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The Effectiveness of Three Evaporative Structures for the Storage of Orange Fleshed Sweet Potato in the Coastal Savanna Zone of Ghana

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Abstract:
The study was conducted at University of Cape Coast Research Farm, Cape Coast, Ghana from September, 2014 to April, 2015. The objective of the study was to compare the effectiveness of three evaporative cooling structures; Brick-walled Evaporative Cooling Chamber (CC), Jute fabric-walled Hexagonal Evaporative Cooling Barn (HexB) and Brick-walled In-ground Evaporative Structure (InG) for the storage of sweet potato root tubers. The study also examined the effect of deficit irrigation and fertilizer application on the shelf life of OFSP roots. The evaporative storage structures reduced root decay, shrinkage, weight loss and weevil infestation in storage as compared to room storage. There was increase in sprouting of OFSP roots stored in evaporative storage structures. Brick walled cool chamber evaporative structure (CC) recorded lower root shrinkage, decay, weight loss and weevil infestation in storage than the other evaporative structures but increased tuber sprouting in storage. Roots from unfertilized plots decayed more severely than roots from fertilized plots in storage. Deficit irrigation resulted in insignificant reduction in percentage root decay.

Keywords: *Deficit irrigation, evaporative structures, fertilizer application, orange fleshed sweet potato, shelf life*

1. Introduction

Storage of fresh horticultural produce after harvest is one of the most pressing problems of tropical countries such as Ghana. Fresh produce such as sweet potato, vegetables and fruits have high moisture content and very short shelf life. Moreover, they are living entities and carry out transpiration, respiration and ripening even after harvest. Metabolism in fresh horticultural produce continues even after harvest and the deterioration rate increases due to ripening, senescence and unfavourable environmental factors (FAO, 1989). Once the roots are detached from the plant, they rely on the stored food reserves to continue with life processes which results in changes in both physical properties and chemical composition of the harvested root. The respiration process results in the oxidation of the starch to release energy for metabolic activities (Kitchen, 2011). The complete combustion of 1 g of glucose produces 1.47 g CO_2 + 16 kJ of energy (Diob, 1998). Thirty two percent (32 %) of energy generated (5.1 kJ) is utilized in metabolic activities and the remaining 10.9 kJ is released as heat resulting in temperature build-up in the storage environment. Consequently, sweet potato roots undergo several physical and chemical changes such as weight loss, shrinkage and decline in sugar and starch content during storage and the extent of changes depend on variety and environmental factors (Teye, 2010). Hence, preserving fresh produce such as sweet potato in the fresh form demands that the chemical, bio-chemical and physiological changes are restricted to a minimum by control of space temperature and humidity (Chandra et al., 1999). However, farmers and traders still practice age-old storage methods leading to large-scale wastage during storage and transportation. Traditionally, after harvest, most roots are kept in temporary huts, bans, pits, cool dry rooms with proper ventilation and on the floor. It is estimated that 30 % to 40 % of the food produced globally is lost in the post-harvest chain or wasted because it is never consumed. However, the world's population is expected to reach 9 billion in 2050 (UNDESA, 2015) and the excessive food lost or wastage will lead to unsustainable use of the world's resources.

Appropriate cool storage technologies are therefore required in tropical countries such as Ghana for on farm storage of fresh produce especially in remote and inaccessible areas, to reduce post-harvest losses. Low-cost, zero energy, environmentally friendly and evaporative cooling storage structures built from locally available materials will be of great benefit to farmers. The cool chamber is a zero-energy evaporative structure developed in India, using locally available materials (Roy, & Pal, 1994). It increased shelf life of fruits and vegetables by 2 to 14 days (15–27 % increase) as compared to room storage and root loss in weight was lower (Lal Basediya et al., 2013). Adoption of the cool chamber developed in India in Ghana can be of great benefit to sweet potato and vegetable farmers and retailers. The world's population is estimated to grow by about 18 % for the year 2030 and will increase greatly the demand for food, raw materials, energy consumption and water. This requires all countries and the UN to adopt necessary measures to ensure sustainability of humanity. One way to meet greater demand for food is the adoption of greater efficiency in the use of scarce water in crop production by the adoption of deficit irrigation (DI) which produces more crops per drop of water. Hence, if irrigation is made more efficient then there would be more water for agricultural use, environmental uses and for towns and cities. Additionally, one of the most important ways of increasing the productivity of crops is the application of fertilizers (Ali et al., 2009). In recent years, the use of organic manures as fertilizers has increased tremendously as a result of serious environmental pollution (Ofoefule et al., 2014) which has resulted from the use of inorganic fertilizers and pesticides. Organic manure has been found to improve the fertility and productivity of soils. Another important factor in meeting increasing food demand is efficient post-harvest system. There are also critical challenges to increasing sweet potato availability which includes; poor crop management strategies such as crop-water management regimes, soil nutrient regimes and inefficient technologies to reduce perishability. The heavy post-harvest losses have resulted in increased prices thereby making it unattractive to those searching for a low-cost nutrition substitute for more expensive and prestigious foods.

