EFFECTS OF CURING AND HUMIDITY ON THE STORAGE STABILITY OF YAMS (D. SSP)

BY

G.O.I. EZEIKE
AGRICULTURAL ENGINEERING DEPARTMENT
UNIVERSITY OF NIGERIA, NSUKKA
(Manuscript received 8th March, 1980 and in revised form 12th Sept. 1980)

ABSTRACT

An experimental study was made of the hygroscopic characteristics as well as the response of yam (D.SPP) tuber to a curing treatment prior to storage.

The results indicate that the yam tuber possesses a sigmoidal isotherm dominated by the local isotherm LI – II. The yam tissue responds favorably to proper curing conditions, which generated a well – developed periderm that is impermeable to moisture and resistant to penetration by pathogens. Microscopic studies showed that interruption of tissue continuity by mechanical injury stimulates physical and chemical processes in the cells of which structural re-differentiation is one visible expression. In 20 weeks, properly cured samples lost about 28 per cent total weight while tubers which did not receive any treatment lost as much as 41 per cent of initial weight in the same time interval.

1. INTRODUCTION

The problem of providing food and feed materials in Nigeria is two-fold. To maintain a certain level of agricultural output that is proportional to the number of hungry mouths that must be fed, presents a problem that inter- relates agriculture, economics and engineering. The other component is the ability to store what cannot be consumed immediately or what must necessarily be stored in order to maintain continuity in other related industries.

Very often farmers are forced to sell almost all the foodstuffs they harvest in order to avoid rather very heavy losses due to deterioration of produce soon after harvest. Thus the function of storage is an important one and serves to form a vital link in the chain of food demand and supply.

In order to design storage structures and to stipulate environments or storage conditions, fundamental studies must be carried out on the crop concerned so as to determine its post-harvest behaviour or characteristic.

Post-harvest behavior of yams (D.SSP) has hitherto presented a major storage problem due mainly to the losses that occur. Coursey (1967) estimated that as much as 60% loss may occur for a storage period of six months. When it is realised that this storage loss has qualitative, quantitative as well as economic dimensions, the seriousness of the problem could be viewed in its proper perspective. The quality of a yam tuber at any time during storage depends partly on its intrinsic quality (condition at harvest) and/or partly on the environmental and physiological factors to which it is exposed. Curing, as a storage technique is known to be beneficial in the case of potatoes but limited information of its effects on yams is available.

2 THEORY

It is well known that some

of the factors that determine the quality of stored yams are:

i. physical factors, such as mechanical damage, desication and high or low temperatures
ii. physiological factors such as natural metabolism
iii. pathogenic factors resulting in micro-biological prolification.

An attempt to solve the problem of yam storage, should recognise the biological as well as the engineering properties of the vegetable. The solution to the overall problem of yam storage should therefore be derived from its anatomy physiology and hygroscopicity.

2.1 Anatomy

The yam tuber is known to be covered by a protective outer skin known as the periderm. Structurally the periderm consists of three parts namely (a) the phellogen or cork cambium, which is the meristem that produces the periderm, (b) the phellem, commonly called cork produced by the phellogen centrifugally and (c) the phelloderm, consisting of the inner derivatives of the phellogen. At time of harvest, this skin is unavoidably broken and removed in varying degrees. Such skin breaks may also occur during handling and transportation and are known to be responsible directly and indirectly for substantial storage losses by encouraging dehydration and by providing an easy path for invasion by micro-organisms. Hudson 1975) indicated that depth of bruising is correlated with cell size, intercellular space and specific gravity of roots of various varieties. It is suggested by Morris and Mann (1955), that in sweet potatoes presence of an active cork cambium together with the thin-walled immature cork cells are generally associated with skin slipping and that a curing procedure hastens the maturity of the cork cells. Working with potatoes, Bruise susceptibility is shown to be highest for tubers having low specific gravity, large cell size and high intercellular space.

In wound healing, the biochemical and structural changes precede and follow meristematic activity, resulting in cell degeneration and tissue reorganization. During curing, the exposed surfaces are sealed off with fatty substances notably suberin. This blocking creates internal conditions favourable for the formation of a cork layer (phellem). The blocking process requires certain external conditions, mainly appropriate amounts of moisture (high humidity) and adequate aeration.

