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Design, Construction and Performance Evaluation of an Underground Storage Structure for Yam Tubers

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Abstract- An underground storage environment for yam tubers was designed and constructed at the college of Engineering, university of Agriculture, Makurdi. The structure which was tested between November 2011 and January 2012, consisted of walls made of burnt bricks, erected from the ground soil level of the underground pit. Thatch and bamboo sticks were used for roofing. Yams were stored in the underground pit structure and also in an open shed for comparison. Test results showed that temperature and humidity in the underground structure ranged from 28.77 oC to 32.70 oC and 70 % to 88 % respectively for 56 days, while that of the open shed fluctuated between 32.90 oC to 36.40 oC and 50 % to 78 % within the same period. The ambient temperature at the location of the storage structure was between 36.40 oC to 40 oC. The reduced temperature achieved in the underground pit together with the average relative humidity, made it possible to store yam tubers for 56 days. In the shed environment however, yams could stay for 35 days. There were no cases of sprouting in both storage environments. However, affloxiation rates were higher in the open shed due to exposure of the tubers to insects and rodents. Yam tubers stored in the underground pit had a cumulative weight loss of 11.0 % while in the open shed a cumulative weight loss of 15.0 % was recorded. The cost of construction of the underground storage structure is N19,000:00.

Index Terms- Design, Construction, Testing, Underground Storage Structure, Yam, Tubers.

I. Introduction

The Yam Plant

The term "yam" is used to embrace many tubers. Yams are any of the ten (10) economically important species of Dioscorea SPP., a genus in the monocotyledonous family *Dioscoriaceae*. These species have a worldwide variety and are cultivated for their edible tubers (enlarged, fleshy, usually underground storage stems). Yams are cultivated throughout the tropics and in parts of the subtropics. It occupies a prominent position in West African Agriculture but is also important in South East Asia (including some adjacent area of China), Japan, and the Caribbean. The crop is a staple food for millions of people in these regions, providing an important source of carbohydrate and more protein on a dry weight basis than commonly assumed (IITA, 1995)

Nutritionally, yams contain 80 – 90 % carbohydrates, 5 – 8 % protein and about 3.5 % minerals (FAO, 1990). They are also high in starch content.Yams are very important food crops in West Africa. Over 90 % of global yam production comes from this region (Onwueme, 1979). Yam production accounts for 4.1 % of the total output of roots and tuber crops (IITA, 1995). However, in sub-Sahara Africa, yam accounts for 26.9 % of total root crop production. Apart from being a source of food, income, and food supplement for livestock, its production from land clearing to harvest by numerous cultivators have attached high cultural importance. (Gebremeskel and Oyewole, 1987; Onwueme and Sinha, 1991; Onwueme, 1979)

The most common problems faced by farmers are the losses of the produce during post-harvest and storage. Wastage of produce generally, occurs because the apparent surplus harvest during the harvest season cannot be consumed within a short period. However, few months after the harvest there is always a diminishing availability of yam produce. Therefore, it becomes imperative that the existing yam tubers are stored in structures for later use. (Williams and Raharatham, 1980)

This study is limited to the design, construction and evaluation of a pit storage structure for yam tubers. Evaluation of the storage structure is centered on effects of temperature, humidity, affloxiation, weight-loss and sprouting.

Conditions/Factors Influencing the Storage of Yams

Successful storage of yams requires the use of healthy and sound tubers, proper curing if possible combined with fungicide treatment, adequate ventilation to remove heat generated by respiration of sprouts and rotted tubers that develop, monitoring the presence of rodents and protection from direct sunlight and rain.

Yams can be best stored in a cool, dry and well ventilated surrounding. Ware yams, seed and commercial yams have similar storage requirements, notwithstanding cultivar differences. Fresh yam tubers can be successfully stored in ambient and refrigerated conditions and the recommended storage temperature is between the ranges of 12 ^oC to 16 ^oC. Optimum conditions of 15 ^oC or 16 ^oC at 70 to 80 % relative humidity have been recommended for cured tubers. (Cooke et al, 1988; Opara, 1999)

Storage environment for yams must inhibit the onset of sprouting (breakage of dormancy) which increase the rate of dry matter and subsequent shrivel and rotting of tubers. Tubers transit and storage life of 6 to 7 months can be achieved under these conditions (Plucknett, 1979; Passam et al, 1978; Opara, 1999).