Therefore, research efforts to determine and recommend pre-harvest treatment and zero energy evaporative storage system which store sweet potato roots better under tropical conditions can be of great benefit to sweet potato farmers and lead to increased production and utilization of sweet potato. The main objective of the study was to compare the effectiveness of three evaporative cooling structures; Brick-walled Evaporative Cooling Chamber (CC), Jute fabric-walled Hexagonal Evaporative Cooling Barn (HexB) and Brick-walled In-ground Evaporative Structure (InG) for the storage of sweet potato root tubers. The study also examined the effect of irrigation and manure application on the quality of OFSP during storage.

2. Materials and Methods

A field experiment was conducted between October, 2014 and January, 2015 planting season at the Teaching and Research Farm of University of Cape Coast in the Central Region of Ghana. The location of Cape Coast is latitude 5.06° N and longitude 5° W with altitude of 31 m above sea level. The location has a major rainy season which starts from March to July and a minor rainy season from September to October. Maximum temperature is between 30 ^oC to 36 ^oC while minimum temperatures range between 22 ^oC to 26 ^oC (Ayittah, 1996). Natural vegetation is coastal savanna (Teye, 2010) consisting of shrubs, grasses and a few scattered trees. The soil at the research site is sandy loam in texture, slightly acid in reaction (pH 5.8), low in nitrogen and potassium contents but marginal in available phosphorus.

Irrigation water quality was analysed to determine major cations and anions such as, Ca, P, NO_3Fe, Cu and Zn. Ca and NO_3 were determined by titration and P by Flame photometer. Fe, Zn and Cu were analysed by Atomic Absorption Spectrometer. Electrical conductivity (EC) was determined by using electrical conductivity meter and pH meter was used to determine pH.

Soil samples from each experimental plot were air-dried, ground and passed through 2 mm-mesh sieve and used for laboratory analysis.

2.1. Experimental Design

There were 16 treatments combinations, consisting of four levels of irrigation; 100%, 90%, 80%, 70% Crop Water Requirement (CWR) and four types of fertilizer, Poultry manure (PM), Cow dung (CD), NPK 15:15:15 and No Fertilizer (Control). The OFSP variety was used for the study. The experimental lay out was Randomized Complete Block Design in a factorial arrangement with three replications. Rain shelter consisting of galvanized steel metal frame roofed with transparent water proof plastic sheet was erected over the plots to prevent any form of precipitation on the plots.

2.2. Calculation of Crop Water Requirement and Irrigation Water Application

Crop water requirement ET_c was calculated using the equation:

$$\mathbf{ET_c = ET_o \times K_c}$$

where, ET_c is the crop evapotranspiration (mm per day), K_c is the crop coefficient (dimensionless) and ET_o is reference crop evapotranspiration (mm per day). An irrigation interval of two days was adopted for the experiment.

2.3. Crop planting and cultural practices

Vines were planted on 10th October, 2014, at 30cm between plants and 70 cm between rows. Poultry manure (15 tons ha^{-1}) and Cow dung (30 tons ha^{-1}) were applied 2 weeks before planting the vines and NPK 15:15:15 (1300 kg ha^{-1}) was applied a week after planting.

Harvested roots from each treatment were sampled, bulked and cured for 5 days before storage in constructed evaporative structures.

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2.4 Storage Structures

Four storage structures were used for the study. The structures were Brick-walled Evaporative Cooling Chamber (CC), Brick-walled In-ground Evaporative Structure (InG), Jute fabric-walled Hexagonal Evaporative Cooling Barn (HexB) and Room storage. The evaporative structures were designed and constructed.

2.4.1. Room Storage

The room was cement blocks structure with corrugated asbestos sheets roof and plywood ceiling. The room was well ventilated. The roots were packed in plastic baskets and kept on the floor.

2.5. Data Collection and Analysis

All data collected were subjected to Analysis of Variance using Gen-stat Discovery software version 4.0. Analysis of Variance was done to determine whether there were significant differences in the parameters studied. For treatments that were significant, mean separation was done using the Least Significant Difference (Lsd) test at 5 % probability level.
The following data were collected**:**

2.5.1 Psychrometric Characteristics of the Storage Structures and Ambient Conditions

Temperature and Relative Humidity were recorded in the storage structures, storage room, under the shed and ambient conditions with digital thermometer and relative humidity meters. Psychrometric characteristics of air such as moisture content, enthalpy, volume of air, etc. were determined with a computer based programme PsycPro version 1.1.16.

2.5.2. Weight Loss

The initial weight of roots was taken before being put in storage. Percentage weight loss in storage was determined on the 4th, 8th and 13th week of storage as in Equation 1:

$$Percentage\ weight\ loss = \frac{Initial\ wt\ roots - Final\ wt}{Initial\ wt\ of\ roots}\ x\ 100 \qquad 1$$

2.5.3. Degree of Shrinkage

Percentage shrinkage was determined by finding the difference in size reduction on the 4th, 8th and 13th week of storage. Diameter of ten roots from each treatment were measured with a Dial Calipers (Opus 150 mm). The percentage shrinkage is computed as in Equation 2:

$$Tuber\ shrinkage\ (\%) = \frac{Initial\ diameter - Final\ diameter}{Initial\ diameter\ of\ roots}\ x\ 100 \qquad 2$$

