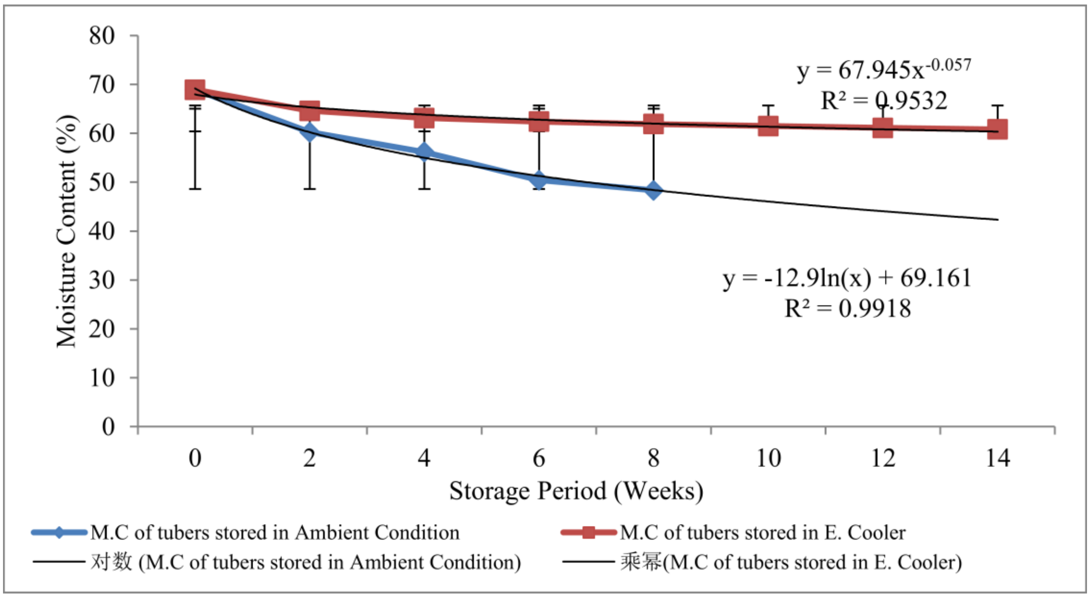

Figure 7 Variation in moisture content of roots during storage. Bars represent standard deviation

The model establishing the relationship between moisture content and storage period (SP) in the two storage methods are presented in Table 6.

Table 6 Mathematical model of effect of storage period of roots on moisture content

Storage method	Model	Coefficient of correlation
Ambient storage	$MC= -12.9\ln(SP) + 69.161$	0.9918
Evaporative cooler storage	$MC= 67.945(SP)^{0.057}$	0.9532

3.7 Energy content of roots during storage

The variation in moisture content of roots during the storage period is presented in Figure 8. From an initial energy content of 501.52 kJ/100g, energy content of roots stored under ambient conditions increased to 652.03, 722.94, 823.05, 858.68 kJ/100g in the *2nd, 4th, 6th and 8th* week respectively with a weekly mean energy content of 711.64 kJ/100g while from an initial energy content of 501.52 kJ/100g, roots stored in the evaporative cooler increased to 576.25, 601.63, 614.49, 623.18, 630.13, 637.08, 642.30 kJ/100g in the *2nd*, *4th*, *6th*, *8th*, *10th*, *12th* and *14th* week respectively with a mean weekly energy content of 603.32 kJ/100g. From the graph, there was a nonlinear increase in energy content of the roots stored under both conditions but with a difference in the margin of increase. In the evaporative cooler storage, the rate of increase in energy content of roots was much higher than the rate of increase under ambient storage. The evaporative cooler reduced the energy content of the sweet potato roots within the storage period as compared to those stored under ambient conditions. Also, the energy content of the root is a function of moisture content of the root. There is an inverse relationship between moisture content and energy content. As mc declined, energy content of the root increased. From the results, as mc decreased from 68.90%, 60.24%, 56.16%, 50.4%, and 48.35% at the *2nd*, *4th*, *6th* and *8th* week respectively, energy content increased from an initial of 501.52, 652.02, 722.94, 823.05, and 858.68 kJ/100g under ambient storage while in the evaporative cooler, as mc declined, from 68.90%, 64.60%, 63.14%, 62.40%, 61.90%, 61.50%, 61.10%, 60.80% energy content increased from an initial of 501.52 to 576.25, 601.63, 614.49, 623.18, 630.13, 637.08, and 642.30 KJ/100g at the *2nd*, *4th*, *6th*, *8th*, *10th*, *12th* and *14th* week respectively. Table 7 contains expressions describing the relationships between energy content (EC) and storage period for the two storage systems.