2.2 Physiology

The physiological processes involved in wound healing have been investigated. (Johnson et al, 1957; Uritani, 1953; Mizicko et al, 1974). All authors (working with potatoes) agree that for both mechanically and disease-induced injury, there is accumulation of phenolic compounds notably chlorogenic acid around injured tissues. By innoculating potato slices with Dihydroquercetin (DHQ) at an optimum concentration of 2 percent, the later workers found that the thickness of the suberized layer was increased and that a well- developed wound periderm formed. DHQ is a phenolic compound extracted from the bark of Douglas fir and is marketed as Bark-383.

The mechanics of wound healing have been closely investigated by Mclure (1960). In this work, 10 potato tuber halves were innoculated by dipping them in a suspension of spores of Rhizopus sp, after which they

were covered with wet towels and subjected to temperatures of 24°C and 29.5°C. Histochemical tests showed that the first visible response to a wound was the accumulation of chlorogenic acid in the cells adjacent to an extending 4-6 cells beneath the cut surfaces, the accumulation spreading inwards. While the zone of cells accumulating chlorogenic acid was still composed of local cells, suberization began in the uppermost of them, starting at the upper corners and spreading along the lateral walls. Suberization progressed centripetally in this manner to deeper lying cells. A wound periderm cambium (phellogen) soon developed from the unsuberized cells and by a process of successive mitoses, the wound periderm cells (cork) was produced and was suberized next. Chlorogenic acid ratings were highly correlated with suberization rating (r=0.94) which were, in turn, highly correlated with would periderm ratings (r=0.97).

It is the purpose of this paper to investigate the response of yam tissue to curing and the effect of curing on tuber weight loss during storage.

2.3 Equilibrium Moisture Content

The concept of equilibrium moisture content is important because it is directly related to primary processing and storage of farm crops. It offers an indication of the sorption tendency of a product under a given set of ambient conditions. It is well known that the relationship between moisture content and air relative humidity at equilibrium is best presented by sigmoid curves or, isotherms. According to Oxley (1948), such curves rise steeply above 80 percent relative humidity. The sigmoid shape has been attributed to qualitative differences in the affinity of water for hygroscopic solids. Three types of water may be distinguished in a biocolloidal system, namely:

1. Absorbed or capillary water which is unbound free water held loosely in the interstitial pores of the material;
2. Absorbed water held more firmly in chemical union by hydrogen bonding to hydroxyl groups.
3. Bound water or water of constitution held by ionic groups such as carboxyl and amino radicals.

Many models have been proposed for describing equilibrium moisture content isotherms. Biological materials have significant differences with respect to composition and characteristics. Therefore, each of these models has some measure of success depending on application and range of interest. A recent critical evaluation of some of these models is given by Young (1976) with application to Virginiatype peanuts.

Henderson's equation which describes the relationship between moisture content and relative humidity is given *in* its original form as

where

RH = relative humidity, decimal

T = Absolute temperature

M_e = Equilibrium moisture content, dry basis

C,n = product dependent constants

This equation is widely used for biological materials and gives excellent agreement between experimental and theoretical values of moisture content in the mid-humidity range. Below 20 percent and above 85 percent relative humidity, experimental

isotherms deviate considerably from calculated curves.

3. EXPERIMENTAL

3.1 Curing Treatments

Whole yam (D.rotundata) tubers were exposed to two different ambients of 25 C and 96 percent relative humidity and 25^{0}C and 67 percent relative humidity (Table I). A Hotpack environmental chamber, Fig.1, was used to provide temperature control to within $\pm$0.5^{0}C. The higher relative humidity was obtained with saturated potassium sulphate solution. The dry and wet-bulb temperatures were determined with a certified aspirator psychrometer. In order to check the relative humidities produced by the salt solutions, a mini-environmental chamber which has a tight seal and incorporates a see-through window was designed. Some yam samples were cut from a tuber, the pieces were between 2.5 to 3.8cm thick. Because of the need to experiment with the material in its natural condition for storage, the cut surfaces were sealed with microwax. This would allow mass exchanges to occur only through the skin. Furthermore, in order to understand the response of injured yam tissues to curing some of these pieces were cut with a sharp blade before being subjected to the curing treatment. The mini-chamber housed a whole tuber, an intact piece and a mechanically-injured piece YS-2. A stainless steel dish (30 x 25 x II cm), containing saturated potassium sulphate solution, was placed at the base of the mini-chamber to provide the desired relative humidity. Similar yam replicates YS-I, were also positioned inside the main chamber (Fig.1). This arrangement allowed simultaneous treatments to be made under isothermal conditions. Table 1 shows the curing treatments given to intact tubers and yam slices. Length of the curing period was 7 days.