2.5.4. Degree of Decay in Storage

Roots were examined for decay on the 4th, 8th and 13th week. Roots with decay regardless of the spread were considered rotten and percentage decay was determined as in Equation 3:

$$Percentage\ decayed\ roots = \frac{No.of\ decayed\ roots}{Total\ No.of\ roots}\ x\ 100 \qquad 3$$

2.5.5. Incidence of Sprouting in Storage

Roots were examined on the 4th, 8th and 13th week for sprouting and 100 % sprouting. Percentage sprouting was computed as in Equation 4:

$$Percentage\ sprouted\ roots = \frac{No.of\ sprouted\ roots}{Total\ No.of\ roots}\ x\ 100 \qquad 4$$

2.5.6. Insect Infestation in Storage

Tubers from each plot were examined for weevil infestation. The number of insects (weevils) among each treatment was determined by counting. The level of insect infestation was determined by determining the number of weevils in each treatment sample.

2.6. Statistical analysis

The data collected were subjected to statistical analysis using Analysis of Variance (ANOVA). The data obtained were analyzed using the GenStat Discovery Edition 4.0 statistical package. Least Significant Difference (LSD) was used to separate the means at 5 % level of probability.

3. Results and Discussion

3.1. Psychrometric Characteristics of Storage Structures

Minimum and maximum temperature of air inside the storage structures, shed and outside (ambient) conditions were recorded as shown in Table 1. Temperatures increased from January to April when storage ended. The highest temperatures were recorded in

March and April. In CC air temperature was reduced by 7.2 ^oC while in HexB and InG temperature was reduced by 5.2 ^oC and 4.6 ^oC respectively. The variation between the minimum and maximum temperature was lower inside the storage structures than that of the surrounding air because the evaporator tended to prevent high temperature build up (afternoon temperature) inside the structures (Table 1). It was also observed that minimum temperatures inside the storage structures were higher than that of the outside air. This could be attributed to respiratory heat produced by roots and the cladding of the structure walls which maintained comparatively stable air conditions inside the structures. Figure 1 shows the mean monthly temperatures recorded in the storage structures, shed and ambient. Evaporation was most effective in causing cooling in the Cool chamber (CC). The mean outside temperature was higher than the mean temperatures in the structures as shown in Figure 1.

Storage System	**Cool chamber**		**HexB**		**InG**		**Room**		**Shed**		**Ambient**	
Month	Min T ^oC	Max T^oC	Min T^oC	Max T^oC	Min T^oC	Max T^oC	Min T^oC	Max T^oC	Max T^oC	Max T^oC	Min T^oC	Max T^oC
Jan	24.7	26.3	24.3	29	26	29	24	29	26	30	26	33.5
Feb	25.3	27.5	24.7	29.3	26.5	29.1	25	29	26	30	26.4	34.5
March	26.2	27.4	25.7	29.6	27.4	30.1	25	30	26.2	30	26.9	34.5
April	26.5	27.8	26.1	29.8	27.6	30.4	25	30	26.1	31	26.6	35

Table 1: Minimum and maximum temperature of air inside structures, shed and ambient during the storage period
Source: Author's Data (2015)

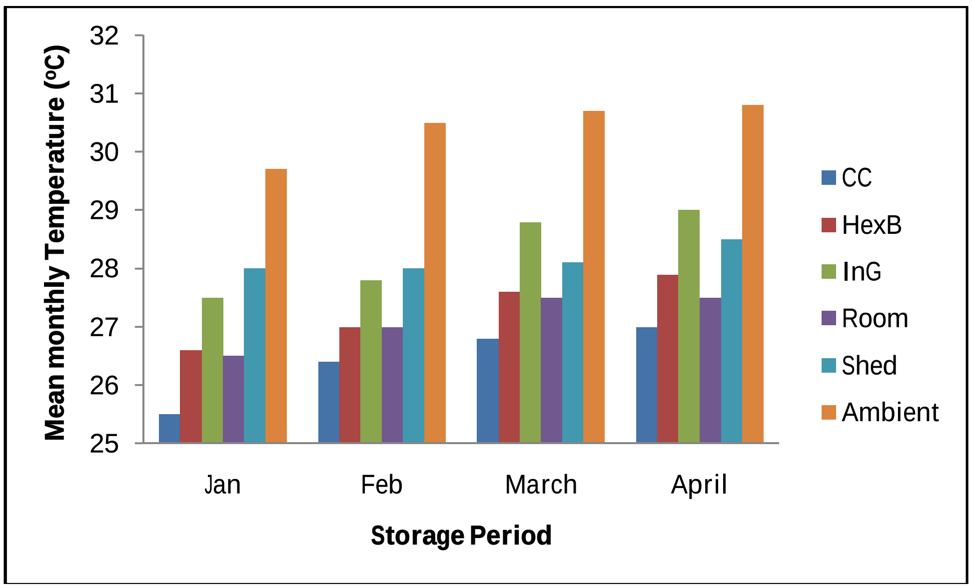

Figure 1: Mean monthly temperature of air inside structures, shed and outside during the storage period

Table 2 shows maximum and minimum relative humidity inside the structures and outside the structures for the entire storage period. The relative humidity inside the structures was about 8-20 % higher than outside. Table 3 shows the mean monthly enthalpy, moisture content and specific volume of air inside the evaporative structures and outside. The enthalpy of the air inside the storage structures ranged from 64.77 kJ kg^{-1} under room conditions to 79.26 kJ kg^{-1}. The enthalpy of the outside air was 80.9 kJ kg^{-1} which was higher than that of the storage structures. This is because the cooling in the evaporative storage structures were adiabatic processes. The high ambient sensible heat blown through the wet pad was converted to latent heat of vaporization of moisture and a depression in the internal enthalpy of air in the storage structures. Furthermore, respiratory heat from the sweet potato roots was too small to raise the enthalpy to equal the enthalpy of the outside air. The specific volume of air in the various storage structures ranged from 0.874 m^3 kg^{-1} (CC) to 0.887 m^3 kg^{-1} (ambient).