Yams must be in an atmosphere where conditions that favor the growth of microorganisms are prevented or discouraged. The essence of maintaining such conditions is to avoid the causative agents of spoilage or storage losses in the produce. The major factors influencing the growth and productivity (reproduction) of microorganisms in yams include; moisture, temperature, relative humidity and the soil type (Kay, 1973).

To store yams effectively, moisture should be controlled at sufficiently low levels so that other factors do not set in, also, the type of soil conducive for storage is taken into consideration.

There are considerable variations in the storage of different varieties of yam. *D alata* is more difficult to store than *D. rotundata*. Under high storage temperatures (160 ^oC and above) and relative humidity (85 % and above) sprouting and decay occurs in water yams (*D. alata*) as compared to *D. rotundata* (white yam) (Maduewese and Onyike, 1981).

However, at high temperatures and lower humidity the case is the same. This is because water yam is water stressed and cannot stay long. Thus, for water yams to be stored, they will require lower temperatures and lower humidity. For instance by burying the tubers inside the ground and covering properly with earth, it can last a few weeks until is ready for use. (Maduewese and Onyike, 1981)

Dormancy in Yams

This is the temporary suspension of visible growth of any plant structure containing a meristem. In yams, it is that period during which sprouting is inhibited. Knowledge of the potential length of dormancy for stored tuber is important because once dormancy breaks, the tubers also senesce rapidly with loss of stored food (carbohydrates). (Coursey, 1967; Coursey, 1983)

The environmental conditions affecting yam tuber dormancy are photoperiod, white and colored light, temperature, relative humidity and partial oxygen pressure. The length of tuber dormancy is endogenously controlled and conditions such as availability of soil moisture or cool temperature are ineffective triggers of sprouting.

The physiological age of tuber also affect their readiness to sprout. But approximately 6months after harvesting, dormancy disappears completely and budless set planted after that period must require nearly the same time to sprout (Onwueme, 1978).

Types of Storage Structures

The different forms and methods of yam storage depend on the intended final use. Yams for planting are usually stored fresh. Those for food are either consumed when fresh or processed into chips and stored dry.

There are several traditional low-cost storage methods and structures for yam tubers. The most common of them include leaving the tubers in the ground until it is required, storage under tree shades, yam barns, underground structures such as pits and ditches, mud structures, thatched huts and cribs. The storage structures are of different shapes and sizes depending on the ability of the farmer locality and cultural practices. The construction materials are usually wood, ropes, palm fronds, guinea corn stalks, and mud. (Osuji, 1985; Cooke et al, 1988; FAO, 2004)

Various problems are associated with the traditional method of yam tuber storage. Leaving the tubers in the ground until it is required is the simplest storage technique practiced by rural farmers. When carried out on the farm, the method of storage prevents the use of farm lands for further cropping. The method is susceptible to rodents and insect attacks, and sprouting usually occur leading to loss in quality of the tubers. Tubers stored in under shades provide good habitat for harmful reptiles and scorpions. They are exposed to rain, pests and rodents. In addition, regular inspection of the tubers will require dismantling and rearranging of yam heaps which is a tedious, hazardous and undesirable process. Storage in underground and mud structures is prone to flooding, wetting, fungi infections, decaying and various forms of affloxiation. Storage in structures made of palm fronds, and guinea corn stalks are susceptible to fire out-break among others. (Osuji, 1985; Satimehin, 1987; Umogbai and Satimehin, 2004)

There are well ventilated weather-proof, insect and rodent proof strong shelters for storage of yam tubers. The financial cost of such structures discourages the peasant farmers who are the major producers of yams from constructing such improved storage structures. (Umogbai and Satemehin, 2004)

II. DESCRIPTION OF THE STORAGE STRUCTURE

The structure consists of walls made of burnt bricks. The roof is made of thatch using bamboo sticks as frame and spear grass for the thatch. Wall height from the ground level is 152.4 cm and the height of the roof from wall level is 100 cm, giving a total height of 252.4 cm.

The inner dimension of the structure is 130 cm x 130 cm. the depth of the pit inside the hut is 60.96 cm. It has an entrance door made of wood measuring 70 cm high and 45 cm wide, and two windows measuring 15 cm x 15 cm. The two windows are positioned opposite each other to provide cross ventilation and are covered with metal net to prevent insects and rodents from getting inside the structure. Fig. 1 is a pictorial view of the structure, while Fig. 2 shows the orthographic view. Fig. 3 is a photograph of the structure. The quantity and dimensions of construction materials for the storage structure are given in Table 1.