Table 1. Curing Treatment given to intact tubers and yam slices

Samples	Dry bulb ^{o}C	Relative humidity, percent
SP 3	25	67
SP	25	69
Yam slices (YS – 1)	25	67
Yam slices YS – 2	25	69

3.2. Preparation of Samples for Light Micrograph.

At the end of the curing period, some of the pieces were sampled for microscopic examination to determine the extent of periderm development. Specimens for microscopic examination were stained in 0.1% totuidine blue 0 (TBO) in 1% sodium tetraborate (borax) and rinsed in distilled water. The specimens for suberine detection were stained for about 10 minutes with saturated Sudan IV in ethylene glycol.

3.3 Storage Records

The anatomical studies were followed closely by observation of weight loss of the cured whole tubers and a control in a storage environment where temperatures fluctuated from 30 to 25^{o}C with a 12-h day length and relative humidity was about 60 percent. The tubers were weighed at the end of each storage week. In addition, sprout initiation and rot development were also observed visually. From these results, weight losses expressed as percentage of original fresh weight were obtained.

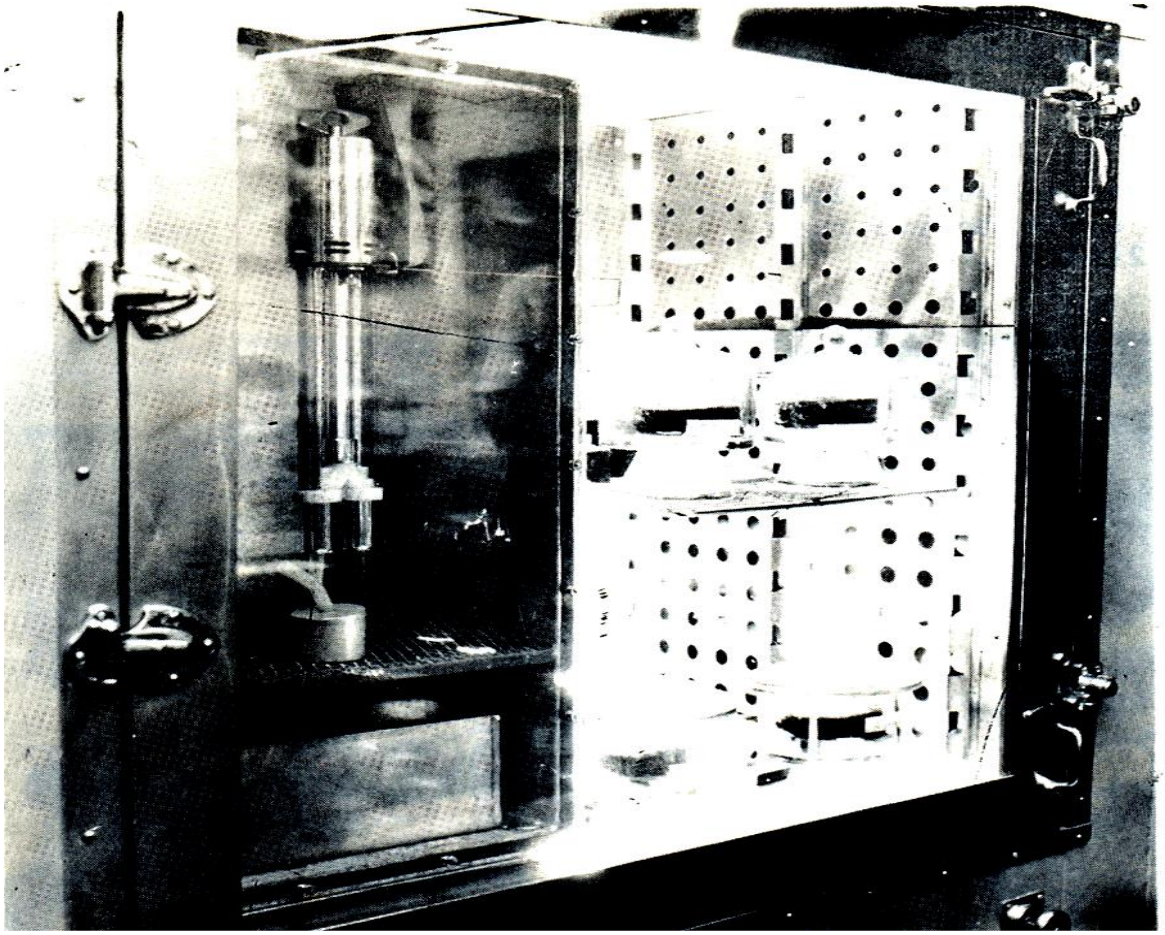

Fig. 1 Experimental Equipment

Fig.2. Natural (X 200) and wound (X 120) periderm.

