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REVIEW OF LITERATURE ON POSTHARVEST OF YAMS

A. K. Thompson[1] and R. D. Bancroft[2]

[1]Cranfield University, Silsoe College, Silsoe, Bedford MK45 4DT.

[2]Natural Resources Institute, University of Greenwich, Central Avenue, Chatham Maritime, Kent, ME4 4TB.

26 July 1996

1. Introduction

Species of yam of the genus *Dioscorea* may be found throughout the humid and semi-humid tropics. World-wide, of the 600 or so species that have been identified perhaps only 20 are consumed with 8 specifically regarded as important sources of staple foodstuffs and medicinal compounds. Pre-eminant amongst these are: *D. alata* L., *D. cayenensis* Lam. (or sometimes referred to as the *D. cayenensis-rotundata* complex), *D. dumentorum* (Kunth.) Pax., *D. esculenta* (Lour.) Burk. and *D. rotundata* Poir.). Also of importance are *D. batatas* Decne., *D. bulbifera* L. and *D. trifida* Lam.. Edible yams contribute significantly to the diet of communities in many regions across Asia, Africa, South and Central America, the Caribbean and the Pacific, however, intensive yam cultivation is presently focused in what has become known as the 'Yam Zone'. This incorporates the West African states of Benin, Cameroon, Côte d'Ivoire, Ghana, Nigeria and Togo. Of the total annual global production of yam some 95-96 % is believed to originate from West Africa (FAO 1994 and Onwueme and Charles 1994). In this region the predominant cultivated species of yam are *D. alata, D. cayenensis, D. dumetorum* and *D. rotundata*. Of these by far the most important food yams are the 'white yam' - *D. rotundata* and the 'water yam' - *D. alata*. Over the past 15 years assessments indicate that world production of yams has been increasing and that this may be seen to be almost entirely due to increased production in Africa (Table 1). The predominant tradition world-wide is to conserve yams in their fresh state and boil, pound, baked, roast or fry tubers for consumption, in some regions of Nigeria (the world's major yam producer), however, as much as 20 to 25 % of the yam crop (specifically *D. rotundata*) may be processed into dried chips and flour (Anon 1982).

Table 1. World-wide annual production figures for yam in '1000 metric tonnes (Source: FAO 1994).

Date	1979 to 1981	1992	1993	1994
Location				
Africa	10,476	25,461	27,190	29,096
North and Central America	39	495	416	430
South America	355	325	305	315
Asia	165	192	197	207
Europe (Portugal)	3	2	2	2
Oceaniana	242	292	290	294
World Total	11,580	26,766	28,399	30,343

2. Postharvest Losses

Postharvest biological losses of yams result both directly and indirectly from a combination of physical, physiological and pathogenic causes. The inherent high moisture and carbohydrate content of the tubers together with their bulky nature and high rates of respiration render them mechanically weak and prone to physical damage, attack by insect pests, animals and colonisation by micro-organisms and physiological deterioration. Losses, although increasingly evident after harvest, often result from damage and infections that have their genesis in the field or at the time of harvest. Damage to the surface tissues of yam tubers whether by feeding insects and rodents, by mechanical damage at harvest and during subsequent handling or by the action of nematodes may all pre-dispose the host tissues to premature physiological deterioration and infection by fungal and bacterial agents.

In the past, due to the lack of hard data, it has been exceptionally difficult to establish a reasonable estimate for the percentage postharvest losses that may be sustained by a yam crop. Research undertaken in Ghana (Mück 1994) estimated that after storage of 2 to 6 months the general losses of root and tuber crops was of the order of 10 to 50 %. Alhassan (1994), also reporting from Ghana, cites postharvest losses of yam and cassava at 30% of the total crop. Various authorities have all proposed different levels of loss for yams (Table 2) and, in common with other perishable commodities, published figures have often cited a potential range of values (Table 3). It is, however, difficult to determine the validity of such generalised data when the basis of such calculations is omitted.

Table 2. A sample of estimates for the postharvest loss of yams

Published Percentage Loss of Yam	*Authority*
5%	Anon (1986), Greeley (1991) and Lipton (1972),
10-15% in 3 months	Coursey (1967)
25%	Ihekoronge and Ngobby (1985) and FAO (1985)
40%	Waitt (1961)
30-50%	FAO (1975)
50% in 6 months	Coursey (1967)

A study of recently published research findings possibly provides more precise estimates of the postharvest losses of yams associated with particular storage regimes and highlights the importance of a number of factors that together influence the storage potential of the tubers, the impact of various categories of postharvest loss and the differing perceptions of such loss.

Table 3. Estimate of percentage postharvest loss of crops in developing countries (Source: Anon 1978).	
Commodity	*Percentage Loss of Total Crop*
Apples	14
Avocados	43
Bananas	20-80
Cabbage	37
Carrots	44
Cassava	10-25
Cauliflower	49
Citrus	20-95
Grapes	27
Lettuce	62
Onions	16-35
Papayas	40-100
Plantain	35-100
Potatoes	5-40
Raisins	20-95
Stone Fruit	28
Sweetpotatoes	35-95
Tomatoes	5-50
Yams	10-60

In 1985 an FAO publication enumerated a number of factors that, at that time, were considered of importance in compromising the shelf-life potential and contributing to the loss of yams stored under traditional methods (Table 4). A more recent survey undertaken in the major yam producing regions of Ghana to document the perceptions of the local producers identified broadly similar categories. What is interesting is the order in which local farmers ranked the severity of the factors (Table 5), clearly prioritising production constraints in a very different manner than that often assumed by agricultural scientists. Damage attributed to rodents was considered a principle concern, more so than postharvest rotting (a finding not dissimilar to that reported by Ezeh in 1995). Theft was also deemed and important factor, much more so than sprouting, and weight loss was not perceived as a constraint in its own right. During this survey the farmer's own assessment of losses varied from between 6 and 25% with an overall mean of 13% (Anon 1994a). In this instance 50-60% of the farmers considered such losses to be relatively low and acceptable although it became apparent to the researchers that the more commercially minded producers tended to assume somewhat higher levels of loss than those who were more subsistence orientated.

