YAMS

Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization
of the United Nations

YAMS: Post-Harvest Operation

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Preface

Yam (also called Ñamé -Spanish and Igname - French) belongs to the genus *Dioscorea*(family Dioscoreaceae). Of the estimated 300-600 species are available, there are just over half-dozen principal species that are grown for consumption, while others are grown for medicinal purposes. Yams originated in the Far East and spread westwards. They have since evolved independently in the Eastern and Western Hemispheres, and today yams are grown widely in throughout the tropics. In the West African yam zone, which is the principal producer on a global basis, D. rotundata, D. alata, and D. esculenta are the most common species. Yams have both economic and social value in many growing areas. Some traditional ceremonies are celebrated with yam as the major food item such the New Yam Festival in parts of West Africa. The production and utilisation of yam is declining in most producing areas due mainly to the high labour demand and the delicate nature of the harvested crop. The small-scale farmers who produce the majority of crop need access to innovations, which will reduce drudgery and improve productivity at all levels (on-farm and post-production operations). The objective of this chapter is to outline the techniques and procedures for harvesting, handling and storing yams. Some physico-mechanical properties of yams will also be presented to assist in the design and selection of appropriate handling and processing systems.

1. Introduction

1.1 Economic and Social Impacts of Yams

Yams are second to cassava as the most important tropical root crop. Yams are a staple crop in many parts of Africa and Southeast Asia. In the South Pacific, the yam is a significant food crop, accounting for over 20%, 8.1%, and 4.6% of the total dietary calorie intake in the Kingdom of Tonga, Solomon Islands, and Papua New Guinea, respectively. Besides their importance as food source, yams also play a significant role in the socio-cultural lives of some producing regions like the celebrated New Yam Festival in West Africa, a practice that has also extended to overseas where there is a significant population of the tribes that observe it. In some parts of Southeastern Nigeria, the meals offered to gods and ancestors consists principally of mashed yam. Yams store relatively longer in comparison with other tropical fresh produce, and therefore stored yam represents stored wealth which can be sold all-year-round by the farmer or marketer. In parts of Igboland in Southeastern Nigeria, it is customary for the parents of a bride to offer her yams for planting as a resource to assist them in raising a family.

Fig. 1. Yam and other root crops on sale in the Kingdom of Tonga at a local market.

1.2 World Production and Trade

Most of the world production of yam is from Africa (about 96%) with Nigeria alone accounting for nearly 75% of the total world production (Tables 1 and 2). World annual production was estimated to be 25 million Mt in 1974, and 24 million Mt in 1992. During the past 5 years, total world production has increased from 32.7 million Mt in 1995 to 37.5 million Mt in 2000 (Table 3). Also during this period, export quantity declined slightly while export income remained fairly steady. During the period 1975-90, total yam cultivated area increased by about 38.8% globally, while the total production increased by 45.8%. However, the importance of yam in the economy of the main producing areas appears be declining due partly to competition with other crops like cassava in Nigeria, and taro in the South Pacific (Opara, 1999). The major producing areas have also continued to experience high population growth rates. During the last four decades, the annual growth rate (%) of per capita production in the major yam zones in Africa has declined (Dorosh, 1988).

Table 1: World production of yam (Dioscorea).

	Area (10^3 ha)	% of World Area	Production (10^3 Mt)	% of World Production†	Yield (Mt.ha^{-1})	% of World Yield
World	2,110	100	20,198	100	9.6	100
Africa	2,049	97.1	19,539	96.7	9.4	97.9
North & Central America	22	1.0	243	1.2	11.1	115.6
South America	10	0.5	48	0.2	4.7	0.5
Asia	15	0.7	168	0.8	11.4	118.8
Oceania	15	0.7	200	1.0	13.5	140.6
Leading countries						
1. Nigeria	1,350	64.0	15,000	74.3	11.1	115.6
2. Cote d’Ivoire	200	9.5	1,700	8.4	8.5	88.5
3. Ghana	160	7.6	800	4.0	5.0	52.1
4. Togo	100	4.7	750	3.7	7.5	78.1
5. Benin	59	2.8	610	3.0	10.3	107.3

Source: Adapted from (FAO, 1975)

Table 2: World’s leading yam producers in 1990.

	Area (103 ha)	% of World Area	Production (103 Mt)	% of World Production	Yield (kg.ha-1)	% of World Yield
World	2,928	100	29,447	100	10,057	100
Africa	2,789	95.3	28,249	95.6	10,127	100.7
West Indies	59	2.0	350	1.2	6,122	60.9
Oceania	18	0.6	284	1.0	15,818	157.3
Asia	15	0.5	198	0.6	12,876	128.0
Nigeria	1,900	64.9	22,000	74.7	11,579	115.1
Cote d’Ivoire	266	9.1	2,528	8.6	9,504	94.5
Benin	90	3.1	992	3.4	11,026	109.6
Ghana	200	6.8	168	2.4	3,500	34.8
Togo	40	1.4	420	1.4	10,500	104.4
Zaire	38	1.3	270	0.9	7,200	71.6

Source: Adapted from (FAO, 1991).

