

## **Minimizing Postharvest Losses in Yam (*Dioscorea spp.*): Treatments and Techniques**

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### **INTRODUCTION**

Yam belongs to the genus *Dioscorea* (Family *Dioscoreaceae*) and is the second most important tropical root crop in West Africa after cassava. Besides their importance as a food source, yams also play a significant role in the socio-cultural lives of some producing regions such as the celebrated New Yam Festival in West Africa. Yams originated in the Far East and spread westwards. Today, yams are grown widely throughout the tropics. West and Central Africa account for about 94% of world production, Nigeria being the major producer.

The most popular and preferred form of consuming yam is the tuber form, either boiled, pounded, roasted or fried. Better financial returns are obtained by selling the yams as tubers rather than as processed yam flour. Thus, farmers prefer to store most of their yams after harvest. Methods of storage vary from delayed harvesting, storage in simple piles or trenches to storage in buildings specially designed for that purpose, and application of modern techniques.

Causes of storage losses of yam tubers include sprouting, transpiration, respiration, rot due to mould and bacteriosis, and attack by insects, nematodes and mammals. Sprouting, transpiration and respiration are physiological activities which depend on the storage environment (mainly temperature and relative humidity). These physiological changes affect the internal composition of the tuber and result in destruction of edible material and changes in nutritional quality. Storage losses in yam of the order of 10-15% after the first three months and approaching 50% after six months storage have been reported.

A number of treatments and techniques have been developed to reduce these physiological activities and also to protect the tuber from postharvest diseases. These include treatment with chemicals, plant extracts, palm wine and gamma irradiation; storage techniques used include cold storage, improved underground storage and improved yam barns. This chapter discusses research into yam postharvest handling aimed at improving the availability of tubers throughout the year.

### **YAM PRODUCTION**

Yam *Dioscorea spp.* is an important food crop especially in the yam zone of West Africa. Although more than six hundred species of the tuber exist, only a few are important as staple food in the tropics. These include white yam (*D. rotundata*), yellow yam (*D. Cayenensis*), water yam (*D. alata*), trifoliate yam (*D. dumetorum*), aerial yam (*D. bulbifera*) and Chinese yam (*D. esculenta*) [1]. West Africa accounts for 90-95% of world yam production with Nigeria the largest single producer. In 2004, global yam production was about 47 million metric tons (MT) with 96% of this coming from Africa. Nigeria alone accounts for about 70 percent of world production [2]. It is the second most important root/tuber crop in Africa with production reaching just under one third the level of cassava. More than 95 percent (2.8 million ha) of the current global area under yam cultivation is in sub-Saharan Africa, where the mean gross yield is 10 t/ha. In Asia, production for 2004 stood at 226,426 MT [2].

Yam production is relatively expensive compared with other root and tuber crops; this is attributed to costly inputs, especially labour and planting material. Traditionally, yams are propagated by whole

tubers (seed yam) or relatively large tuber pieces. Today yam mini-sets (or small pieces of yam) are increasingly been used as planting material [3]. The tubers are retained from the harvest for the next planting season. The tubers (Figure 1) which are the only edible part have both a tremendous capacity to store food reserves and ability to grow into the deep layer of the soil. The top growth consists of twining vines that may be several meters long depending on species and growing conditions [Figure 2] and require trellises over which to climb.



**Figure 1: Yam tuber**



**Figure 2: The yam plant**

Maturity assessment is critical to achieve good quality yam. In the field a mature crop is distinguishable by cessation of vegetation growth and yellowing of leaves. The period from planting or field emergence to maturity is variable depending on the species. Tubers may be harvested 6-10 months after emergence or once at 4-5 months and again at 8-10 months, depending on species [4]. The yield depends on the size of the seed piece, species and environment but normally ranges from 8-50 t/ha in 6-10 months.