Figure 2 shows the mean monthly air relative humidity inside the storage structures and outside. The mean air relative humidity outside was lower than relative humidity inside the evaporative structures as shown in Figure 2.

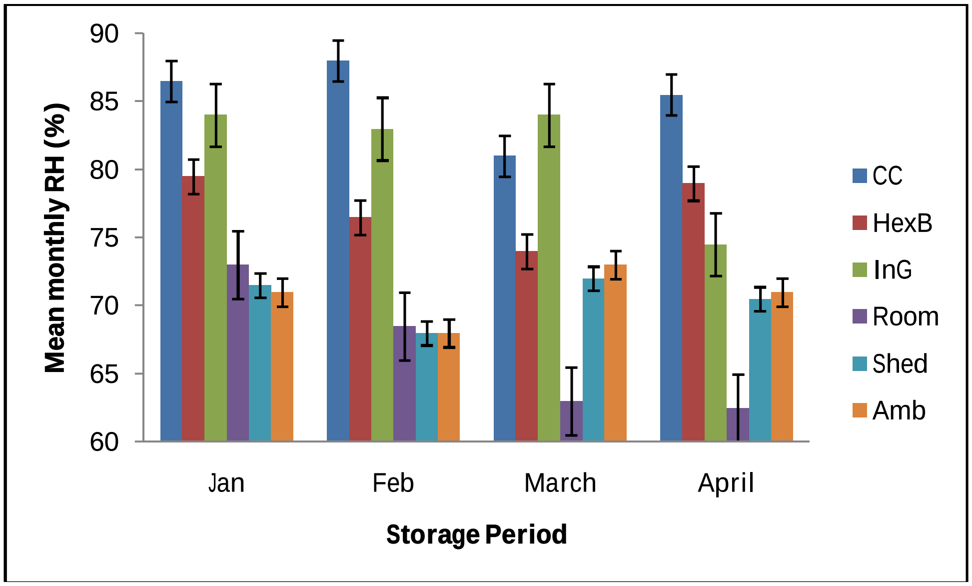

Figure 2: Mean monthly Relative humidity of storage structures, shed and ambient (outside)

Storage System / Month	Cool chamber		HexB		InG		Room		Shed		Ambient	
	Min Rh	Max Rh	Min Rh	Max Rh	Min Rh	Max Rh	Min Rh	Max Rh	Max Rh	Max Rh	Min Rh	Max Rh
Jan	79	94	66	93	73	95	70	76	63	80	61	81
Feb	81	95	61	92	72	94	62	75	54	82	51	85
March	71	91	57	91	73	95	55	71	52	92	50	96
April	77	94	68	90	67	82	60	65	60	81	58	83

Table 2: Minimum and maximum Relative humidity (%) of air inside structures, shed and ambient
Source: Author's Data (2015)

Psychrometric properties of storage structures						
Storage system	CC	HexB	InG	Room	Shed	Amb
Dry bulb Temp DB (° C)	27.3	27.3	28.3	27.10	28.2	30.4
Wet bulb Temp WB (° C)	24.44	24.15	25.69	22.37	23.4	25.9
Relative Humidity RH (%)	83.3	77.3	81.4	66.8	70.5	70.8
Humidity Ratio W (g/kg)	18.65	17.79	19.83	15.13	17.09	19.56
Specific volume V (m^3/kg)	0.874	0.875	0.881	0.871	0.877	0.887
Enthalpy h (kJ/kg)	74.01	72.76	79.26	65.77	71.89	80.49
Dew Point Temp DP (° C)	23.73	22.98	24.81	20.40	22.33	24.50
Density d (kg/m^3)	1.17	1.16	1.16	1.17	1.16	1.15
Vapour Pressure V (mm Hg)	22.0	21.1	23.5	18.0	20.2	23.1
Absolute humidity (g/m^3)	21.346	20.334	22.625	17.379	19.488	22.061

Table 3: Mean Psychrometric properties of air inside storage structures, shed and outside
Source: Author's Data (2015)

3.2. Weight loss in Storage

After 4 weeks of storage, structure significantly ($p<0.01$) influenced root weight loss in storage. Root weight loss in CC was the least, 5.7 6 % which was significantly lower than HexB (10.47 %) and room storage (16.07 %) but not significantly different from InG storage (7.73 %) as shown in Table 4. Similarly, type of storage structure significantly ($p<0.01$) influenced cumulative weight loss after 8 weeks of storage as shown in Table 4. CC storage recorded the lowest cumulative weight loss (11.12 %) as compared to weight loss in HexB and InG. Room storage recorded the highest weight loss of 28.97 % which can be attributed to lower relative humidity (62.5-73 %) (Figure 2).