Table 3: Recent data on world production and trade in yams.

	2000	1999	1998	1997	1996	1995
Production, Mt	37,532,138	37,552,383	35,753,519	34,705,657	33,587,195	32,765,435
Exports- Mt	-	23,198	21,080	28,069	27,493	26,264
Exports- 1000US$	-	20,077	19,212	20,873	20,810	21,108

Source: (FAO/STAT, 2000).

1.3 Primary product

Yams are mainly grown for direct human consumption and are marketed as fresh produce in all the growing regions. Common methods of preparation include boiling, baking or frying. Boiled and baked yam can be eaten with vegetable sauce or palm oil. Boiled yam can also be pounded or mashed in mortar and eaten as ‘fufu’ or ‘utara’. Commercially food processing equipment for boiling and mashing of yam into fufu at the press of a button are now available in the market. Yam cultivars, which contain toxic substances such as dioscorene, are first sliced and soaked in salt water for several hours before further processing for consumption.

1.4 Secondary and derived product

Yam tubers are also processed into several food products such as the yam flour, which are enjoyed in many parts of the tropics (see Section 2). Industrial processing and utilisation of yam includes starch, poultry and livestock feed, and production of yam flour.

1.5 Requirements for export and quality assurance

There are no specific standards for yam export, but intending exporters must seek information on the quality and phytosanitary regulations of the importing country as well as the product specifications required by the importer. As a guide, exporters should apply the general requirements for the International OECD Quality Standard (Opara, 2001) which issues such as minimum requirements, quality requirements, sizing, tolerance and packaging. These should be interpreted to assist in meeting the specifications agreed with the importer.

1.6 Consumer Preferences

There is considerable consumer preferences for the different yam varieties among the growing regions. White-fleshed yams which have firm texture (mainly *D. rotundata*) are the most popular in West Africa, while in the South Pacific, *D. alata* cultivars (water yam, white purplish with loose watery texture) are most common (Opara, 1999). Consumer preferences might account for some of the predominance of certain cultivars in some region, in addition to agro-climatological impacts on the growing attributes of the species. In parts of West Africa, yams, which have loose texture, are often mixed with gari and pounded with gari to prepare fufu of ‘soft’ texture.

2. Post-Production Operations

2.1 Pre-harvest Operations

Maturity assessment is critical to achieving good quality yam. In the field, mature crop is generally distinguishable by cessation of vegetative growth and yellowing of leaves. The period from planting or field emergence to maturity is variable depending on the species (Table 4), and there is no standard reliable and objective index of yam tuber maturity. Some crude indices have been reported based on percentage of tuber length that was whitish at harvest, non-friable after cooking, or bitter after cooking (Onwueme, 1977). The most frequently reported measure is the period from planting to harvest (growing period), but it has been suggested that the time from emergence to maturity provides a better measure of growing period since planted tuber can remain dormant for some time (Onwueme and Charles, 1994).

Table 4: Time from planting to maturity and yield for different yams species.

Species/Common name	Period from planting to maturity	Yield and size of tubers
D. alata Water yam	220-300 days	20-25 $t.ha^{-1}$ 1-3 tubers per plant 5-10 kg per tuber
D. Bulbifera Potato yam	140-180 days; 90-120 days	Aerial: 2-15 $t.ha^{-1}$; 3-5 $t.ha^{-1}$ Underground: 2-8 $t.ha^{-1}$
D. Cayenensis Yellow yam	280-350 days	30 $t.ha^{-1}$ 2 kg per tuber (mean) 7-10 kg per tuber (highest)
D. Dumentorum Bitter yam	240-300 days	> those of most other cultivated West Africa yams
D. esculenta Lesser yam	200-300 days	7-20 $t.ha^{-1}$ 25-35 $t.ha^{-1}$ (exceptional) 5-20 tubers per plant
D. Opposita Chinese yam	24 weeks	4-6 $t.ha^{-1}$
D. rotundata White yam	200-330 days	16-20 $t.ha^{-1}$
D. trifida Cush-cush yam	280-330 days	15-20 $t.ha^{-1}$

Source: (Opara, 1999).