3.4 Equilibrium Moisture Content

In order to derive the sorption isotherm, a Hotpack environmental chamber was used to provide temperature control. Various humidities were obtained using saturated salt solutions (table 2).

Yam slices of thickness 2.5 to 3.8 cm were placed in side glass desiccators containing the saturated salt solutions. The desiccators were then positioned in the Hotpack chamber for the conditioning process. This arrangement allowed simultaneous determination to be made under isothermal conditions. The yam samples were periodically, until they attained constant weight. The conditioning times varies from 12 to 14 days.

EMC was determined at the end of the conditioning period by drying 2 or 3 portions of each sample to constant weight in a forced convection oven set at 105°C for a period of approximately 48 hours.

Table 2: Relative humidities produced by saturated salt solution

Dry bulb	Temperature 32°C
Salt	Relative humidity (%)
NaCl (Sodium Chloride)	75.20
K_2Cr or (Potassium chromate)	
$Mncl_2.4H_2o$ (Managanese chloride)	86.20
K_2 S0*$_4$ (Potassium sulphate)	53.80
	96.6

*Obtained from Literature

4. RESULTS AND DISCUSSION

4.1 Physiological

The ability of yam tissue to form a periderm layer and a protective cork is revealed in fig. 2(a). The phellem (cork) may be seen as a group of elongated cells extending over 10 layers deep. This well developed periderm is generated by proper curing treatment. It was evident that injured yam tissue quickly develops a wound periderm under favourable conditions (Fig. 2(b)). The white lines indicate the zone of this wound periderm which may be observed to extend to the wound surface. It may be observed that the cells surrounding the wounded tissues and those composing the natural periderm of Fig. 2(a) appear to be compacted and dense. This reveals their role in serving as a barrier against penetration by micro-organisms and moisture loss.

It is apparent that the development of wound periderm following the physiological stimuli provided by curing, was complete. The protective cork was formed even at the tip of the injury as is seen from Fig. 3(b).