### **IMPORTANCE OF YAM**

Yam is important because of its excellent eating quality; they are a preferred food at social gatherings. People consume yams, sweet in flavour, as a cooked vegetable fried or roasted. In West Africa yam is often pounded into a thick paste after boiling (pounded yam) and is eaten with soup [Figures 3 & 4]. Pounded yam is the most popular food form of yam in West Africa and is often reserved for special occasions in the urban areas. Presently, whole roasted yam has become a popular street or fast food in urban areas throughout the West African yam belt [3]. Virtually all production is used for human food. In the major yam producing countries, average consumption is 0.5 - 1.0 kg yam daily [5]. Yam is a preferred food and a food security crop in some sub-Saharan African countries. Unlike cassava, sweet potato and aroids, yam tubers can be stored for periods of up to 4 or even 6 months at ambient temperatures.

Sahore *et al.*, [6] studied changes in nutritional properties of yam (*Dioscorea spp.*), green plantain (*Musa spp.*) and cassava (*Manihot esculenta*) during storage and showed that yam tubers underwent only slight changes over a four week period while cassava and green plantain could be kept only for a week without significant deterioration. This characteristic contributes to the sustaining of food supply, especially in the difficult (food scarce) period at the start of the wet season. Yams are also processed into yam chips and flour that is used in the preparation of a paste. The problems encountered by processors include a lack of suitable raw materials, drying and storage equipment, and poor quality of the processed product.



**Figure 3: Preparation of pounded yam**

**Figure 4: Pounded yam meal with meat and vegetables**

Apart from being used for family food, yams are also a cash crop for farmers. Studies show that yam is a highly profitable crop in the yam zone constituting an average 32% of farmers' gross income derived from arable crops [7]. Figures 5 and 6 show a typical yam market in Niger State of Nigeria. Yam also plays a significant role in African socio-cultural traditions. The commercial importance of the crop has not eroded its traditional status. It is an indispensable part of the bride price and in Eastern Nigeria new yam festivals are celebrated annually during the months of August and September. In South-Eastern Nigeria, the cultivation and consumption of yam dates back several centuries. In this area, yam is a totem of masculinity and the centre of annual harvest celebrations; it is also a calendar crop around which the farming season and the annual festival revolves.



**Figure 5: Yam collection centre at Garatu, Niger State of Nigeria**



**Figure 6: Buying and selling of yam in Niger State of Nigeria.**

### **NUTRITIONAL VALUE OF YAMS**

Yams are an excellent source of carbohydrate, energy, vitamins (especially vitamin C), minerals and protein. Some cultivars of yam tuber have been found to contain protein levels of 3.2 – 13.9% of dry weight. A yam meal could supply 100% of the energy and protein, 13% of the calcium and 80% of the iron requirement of an adult male [8]. Some food yams have been shown to contain phosphorous and vitamins such as thiamine, riboflavin, niacin and ascorbic acid.

The chemical composition of yam is characterised by a high moisture content and dry matter. The dry matter is composed mainly of carbohydrate, vitamins as well as protein and minerals. Nutrient content varies with species and cooking procedure. Cooking with the peel intact helps retain vitamins [5]. Table 1 shows the ranges of nutritional composition for edible yams species.

**Table 1: Nutritional value of yam (Nutrient in 100 g of edible portion)**

<b>Nutrient</b>	<b>Range</b>
Calories (kcal)	71 – 135
Moisture (%)	65 – 81
Protein (g)	1.4 – 3.5
Fat (g)	0.2 – 0.4
Carbohydrate (g)	16.4 – 31.8
Fibre (g)	0.40 – 10.0
Ash (g)	0.6 – 1.7
Calcium (mg)	12 – 69
Phosphorous (mg)	17 – 61
Iron (mg)	0.7 – 5.2
Sodium (mg)	8.0 – 12.00
Potassium (mg)	294 – 397.00
$\beta$ -carotene (mg)	0.0 – 10.0
Thiamine (mg)	0.01 – 0.11
Riboflavin (mg)	0.01 – 0.04
Niacin (mg)	0.30 – 0.80
Ascorbic acid (mg)	4.00 – 18

Source (Osagie, 1992)