Most edible yams reach maturity in 8-11 months after planting. Techniques such as using physiologically aged planting material, pre-sprouting of setts, application of sprout-promoting substances (e.g. ethephon and 2-chloroethanol and harvesting before complete shoot senescence can decrease the during of field dormancy and thereby reduce the length period from emergence to maturity (Onwueme, 1977; Gregory, 1968; Martin et al., 1974). In many parts of West African yam zone, mature yams are harvested at the end of the rainy season or early part of the dry season, which coincides with the end of vegetative growth. Yams for long-term storage (for marketing or seed) are usually harvested during the harmattan period (Dec-Jan) in many parts of southeastern Nigeria when the crops has attained maximum growth and maturity. During this period, the soil is generally hard and tuber breakage during harvesting can be an economical problem.

Average yield of tubers is variable amongst the major producing areas, and is influenced by the species, seed piece, and growing environment (Table 4). Yields range between 8-50 Mt.ha^{-1} in 6-10 months. Yields of 8-30 Mt.ha^{-1} in commercial yam production has also been reported, the exact value depending on the location, variety, and cultivation practices (Onwueme and Charles, 1994. Many yam cultivars produce only a single large tuber, and the approximate multiplication ratio (fresh-weight yield:weight of planting material) for yam is about 5. Between 1975-1990, there were yield increases in all major producing countries except Ghana. During this period, the average world yield increased by nearly 11%.

2.2 Harvesting

Harvesting is done by hand using sticks, spades or diggers. Sticks and spades made of wood are preferred to metallic tools as they are less likely to damage the fragile tubers; however, tools need regular replacement. Yam harvesting is a labour-intensive operation that involves standing, bending, squatting, and sometimes sitting on the ground depending the size of mound, size of tuber or depth of tuber penetration. In rainforest areas, tubers growing into areas where there are roots of trees can pose a problem during harvesting and often receive considerable physical damage. Many also get deformed during growth as a result of the obstacles they encounter. These tubers are usually downgraded. Aerial tubers or bulbils are harvested by manual plucking from the vine.

Although some success in mechanical yam harvesting has been reported, especially for *D. composita* tubers for pharmaceutical uses (Nystrom et al., 1983), these machines are still limited to research and demonstration purposes. The use of a potato spinner has been suggested for harvesting species which produce a number of small tubers (Onwueme, 1997). Current crop production practices and species used pose considerable hurdles to successful mechanisation of yam production, particularly for small-scale rural farmers. Extensive changes in current traditional cultivation practices, including staking and mixed cropping, and possibly tuber architecture and physical properties will be required.

Yams can be harvested once (single harvesting) or twice (double harvesting) during the season to obtain a first (early) and second (late) harvest. The first harvest has also been referred to by the terms ‘topping’, ‘beheading’, and ‘milking’, all of which have been considered inadequate and obsolete. In single harvesting, each plant is harvested once and this occurs at the end of the season when crop is mature. The harvesting processes involves digging around the tuber to loosen it from the soil, lifting it, and cutting from the vine with the corm attached to the tuber. The time of harvest is critical in terms of tuber maturity, yield and postharvest quality. Depending on the cultivar, the period from planting or emergence to maturity varies from about 6-7 months or even 6-10 months.

Periods of 8-10 months and 4-5 months from planting or emergence to maturity have been recommended for double-harvesting (Martin, 1984; Onwueme, 1977); harvest first at 5-6 months after planting and then 3-4 months later has also been reported (Bencini, 1991). First harvest is carried out by removing the soil around the tuber carefully and cutting the lower portion, leaving the upper part of the tuber or the “head” to heal and continue to grow. The soil is returned and the plant is left to grow to the end of the season for the second harvest. Some yam cultivars produce several small tubers in the second growth following the early harvest. Double harvesting is most applicable to short-term varieties such as D. rotundata, and to lesser extents D. Cayenensis and D. alata. Similar yields have been reported for single and double harvesting; however, single-harvested tubers had better eating quality than the double-harvested tubers (Onwueme and Charles, 1994).

2.3 Transport & Packaging

After harvest, yam tubers are traditionally placed into woven baskets made from parts of the palm tree or coconut fronds. These are ideal for transporting small quantity of tubers over short walking distances. The basket is carried on the head, shoulder, or tied to a bicycle and transported to the market or storage facility. Compression damage is reduced since the basket is able to bend and thereby reduce the amount of force acting on individual tubers. However, when large quantities of tuber are harvested, these baskets are not suitable because of their limited size. Packaging tubers in full telescopic fibreboard cartons with paper wrapping or excelsior reduces bruising and enables large quantity of tuber to be transported over long distances. Tubers can be contained in loose packs, or units of 11 kg and 23 kg (McGregor, 1987). The cartons are hand-loaded or unitised on pallets.

Storing yams in modified atmosphere packaging (MAP) has beneficial effects, particularly using appropriate packaging material with suitable size and number) of holes for gas permeation. Sealing yam tubers in polyethylene film bags reduced storage losses due to weight loss and development of necrotic tissue (Table 5). Coating tubers with Epolene E10 (a commercial vegetable wax improved the appearance quality but there was no effect on levels of fungal infection (Thompson et al., 1977). The effect of this treatment on weight loss of tuber was inconsistent.