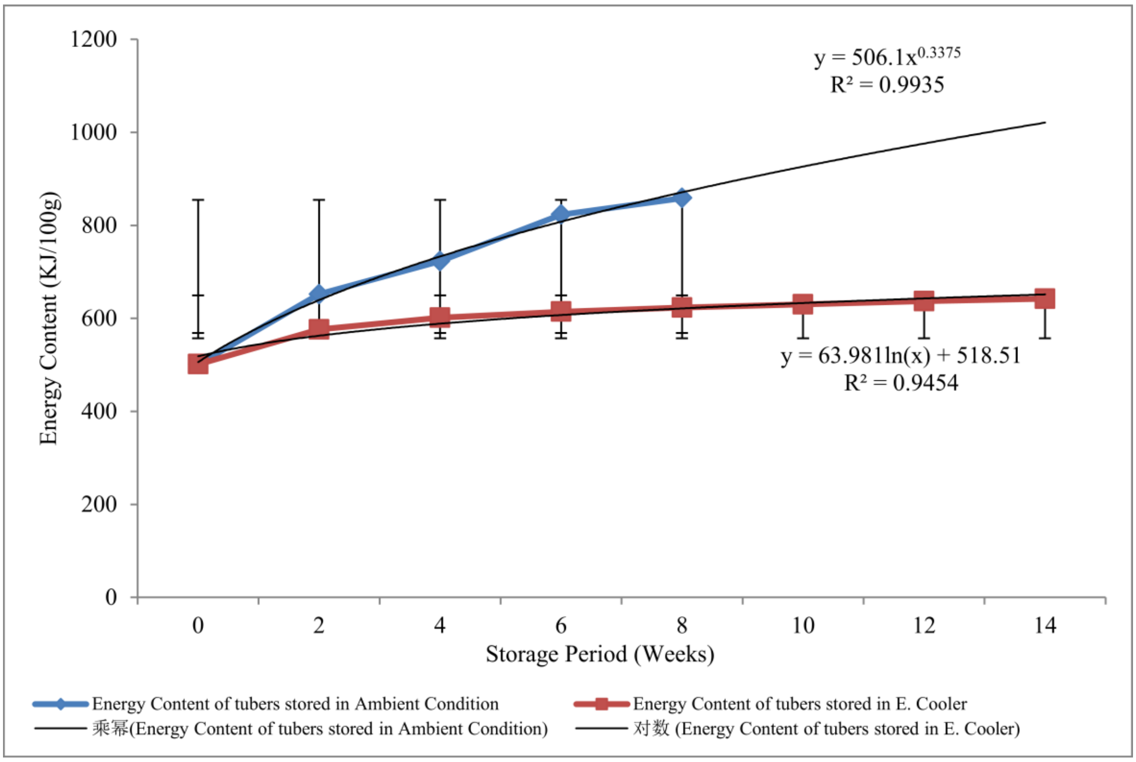

Figure 8 Variation in energy content of roots during storage. Bars represent standard deviation

Table 7 Mathematical model of effect of storage period of roots on energy content

Storage method	Model	Coefficient of correlation
Ambient storage	$EC = 506.1(SP)^{0.3375}$	0.9935
Evaporative cooler storage	$EC = 63.98\ln(SP) + 518.51$	0.9454

4 Conclusions

1. The mean monthly dry bulb temperature (Tdb), wet bulb temperature (Twb), relative humidity, (RH), humidity ratio (W) and water vapour pressure (Pw) were 27.25^{0}C, 23.00^{0}C, 70.50%, 0.016 kgwater/kg d.a., 2586 Pa and 24.12^{0}C, 22.79^{0}C, 89.50%, 0.018 kgwater/kg d.a., 2932 Pa for the ambient storage and evaporative cooler storage respectively. The efficiency of the constructed evaporative cooler was 87.17%.