Table 4. Summary of factors with the potential to aggravate postharvest losses of yams (Source: FAO 1985)	
	Factor
a)	Nematode infestation particularly by *Scutellonema spp.*;
b)	Postharvest rots caused by both parasitic and saprophytic micro-organisms that invade yam tubers via wounds caused by nematodes and physical damage during harvesting and subsequent handling, storage and transport;
c)	Damage caused by rodents and occasionally other animals feeding on tubers;
d)	Damage by insect infestations of mealy bug and scale insects that feed on the tissues of the yam tubers;
e)	Weight loss resulting from sprouting, transpiration and respiration, and
f)	Loss of culinary quality and palatability often associated with sprouting and prolonged storage.

Table 5. The three most important postharvest problems of yams identified by producers during a survey conducted in the Brong Ahafo and Northern Regions of Ghana (Source: Anon 1994a)

Figures represent the percentage of interviewees answering with an affirmative response for a given category of problem and at a particular level of severity.

Category	*First Problem*	*Second Problem*	*Third Problem*	*Total*
No Answer	0.00	10.30	41.52	32.37
Rodents	48.90	24.55	8.18	21.00
Rotting	16.72	16.36	7.58	10.77
Theft	11.25	11.82	12.42	9.86
Sprouting	0.91	3.03	9.09	3.71
General Pests	2.74	6.67	1.21	2.88
Termites	5.17	9.09	5.15	5.31
Insects	0.91	3.33	2.12	1.67
Bush Fire	1.82	5.45	4.24	3.41
Weather	3.04	4.24	3.33	3.18
Marketing	1.52	0.61	0.30	0.76
Animals	2.74	2.12	1.82	2.27
Other	3.95	2.42	3.03	2.73
No of Interviewees	329	330	330	1319

For many years recommendations have been published and circulated indicating, in very general terms, the differences in storability attributed to various species and varieties of yam and the postharvest management strategies that, if followed, would help to conserve the quality of tubers whilst in store (FAO 1985). See also Table 6. Of the producers canvassed during the Ghanaian survey, 90% said they practised sprout removal during storage and 84% screened out rotting tubers to diminish postharvest losses. Only 8% attempted to cure tubers before storage and a minimal number (4%) used sprays to control insects. The chemical controls used in this instance were DDT or Phostoxin.

Table 6. Recommendations for the reduction of postharvest losses of yams when held in traditional stores (after FAO 1985).

a)	Selection of appropriate varieties that are easy to harvest and have good storage characteristics (i.e. ovoid shaped tubers, good healing capacity and long dormancy);
b)	Careful handling during harvesting and transportation to reduce physical damage to tubers (i.e. avoid of scraping/abrading, bruising and cutting tubers);
c)	Cure tubers prior to storage but avoid prolonged exposure of tubers to string sunlight; and
d)	Careful grading and selection of only sound tubers for storage (i.e. select only tubers free from nematodes, rots and physical damage for storage).

The genetic potential of different yam varieties is acknowledged to have a very significant influence on the storability of the harvested tubers. So much so that throughout West Africa communities have developed different culinary traditions. Across the region consumers prefer yams tubers of *D. rotundata*, however, the tubers of *D. rotundata* store less well than those of *D. alata*. In Côte d'Ivoire and Ghana, therefore, *D. rotundata* is consumed relatively soon following harvest whereas *D. alata* is often held in store until the supplies of *D. rotundata* are depleted. There is also some anecdotal evidence that in Côte d'Ivoir consumers find the varieties such as Bètè bètè (*D. alata*) have a better taste and hence are more acceptable following a period in store (Girardin *et al*. 1996). As has already been noted, in Nigeria, a significant proportion of the yam crop is conserved as dried chips or flour, a practice that is not general in countries such as Ghana or Côte d'Ivoire.

To what extent the farmers involved in the Ghanaian survey already mentioned elected to grow specific yam varieties on account of their postharvest storage potential was not determined, however, other data collected by Anamoh and Bacho (1994) indicated that the growers were keenly aware of the characteristic qualities of yam varieties. Tables 7 and 8 illustrate the variability in the storage potential of local varieties of yams as measured by postharvest loss of tubers in three different districts in Ghana as perceived by the farmers.

Table 7. Farmers estimation of storage potential and probable percentage wastage of yams held for different periods after harvest. Data collected from farmers of Babatokuma, Kintampo District, Ghana 1994 (Source: Anamoh and Bacho 1994).

Variety	*Length of Storage Period*	*Percentage Losses (%)*	
		By the end of the storage period	*After three months*
Laribako	3 months	<10	<10
Puna	3 months	<10	<10
Lilli	3 months	50	50
Bocholo	3 months	50	50
Kyikyirboya	3 months	50	50
Zong	8-9 months	0	0
Tiporo	8-9 months	0	0
Tilla	8-9 months	0	0
Baayire	8-9 months	0	0
Nusoror	8-9 months	0	0
Shanta	9 months	0	0
Kofi Nsia	12+ months	0	0
Kpirijo	12+ months	0	0
Wasabaa	12+ months	0	0
Seidu Bile	12+ months	0	0
Serwa Kupuntijo	These were new varieties so farmers were unfamiliar with their characteristics.		