Table 5: Effects of packaging material on the quality of D. trifida after 64 days at 20-29°C and 46-62% rh. Fungal score was 0 = no surface fungal growth, 5 = tubers surface entirely covered with fungi. Necrotic tissue was estimated on the total cut surface of lengthway halves.

Type of package	Weight loss (%)	Fungal score	Necrotic tissue (%)
Paper bags	23.6	0.2	5
Polyethylene bags with 0.15% of the area as holes	15.7	0.2	7
Sealed 0.03 mm thick polyethylene bags	5.4	0.4	4

Source: (Thompson et al., 1977).

2.4 Curing of Yam Tuber

Curing of root crops allows suberisation of surface injuries and reduces subsequent weight loss and rotting in root crops. Curing of yams is recommended before storage so as to “heal” any physical injury, which may have occurred during harvesting and handling. This can be accomplished under tropical ambient conditions or in a controlled environment. Traditionally, yams are cured by drying the tubers in the sun for a few days. The optimum conditions for curing are 29°-32°C at 90-96% rh for 4-8 days (McGregor, 1987). Tubers cured at higher temperature (40°C) for 24 hours or treated with gamma radiation at 12.5 krads were free of mold and had least losses during subsequent storage. Storing at 15°C with prompt removal of sprouts was found to improve the eating quality of tubers (Coursey, 1967), presumably due the waterloss associated with curing and the inhibition of the biochemical synthesis that accompany sprouting.

2.5 Cleaning

Prior to long-term storage and marketing, yams are cleaned (without water) by scrapping off soil and other debris on the surface. A knife or piece of stick is usually used. The root ‘hairs’ are also removed to so that the tuber has a smooth surface. Water must not be used to clean tubers before storage because of increased susceptibility to microbial infection and growth under the ambient humid storage conditions.

2.6 Storage

The three main conditions are necessary for successful yam storage: aeration, reduction of temperature, and regular inspection of produce. Ventilation prevents moisture condensation on the tuber surface and assists in removing the heat of respiration. Low temperature is necessary to reduce losses from respiration, sprouting and rotting; however, cold storage must be maintained around 12-15°C below which physiological deterioration such as chilling injury occurs. Regular inspection of tubers is important to remove sprouts, rotted tubers, and to monitor the presence of rodents and other pests. In general, tubers should be protected from high temperatures and provided with good ventilation during storage. The storage environment must also inhibit the onset of sprouting (breakage of dormancy) which increases the rate of loss of dry matter and subsequent shrivel and rotting of tuber. Both ware yam and seed yam have similar storage requirements.

Notwithstanding cultivar differences, fresh yam tuber can be successfully stored in ambient and refrigerated conditions (Table 6). The recommended storage temperature is in the range 12°-16°C. Optimum conditions of 15°C or 16°C at 70-80% rh or 70% rh have been recommended for cured tubers (Martin, 1984; McGregor, 1987). Transit and storage life of 6-7 months can be achieved under these conditions. The onset of sprouting is enhanced at ambient conditions, especially if ventilation is inadequate. For example, during storage at ambient conditions (20°-29°C, 46-62% rh), D. trifida began to sprout within 3 weeks (Thompson, 1996). Yam tuber decay occurs at higher humidity, and like most tropical crops, they are susceptible to chilling injury (CI) at low storage temperatures. To avoid tuber damage, minimum storage temperatures of 10°C, 12°C and 13°C (Martin, 1984; McGregor, 1987) at or below which CI occurs have therefore been recommended. Storage of D. rotundata tubers at 12.5C resulted in CI (Coursey, 1968), and storage of D. alata at either 3° or 12°C resulted in total physiological breakdown within 3-4 weeks (Czyhrinciw and Jaffe, 1951). Storage of D. alata at 5°C for 6 weeks gave good results but CI symptoms developed rapidly when tubers were subsequently put in ambient (25°C) conditions (Coursey, 1961). There is no reliable data on beneficial effects on CA technology on the commercial storage is important yam cultivars.

Table 6: Recommended storage conditions for yams (Dioscorea spp.).

Cultivar	Temperature (°C)	Relative humidity (%)	Length of storage
D. trifida	3	-	1 month
Elephant yam	10	-	several months
D. alata	12.5	-	8 weeks
D. cayenensis	13	95	< 4 months
D. alata, cured	15-17	70	180
D. alata, non-cured	15-17	70	150
White yam, Guinea yam	16	80	several months
Yellow yam, Twelve month yam	16	80	60 days
Cush cush, Indian yam	16-18	60-65	several months
Lesser yam, Chinese yam	25	-	60 days
Water yam, Greater yam	30	60	several months
Unknown Cultivar			
	13.3	85-90	50-115 days
	16	65	4 months
	16	70-80	6-7 months

Source: (Opara, 1999).