Soil amendment did not significantly ($p<0.05$ influence tuber weight in storage after 4 weeks of storage. Similarly, manure application did not significantly influence cumulative tuber weight loss after 8 weeks of storage (Table 4). However, NPK fertilized roots suffered the highest percentage weight loss in storage 22.42 %. This observation is contrary to observation by Sowley et al. (2015) that NPK application resulted in lower weight loss of roots in storage as compared to PM application and control.

After 13 weeks of storage, weight loss was highly significant (p<0.01) among the different treatments. PM application resulted in the lowest weight loss (40.4 %) which was significantly lower than weight loss in CD (52.2 %) and NPK (50.9 %) application (Table 4). This could be attributed to higher dry matter content of PM fertilized roots.
The interaction of storage structure and manure significantly (p<0.05) influenced cumulative root weight loss in storage after 8 weeks as shown in Table 5. CD fertilized roots in room storage recorded the highest weight loss (34.91 %) after 8 weeks of storage while PM fertilized roots stored in CC (cool chamber) experienced the least weight loss, 8.83 % as shown in Table 5.

Treatment		Percentage weight loss	
Irr. ET_c %	Root weight loss 4 wk	Cum root weight loss 8 wk	Cum root weight loss 13wk
CC	5.76	11.12	26.8
HexB	10.47	20.07	68.6
InG	7.73	20.96	47.4
Room	16.07	28.79	47.4
F-test	**	**	**
LSD	3.275	4.687	6.20
CV (%)	46	32.5	18.3
Manure/NPK			
PM	10.58	20.84	40.4
CD	9.31	19.81	52.2
NPK	9.88	22.42	50.9
Control	10.25	17.86	46.6
F-test	NS	NS	**
LSD	1.768	4.687	6.20
CV (%)	46.0	32.5	18.3

*Table 4: Effects of Structure, NPK and manure on weight loss of OFSP tubers after 4, 8 and 13 weeks in storage at Cape Coast Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at p<0.01 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.*

Percentage weight loss				
Treatments	Manure			
Structure	Cont.	CD	NPK	PM
CC	11.15	10.28	14.21	8.83
Hex B	16.18	19.16	19.42	25.49
InG	17.04	14.87	24.41	27.51
Room	27.07	34.91	31.64	21.52
F-test	*			
LSD	4.687			
CV (%)	32.5			

*Table 5: Interaction effect of storage structure and manure on sweet potato root cumulative weight loss after 8 weeks of storage Source: Author's Data (2015) Where * = significant at p<0.05 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means*

Similarly, storage structure and manure significantly (p<0.01) influenced cumulative weight loss of roots after 13 weeks of storage (Table 6). The highest weight loss was recorded in NPK produced roots in HexB (85.2 %) while PM fertilized roots in CC recorded the lowest weight loss 20.2 %. Irrespective soil amendment CC storage recorded relatively low weight loss (20.2 % to 30.3 %) while HexB storage recorded higher weight loss (61.0 % to 85.2 %) as shown in Table 6.

Percentage root weight loss				
Treatments	Fertilization			
Structure	Cont	CD	NPK	PM
CC	27.3	30.3	29.6	20.2
Hex B	64.6	63.4	85.2	61.0
InG	48.5	52.4	48.6	40.2
Room	46.2	62.8	40.2	40.3
F-test	**			
LSD	12.40			
CV (%)	18.3			

*Table 6: Interaction effect of storage structure and manure on cumulative weight loss of sweet potato roots after 13 weeks of storage Source: Author's Data (2015) Where ** = significant at p<0.05 probability level; LSD = Least Significant Difference between means.*

The interaction of irrigation and storage structure significantly ($p<0.05$) influenced root weight loss in storage after 4 weeks of storage as shown in Table 7. Roots from plots irrigated with 90 % ET_c in room storage suffered the highest weight loss of 18.68 % after 4 weeks of storage while roots which received 80 % ET_c in CC recorded 2.79 % weight loss which was the least. Irrigation had no significant effect on weight loss after 4 weeks of storage as shown in Table 7. DI at 80 % CWR resulted in the lowest weight loss (8.99 %).

Percentage root weight loss					
Treatments	**Irrigation % ET_c**				
Structure	70 %	80 %	90 %	100 %	Mean
CC	4.54	2.79	7.50	8.22	5.76
Hex B	9.27	11.77	14.47	6.36	10.47
InG	10.80	5.49	6.99	7.62	7.73
Room	13.87	15.93	18.68	15.81	16.07
Mean	9.62	8.99	11.91	9.50	
F-test	*				
LSD	6.717				
CV (%)	47.1				

Table 7: Interaction effect of storage structure and irrigation on weight loss of sweet potato roots after 4 weeks
*Source: Author's Data (2015) Where * = significant at p<0.05 probability level; LSD = Least Significant Difference between means.*