On the issue of what may or may not constitute a postharvest loss, Anon (1994b) described a survey conducted in Ghana where it was shown that the perception of postharvest losses varied between various categories of interviewees. In general, subsistence farmers tended to measure postharvest losses in terms of the actual quantity of yams discarded during storage, while other key players involved in the production and marketing of yams had somewhat different perceptions. Commercial farmers were similarly aware of quantitative losses but also recognised the diminished economic value and price discounting associated with damaged and partially damaged tubers. The perception of what constituted an economic loss was most keenly developed amongst traders whose success in the market place depended on their appreciation of the relationship between quality and economic value and how this may vary in accordance with the quality of the commodity, market trends and fluctuations in supply and demand.

Table 8. Farmers estimation of storage potential and probable percentage wastage of yams held for different periods after harvest. Data collected from farmers of Mandari, Bole District and Chama, Tamale District, Ghana 1994 (Source: Anamoh and Bacho 1994).

Variety	*Actual Storage Period*	*Percentage Losses (%)*	
		Within three months	*At end of the actual storage period*
Kpasajo	1 week	100	20
Black Kangba	1 week	100	20
Laribako	1-2 weeks	100	20
Puna	1-2 weeks	100	20
Akaba	2 months	25-30	10-15
Sakpieo	2 months	40	20
Tantanpula	3 months	25-40	25-40
Lobere/Logpere	3 months	25	25
Tilla	3 months	25	25
Nyuwa	3 months	0	10
Shanta	3 months	25	25
Baayire	3 months	10	10
Kukurikpa	4 months	0	5
Loko	4 months	0	5
Beeso	4 months	0	5
Yellow Kangba	4 months	40	20
Seidu Bile	12+ months	0	5

Recent research in both Ghana and Côte d'Ivoire has sought to measure the influence of variety and different storage structures on the various categories of postharvest waste. Henckes *et al.* (1995) observed that, at the end of a 16 week storage trial in Ghana, those yams maintained in a raised hut structure constructed of poles and grass mats sustained a mean loss of 9% as a consequence of rots (as measured in terms of the absolute weight of material discarded) in comparison to 20% and 26% for 'dede' and pit storage. In this context the 'dede' was a relatively simple shelter not dissimilar to that of the raised hut save that it had a flat roof and was constructed on the ground, while the pit was a form of storage trench dug into the earth surrounded by a shallow mud wall and protected by a thatched roof. Although not analysed statistically, the Ghanaian results suggest an interaction between the storage structures and variety (Table 9).

Table 9. Interaction of yam cultivar and storage structure on percentage weight of tubers lost to postharvest rots during a 16 week storage trial in Ghana (Source: Henkes *et al.* 1995)

	Local Yam Varieties									
	Moniyo			*Laribako*			*Shanta*			
	Storage Structures									
Period in Storage	*Dede*	*Pit*	*Raised Hut*	*Dede*	*Pit*	*Raised Hut*	*Dede*	*Pit*	*Raised Hut*	*Total*
0	0	0	0	0	0	0	0	0	0	0
4	1	0	1	0	0	0	0	1	0	0
8	1	1	1	2	2	2	0	2	1	1
12	4	3	3	5	8	3	1	2	2	3
14	21	7	0	16	14	3	3	7	1	8
16	28	29	7	31	48	18	2	1	1	18

Observations made of storage trails conducted by in Côte d'Ivoire over a period of six months indicate more severe loss of yams (as measured by weight of tubers discarded) due to a combination of rotting and moisture loss (Doumbia *et al.* pers. comm. 1996). Varieties of *D. rotundata* held in pits lost 73% by weight in comparison to those held in thatched stores where the weight loss was 81%. This was in contrast to *D. alata* varieties which sustained losses of 46 and 54% in the pits and thatched stores respectively. In concomitant trials both *D. rotundata* and *D. alata* yams were treated with thiabendazole in a bid to exclude postharvest rots from the system. The results form this experiment once again indicated that *D. alata* varieties were less prone to weight loss in comparison to the *D. rotundata* cultivar Krenglé. The latter deteriorated completely when maintained in a pit but, when held under thatch, sustained no greater weight loss than the *D. alata* cultivars Bètè bètè and Florido (Table 10).

Table 10. Interaction of yam varieties and cultivars and storage structure on percentage weight of tubers lost to postharvest rots and moisture loss following a 6 month storage trial in Côte d'Ivoire (Source: Doumbia *et al.* pers. comm. 1996)				
	Variety			
	Dioscorea rotundata		*Dioscorea alata*	
Experiment A: Conducted over a six month period, data represents means pooled from 3 storage locations. Weight loss represents that incurred as a result of both moisture loss and rots.				
Storage Structures				
Pit	73		46	
Thatch	81		54	
Experiment B: Conducted over a six month period. Weight loss represents that incurred as a result of both moisture loss and rots. All tubers were treated with thiabendazole prior to storage.				
	Cultivar			
	*Kreng*lé		*Bètè bètè*	*Florido*
Storage Structures				
Pit	100		45	47
Thatch	47		43	48

It is apparent from the research findings already cited that, in addition to absolute biological losses and depreciation in quality brought about by pests and diseases after harvest, the storage potential of yam tubers is profoundly influenced by the environmental conditions pertaining during storage and also by innate physiological factors. Once severed from the vine and lifted from the field, tubers will begin to loose moisture. The reduction of the weight of individual tubers occurs as a result of evapo-transpiration from the surface and from sites of damage and infection and also from post-harvest respiration and conversion of starch reserves to sugar during storage and subsequent sprout germination. As a consequence, as already noted, one relatively simple variable often used by researchers to gauge the physiological status of yams is their fresh weight.