There are several traditional storage structures used for yam storage including: (a) leaving the tubers in the ground until required, (b) the yam barn, and (c) Underground structures (Opara, 1999). Leaving the tubers in the ground until required is the simplest storage technique practised by rural small-scale farmers. When carried out on-farm, this type of storage prevents the use of the farmland for further cropping. Harvested yams can also be put in ashes and covered with soil, with or without grass mulch until required.

The *yam barn* is the principal traditional yam storage structures in the major producing areas. Barns are usually located in a shaded areas and constructed so as to facilitate adequate ventilation while protecting tubers from flooding and insect attack. Barns consist of a vertical wooden framework to which the tubers are individually attached (Fig. 2). Two tubers are tied to a rope at each end hung on horizontal poles 1-2 m high. Barns up to 4 m high are uncommon. Depending on the quantity of tuber to be stored, frames can be 2 m or more in length. The ropes are usually fibrous, but in Southeastern Nigeria, they are made from the raffia obtained from top part of Palm wine tree. Many farmers have permanent barns, which need annual maintenance during the year’s harvest. In these situations, growing trees are used as vertical posts, which are trimmed periodically to remove excessive leaves and branches. 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. The use of open-sided shelves made from live poles, bamboo poles or sawn wood has been recommended to enable careful handling and easy inspection in comparison with tying tubers to poles which can cause physical damage and rotting (Bencini, 1991). In barn storage, yams have a maximum storage life of 6 months and are therefore most suited for long-term varieties. Storage losses can be high and up to 10-15% in 3 months, and 30-50% after 6 months if tubers are not treated for rotting using fungicides such as Benlate, Captan or Thiabendazole.

Fig. 2. Tipical Yam Barn in West Africa.

Yams are also stored in underground structures such as pits, ditches and clamps. These are suitable for limited storage periods, especially the early varieties that are often harvested before the end of the rainy season. During construction of pits, the earth dug out is used to build a low wall around the edge. The temperature in the storage space can also be moderated by placing cut vegetation over the ditch, clamp or pit. In these structures, ventilation and rodent attack of tubers is a major problem, and it is difficult to inspect the tubers.

Well-ventilated, weatherproof, and stronger shelters can be built as to improve the performance of the traditional shelters described above. New features may also be provided to exclude pests and rodents. A typical improved yam barn has sidewall 1.2 m high and wire mesh to ward off rodents and birds (Akoroda and Hahn, 1995). The roof was double thatch and extended to the eaves with smooth floor of cement or mud, and only one entry door was provided to guard against entry of rodents. Tubers were stored on platforms or shelves. Tubers stored in such improved structures had only 10% spoilage after 5-6 months.

2.7 Processing

Industrial uses of yam includes starch, poultry and livestock feed, and production of yam flour. Readers interested in detailed information on specific yam processing methods, equipment, and packaging techniques can find these information in an FAO technical compendium (Bencini, 1991). Residues from sifting and peels are used as animal feed in many rural areas. One of the major disadvantages of industrial processing of yam for food is that nutrient losses in these products can be high, particularly minerals and vitamins. In products obtained from secondary processing such as biscuits and fufu, the amount of loss depends principally on the amount of edible surface exposed during processing operations. Primary unit operations such as milling affect the thiamine and riboflavin contents of *D. rotundata*, with average losses of 22% and 37%, respectively. Sun drying results in high losses of B vitamins with little change in mineral content. Pounding yam flour in a traditional wooden mortar or grinding in an electric mixer had similar effects.

2.8 Dormancy in Yams

Dormancy is the temporary suspension of visible growth of any plant structure containing a meristem, and in stored yam tubers, it is the 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 the stored food (carbohydrate) (Passam and Noon, 1977). Yam tuber does not sprout during the early part of storage, even under suitable growth conditions. The environmental conditions affecting yam tuber dormancy are photoperiod, white and coloured lights, 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. Physiological age of tubers affects their readiness to sprout, but by approximately 6 months after harvesting, dormancy disappears completely and budless setts planted after that period will require nearly the same time to sprout (Onwueme, 1975). The length of dormant period is affected by the yam species (Table 7). These data are useful for developing suitable storage and marketing strategies, and also for scheduling the next planting.

Table 7: Dormancy period of tubers of major edible yam species.

Species	Locality	Period of dormancy (weeks)
D. alata	Caribbean	14-16
	Nigeria	14-16
D. bulbifera	Nigeria	19-20
D. cayenensis	Nigeria	4-8
D. dumetorum	Nigeria	14-16
D. esculenta	Caribbean	4-8
	Nigeria	12-18
D. rotundata	Nigeria	12-14
		14-16
D. trifida	Caribbean	2-4

Source: (Opara, 1999).