3.3. Shrinkage (Loss in size)

Storage structure significantly influenced root shrinkage after four weeks of storage as shown in Table 8. Root shrinkage was significantly higher in room storage than in the evaporative structures. The ranking order of root shrinkage in storage was room storage (3.83 %) >InG (2.46 %) >HexB (2.37 %) > CC (2.04 %) as shown in Table 8. Room storage recorded the highest shrinkage (3.83 %) which was significantly higher ($p<0.01$) than shrinkage recorded in the evaporative structures CC, HexB and InG. This could be attributed to lower relative humidity in the room during the storage period as shown in Table 2 and Figure 2. However, percentage shrinkage in CC was not significantly lower than shrinkage in InG (2.47 %) and HexB (2.37 %) evaporative structures. Additionally, storage structure had significant ($p<0.01$) influence on cumulative root shrinkage after 8 weeks of storage as shown in Table 8. Room storage recorded the highest shrinkage in root size (8.63 %) among the four different storage structures. The evaporative structures were significantly better than room storage in terms of shrinkage. Differences in root shrinkage among the three evaporative structures were, however, not significant. However, CC recorded the lowest root shrinkage 3.67 % as compared to 4.08 % and 4.71 % for InG and HexB, respectively. On the contrary root shrinkage were not significantly different among the four storage structures after thirteen weeks of storage (Table 8). Cool Chamber recorded the lowest percentage root shrinkage (5.51 %) which could be attributed to lower temperatures 25.5-27 ^{o}C (Table 1), higher average relative humidity (81-88 %) and lower weevil infestation. Room storage recorded the highest percentage shrinkage (9.18 %) while InG and HexB recorded 6.33 % and 6.01 %, respectively (Table 8).

	Treatment	**Percentage shrinkage (loss in size)**	
Irr. ET_c %	**Root shrinkage 4 wk**	**Cum. root shrinkage 8wk**	**Cum. root shrinkage 13wk**
CC	2.04	3.67	5.51
HexB	2.37	4.71	6.01
InG	2.46	4.08	6.33
Room	3.83	8.63	9.18
F-test	**	**	NS
LSD	0.485	1.624	4.58
CV (%)	51.2	43.2	49.1
Fertilization			
PM	3.06	4.74	5.41
CD	2.50	4.89	5.77
NPK	2.76	5.61	6.17
Control	2.39	5.86	6.98
F-test	NS	NS	NS
LSD	0.485	1.624	4.58
CV (%)	51.2	43.2	49.1

Table 8: Effects of structure and manure on cumulative shrinkage of OFSP tubers after 4, 8 and 13 weeks of storage in Cool Chamber
*Source: Author's Data (2015) NS = non-significant and ** = highly significant at p<0.01 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means*

Soil amendment (PM, CD and NPK) did not significantly influence root shrinkage in storage after four weeks of storage as (Table 8). The interaction of manure and storage structure also had no significant influence on root shrinkage after four weeks of storage. Soil amendment had no significant influence on root shrinkage after eight weeks of storage. Similarly the interaction of manure and storage structure had no significant influence on root shrinkage after eight weeks of storage as shown in Table 8. However the highest root shrinkage were recorded in the control experiment (5.86 %). Deficit irrigation as well did not significantly influence root shrinkage after eight weeks of storage.

After thirteen weeks of storage, soil amendment had no significant influence on root shrinkage. However, the control recorded the highest percentage shrinkage (6.98 %) after thirteen weeks of storage. It can also be noted that deficit irrigation and the interaction of soil amendments and irrigation had no significant influence on root shrinkage in storage.

3.4. Decay of Roots in Storage

Storage structure significantly influenced root decay in storage as shown in Table 9. After 4 weeks of storage roots in InG storage recorded the lowest percentage decay 12.8%, while roots in CC, HexB and Room storage recorded 16.9 %, 20.5 % and 26.1% decay, respectively. However, after eight weeks, storage structure effect on root decay was not significant (Table 9). CC storage reduced root decay even though it was not significantly better than room storage, InG and HexB storage. After 13 weeks, storage structure significantly influenced root decay in storage. Cool chamber recorded the lowest percentage root decay (44.5 %). InG storage, room storage and HexB storage recoded 49.0 %, 62.9 % and 84.0 % root decay, respectively.

	Treatment	Percentage Root decay	
Structure	**Percentage root decay 4 wk**	**Cumulative root decay 8 wk**	**Cumulative root decay 13 wk**
CC	16.9	29.9	44.5
HexB	20.5	31.2	84.0
InG	12.8	36.8	49.0
Room	26.1	46.7	62.9
F-test	*	NS	**
LSD	9.43	17.5	13.24
CV (%)	69	68	30.9
Fertilization			
PM	12.9	20.84	48.1
CD	17.3	19.81	58.8
NPK	19.8	22.42	73.4
Control	26.1	17.86	60.1
F-test	*	NS	**
LSD	9.43	17.5	13.24
CV (%)	69	68	30.9

Table 9: Effects of Structure, NPK and manure on percentage decay of OFSP roots after 4, 8 and 13 weeks in storage
*Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at p<0.01 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means*

Soil amendment significantly ($p<0.05$) influenced percentage root decay after 4 weeks of storage as shown in Table 9. PM treatment resulted in the lowest root decay (12.9 %) which is 50.57 % reduction in percentage decay as compared to 26.1 % decay for Control. This observation is supported by Sowley et al. (2015) and Data et al. (1989) who reported that OFSP produced with PM suffered much less decay as compared to unfertilized roots. The ranking order of decay as influenced by soil amendment was Control (26.1 %) > NPK (19.8 %) > CD (17.3 %)> PM (12.9 %). Sowley et al. (2015) made similar observation that OFSP roots amended with PM and NPK suffered much less rot than unfertilized tubers. After 13 weeks of storage soil amendments significantly ($p<0.01$) influenced root decay as shown in Table 9. The ranking order of root decay as influenced by soil amendment was NPK (73.4 %) > Control (60.1 %) > CD (58.8 %)> PM (48.1%).