Yams may also contain small quantities of polyphenolic compounds (e.g. tannins), alkaloids and steroid derivatives. The carbohydrate content of the yam tuber represents its major dry matter component and may be classified as starch, nonstarch, polysaccharides and sugar. Starch in yam tubers is frequently converted to sugars probably as a result of stresses experienced during growth and storage. The sugar content is influenced by variety, location and cultural treatment. The free sugars consist mainly of sucrose and glucose, with the former predominating. Fructose and maltose have been detected during dormancy/sprouting periods [9]. The published protein content of yam tubers varies very considerably between both species and cultivars and depends on various factors including cultural practices, climate and edaphic factors under which it was grown, its maturity at harvest and length of storage time. High protein content is characteristic of very vigorous varieties with *D. alata* tubers having the highest protein levels among the edible yams. Although the protein content of yam is lower than that in most cereals, yam can provide more protein per hectare per year than maize, rice, sorghum and soybean (Idusogie (1971) as referenced by [5]). However, the value of cooked yam as a source of protein is limited by its bulk, the water content being very high.

## **YAM STORAGE AND STORAGE STRUCTURES**

Yam is an annual crop, so for it to be available throughout the year, harvested tubers must be stored for six to eight months before new yams are harvested. The possibility to store fresh yam tubers is decisively influenced by their dormancy which occurs shortly after their physiological maturity (wilting point). During dormancy, the metabolic function of the tuber is reduced to a minimum. It allows the tuber as an organ of vegetative propagation to overcome an unfavourable climatic period. Consequently, varieties of yam native to regions with marked arid seasons have a longer period of dormancy than those with a shorter dry season. The duration of natural dormancy fluctuates according to the variety of yam between four and eighteen weeks [8]. During the storage period a substantial amount of yam is lost. Some of these losses are endogenous, i.e. physiological, and include transpiration, respiration and germination. Other losses are caused by exogenous factors like insects, pests, nematodes, rodents, rot bacteria and fungi on the stored product [10]. Good management can easily control the exogenous loss factors while the environment controls other sources of loss.

Yam storage structures and methods were evaluated in the former Bendel State of Nigeria [11] in the middle belt of Nigeria [12; 13] and in Western Nigeria [14]. This work showed that the storage structures used depend on the construction material available, amount of tuber produced, prevailing climatic condition of the area, purpose of yam tuber storage, socio-cultural aspects of storage and the resources of the farmer, in particular the availability of labour and capital. In the humid forest zone yam is stored in a yam barn which is the principal traditional yam storage structure in the major producing areas. Barns in the humid forest zone are usually located under the shade and constructed so as to facilitate adequate ventilation while protecting tubers from flooding, direct sunlight and insect attack. There are several designs, but they all consist of a vertical wooden framework to which the tubers are individually attached [4; 11]. Tubers are tied to a rope and hung on horizontal poles 1-2 m high (Figure 7); barns up to 4 m high are not uncommon. Depending on the quantity of tuber to be stored, frames can be 2 m or more in length. The ropes are usually fibrous; in south-eastern Nigeria they are made from the raffia obtained from the top part of the palm wine tree. Many farmers have permanent barns that need annual maintenance during the year's harvest. In these situations, the vertical posts are often made from growing trees which are trimmed periodically. Palm fronds and other materials are used to provide shade. The vegetative growth on the vertical trees also shades the tubers from excessive solar heat and rain [4].