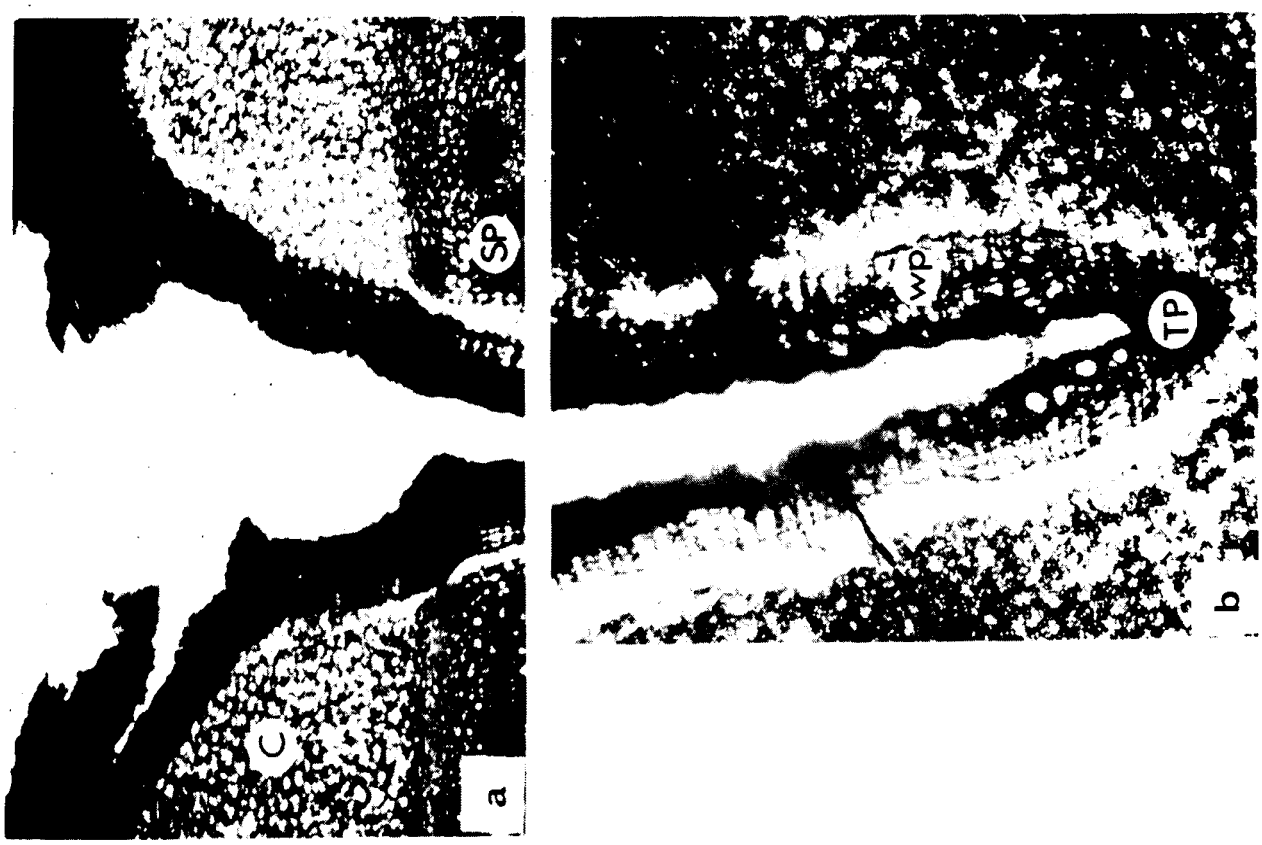

Fig. 3. Cross-section of an injury (X 150)

A secretory inclusion was observed in the region of the phellem (Fig.4(c). This idioblast is probably a calcium oxalate crystal. Recently, Al-Rais et al. (1971) reported the isolation of calcium oxalate crystals from tubers of D.alata. Figs. 4(a) and (b) reveal the disposition of suberin along the middle lamellae of cork cells. The function of this material in disease resistance and its impervious nature to moisture are now well known. Under the microscope, the middle lamellae are pink in colour when stained with Sudan IV. Murray (1971) has reported the accumulation of phenolic compounds in yam tubers following shock loadings of 0.6 - 2.66 kg/cm^2 applied for 4 seconds.