Using this approach in the past, a number of researchers have published data describing various rates of weight loss of stored tubers under different storage regimes. For example, at the end of a 6 month storage trial in Nigeria, Nwankiti *et al.* (1985) noted a weight loss of some 40% from tubers held in a traditional yam barn. A figure not dissimilar to that observed more recently by *Doumbia et al.* pers. comm. (1996) in association with storage in a thatched structure (Table 10). Monitoring a yam of a different species in Cameroon, Lyonga (1985) has quoted losses of 29 to 47% when tubers were stored for two months on slatted wooden trays under ambient conditions. The observations made by Ezeike (1985) also draw attention to the significant influence that the storage structure may have on the rate of weight loss of tubers. In his experiments he found that weight loss of tubers stored in ventilated pits for 5 months was 15 to 25% in comparison to a 60% loss recorded for yams stored in yam barns. In all these earlier works, however, it is difficult to discern what component of the weight loss may have been attributed to pathogenic rots and what the result of a direct loss of moisture without the involvement of spoilage organisms.

Girardin *et al.* (1996 in press) have conducted a series of experiments designed to examine and improve the traditional yam storage techniques being used in Côte d'Ivoire. To this end fluctuations of temperature and relative humidity within three different storage structures (yam-barns, sheds and pits) were monitored over time and an assessment was made of the efficacy of these structures in conserving the wet weight, storage potential and culinary quality of fresh yam tubers of different size categories. In all, four yam varieties were observed; two varieties of *D. cayenensis-rotundata* (Krenglé and Lokpa) and two of *D. alata* (Bètè bètè and Florido). Only healthy sound yam tubers were initially selected for storage trials and, according to the nature of experimental design, yam tubers were subsequently treated with thiabendazole to control fungal infections (dipped in 500 p.p.m. for 30 minutes) and deltamethrine (Decis-SOFACO) to control insects (dipped in 25 p.p.m. for 30 minutes), had their sprouts removed during storage to reduce their rate of moisture loss or were treated with the phytohormone - giberellic acid (GA_3) to suppress sprouting altogether. Experiments comparing the qualitative and quantitative losses of fresh yam tubers recovered from the various storage environments were monitored during two storage seasons in 1992-93 and 1993-94.

It was observed that although the mean temperatures recorded in both pit and shed storage structures were very similar, the range by which diurnal temperatures fluctuated was reduced in the pits structures in comparison to sheds (21.5 to 27.6 and 19.7 to 32.4°C respectively). With respect to levels of relative humidity, again the range of diurnal variation was much greater in storage sheds than in the pits. Data recovered over two storage seasons suggests that the mean relative humidity in pits varied from 76.2 to 99.3%(RH) while that of the sheds fluctuated from 57.8 to 92%. Overall the relative humidity was found to be greater in pits than for the above ground structures particularly after the start of the rainy season.

After a period of 6.5 months, the gross moisture loss from tubers of the *D. cayenensis-rotundata* varieties held in sheds was significantly greater than that observed in either pits or barns. With relative weights at the end of the trails being 40.7, 53.5 and 52.7% respectively of their original pre-storage values. More detailed analysis by Girardin *et al.* (1996 in press) notes considerable variation in response of varieties of yam from one season to another. Within any particular season the absolute fresh weight loss and rate of moisture loss was influenced by both the variety and size of tubers. As seen in the results presented by *Doumbia et al.* (pers. comm. 1996) and confirming observations made by the FAO (1985), the storage potential of the *D. cayenensis-rotundata* varieties was less than that of the *D. alata*. *Dioscorea cayenensis-rotundata* specimens showing a greater susceptibility to rots. The nature of the storage structure was shown to have a significant impact on the rate of moisture loss especially during early storage with the rate of weight loss in pits being some 40-50% less than that observed in the sheds. Following the germination of yams sprouts the rate and extent of weight loss was found to be a function of both variety and storage structure. Although not traditionally practised in Côte d'Ivoire, the removing of yam sprouts throughout the storage season was observed to help reduce gross weight loss from tubers in comparison to those that were not de-sprouted.

Reduction in weight loss of tubers during storage may also result from successful pre-storage curing of tubers (see Section 7 below). In the absence of curing *D. rotundata*, held for 113 days under ambient conditions in Jamaica, were observed to loose 39.2% of their weight. Similar studies on *D. cayenensis* (Thompson, A.K. unpublished) indicated not only that curing is able to ameliorate weight loss but that the effect was also influenced by varietal characteristics (see Table 11).

Table 11. Percentage weight loss of two varieties of *Dioscorea cayenensis* during 105 days storage in Jamaican under ambient conditions of 25 to 34°C and 64 to 95% Relative Humidity (RH).

Conditioning Treatment	*Variety*	
	Roundleaf	Common
Cured[+]	18.0	30.3
Not Cured	22.4	44.5

[+]Curing conditions were 35 to 40°C and 95 to 100% RH for 24 hours

When considering the available information that seeks to quantify and describe the postharvest losses of yams very little data has been published that addresses the socio-economic components of the system. One recent study conducted by in Nigeria (Okoh in press 1996) does suggest that postharvest losses of the order of 12.4% (3.2% of tubers absolutely wasted and 9.2 % of tubers unfit for commercial sale) could equate to a loss of 10.45% of the expected gross revenue for the farmers affected. To determine the economic viability of introducing different forms of technical interventions into existing indigenous yam production and marketing systems more studies are required to determine the economics realities faced by the producers and traders.