**Figure 7: Typical yam barn in the humid forest zone (individual yams tied to live poles)**

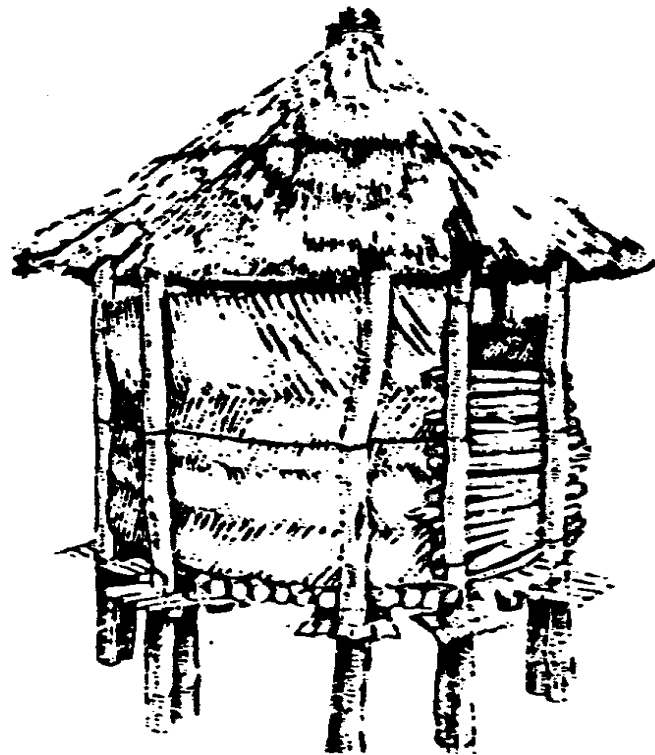
The yam barn in the Guinea Savannah zone is constructed from guinea corn stalk, sticks, grass and yam vines. The yams are heaped at different positions in the barn [12; 13]. Such barns are constructed every year and are situated near the house under a tree to protect the tuber from excessive heat (Figures 8 and 9). At the end of the storage period the barn is burnt down and in December/January a new structure is built for the next harvest [13]. Unlike the humid forest where it is important that the yams are separated to avoid rotting, in drier areas such as Niger State the yams can be stacked into piles in the barn [10; 13]. At the onset of the rainy season the yams are transferred to a mud hut or guinea corn storage rhombu to protect them from the rain. Another yam storage structure found in the savanna region is the yam house or yam crib [4; 10]. “Yam houses” have thatched roofs and wooden floors, and the walls are sometimes made simply out of bamboo. They are raised well off the ground with rat guards fitted to the pillars. Yam tubers are stacked carefully inside the crib (Figure 10). Yam is also stored underground in trench or clamp silos. In both methods a pit is excavated and lined with straw or similar material [15]. The tubers are then stored on the layer of straw either horizontally on top of each other or with the tip vertically downwards beside each other. The yams are then covered with straw or similar materials; in some cases a layer of earth is also added.



**Figure 8: The yam barn in the Guinea Savanna zone**



**Figure 9: The interior view of a typical yam storage in the southern Guinea Savanna zone (piled into heaps in a yam barn)**



**Figure 10: A traditional yam house used in the Savanna region (redrawn from Wilson, 1980)**

### **QUALITY CHANGES OF YAM TUBER DURING STORAGE**

Causes of storage losses of yam tubers include sprouting, transpiration, respiration, rot due to mould and bacteriosis, insects, nematodes and mammals [16]. Sprouting, transpiration and respiration are physiological activities which depend on the storage environment, mainly temperature and relative humidity [16]. These physiological changes affect the internal composition of the tuber and result in destruction of edible material, which under normal storage conditions can often reach 10% after 3 months, and up to 25% after 5 months of storage [16].

Investigations on the biochemical changes in stored yam tubers have shown that changes in starch, sugars, and protein take place during long-term storage [17; 18]. A study of yam tuber (*D. dumetorum*)

stored under ambient and cold room conditions showed a rapid drop in moisture and starch content and an increase in the total alcohol-soluble sugars and reducing sugars after 72 hours of storage [17]. The rate of decrease in moisture and starch content and the rate of increase in sugar level were higher in tubers stored at room temperature than those stored under cold room conditions. A similar trend was observed for *D. rotundata* cv. Oshei and *D. dumetorum* cv. Jakiri after 110 days of storage under ambient conditions [18]; weight losses reached 31% in Oshei tubers and 35% in Jakiri due to sprouting and dehydration. Starch content decreased by approximately 3.5-4.5 g/100 g while sugar and fibre values increased slightly in both cultivars.

A study of the physical, chemical and sensory changes occurring in white yams (*Dioscorea rotundata*) and yellow yams (*Dioscorea cayenensis*) stored for 150 days in traditional barns showed losses in moisture, dry matter, crude protein and ascorbic acid after 120 days of storage [19]. Sensory evaluation rated the stored tubers higher than the fresh tubers. A similar study [20] reported a 17-22% reduction in weight, 30-50% reduction in crude protein and 38-49 % increase in sugar content for two cultivars of white yams (*D. rotundata*) stored in a barn. Generally, in stored tubers there is reduction in weight, crude protein, starch and mineral content while the sugar and fibre contents increase [21].