Manure and storage structure interaction significantly influenced percentage decay after 8 weeks in storage (Table 10). NPK produced roots stored in InG and PM produced roots stored in CC recorded significantly lower percentage decay 14.2 % and16.3% respectively after 8 weeks of storage. On the contrary PM produced roots stored in InG recorded the highest percentage decay (67.5%). Similarly, manure and storage structure interaction significantly ($p<0.01$) influenced percentage decay after 13 weeks in storage (Table 11).

Cumulative percentage decay				
Treatments	Fertilization			
Structure	Cont.	CD	NPK	PM
CC	29.6	32.9	41.0	16.3
Hex B	42.1	33.8	14.2	34.6
InG	21.7	19.6	38.5	67.5
Room	48.7	42.3	68.3	27.6
F-test	*			
LSD	35.03			
CV (%)	68			

Table 10: Interaction effect of storage structure and manure on sweet potato root cumulative percentage decay after 8 weeks of storage
*Source: Author's Data (2015) Where * = significant at p<0.05 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means*

PM fertilized roots in CC recorded the lowest 21.6 % decay after 13 weeks in storage. On the contrary roots produced from control plots recorded 100 % decay after 13 weeks of storage. Similar observation was reported by Sowley et al. (2015) and Data et al. (1989) that roots from unfertilized plots decayed more severely than roots from fertilized plots in storage. However Sowley et al. (2015) reported that NPK produced roots suffered less decay in storage which is contrary to current finding that NPK produced roots suffered 100 % root decay after 13 weeks in storage as shown in Table 11.

Cumulative percentage decay				
Treatments	Manure			
Structure	CD	Cont.	NPK	PM
CC	47.9	54.1	54.4	21.6
Hex B	92.9	100	84.2	58.8
InG	37.0	30.8	55.1	72.9
Room	57.5	55.4	100	38.8
F-test	**			
LSD	26.49			
CV (%)	30.9			

Table 11: Interaction effect of storage structure and manure on sweet potato root cumulative percentage decay after 13 weeks of storage
*Source: Author's Data (2015) Where ** = highly significant at p<0.01 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means*

Level of irrigation did not significantly influence root decay after 13 weeks of storage. This is contrary to the findings by Thompson et al. (1992) which indicated that sweet potato root decay is responsive to amount of water application. The ranking order of root decay after 13 weeks of storage as influenced by irrigation was 70 ET_c (67.1) > 100 % ET_c (62.8 %) > 80 % (61.2 %) > 90 % ET_c 46.6 %. Thus it can be stated that DI (90 % ET_c) resulted in lower root decay (46.6%) in storage. However further reduction of water application to 70 % ET_c increased root decay to 67.1 %.

3.5. Sprouting in Storage

From Table 12 percentage sprouting of roots in storage was not influenced by manure application, level of irrigation and storage structure after four weeks of storage. HexB recorded the highest sprouting (45.3 %). Manure application did not significantly influence sprouting in storage, however, the ranking order of sprouting was CD (42.5 %) > Control (40.3 %) > NPK (34.3 %) > PM (33.0 %) as shown in Table 12. This suggestion is contrary to the findings by Data *et al.* (1989) that white-fleshed sweet potato roots fertilized with PM exhibited higher percentage of sprouting than roots fertilized with NPK and unfertilized roots.

After eight weeks of storage, cumulative sprouting of roots was significantly (p<0.01) influenced by storage structure as shown in Table 12. In CC sprouting was 83.5 % which was the highest while InG recorded the lowest cumulative sprouting (38.4 %). HexB and Room storage recorded 72.9 % and 61.1 % respectively. The high percentage sprouting in CC can be attributable to high relative humidity in the structure as shown in Table 2. It can thus be stated that even though CC provides relatively cooler temperatures and higher relative humidity it also promotes sprouting of roots in storage.

Manure application did not significantly influence root sprouting after 4 and 8 weeks in storage (Table 12). Level of irrigation had no significant influence on root sprouting. However interaction effect of manure and structure significantly (p<0.05) influenced sprouting after 8 weeks in storage (Table 13). PM fertilized roots in InG storage recorded the lowest sprouting (7.1 %) while roots from control in CC storage recorded the highest sprouting (87.5 %) as shown in Table 13. At the end of 13 weeks almost all roots had sprouted in CC and HexB.