3. Export Grading and Handling

International trade in yams has been increasing over the last few decades. The principal exporters being Barbados and Jamaica in the Caribbean, Brazil and the countries of West Africa particularly Côte d'Ivoire, Ghana and Nigeria. The majority of this trade is directed at the African, West Indian and Asian expatriate and immigrant communities that have developed in Europe and North America particularly in the USA, and UK but also to a lesser extent in Canada, France and the Netherlands. There are few available statistics quantifying the present volume of trade particularly from the major producers in West Africa but a report prepared by Ghartey (1995) provides some interesting insights into the recent development and future potential of the yam export trade originating in Ghana. In the past the volume of exports from Ghana has been small and variable from year to year. Recent trends, however, indicate a sustained growth in annual exports from 2,122 metric tonnes in 1990 to 3574 and 5323 tonnes in 1993 and 1994 respectively. During this period the commercial value of this trade has risen from an estimated US$ 969,855 in 1990 to US$ 3,059,614 in 1994.

Although potentially an increasingly important foreign exchange earner for Ghana, Ghartey (1995) identifies a number of technical constraints within the existing system that impinge on the success of the export trade. Many of these problems stem from a lack of knowledge and experience throughout the production, transport and marketing chains and are likely to be similar to those encountered in other yam exporting systems. Considerable spoilage of yam tubers has been observed by importers (Bancroft pers. comm. 1996) and, although a proportion of these losses are likely to be due to improper handling and storage prior to retail sale, the evidence suggests that the source of the problem often lies with improper grading of tubers at the point of harvest, failure to ensure sensitive handling of the merchandise during transportation and storage and, inadequate packaging. In the light of his observations, Ghartey (1995) made some recommendations to improve the selection and grading of yams for export in Ghana. He suggested that yams should be:

- fresh, intact, firm to touch,
- weigh between 0.5 and 4.5 kg,
- between 300 to 450 mm in length,
- free from surface cuts, bruises, skin burns, "sleeper" and other signs of deterioration,
- free from external moisture,
- free from sprouting and hair/roots,
- free from insect infestation, nematode gall and microbial infection,
- free from outgrowths and visible buds,
- free from soil,
- and that the skin should be of a uniform coloration

Table 12. An optimum handling system for the export marketing yam tubers (Source: Medlicott - undated).
• No yams are to be exported which have been harvested more than 14 days prior to

shipment;
• Yams to be graded in the field to remove damaged or diseased tubers;
• If transported to the packing facility in sacks, the yams to be transferred immediately to field crates;
• Tubers to be washed by hand in water to remove all soil, and the excess "hairs". Water to be changed regularly to prevent the build-up of soil and contaminants;
• After washing, tubers to be placed in field crates and dipped in a solution of 0.05% thiabendazole for 15 to 30 seconds;
• After washing and fungicide treatment, the crates are to be left overnight in a well ventilated area to enable drying of the tubers; wet or damp yams should not be packed into cartons;
• After packing in cartons, the yams are to be left under ambient conditions to cure for three to six days; No yams cured for less then three days should be exported, and these should be delayed until the following shipment;
• During sea-shipment and storage the required temperature is 12° to 13°C."

A somewhat more detailed general methodology has been proposed by Medlicott (undated). See Table 12. In very many instances the technical requirements that would safeguard the quality of the merchandise are not in themselves difficult to address. What is often lacking is an appreciation by personnel involved in the handling of the goods of the importance of various protocols. In some circumstances the resolution of such problems often depends on education and the dissemination of appropriate knowledge and management skills, in others, the lack of capital and other resources is likely to prevent the adoption of more sound packaging systems.

4. Packaging

In common with other bulky horticultural produce, the use of various designs of cartons have proved to be possibly the most efficient and economic means of packaging and transporting yams.

Cartons to be used in the export of yams from Jamaica have been studied by Thompson *et al.* (1979). Trial shipments, supported by laboratory tests, demonstrated that a particular design of fibreboard box could reduce damage to the tubers and improve the cost-effectiveness of the transport operation. At that time, their recommendations were that the carton in use should be redesigned from the telescopic box (Code 0320) with internal dimensions of 456 mm x 406 mm x 203 mm(high), to either a one piece slotted box (Code 0201) or a two piece telescopic box (Code 0320), but with different dimensions. The dimensions suggested were 480 mm x 316 mm x 280 mm (high). These designs would allow for the use of less board, be more ridged and facilitate bonded stacking. Thompson *et al.* (1979) also proposed that the material used should be 69/33/69 lb. per 1,000 square feet.

In the context of the Ghanaian yam export market, Ghartey (1995) has recommended packaging in fibreboard cartons with the following specifications: A half slotted telescopic carton with an internal volume of 53.6 litres inner dimensions of 555 x 370 x 267 mm (high). The material to be a double wall with an outer surface of 300 ± 50 g m^{-2} capacity and sufficient ventilation holes to permit the free passage of air.

For the marketing of yams, Medlicott (undated) has recommended a two-piece full telescopic corrugated carton, preferably double walled ("banana" type) or a one-piece self-locking waxed carton, of dimensions: 20 x 51 x 34 cm or 29.5 x 44 x 29.5 cm. He gave the specifications as to a bursting strength of 275 to 300 lb. in^{-2}, with higher values being required for long term storage and sea-shipment. Where metal staples were to be used in carton construction, care was advised to ensure complete closure of the staples to avoid tuber damage.

As regards stowage, Medlicott (undated) recommended that, assuming that the minimum size specifications were attained, yams should be loosely packed with no separation of size grades. Depending on the market and importer requirements he also suggested that net weights in each box should be 12.6 or 18.2 kg. For sea-shipment, an additional 5% packing weight was considered appropriate to account for weight losses during storage and transport. Cartons should not be overfilled during packing.