## METHODS OF IMPROVING YAM STORAGE

Yam storage problems are essentially of three kinds: (a) direct damage by diseases, pest and nematodes in the field and in storage; (b) sprouting losses; and (c) respiratory and evaporation losses. All these reduce the overall quantity and quality of the tubers with food reserves being increasingly depleted by one or more of these causes. In normal conditions, tubers of many clones remained dormant for 10-12 weeks before sprouting started. Researchers have worked on a number of methods and techniques to improve yam storage. Different intensities of gamma irradiation offered some technical advantages for storing yam tuber for fresh consumption [22; 23; 24]. Irradiation was an effective treatment for the inhibition of sprouting of yam (*D. rotundata*) for a storage period of six months at doses of between 7.5 and 15 krad without inducing adverse changes in acceptability or physiological properties [22]. An average dose of 120 Gy and a dose rate of 114 Gy/hr were applied to the cultivar *D. rotundata* cv. Asana and irradiated and non-irradiated tubers stored for 6 months side by side using two different types of storage, viz. barn and storage on the ground; results showed that irradiation reduced sprouting in both storage types [23]. However, rotting increased with storage time and there was less rotting in the yams stored in the barn than those stored on the ground. It was also observed that there was less rotting in the non-irradiated yams stored on the ground than the irradiated ones. After six months of storage food products made from irradiated yams were judged to be better in quality than those made from the non-irradiated ones. Differences in varietal responses to gamma irradiation have been reported [24].

Some chemical compounds have been used to prolong dormancy and retard sprouting [25-29]. Gibberillic acid (GA) when applied to tubers soon after harvest was able to extend dormancy by 9-11 weeks for *D. rotundata* and by 13 weeks for *D. alata* species of yam tuber [25; 26]. *D. alata* tubers treated with GA at the beginning of storage germinated 4 weeks later than controls, the effect being less when treatments were given later; treatments given after three months of storage were too late to inhibit germination [27]. Chloroisopropyl phenylcarbamate (CIPC) solution and powder which is successfully used to inhibit dormancy on potato tubers did not have any effect on *D. rotundata* [28]. The effect of maleic hydrazide in controlling sprouting in yam showed that soaking the tubers of *D. esculenta* and *D. rotundata* in 1000 ppm solutions for ten hours before storage reduced the rate of sprouting by 16% and 8% in *D. esculenta* and *D. rotundata* respectively [29]. However, others [22] reported that maleic hydrazide was not effective in inhibiting sprouting in *D. rotundata* tubers. Other chemicals used in yam storage include commercial wax, lime, benlate and captan. The observed effects of chemicals on the storage life of yam tubers have been summarised, with there being species and cultivar differences in the response of yams to chemical treatments [5; 30].

Plant extracts have been used to improve the quality of stored yam tubers [31-33]. The effect of neem bark water extract, neem bark slurry and neem leaf slurry treatments on the quality of stored yam



showed that sprouting was delayed by one month in all neem-treated tubers [32]. Rotting was also delayed by three months in tubers treated with neem bark extract; a similar result was observed when using neem bark extract and neem leaf slurry for sprouting [33]. However, the neem treatments in this case did not have any effect in reducing or delaying rotting. The effect of lime and neem wood ash treatment in three different cultivars of bruised *D. rotundata* tubers showed that lime was more effective in controlling rot in stored yam tubers than neem wood ash [31]. Another means of controlling rot and inhibiting sprouting in yam tubers is the use of palm wine; farmers claim that tubers treated with palm wine show less rot but this claim is yet to be substantiated.