R7	Ground: soil surface	1	Soil
G6	Structure wall	1	Burnt bricks
S5	Window vent	2	
W4	Roof	1	Thatch
R3	Entrance door	1	Wood
E2	Entrance	1	
E1	Underground pit	1	Burnt bricks
SN	Component	Qty	Material

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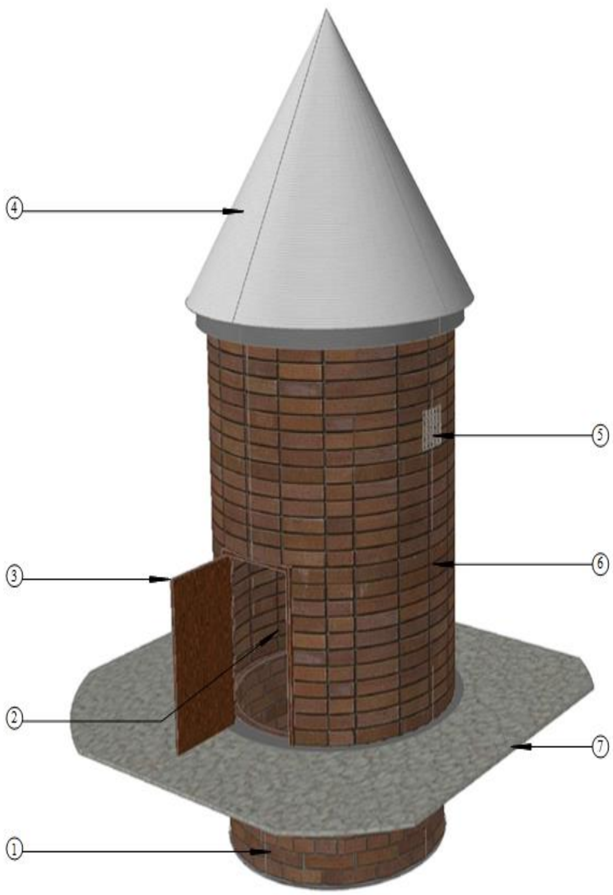

Fig. 1: A pictorial view of the underground yam storage structure

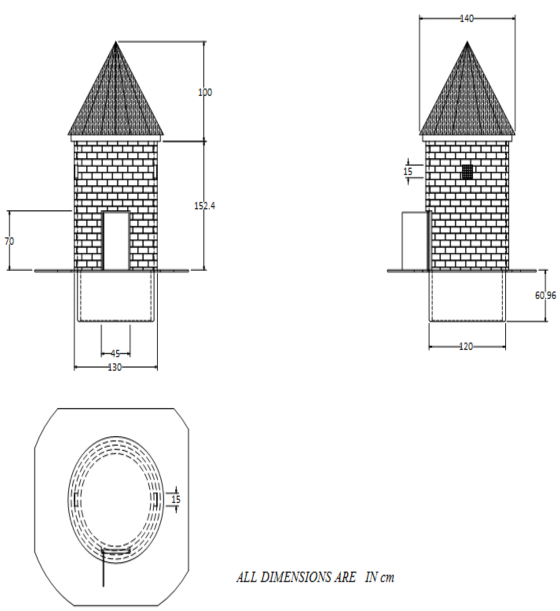

Fig. 2: Orthographic view of the underground yam storage structure

Table 1: Quantities and dimensions of construction materials

S/No.	Item	Material	Quantity	Dimension
1.	Burnt bricks	Fired clay	200	30 x 16 x 11 cm
2.	Door	Wood	1	70 x 45 cm
3.	Window	Net	-	15 x 15 cm
4.	Thatch	Spear grass	3bundles	-
5.	Ropes	Twine	4rolls	-
6.	Sticks	Bamboo	30	-
7	Cement	Cement	Half bag	-