The packing yams in coir dust for the export market was investigated in Jamaica (Thompson unpublished results) and is now commonly used. The coir preserves the tubers and has also been shown to be an essential adjunct to postharvest fungicidal treatments. In this context, the coir dust absorbs any excess fungicide on the surface of the tubers thus preventing possible spoilage from bacterial rots that may develop if the tubers are packed wet (Thompson *et al.* 1977).

From time to time other packaging and coating materials have been investigated for use with yams. The wrapping of yams in polyethylene bags has not proved successful for, although sound tubers loose little moisture when stored in this manner, fungal growth on the surface of the tubers is often considerable. On occasion it may be that there would be some benefit in the use of plastic bags on yams in conjunction with fungicides and reduced temperature storage (Thompson *et al.* 1977). The waxing of yams with emulsions such as Epolene (an E10 vegetable wax) have also been tried, however, although the waxed tubers had a good outward appearance, the treatment was not observed to reduce postharvest rots and the effect on moisture loss was inconsistent (Thompson *et al.* 1977).

5. Damage During Handling and Transportation

By their size and very nature yam tubers are vulnerable to mechanical damage during production, handling and storage operations. In an investigation into the consequences of the poor handling of yam (Thompson 1972a) demonstrated that subjecting tubers to the level of impacts, commonly encountered during handling, resulted in greatly increased losses during subsequent storage (Table 13).

Table 13. Effects of dropping tubers of *Dioscorea trifida* from a height of 2 meters onto a concrete floor on their subsequent losses during storage at about 28 °C for 64 days (Source: Thompson 1972a).

Treatment	Fresh weight loss (%)	Fungal score+	Internal necrosis (%)	Sprouting %
Dropped	47.5	1.5	61	64
Not dropped	23.6	0.2	5	97

+ Mean of 7 weekly observations where 0 = No mould and 5 = Tuber surface covered in mould.

The contribution of modules of deformability, bioyield strength, rupture strength and density of yam tuber in predicting failure conditions for the flesh which will result in damage under dead and impact loading has been described by Nwandikom (1990). The invariable consequence of such mechanical damage is the infection of the cortical tissues of the yam by pathogenic and saprophytic micro-organism leading to quality depreciation and absolute losses. Mozie (1981/1982a) showed that micro-organisms that can cause rot on yams do not enter through a sound unbroken skin, and also the more serious the injury the more rot and weight losses can be expected during subsequent storage.

In a survey conducted in rural districts of Ghana, the distance from the yam farms to the nearest road was found to be of the order of 2 to 7 miles (Anon, 1994a). Movement of produce over such distances and onto the local markets or points of sale were generally by headload, bicycle and lorry. A questionnaire of producers suggested that 35% of respondents relied on headloads as their only means of transporting yams from the farms, whereas 17% cited the use of headloads and bicycles, and a further 13% used headloads, bicycles and cars or lorries (trucks) to transport their produce. Depending on the area surveyed, so accessibility to vehicular transport changed. In one district 20% of the farmers interviewed transported their yams exclusively by lorry and another 54% mentioned the use of lorries as an option, while in a contrasting district 45% of farmers had no access to other forms of transport and, as a consequence had to carry their yams by headload. In this particular survey no assessment was made of the extent of damage incurred by the yam tubers as a result of these various modes of carriage and indeed there seems to be no published studies that have attempted to quantify such losses. It is generally assumed, however, that much of wastage of tubers that occurs later on during subsequent storage, transportation and sale may be attributed to deficiencies in the handling protocols along these traditional marketing chains.

Research undertaken by Thompson (1972a) in Jamaica provides some insights into the consequences of poor transport and handling protocols associated with the export trade of yams. In this instance, the areas of yam production were some 60 to 100 km from the central packhouse where the produce was loaded into full telescopic corrugated cartons in readiness for shipment overseas. Transport from the field to the packhouse was by truck in which the tubers were originally loosely stacked without recourse to any packing material. An assessment of this process revealed that only 49% of the yams handled in this fashion were suitable for export by the time they reached the packhouse and that the rejects had to be sold on the local market at a lower price than those accepted for exported. When the yams were harvested directly into boxes in the field and transported in the same boxes to the packhouse the proportion of the consignments that were of export quality rose to 84%. A financial analysis of the new system showed that the extra cost of the boxes required to safeguard the quality of the tubers was easily offset by the increased revenue recovered as a consequence of the higher proportion of exportable tubers.

Although published data is not available, it is likely that similar if not greater rates of quality depreciation occur in all yam producing areas. Anecdotal evidence gathered in Ghana (Gray unpublished 1996) suggests that delays and lack of transport, inappropriate modes of transport and poor infrastructure have a profound impact on the domestic marketing of yams and are not an insignificant factor contributing to the poor quality of yams collected for export (Ghartey 1995). With regard to the inter-regional and international trade in yams, if economically viable, transport is possible either by air or sea. Sea transportation is the more common option requiring refrigerated holds or reefer containers with the inlet air temperature set at 13°C (Thompson 1972a, Medlicott undated and Ghartey 1995). Once again data recording the rates of loss of yams incurred during such shipments is not readily available and the true extent of the problem remains to be determined.