Structure	Root sprouting 4 wk	Cum root sprouting 8 wk
CC	40.1	83.5
HexB	45.3	72.9
InG	36.8	38.4
Room	27.9	61.1
F-test	NS	**
LSD	12.87	18.19
CV (%)	48.2	39.9
Manure/NPK		
PM	33.0	58.4
CD	42.5	67.1
NPK	34.3	61.5
Control	40.3	68.8
F-test	NS	NS
LSD	12.87	18.19
CV (%)	48.2	39.9

Table 12: Effects of Structure, NPK and manure on sprouting of OFSP tubers after 4 and 8 weeks in storage at Cape Coast
*Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at p<0.01 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.*

Percentage root sprouting				
Treatments	Fertilization			
Structure	Cont.	CD	NPK	PM
CC	87.5	76.7	79.8	89.9
Hex B	85.4	71.1	78.8	56.2
InG	32.5	72.5	41.7	7.1
Room	69.8	48.3	45.8	80.4
F-test	*			
LSD	36.37			
CV (%)	39.9			

Table 13: Interaction effect of storage structure and manure on cumulative root sprouting after 8 weeks of storage
*Source: Author's Data (2015) Where * = significant at p<0.05 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means*

3.6. Insect Infestation in Storage

After 4 weeks of storage, storage structure highly significantly (p<0.01) influenced weevils infestation among roots (Table 41). CC storage structure recorded the lowest weevil number (2.12) which could be attributed to high Relative humidity (moist conditions) in the structure. The order of number of weevils in the structures was as follows: CC (2.12) <HexB (3.12) <InG (4.68) < Room (9.32). Similarly, after 8 weeks, storage structure significantly (p<0.01) influenced cumulative number of weevils in structure. The ranking order of number of weevils was: CC (3.19) <HexB (9.25) < Room (23.91) <InG (26.57). The same thing can be said about the number of weevils after 13 weeks of storage. Storage structure effect on weevil infestation was highly significant (p<0.01). CC recorded the lowest number (5.9) which can be attributed to higher relative humidity (moist condition) in the structure. The moist condition was not conducive for the survival of the weevil. It is well known that sweet potato weevil is more prevalent in dry conditions. The order of number of weevils in the structures was: Room (32.2) >InG (27.7) >HexB (24.9) > CC (5.9) as shown in Table 14. Room conditions was conducive for weevil survival.

Soil amendment did not significantly influence weevil number in storage after 4, 8 and 13 weeks as shown in Table 14. Deficit irrigation and manure and their interactions did not significantly reduce number of weevils in storage. The number of weevils was in this order; 70 % ET_c(18.7) > 100 % ET_c (17.6) > 90 % ET_c (14.0) > 80 % ET_c (12.7).

The interaction of soil amendment and storage structure significantly influenced weevil number in storage after 8 weeks as shown in Table 15. CD fertilized roots in CC recorded the lowest weevil number (1.25) in storage while roots from control plots in InG storage recorded the highest number of weevils (36.77).

Treatment	Number of weevils		
Structure	Number of weevils 4 wk	Cum number of weevils 8 wk	Cum number of weevils 13 wk
CC	2.12	3.19	5.9
HexB	3.12	9.25	24.9
InG	4.68	26.57	27.7
Room	9.32	23.91	32.2
F-test	**	**	**
LSD	3.275	4.695	6.58
CV (%)	46	41.9	40.8
Fertilization			
PM	4.69	15.82	22.9
CD	4.19	16.19	24.1
NPK	5.19	16.15	24.2
Control	5.19	14.76	19.4
F-test	NS	NS	NS
LSD	1.768	4.695	6.58
CV (%)	46.0	41.9	40.8

Table 14: Effects of Structure and Fertilization on weevil numbers in OFSP roots after 4, 8 and 13 weeks in storage
*Source: Author's Data (2015) Where NS = non-significant and ** = highly significant at p<0.01 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means.*

Number of weevils				
Treatments	**Fertilization**			
Structure	CD	Cont.	NPK	PM
CC	1.25	5.25	3.75	2.50
Hex B	5.75	8.00	14.25	9.00
InG	25.00	36.77	23.50	21.03
Room	32.77	9.00	23.11	30.75
F-test	**			
LSD	9.39			
CV (%)	41.9			

Table 15: Interaction effect of storage structure and fertilization on number of weevils after 8 weeks of storage
*Source: Author's Data (2015) Where * = significant at p<0.05 probability level; CV = coefficient of variation; LSD = Least Significant Difference between means*

4. Conclusions

The evaporative storage structures significantly reduced percentage root decay, shrinkage, weight loss and weevil infestation in storage as compared to room storage. However, there was increase in sprouting of OFSP roots stored in evaporative storage structures. Brick walled cool chamber evaporative structure (CC) recorded lower root shrinkage, decay, weight loss and weevil infestation in storage as compared to the other evaporative structures. However tuber sprouting increased in cool chamber storage. Soil amendment significantly influenced percentage root decay. Application of PM reduced percentage root decay after 13 weeks of storage. PM and CD reduced weight loss in storage significantly. After 13 weeks in storage PM reduced percentage decay in roots in CC storage (21.6%) while roots from control plots recorded 100 % decay. Thus roots from unfertilized plots decayed more severely than roots from fertilized plots in storage. Deficit irrigation (water stress) resulted in insignificant reduction in percentage root decay. Irrigation, manure and their interaction did not significantly influence weevil infestation in storage. The study should be carried out in other agro ecological areas since environmental conditions such as climate influence the results.

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