3. Overall Losses

Post-harvest losses occur at various stages from production, postharvest handling, marketing, distribution and processing. These include losses in quantity and tuber quality, arising from physical damage, rodent attack, fungal and bacterial diseases, and physiological processes such as sprouting, dehydration, and respiration. Estimated loss of 10-60% of total crop has been reported (NAS, 1978). Weightloss during storage in traditional or improved barns, or clamp storage can reach 10-12% in the first 3 months and 30-60% after 6 months. Weight losses alone of 33-67% after 6 months storage have been reported (Coursey, 1967). In West Africa alone, this amounted to an annual loss of one million tonnes of tuber (Akoroda and Hahn, 1995).

The magnitude of weight loss in stored yams increases rapidly after the first months (Table 8). Transit losses of about 15-40% occur in some developing countries due mainly to inefficient storage and transport facilities. Losses of *D. alata* cultivars varied from 7-23% during 4 months of storage (Gooding, 1960), and in Puerto Rico, postharvest losses of yams due to decay exceeded 50% (Burton, 1970). Processing losses during culinary preparation of peeled yam can amount to 10-15%.

Table 8: Weight loss in stored yams.

		Percentage weight loss during storage				
Country	**Species**	**1 month**	**2 months**	**3 months**	**4 months**	**5 months**
Puerto Rico	Guinea yams	1	3	8	(sound tubers)	
		2	6	11	(tubers slightly infected by rots)	
Nigeria	D. rotundata	5	7	12	20	29
		4	6	10	14	21
		3	6	14	23	30
	D. cayenensis	6	17	29	39	48
Ghana	D. rotundata	1	5-7	15-17	26-27	34-40

Source: (Coursey, 1967).

4. Pests & Disease Control

Yams are susceptible to a variety of pest and diseases during growth as well as postharvest. Attack by the yam beetle, and microorganisms such as nematodes and yam virus are the most devastating. The major postharvest disease is tuber rots caused mostly by fungi.. Table 9 summarises the common pests and diseases, their characteristics and potential remedies. Fumigation is generally carried out using methyl bromide, the application must be checked with appropriate regulatory authority and with the importer if produce is destined overseas. Fencing, poisoning, and trap setting are common methods for controlling rodents.

Table 9: Pests and diseases of yams and recommended control strategies.

Common name	**Organism**	**Incidence & characteristics**	**Control strategy**
Yam beetle	*Heteroligus* meles	A major pest in West Africa; adults migrate by flying to other farms/plots; they feed on the tuber, thereby leaves holes on them. Tubers loss appearance quality and become prone to rotting during storage.	Dust the sets with insecticide before planting. Note that some insecticides can be persistent and harmful to the environment. Very late planting can reduce infestation but affect yields.
Chrysomelid beetle	Lilioceris livida		Removal of lavae by hand or spraying carbaryl
Scales	Aspidiella hartii		Removal of pests with a brush and treatment with diazinon plus white oil or malathion prior to planting
Mealy bugs	Planococcus citri		Use of clean stock
Yam anthracnose	Fungi such*as Colletotrichum*and *Glomerellacingulata* implicated.	Occurs in all yam producing area; infection from inoculum borne within the planting sett or in the soil; results in blackening and die-back of the leaves and shoot.	Use resistant cultivar (e.g. TDA 291, TDA 297). Maneb or benomyl and good field sanitation.
Nematodes	Yam nematode (*Scutellonema bradys*) and the root knot nematode (*Meloidogyne spp*) are the most serious.	They reside in the tuber and remain active during storage. Wounded areas provide entry for decay-causing bacterial and fungi.	Crop rotation and fallowing, and planting with healthy materials. Soil fumigation with nematicides may be uneconomical.
Yam virus complex		Occurs throughout the West African yam zone. Reduces yields considerably	Use virus-free planting materials or resistant cultivars. Thermotherapy and meristem culture.

Common name	**Organism**	**Incidence & characteristics**	**Control strategy**
Tuber rots	Soft rots caused by*Penicillium* spp.,*Fusarium*oxysporum, and*Botrydiplodia* theobromae. Dry rots caused by*Rosselinia* and*Sphaerostilbe* . Other fungi*: Rhizopus nodosus. F. solani.*	Infection in the field can persist and lead to rotting during storage	Plant with disease-free material. Crop rotation. Minimise physical damage of tuber during postharvest operations. Treat the sett or tuber with systemic fungicide or alkaline material such as Bordeaux mixture. Provide adequate aeration and inspect stored tuber regularly.
Source: (Opara, 1999).			