6. Marketing and Market Requirements

Information published by Alhassan (1994) and Anon (1994a) has suggested that in certain rural yam producing areas of Ghana, although some 52% of yam farmers considered yams as their principle cash crop, the incentive to produce tubers for commercial sale varied considerably between farmers and was often location specific. In the more rural areas with less ready access to roads or transportation, the proportion of the total crop sold commercially could be of the order of 24 to 30%. In more favoured yam producing locations commercial sales rose to 60-76% of the crop with the residue being used for home consumption. Surveys indicate that the producer's choice of yam variety was generally a compromise between culinary quality and storability. From a commercial standpoint an average of 34% of producers sold their produce from the farm gate. Another 31% of farmers marketed their tubers both from their own farms and at markets and the remaining respondents (35%) habitually transporting their produce to market for sale. Data collected in the Brong Ahafo Region of Ghana (Anon 1994a) suggested that, on average, only 5% of the commercially available yam crop was sold by the producers directly to private consumers and that 74% of all sales were exclusively to traders who then became the main agents in the nation-wide distribution of yams which ultimately led to both domestic and export sales. Some 21% of sales were apparently a mixture of transactions with consumers and traders. In this particular economy the producers are invariably the passive partners relying very much on the custom of the traders and middlemen to ensure the timely sale of their produce. As a consequence it is the traders who manipulate trends within the marketing system by accepting or rejecting particular qualities and varieties of yam in accordance to market pressures. Absolute quality standards are not enforceable and the day to day standards of produce vary throughout any given period in accordance with the seasonal availability of supplies and consumer demands.

The situation is very much more finely controlled when the export market for yams is considered. For example Medlicott (undated) listed 6 specific quality requirements for export the export of yams as follows:

- All soil removed,
- Skin intact over 90% of the surface,
- No harvest wounds,
- No soft rots or surface mould,
- No chemical residues, and
- No insect marks or borer damage.

In terms of size of tubers and varietal preferences, it has been suggested that the UK market prefers large tubers packed to 18.2 kg and that the Caribbean variety White Lisbon is preferred to Red Lisbon (both *D. alata*). In contrast importers in Holland and Canada find a wider range of sizes and varieties acceptable.

Ghartey (1995) mentioned 8 varieties of yam (all *D. rotundata*) exported from Ghana but indicated that 'Puna' was the variety preferred by importers because of its high quality in terms of flavour, texture and better taste. This was claimed to give Ghana a competitive edge in marketing since it is the only country to supply this variety.

7. Curing

The term curing in root and tuber crops is used to describe their exposure to comparatively high temperatures (30-40°C) and humidities (80-95% RH) for short periods with the intention of enhancing their subsequent storage life. Its effect is to encourage rapid wound healing through cell suberization and periderm formation which retards water loss and acts as a barrier to invasion by micro-organisms.

Curing was originally developed for potatoes (Priestley and Woffenden, 1923) and sweet potatoes (Artschwager and Starrett, 1931) and has become an accepted commercial practice. More recent observations (Gonzales and de Rivera, 1972; Thompson, 1972b; Thompson *et al.*, 1973; Martin, 1974) have indicated that such curing processes can be beneficial in the storage of yam. Work on the two species, *D. rotundata* and *D. cayenensis,* showed that exposure of the tubers to 35 to 40 °C and 95 to 100 % RH could initiate the curing process (Been *et al.* 1974, Been *et al.* 1976). The gross effect of which was to form a suberized layer and a cork cambium in a similar way to that reported for potatoes (Figure 1) (Thompson *et al.* 1977). As a consequence, cured tubers have been shown to exhibit a lower weight loss throughout storage compared to those which had not been cured (Figure 2). Osagie (1992) cites work undertaken by Ikediobi *et al.* (1989) and Knobloch *et al.* (1989) that describes the related biochemical and bio-physiological changes that occur during the wound healing process in yams. This topic remains under-researched and much is still to be discovered regarding the mechanisms that control wound healing and how the process may be influenced by external environmental conditions. One intriguing set of observations suggests that light of various spectra may influence the rate of periderm formation in yams (Osagie 1992). Irradiation with red light appeared to be less beneficial than that of the yellow, green and blue spectra. These latter wavelengths appearing to enhance the curing process and suppress spoilage.

Figure 1. Histological sections through the cut surfaces of yam tubers (*Dioscorea cayenensis*) after 7 days curing and 8 days subsequent storage. Curing conditions were either: A: direct sunlight, B: 26 °C and 66 % RH, C: 30 °C and 91 % RH, or D: 40 °C and 98 % RH (Thompson *et al.* 1976).

Figure 2. Effect of curing at 35 to 40 °C and 95 to 100 % RH compared to tubers which were not cured on the rate of weight loss of yams (*Dioscorea rotundata*) during storage in Jamaica under ambient conditions of 25 to 34 °C and 64 to 92% RH (Source: Thompson *et al.* 1972a and unpublished data).

Passam *et al.* (1976) found that curing of *D. rotundata* tubers occurred over a range of temperatures, with periderm formation occurring within 4 to 5, 5 and 7 days at 35, 25, and 17°C respectively. Humidity levels were not specified. It was also demonstrated that under these conditions curing was only effective on relatively deep wounds such as those inflicted by knife-cuts while superficial wounds (peeling and abrasion) dried, but did not heal further. These researchers postulated that the efficiency of curing process was not only a function of periderm regeneration on the cut surface of yams but that the formation of both a starch and suberin layer was also necessary to ameliorate water loss and that the more successful and complete the curing process the greater the impact on moisture loss. In this regard it would appear that the wrapping of damaged tubers in of polyethylene bags or films was not desirable as the latter appeared to have not only a detrimental effect on the wound healing process (to the extent that in the longer term the rate of moisture loss was not reduced) but also encouraged mould growth on the damaged surfaces of yams.

With reference to *D. alata*, Gonzalez and de Rivera (1972) have recommended exposures of 29.4 to 32.2 °C and 90 to 95 % RH for about four days to affect curing. In subsequent storage at 15 to 19 °C and 70 % RH they reported that cured tubers lost approximately 11 % of their weight after 190 days while tubers which had not been cured lost on average 23 % in 150 days.