2. Weight losses and percentage weight losses in the cooler storage were, 1781.10, 1652.80, 1633.20, 1624.95, 1610.65, 1590.65, 1570.65 g and 10.95%, 17.37%, 18.34%, 18.75%, 19.81%, 20.47% and 21.47% at the 2nd, 4th, 6th, 8th, 10th, 12th and 14th week respectively. While from an initial weight of 2000 g, weight decrease from the 2nd, 4th, 6th and 8th week in the ambient storage were, 1647.00, 1532.40, 1413.80, and 1298.30 g with corresponding percentage weight losses of 17.65%, 23.38%, 29.31% and 35.09% respectively.

3. The weekly mean shrinkage and unwholesomeness in the evaporative cooler storage and ambient storage were 31.78%, 33.33% and 25.68%, 20%

respectively. The mc at the end of the storage period in the ambient condition was 48.35% as compared to 60.80% for storage in the evaporative cooler, a difference of 12.45% which lasted until the 14th week. The weekly mean increase in the energy content of roots stored under ambient condition and in the evaporative cooler was 3.70% and 14.77% respectively.

4. Evaporative cooling system not only lowers the air temperature surrounding the produce, it also increases the moisture content of the air. This helps prevent the drying amount of the produce, therefore extends the shelf life of horticultural produce. Evaporative cooling system is well suited where; temperatures are high, humidity is low, water can be spared for this use, and air movement is available.

5. 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.

References

Abano E.E., E. Teye, R.S. Amoah and J.P. Tetteh, 2011. Design, construction and testing of an evaporative cooling barn for storing sweet potatoes in the tropics. *Asian Journal of Agricultural Research*, 5(2):115-126.

Adebisi O. W.; J.C. Igbeka and T. O. Olurin 2009. Performance Evaluation of absorbent materials in Evaporative Cooling System for the Storage of Fruits and Vegetables. *International Journal of Food Engineering*, 5(3):1-15 Anyanwu E.E; 2004. Design and measured performance of a porous evaporative cooler for preservation of fruits and vegetables. *Energy Conversion and Management*, 45(13–14):2187-2195.

AOAC, 1995. Official Methods of Analysis, 16th Ed. Association of Official Analytical Chemists, Washington, DC.

Bhowmic SR and JC. Pan. Shelf life of mature green tomatoes stored in controlled atmosphere and high humidity. *Journal of Food Science*,57(4):948-953 Bradbury, J.H., 1986. Determination of energy from moisture content in foods contain in small amount of fat and dietary fiber. Journal of Agricultural & Food Chemmistry, 34(2):358-361Chouksey R.G. 1985 Design of passive ventilated and evaporatively cooled storage structures for potato and other semi perishables. In: Proc. Silver jubilee convention of ISAE held at Bhopal, India, October 29–31, pp 45–51

Das SK and Chandra. Economic analysis of evaporatively cooled storage of horticultural produce. Agric Eng Today. 2001; 25(3–4):1–9.

Datta S, P.N. Sahgal, S. Subrahmaniyam, SC. Dhingra, and V.V.N. Kishore. 1987. Design and operating characteristics of evaporative cooling systems. *International Journal of Refrigeration*, 10(4):205-208

El-Refaie, M. F. and S. Kaseb, 2009. Speculation in the feasibility of evaporative cooling. *Building and Environment*, 44(4):826-838. FAO. 1986. Improvement of post-harvest fresh fruits and vegetables handling- a manual. Bangkok: UNFAO regional office for Asia and the pacific.

Issues and Challenges in Rice Technological Development for Sustainable Food Security 2002.Keynote Address: Twentieth. International Rice Commission (IRC), 2002. IRC: 02/05.

Jain .D 2007. Development and testing of two- stage evaporative cooler. *Building and Environment*, 42(7):2549-2554.

Katsoulas N; A. Baille and C. Kittas. 2001. Effect of misting on transpiration and Conductance of a greenhouse rose canopy. *Agricultural and Forest Meteorology*, 106(3):233-247

Kibar, H., 2012. Design and management of postharvest potato (*Solanum tuberosum* L.) storage structures. University of Ordu. *Journal of Science and Technology*, 2(1): 23-48.

Kibar, H., 2015. Influence of storage conditions on the quality properties of wheat varieties. *Journal of Stored Products Research*, 62:8-15.

Kittas C., T. Bartzanas, and A. Jaffrin. 2003. Temperature Gradients in a Partially Shade Large Greenhouse equipped with Evaporative Cooling. *Biosystem Engineering*, 85(1):87-94.