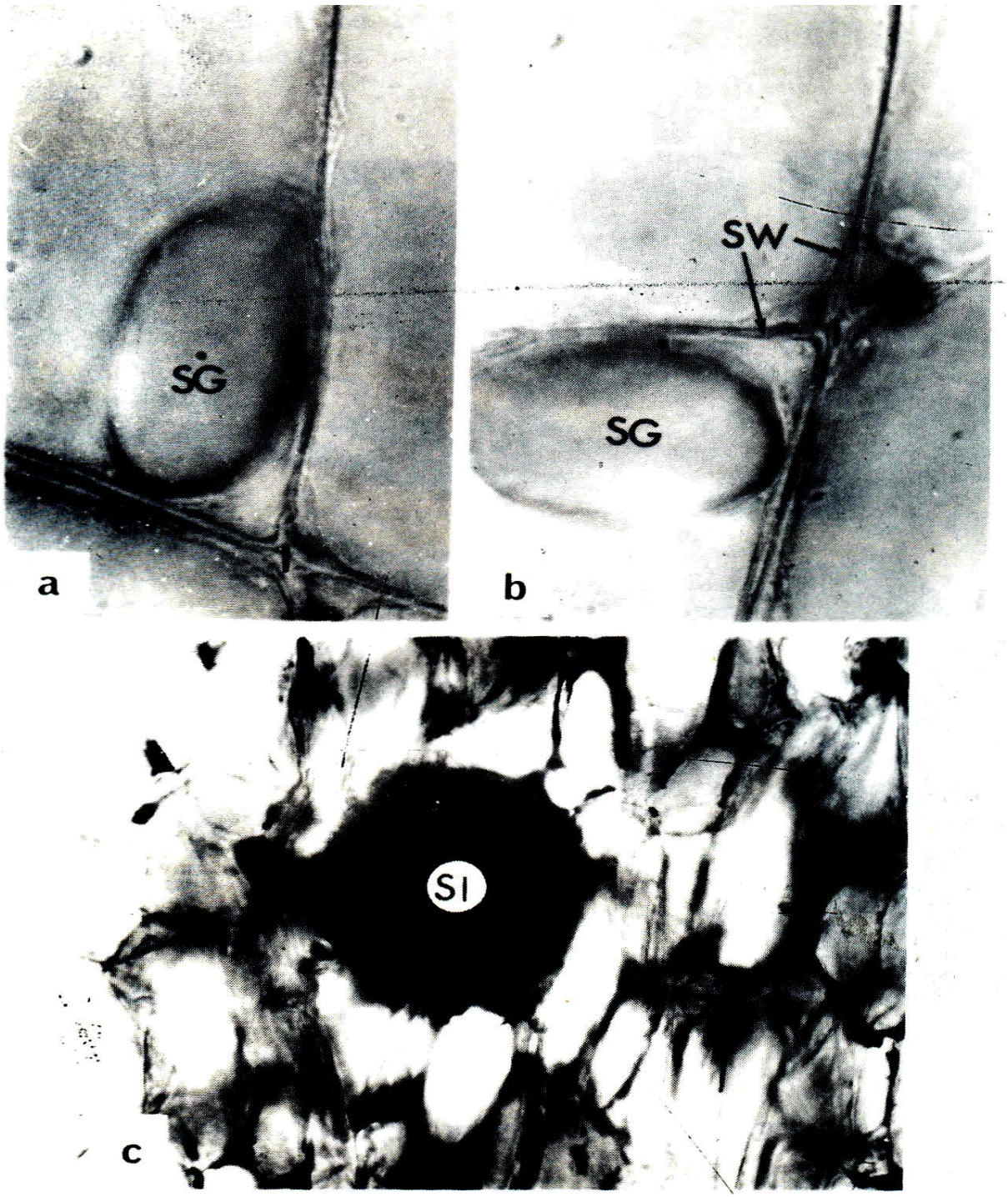

Fig. 4 Light micrograph of suberized cell walls (a x 640; b x 400)

From our experiments, it would appear that a curing atmosphere of 25°C and 96 percent relative humidity applicable for 7 days, creates favourable conditions for formation and maturity (suberization) of protective cork. In our opinion, temperatures far in excess of 25°C, while shortening the suberization period will on the other hand, generate surface roughness and irregularities due to temperature stress and will also lead to excessive moisture loss during the curing period.

4.2 Weight Loss

The graph of percent weight loss of the tubers versus storage time (Fig.5) reveal considerable individual variation in tuber weight loss.