5. Economic and Social Considerations

5.1 Overview of costs and losses

Yams are important in the diet and socio-cultural life of people in the growing regions. Their overall significance is gradually declining due to increased competition with other food sources such as cassava and wheat bread. The multiple weeding required to get good yield is a major cost and limitation to yam cultivation, especially for medium-scale smallholders who do not have sufficient family labour. Current estimates indicate that quantitative losses are high and this translates into substantial amounts when the labour involved in bush clearing, planting, weeding and harvesting are included. Qualitative and nutritional losses are also high in yams and these have both economic, social and health implications particularly in the growing areas where it is a major food material. The higher the exposed surface area of tissue during processing, the higher the incidence of losses in minerals and vitamins. Both sun drying and milling contribute to losses in thiamine, riboflavin and B vitamins. Developing improved unit operations for yam processing could assist in improving the nutritional status of rural people in the yam regions.

5.2 Major problems & proposed improvements

Reducing the drudgery of manual operations through improved simple implements in hand tools and reducing crop losses through better storage must be important priorities. Potential strategies to improve traditional storage structures have been discussed earlier. These will require access to finance and the equipment.

5.3 Gender aspects

Yam growing and handling involves many operations, some of which follow gender lines in some regions. In the south-eastern part of Nigeria, for instance, men and women combine efforts to do the planting; the women carry out weeding which is usually 2-3 times before harvest; and men and women combine efforts again at crop maturity to do the harvest.

5.4 Nutritional facts and phyisco-chemical properties of yam

Nutritional Facts

Yams have high contents of moisture, dry matter, starch, potassium, and low vitamin A. Yams contain about 5-10 mg.100 g^{-1} vitamin C, and the limiting essential amino acids are isoleucine and those containing sulphur. They also contain a steroid sapogenin compound called diosgenin, which can be extracted and used as base for drugs such as cortisone and hormonal drugs. Some species contain alkaloids (e.g. dioscorine $C_{13}H_{19}O_2N$) and steroid derivatives. Table 10 provides a summary of the nutritional values of yams while Table 11 provides that data for individual yam species. It should be noted that the method preparation affects the final nutritional status of yam-based foods. These data are useful in designing new product formulations as well as efficient food process operations.

Table 10: Range of nutritional values of yam (nutrients in 100-g edible portion).

Nutrient	Tuber	Bulbils
Calories	71.00 - 135.00	78.0
Moisture (%)	81.00 - 65.00	79.4
Protein (g)	1.40 - 3.50	1.4
Fat (g)	0.40 - 0.20	0.2
Carbohydrate (g)	16.40 - 31.80	18.0
Fibre (g)	0.40 - 10.00	1.2
Ash (g)	0.60 - 1.70	1.0
Calcium (mg)	12.00 - 69.00	40.0
Phosphorous (mg)	17.00 - 61.00	58.0
Iron (mg)	0.70 - 5.20	2.0
Sodium (mg)	8.00 - 12.00	
Potassium (mg)	294.00 - 397.00	
b -Carotene eq. (mg)	0.00 - 10.00	
Thiamin (mg)	0.01 - 0.11	
Riboflavin (mg)	0.01 - 0.04	
Niacin (mg)	0.30 - 0.80	
Ascorbic acid (mg)	4.00 - 18.00	

Table 11: Nutrient content of yam species (Dioscorea spp.) per 100-g edible tuber portions.

	D. spp.	**D. Alata Water yam**	**D. Bulbifera Potato yam**	**D. Cayenensis Yellow yam**	**D. Dumentorum Bitter yam**	**D. esculenta Lesser yam**	**D. rotundata White yam**	**D. trifida Cush-cush yam**
Water (ml)	69	65 76†	71 (79)‡	80	67	70 74†	80	80.7
Calories	119	135 87	112 (78)	71	124	112 102	71	
Protein (g)	1.9	2.3 1.9	1.5 (1.4)	1.5	3.2	3.5 1.5	1.5	2.54
Fat (g)	0.2	0.1 0.2	0.1 (0.2)	0.1	0.1	0.1 0.2	0.1	0.44
Carbohydrate (g)	27.8	31 20	26 (18)	16	28	25 24	16	38
Fibre (g)	0.8	1.5 0.6	0.9 (1.2)	0.6	0.8	0.5 0.6	0.6	
Calcium (mg)	52	28 38	69 (40)	36	52	62 12	36	8
Phosphorous (mg)	61	52 28	29 (58)	17	45	53 35	17	38
Iron (mg)	0.8	1.6 1.1	(2.0)	5.2		0.8	5.2	0.52
Vitamins								
β-carotene equiv. (µg)	10	10 5						
Thiamine (mg)	0.11	0.05 0.10				0.10		
Riboflavin (mg)	0.02	0.03 0.04				0.01		
Niacin (mg)	0.3	0.5 0.5				0.8		
Ascorbic acid (mg)	6	12 6				15		

†Two values reported; ‡Bulbil or aerial tuber. Source: (Opara, 1999).