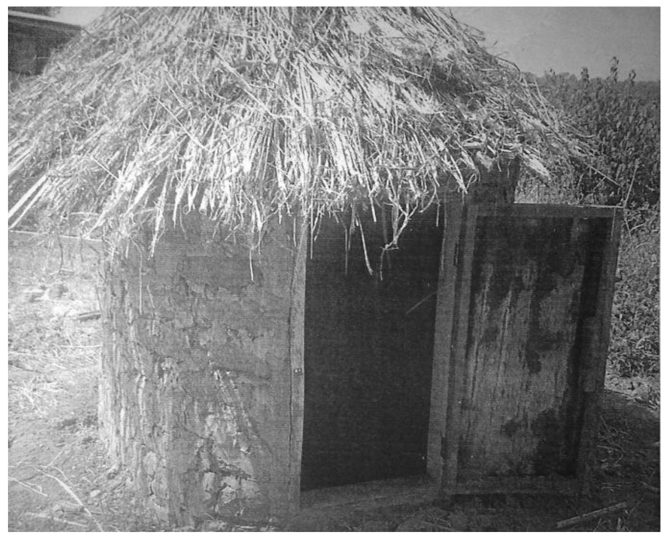

Fig. 3: The underground storage (front view)

Evaluation of the Storage Structure

Matured yam tubers of *D.rotunda* from the second harvest period of 2011 growing season were obtained from the yam market in Makurdi. Proper inspection was carried out in order not to use yam tubers that were injured mechanically and also to avoid yams gathered from early harvest period which are quite difficult to store due to high water stress. Yams from first harvest normally have high water stress and rot very quickly as compared with those of second harvest which suffer little or no water stresses (Opara, 1999; http:/www.sciencedirect.com). Forty yam tubers were used for the evaluation. Twenty were put inside the underground pit of the newly constructed storage structure while twenty were put in an open shed commonly used by local farmers. The shed was placed close to the constructed storage structure for good comparism.

Evaluation was centered on temperature, humidity, weight loss, affloxiation and sprouting. In order to maintain the storage environment and extend the shelf life of the stored produce, sodium hydroxide pellets were placed inside the storage structure to remove the excess carbon dioxide that could generate due to respiration (Burton, 1974).

Temperature

Temperature readings which are the degree of hotness or coldness of the storage structure and environment were taken on a daily basis in the afternoon between 12:00 noon and 1:00 pm, using wet and dry bulb thermometers. This is the period of the day when there is great difference between temperatures of the storage structure and the ambient temperature. (Umogbai and Satimehin, 2004)

Relative Humidity

The amount of moisture contained in the atmosphere of the storage structure and in the shed was determined with the use of a hygrometer tables and psychometric chart, having taken the temperatures using the wet and dry bulb thermometers.

Weight Loss

The weights of the stored yam tubers in the storage structure and shed were taken on a daily basis using weighing balance.

Affloxiation/Sprouting

Visual inspection and counting was done for yam tubers in the storage structure and shed. The affloxiation and sprouting index were then determined as follows:

$$\text{Affloxiation} = \frac{\text{Number of Detriorated Tubers}}{\text{Total number of Tubers}} \times 100 \quad 1$$

$$\text{Sprouting index} = \frac{\text{Number of Sprouted Tubers}}{\text{Total number of Tubers}} \times 100 \quad 2$$

(Opara, 1999)

Simple statistical analysis of mean, standard deviation and error were used in computation of results.

$$Mean = \frac{\sum x}{n} \quad 3$$

$$S.D = \sqrt{\frac{\sum(x-\bar{x})2}{n}} \quad 4$$

$$P.E = \frac{Experimental\ value - Theoretical\ value}{Theoretical\ value} \times 100\% \quad 5$$

Where: x = Temperature and humidity values
n = Number of weeks
$\bar{x}$ = Mean
S.D = Standard deviation
P.E = Percentage error

III. RESULTS AND DISCUSSION

The variation in pit air temperature showed a slight patterned increase in the underground structure. It is likely that the two vents on both sides of the storage structure and the thatch roof facilitated the lower temperature recorded in the pit. (Fig. 4)