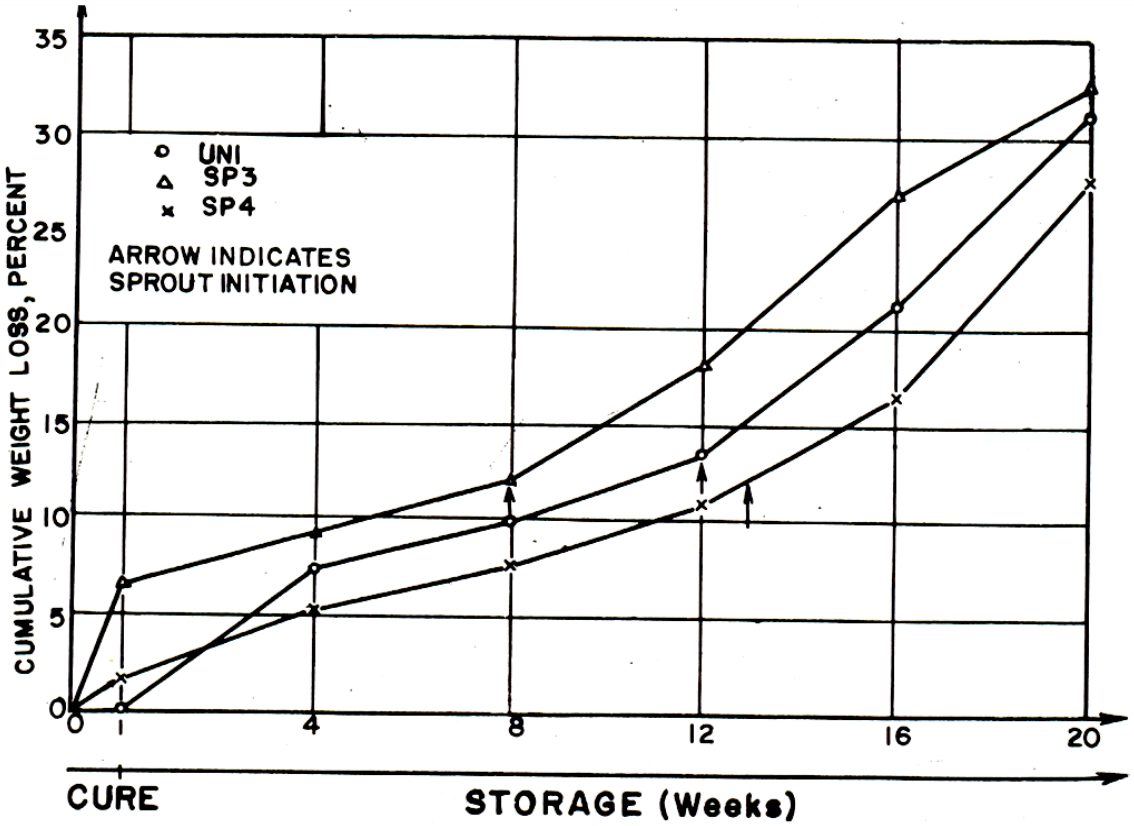

Fig. 5 Cummulative Weight loss Vs Storage Time

Typically, the tubers lost weight non-linearly with time. This weight loss is thought to be the combined effects of moisture evaporation, respiration, resulting in destruction of dry matter and possibly micro – biological degradation.

At the end of the first week, the control UNI had lost about 4.3 percent of initial fresh weight, much of which is thought to be due to surface evaporation. The other cured samples, SP3 and SP4 (Table 1) in one week if treatment loss 6.6 and 1.64 percent of initial weight,
respectively. The variability is probably due to different conditions of curing, since humidity is a critical factor in moisture loss. Thereafter, it could be observed from Fig.5 that SP4 received the best conditions of curing and wound healing, since it lost the least weight consistently for the storage period of 20 weeks. An average rate of about 0.5 percent weight

loss per week for the first few weeks was recorded. The control seemed to be intermediate in keeping quality. The observed rapid increase in weight loss of SP3 would indicate the inadequacy of the curing conditions. This sample also developed a rot condition which initiated at the proximal region and spread towards the tuber centre. At the end of 12 weeks, all samples had sprouted, at which the tubers started to lose weight more rapidly. This increase in weight loss following sprouting may be due partly to destruction of Dry matter, partly to the fact that sprouts would be more permeable to flow of water vapour and partly to the increased surface area provided by the sprouts. At the end of 20 weeks, the sample SP4 recorded about 28 percent total weight loss. It has been reported that tubers of yam (D.rotundata) lost 41.6 percent of initial weight in 5 months while those stored in clamps lost 49 percent of their initial weight.

Equation 1 was solved using the experimental data. Values of the hygroscopic constants obtained were as follows:

a=7.91

b=9.76 x 10^{-23}

A program was developed, making use of these constants, to generate data for a full range desorption isotherm (Fig.6).

The moisture sorption (MS) isotherms of heterogeneous biological products represent-integrated hygroscopic properties of numerous constituents which vary in respect to both quality and quantity. Of the total DM content of the yams, over 80 percent is starch. In general, MS curves are composites of local isotherms. These local isotherms are closely linked to the amount and type of water in a product and generally represent varying binding energies.

For yam, the MS isotherm (Fig.6) conforms to a smooth sigmoid curve, characteristic of the sorption phenemenon for most agricultural materials. According to Rockland (1969), products such as rice which contain high proportions of starch or cellulose and small amounts of protein and other soluble solids possess the broadest Li-II range. The MS isotherms for yam (Fig.6) seem to exhibit this characteristic. It is expected that this broad LI-1I region defines the products maximum stability zone within an optimum moisture range.