Physico- chemical & rheological properties

Tuber size and shape are variable depending on the species and growing conditions. Tuber size can range from a few centimetres and grams, to 2-3 m and over 50 kg. The tuber of most important cultivars are cylindrical in shape, with some root ‘hairs’. Tannin cells and cells containing bundles of crystals (raphids) are also present, and these crystals are responsible for the itchiness of raw yam tuber and some other root crops when eaten or placed in contact with the skin.

Respiration rates of yam tuber are important in the design of storage structures and their environmental control facilities. Respiration data is also useful in the design of MA packaging and coating of tubers with waxes to extend their shelf life. Respiration rate is a good indicator of metabolic activity in tissue and therefore provides a useful guide to potential storage life. It is usually measured by the rate of O_2 depletion or by the rate of CO_2 evolution. Tuber age, degree of physical damage and/or spoilage by microorganisms affect the rate of respiration. Yams respire actively at harvest and during sprouting. Respiratory activity is minimal during the period of dormancy. Rates of respiration can vary from 5-20 mL $CO_2.kg^{-1}$ fresh $weight.hr^{-1}$ in healthy tuber (D. rotundata) to over 35 mL $CO_2.kg^{-1}$ fresh $weight.hr^{-1}$ in decaying tuber.

Respiratory weight loss contributes significantly to total storage loss and yams stored for 5 months may loose up to 10% of dry matter content through respiration (Coursey and Walker, 1960). During storage, the increase in both heat of respiration and heat load is greater at high initial store temperatures. Under tropical conditions (15-35°C), the heat of respiration can account for up to 89-100% of the total heat load in storage especially if the tubers are free from infection by mold and other micro-organisms (Alakali et al., 1995). Accurate data on heat load is essential in designing improved and efficient coldstorage facilities. The relationship between heat load from respiration and heat of respiration for yams is:

$$\mathbf{Qp = 0.021 + 4.247Qr}$$

where Qp = heat load from respiration and Qr = heat of respiration (R = 0.99).

Regression equations can also be used to estimate the storage air temperature based on data on initial storage temperatures (Table 12).

Table 12: Linear regression equations of storage air temperature and storage time (X in hours).

Initial storage temperature (°C)	Regression equation	Correlation coefficient
15	16.24 + 0.131X	0.96
20	20.97 + 0.176X	0.98
25	24.27 + 0.171X	0.98
30	29.82 + 0.194X	0.99
35	32.98 + 0.1217X	0.98

Source: (Alakali et al., 1995).

The thermo-physical and rheological properties of yam are also important in designing handling and processing operations. They are also useful in predicting starch behaviour during cooking and cooling processes. Some of the relevant properties include specific heat capacity of tuber, size of starch granules, viscosity, and gelatinisation temperature. Tuber moisture content varies considerably among species, harvest date and length of storage, and for design purposes an average moisture content of about 73.5% is recommended (Hardenburg et al., 1986).The *specific heat* of yam tuber can be estimated from Siebel’s equation based on the moisture content (Siebel, 1892):

$$\mathbf{S = 0.0335 \times (\%\ H_20\ in\ food) + 0.8370,\ kJ.kg^{-1}.°C^{-1}}$$

In industrial processing the range of starch granules and their gelatinisation temperatures are economically important for good product formulation and equipment performance. The granules of yam starch from the different species may be classified into four groups based on size and form (Table 13). Other rheological properties of yams also vary among the species (Table 14).

Table 13: Starch granule size and range of gelatinisation temperatures of yams.

Species	**Granule size (µ)**	**Gelatinisation temperature (°C)**
D. alata	5-50	69.0-78.5
D. rotundata	5-45	64.5-75.5
D. cayenensis	3-25	71.0-78.0
D. opposita	5-60	65.5-75.5
D. Bulbifera	5-45	72.0-80.0
D. esculenta	1-15	69.5-80.5
D. hispida	1-5	75.5-83.0
D. dumetorum	1-4	77.0-85.5
D. trifida	10-65	-

Source: (Coursey, 1967; Emiola and Delarosa, 1981).

Table 14: Categorisation of yam species based as follows starch granule size and form.

Examples of species	**Starch characteristics**
D. alata D. rotundata D. opposita	Fairly large granules, oval or egg-shaped, elongated rounded squares, or mussel-shell-shaped, sometimes with one side flattened
D. bulbifera D. cayenensis	Many fairly large granules, of rounded triangular form, sometime elongated, rarely trapezoidal form
D. esculenta D. hispida D. dumetorum	All granules small, rounded or polyhedral, sometimes complex, as though built up from many smaller granules
D. digitata D.sinuata D. belizensis	All granules small, rounded in form, often joined together at one or more surfaces. Starches of this group are very similar to cassava or sweet potato starches

Source: (Siedman, 1964).

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7 Annex

List of tables

List of figures