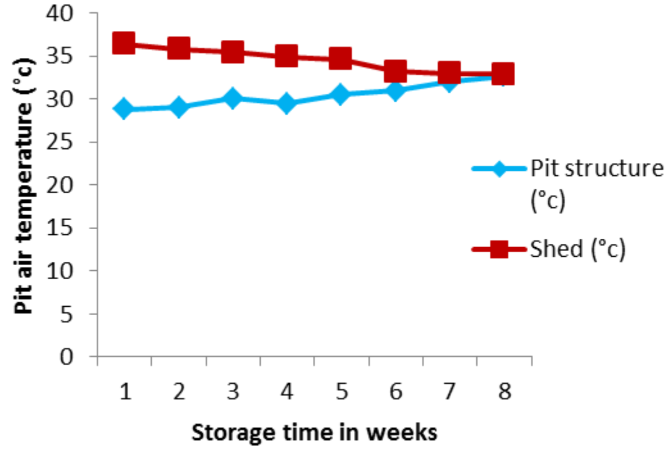

Figure 4: Variation of air temperature during storage period

This temperature distribution trend is significant, when analyzing weight loss in tuber particularly in a given environment where the subject of study is becoming pertinent. High temperature environment facilitate increased respiration rates, thereby exerting high tuber vapor pressure and enhance significant sprouting activity during the later storage life and subsequent weight loss of the tubers. The reason is because at high temperature, there is that tendency for an increased metabolic activity thus transpiration processes is associated with the total energy content of the tuber which results into greater weight loss (Kay, 1973).

Comparing the cumulative weight loss of the tubers stored in the underground structure and those stored in the shed, it was observed that yam tubers in the underground structure sustained a weight loss of 1.5 to 11.0 % in 8weeks of storage, while those in the shed had weight loss ranging from 3.0 to 15.0 % in the same storage period. (Fig. 5)

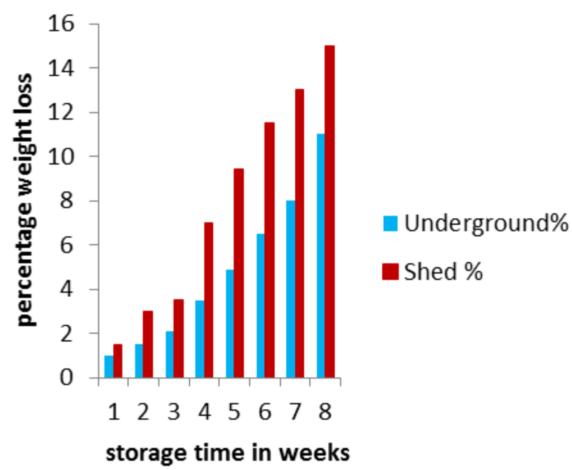

Figure 5: Weight loss against storage time

From figure 6, it was observed that relative humidity readings that were taken in the morning and evening are approximately the maximum values. Thus, relative humidity between the periods of week 1 to 3 was recorded to be very high due to the prevailing rainy season which gradually reduced towards the end of the year. Higher humidity is capable of enhancing dehydration of tubers due to the generated ambient vapor pressure which are relatively high. This therefore ensures a greater driving potential for moisture exchange that would have been experienced in weeks 4 to 8. Also, it can be seen that humidity values attained in week 1 to 3 are near optimum and therefore will require necessary curing of the yam tubers.

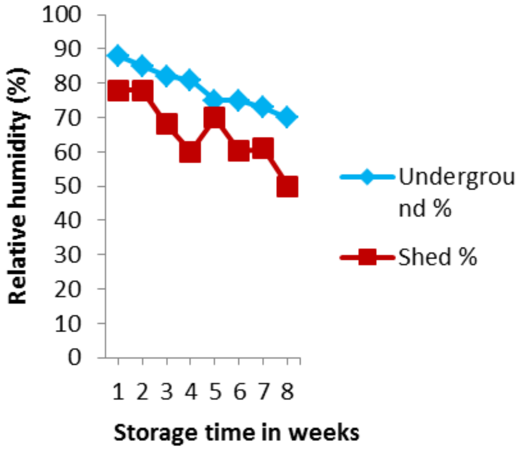

Figure 6: Relative humidity during storage

The high humidity values attained from week 1 to 3 was attributed to the soil moisture condition which was very high due to the rainy season at that particular period of the year. The air in contact with it was often laden with moisture and high humidity condenses moisture from air.

An important problem associated with the storage of root crops generally, especially underground is the mechanism that will regulate dormancy. It was observed that sprout development did not occur for the storage period of 8 weeks. The temperature in both structures were considerably high, however the presence of vents which gave adequate ventilation in the underground pit structure might have removed totally, the inhibition of localized heat pockets from the structure which tends to promote sprouting activity.