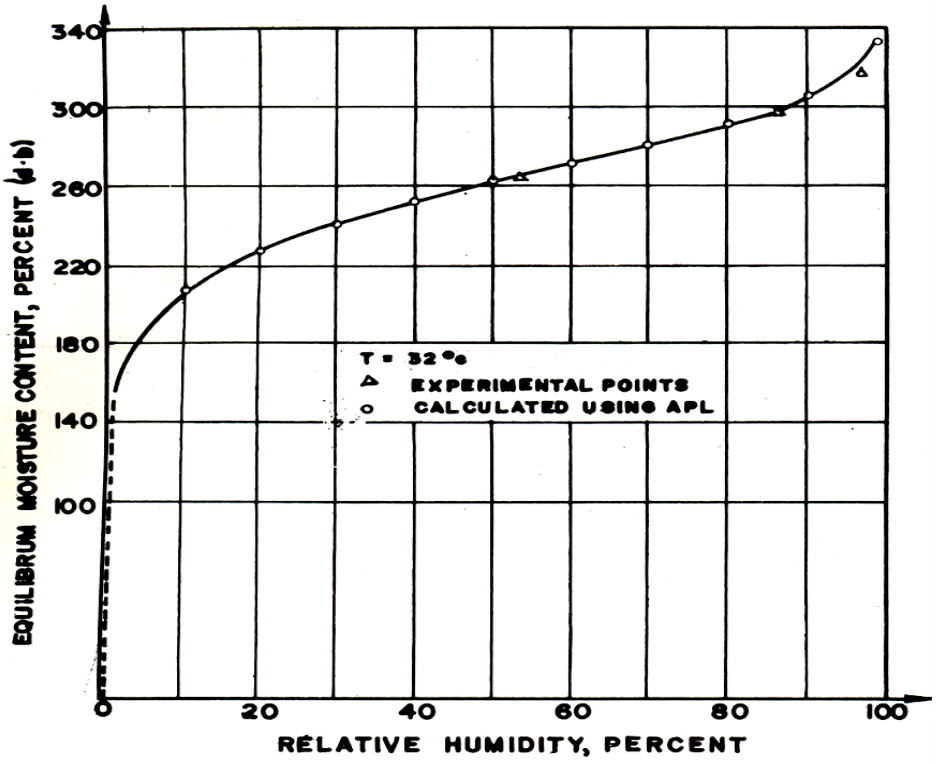

Fig.6. Equilibrium Moisture Curve, Yam Tuber.

CONCLUSION

The results of this study indicate that the yam tuber behaves like most agricultural materials with respect to desorption characteristics. It possesses a smooth sigmoid isotherm that is dominated by the local isotherm LI-II.

In addition, subjecting the yam tuber to proper curing, conditions minimises tuber weight loss in storage. Such curing treatments generate a well-developed cork layer which is impermeable to moisture and offers resistance to penetration by micro-organisms.

Furthermore, the yam tissue possesses the ability to form wound periderm following mechanical injury. Such information is vital in considering the problem of unavoidable skin breaks at harvest.Therefore, by properly manipulating the environment before and during storage of yams, we can achieve an effective solution to the storage problem presented by yams over the years. The commercial extension of this technique will be a worthwhile venture and this is strongly advocated.

REFERENCES

1. Al-Rais, A.H.; Myers, A.; Watson, L. 1971. The isolation and properties of Oxalate crystals from plants. Annals of Botany, Vol.35.
2. Coursey, D.G. 1967. Yam storage - I: A review of yam storage practices and information on storage losses. J.Stored Prod. Res., Vol.2.
3. Hudson, D.E. 1975. The relationship of cell size, intercellular pace, and specific gravity to bruise depth in potatoes. American Potato Journal, Vol.52.
4. Johnson, G.: Schaal, L.A. 1957. Accumulation of phenolic substances and ascorbic acid in potato tuber tissue upon injury and their possible role in disease resistance.Am. Potato Journal, Vol.34.
5. Mclure, T.T. 1960. Chlorogenic acid accumulation and wound

healing in sweet potato roots. Am Journal of Botany, Vol. 47.
6. Mizicko, J.I. Livingston, C.H.; Johnson, G. 1974. The effects of Dihydroquercetin on the cut surface of seed potatoes. Am. Potato Journal, Vol. 51.
7. Morris, L.L.; Mann, L.K. 1955. Wound healing, keeping quality, and compositional changes during curing and storage of sweet potatoes. HILGADIA, Vol.24(7).
8. Murray, S.A. 1971. Shock effects on plants: Tannic acid and chlorogenic acid in yam roots. Experientia, Vol. 27(2).
9. Olurunda O., Adesuji, S.A. A comparison between the barn and clamp methods of storing yams. Field Crops Abstracts Vol.27
10. Oxley, T.A. 1948. The scientific principles of grain storage. Northern Publishing, Liverpool.
11. Rockland, L.B. 1969. Water activity and storage stability. Food Technology, Vol. 23.
12. Uritani, I. 1953. Phytopathological chemistry of bloack rotted sweet potato. Journal Agric. Chem. SCO. Japan, Vol. 27.
13. Young, J.H. 1976. Evaluation of models to describe sorption and desorption equilibrium moisture content isotherms of Virginia-type peanuts. Trans. A.S.A.E.