Lertsatitthanakorn C, S Rerngwongwitaya, Soponronnarit S. 2006. Field experiments and economic evaluation of an evaporative cooling system in a silkworm rearing house. *Biosystems Engineering*, 93(2):213-219. Mariga, I. K. 2000. “Crop Science Research in Zimbabwe”. In: M. Ruth & C. Eicher (Eds.), Zimbabwe's Agricultural Revolution, p. 219. Zimbabwe: University of Zimbabwe Publications.

Mule, S. C. 2009. Studies on development and performance evaluation of on-farm evaporative cooler for storage of sapota fruits. Unpublished.

Otterbein R. 1996. Installing and maintaining evaporative coolers. May/June. Home Energy Magazine. http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/96/96051 1. Html.

Picha, D. H. 1986. Weight loss in sweet potato during curing and storage: Contribution of transpiration and respiration. *Journal of the American Society for Horticultural Science*, 111(6):889-892.

Purseglove, J. W. 1968. Convulvulaceae in tropical crops. Dicotyledons. London: Longmans, Green and Co. Ltd. pp. 78- 88.

Purseglove, J. W. 1991. Tropical crops. Dicotyledons. New York: Longman Scientific and Technical. John Wiley and Sons Inc., pp. 58-65.

Redulla, 1984b. Keeping perishables without refrigeration: use of a drip cooler. Appropriate Postharvest Technology 1(2): 13-15.

Redulla. 1984a. Temperature and relative humidity in two types of evaporative coolers. Postharvest Research Notes, 1(1): 25-28.

Rees, D., Q. E. Van-Oirschot, A., Amour, R., Rwiza, E., Kapinga, R. and T. Carey. 2003. Cultivar variation in keeping quality of Sweet potatoes. *Postharvest Biology & Technology*, 28(2):313-325 .Rees, D., R. Kapinga, K. Mtunda, D. Chilosa, E. Rwiza, M. Kilima, H. Kiozya and R. Munisi. 2001. Effect of damage on market value and shelf-life of sweet potato in urban markets of Tanzania. Tropical Science, (41): 1–9.

Roots, 1994. Newsletter of the Southern Africa root crops research network (SARRANET) and the East Africa crops research network (EARRNET). 1(1) September 1994.

Sandooja J.K., R.K. Sharma, M.L. Pandit and B.R. Batra. 1897. Storage studies to tomato in zero-energy cool chamber in relation to storage of maturity and packaging material used. Haryana Agric Univ J Res. 17(3):216–217.

Singh M, and K.G. Naranyahgkeda. 1999. Investigation and development of indirect evaporative cooling using plastic heat exchanger. Mech Eng Bull.; 14(7):61–65

Singh R.K.P. and K.K. Satapathy 2006. Performance evaluation of zero energy chamber in hilly region. Agric Eng Today. 30(5–6).

SRID, 2007. Regional and district cropped area, yield and production statistics. Ministry of Food and Agriculture, Ghana.

Taye S. Mogaji l. and O. P. Fapetu, 2011. Development of an evaporative cooling system for the preservation of fresh vegetables, *African Journal of Food Science*. 5(4):255-266..

Teye, E., 2010. Developing appropriate storage technology for sweet potato (Ipomoea batatas lam) in the coastal savannah zone of Ghana. M.Phil. Thesis, University of Cape Coast, Ghana.

Thompson, J.F. and R.W. Scheuerman. 1993.Curing and storing California sweet potatoes. Merced County Cooperative Extension, Merced, California 95340.

Wasker DP, S.K. Nikam, V.K. Garande. Effect of different packaging materials on storage behaviour of sapota under room temperature and cool chamber. *Indian J. Agric.Res.*1999(33):240–244.

Watt J R. 1986.Evaporative cooling handbook. 2nd edition. Chapman and Halt, New York 1986.

Woolfe, J. A. 1992. Post-harvest procedures: II. Processing. In Sweet potato-an untapped food source, Cambridge, UK: Cambridge University Press. (pp. 292-313).

Xuan Y. M., F. Xiao, X .F. Niu, X. Huang, S. W. Wang. 2012. Research and application of evaporative cooling in China: A review (I). *Renewable and Sustainable Energy Reviews*, 16(5):3535-3546.