Table 2: Various temperatures in the storage area against time

Week	Ambient (°C)	Wet-bulb (°C)	Underground pit (°C)	Control environment (°C)
1.	36.40	27.50	28.77	36.40
2.	37.90	26.95	29.00	35.80
3.	38.70	27.30	30.10	35.40
4.	38.90	26.70	29.50	34.90
5.	38.60	27.05	30.50	34.60
6.	40.00	27.10	30.98	33.20
7.	40.00	28.00	32.00	32.95
8.	39.00	28.20	32.70	32.90

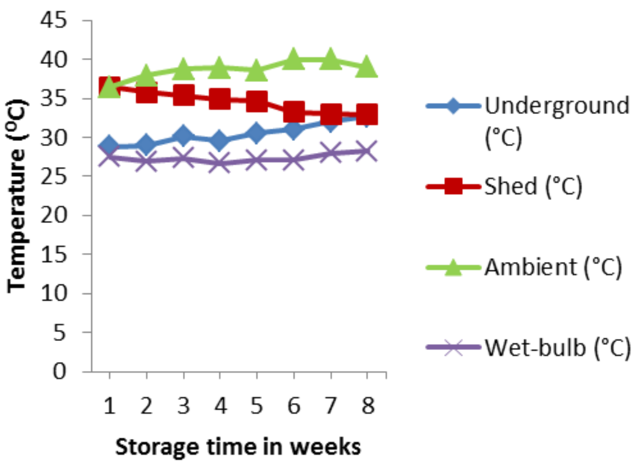

Figure 7: Various temperatures in the storage area against time.

One probable reason for the lower temperatures in the underground storage is the heat balance within the storage structure. Table 2 and Figure 7 show the relationship between the ambient temperature, air temperature in the underground structure, wet bulb temperature and temperature in the shed. The lower temperatures recorded in the underground structure result from the sensible latent heat exchange between air and soil.

The heat exchange between air and soil was observed to cause affloxiation. The rate of deterioration of yam tubers in the underground structure for the storage period of 8 weeks occurred increasingly in the first few weeks of storage. This was due to initial high humidity recorded in the storage structure, as a result of the outgoing rainy season. The temperature of the underground structure was considerably low during the first few weeks together with the soil moisture very high. This subjected quite a good number of yam tubers to spoilage. However, in the shed environment, the higher temperature and lower humidity subjected the tubers to spoilage. Yam tubers were observed to develop cracks and break easily during the storage period. Also, the tubers in the shed eventually became very dry and subsequent deterioration occurred.

Table 3: Number of yam tubers that were affected by affloxiation for the period of 56days

Week	Underground pit	Shed environment
1.	10	-
2.	15	-
3.	20	-
4.	5	20
5.	-	15
6.	-	10
7.	-	5
8.	-	10

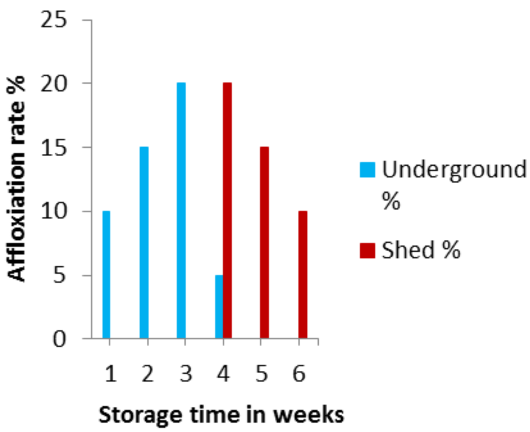

Figure 8: Affloxiation rate during storage period.

From observation, yams in the underground began to spoil in the first few weeks of storage, while the later storage period recorded no signs of tuber spoilage. On the other hand, the shed environment did not show any signs of tuber infestation in the first few weeks of storage. Tuber breakage and subsequent deterioration began in week four of the storage period of 8 weeks. (Table 3 and Figure 8)

IV. CONCLUSION

A total of 40 yam tubers (*Dioscorea rotundata*) stored in under tropical conditions for two months were used to obtain data on yam tubers as regard their storage qualities affected by environmental factors such as temperature, moisture and relative humidity. Weight loss, affloxiation and sprouting were also determined. Two storage environments were used for the experimental work. An underground pit structure and an open shed.

The yam tubers were observed carefully for cases of sprouting which did not occur. However, affloxiation rate were recorded, together with tuber weight loss associated with physical and pathogenic sources. From the results generated, the underground structure was observed to have a lower air temperature as compared to the shed environment but, the relative humidity in the shed environment appeared to be higher, thereby causing a faster deterioration and tuber loss.

Results show that, the underground pit storage structure would serve adequately for use by farmers in rural communities. The need for electricity for refrigeration and ventilation using electric fans would be eliminated. In general, test results revealed that yam tuber stored in the underground storage structure performed better and last longer than yams stored in the open shed.

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