The use of improved yam storage structures has been reported by some authors [1; 14]. The improved barn is rectangular in shape with varying dimensions. The floor is cemented and raised above the ground level to prevent pests from gaining access to the barn. The walls are constructed of plastered concrete one meter above the ground and the rest is prefabricated chicken wire mesh joined together by welding [14]. The roof is either corrugated aluminium sheet, raffia mats or grass. Inside the building are a number of wooden shelves which have compartments and the yams are arranged on these shelves. The advantage of this structure is that placing the tubers on the shelf require less time and labour, provides adequate ventilation (through the wire mesh) and the space between the wall and the shelves facilitate free movement during inspection of the tubers [1; 14]. Studies were undertaken to obtain quantitative data on the weight loss of stored yam tubers as affected by air temperature, relative humidity, length of storage on sprouting and tuber weight [34-36]. Yam tubers stored for six months in a traditional yam barn, a pit structure with cross and vertical ventilation via a centrally located chimney and another pit structure without a chimney showed that the psychrometric air conditions were characteristically different in the three structures [34]. Average air temperature was 25°C, 27°C and 35°C for pit with chimney, pit without chimney and barn respectively and the humidity was highest in the pit with chimney and lowest in the barn. The low temperature in the pits was due to shielding from solar radiation and the cooling effect of the shaded soil mass surrounding the pit structure. The low temperature in the pit with a chimney resulted in delayed sprouting and reduced weight loss compared to the other structures. Similar results were obtained by others [35; 36]. In addition to the low temperature in the pits, the diurnal temperature variation was also low compared to the barn.

In another study the storage environment was modified by ventilating the barn [21; 37]. The effect of intermittent and continuous air flow (achieved by placing a standing fan in the barn) on weight loss and sprouting of white yam tubers was a significant reduction in sprouting and weight loss of tubers when supplied with air flow [37]. A similar result for sprouting and weight loss was observed when intermittent (six hourly) air flow was incorporated in a conventional yam barn [21]. At the end of the storage period, the percentage of rotting was significantly lower in the barn with intermittent air flow (less than 2%) compared to the barn with no air flow where 12% of the tubers were decayed [21].

Regular removal of sprouts as a means of reducing weight loss in stored tubers has been studied [20; 27; 38]. By removing the growing shoots weekly, weight loss of stored yam tubers can be reduced and useful storage life increased [27]. If tubers are stored on shelves where air circulates freely around them, then the new sprouts can be easily seen and rapidly removed. This technique will extend the storage life by up to 8 months. Monthly removal of sprouts reduced fresh weight loss during 5 months storage by 11% for cultivars of *D. alata* and *D. rotundata* tubers [38]. There were differences in weight loss due to the sprout cutting technique; cutting of the sprout at the base rather than 1 cm from the base was recommended. Table 2 shows the percentage weight loss for tubers with and without sprouts removed after eighteen weeks of storage in the barn and improved pit storage for two cultivars (*giwa* and *asuba*) of *D. rotundata* tubers [36]; the weight loss for tubers with sprouts removed is lower than when the sprout was not removed.

**Table 2: Weight loss for tubers with and without sprouts after 18 weeks of storage (Osunde 2003)**

Treatment	Weight loss %			
	<i>Giwa</i>		<i>Asuba</i>	
	Barn	Pit	Barn	Pit
Sprout removed	22	20	20	18
Sprout not removed	26.3	24.3	22.7	22.7

Storage of yam tubers at a relative humidity of 80% and temperature of 16°C reduces moisture loss and delays sprouting. Adesuye [14] stated that 15°C is a safe temperature for storage of yam and it inhibits sprouting for six months. However, changing the temperature to influence dormancy is limited because the tissue is destroyed when the temperature falls below 15°C. In addition, influencing the storage climate by external energy (refrigeration) is restricted economically due to the high energy cost.

## CONCLUSION

Yams are the most nourishing plants in the diet of many inhabitants of inter-tropical regions, to such an extent that their very existence is centred on this crop. The average inhabitant of the yam zone consumes between half and one kilogram of yam daily, representing about half of their total calorific intake. Yams are generally abundant and sold cheaply at harvest time, but later (especially during the planting season) they become scarce and expensive. If yam could be stored without heavy loss, supplies could become steadier, prices would fluctuate less and farmers would be encouraged to grow them by being assured of a steadier income.

This chapter has presented a number of techniques and treatments to improve the quality and quantity of stored yam tuber. However, there is a need for further research into the postharvest storage of yam tuber to better understand differences in varietal responses to treatments. Such research should be conducted in the farmer's field with his active cooperation, so that a large part of the research may be directly linked to his needs, and may thus affect him in the most active way. Finally, there is the need for better funding both locally (in yam growing regions) and internationally (funding organizations) for yam postharvest research and technology transfer.

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