The practical deployment of curing environments suggest that the process could be used commercially. Akoroda (1995) described curing over a 6 day period in a crib covered with a tarpaulin where the conditions varied between 24 to 36 °C and 60 to 95 % RH. As a result of such simple pre-conditioning, during subsequent ambient storage, the losses of tubers to rotting organisms were observed to be less in cured tubers than in the controls. Hahn *et al.* (1993) has also mentioned a method of curing which involved spreading tubers out evenly in the shade for 2 or 3 days after harvest, a procedure not dissimilar to that traditionally practised by some farmers in West Africa, who cure their yams after harvest by exposing them to direct sunlight for 1 or 2 days before storage.

Ravindran and Wanasundera (1993) were successful in curing the fresh tubers of 6 cultivars of *D. alata* and 3 cultivars of *D. esculenta* by simple exposure to sunlight for 3 days after harvest under ambient conditions which averaged 29°C and 84% RH. They did, however, report problems of bacterial soft rots developing on cured tubers during subsequent storage, but this was overcome by loading the tubers into a curing room, heating them to the curing temperature and then injecting the steam to increase the humidity (Cecil, J. unpublished FAO report). Tubers cured in this way had reduced weight loss, reduced fungal infection and reduced necrotic tissue after storage compared with tubers which had not been cured. When stored at tropical ambient temperatures, these tubers did, however, produce sprouts approximately two weeks earlier than the controls, a response that could have been due to the increased cambial activity associated with the curing process (Thompson *et al.* 1972b).

8. Diseases

Rot causing organisms

Yams are susceptible to predation and attack from a range of pests and diseases. In the field the vines and foliar portions of the plant may be damaged by systemic virus infections and fungal pathogens (such as *Colletotrichum* spp.). Postharvest, tubers are susceptible to a range of rot causing organisms. Anon (1986) reported 16 genera of micro-organisms associated with dry rot, watery rot and soft rot of yams plus internal brown spot, which has been associated with virus infection, while Thompson *et al.* (1977) has reported 15 different genera of fungi in association with the storage deterioration of yam tubers. From more than one thousand rot samples of root vegetables on the Orissa markets 11 fungal species were isolated and associated with 22 different host-pathogen combinations. Typical rots on yams caused by species of *Aspergillus, Botryodiplodia, Fusarium, Penicillium*, and *Rhizopus* have been described by Noon (1978). In later work spoilage of yam tubers has also been shown to be initiated by *Aspergillus niger*, *Rhizopus arrhizus*, *Rhizoctonia solani* and *Sclerotium* (*Corticium*) *rolfsii* (Mishra *et al.* 1989).

Symptoms of the more common fungal rots are exemplified by the spoilage associated with *Rhizopus oryzae*, a disease often found on tubers that have been harvested from soil with a high moisture (Moura 1987). Following infection, a wet necrosis develops in the cortex of the tubers, in the case of *R. oryzae* this is almost always in the growth zone of the tuber. Later the internal tissues of the tuber begin to breakdown with a white mycelium appearing on the necrotic area, particularly during storage. Another storage rot of yams, commonly referred to as 'dead skin', has recently become a major constraint to yam production in the Caribbean. The fungal pathogen *Colletotrichum. gloeosporioides* (*Glomerella cingulata*) has been consistently isolated from affected tubers. Unlike the soft or wet rots, the symptoms here are dry with portions of the outer skin of infected tubers becoming corrupted and desiccated (Green and Simons 1994).

Methods of infection and conditions for growth

The sources of inoculum which may lead to tuber infection, colonisation and eventual spoilage are considered to be widespread in the field and storage environments. It is thought likely that the external surface of tubers become contaminated both in the field and when placed in stores. In the absence of infection and the appropriate conditions of temperature and humidity to promote the development of disease, tubers may remain sound until natural physiological deterioration and senescence occur following sprout germination and the development of the vine. Should tubers be physically damaged or subject to physiological stress, their natural resistance mechanisms are likely to become compromised prematurely and spoilage may result. This is particularly noticeable when tubers are stored in pits or clamps. Under these circumstances damage and losses associated with insect pests and rodents may be reduced but the destruction of tuber resulting from the continued action of nematodes and the rotting organisms can be exacerbated.

In a study to investigate the importance of wounding in the genesis of spoilage, Mozie (1981/1982a) monitored the development of soft rots on tubers of *D. rotundata* over a storage period of 40 weeks. After 36 weeks in store all those tubers that had sustained serious cuts had become infected, while only 80% of those with slight cuts showed symptoms of soft rot and none of the undamaged specimens showed signs of decay.

The optimum conditions for the development of fungal rots on yams have been reported to be between 26 to 30°C and 80% RH and higher (Ogundana *et al.*, 1970). Burton (1970) has suggested a somewhat lower temperature threshold with a range of 22 to 29°C. It is probable that each particular spoilage organism will have slightly divergent optimum requirements, for example Noon and Colhoun (1979), showed that *B. theobromae* is an important yam pathogen at 35°C while at 20°C or lower it is of little significance. The rate of spread of fungal lesions has been associated with prevailing levels of relative humidity, or, more precisely, the vapour pressure deficit of the atmosphere. In drier conditions the rate of spread of rots may be diminished, however, this may also lead to accentuated water loss on account of increased evapo-transpiration. Slight modifications in the levels of humidity found within yam stores have been shown to have a profound effect on the rate of development of rots. Adeniji (1970) reported considerable reductions in fungal rots when tubers were stored in such a way that free air circulation was maintained throughout consignment as compared to those losses incurred when tubers were simply stock-piling on the floor of a shed. Environments that permit the formation of condensation on the surface of tubers will generally result in greater losses on account of the increased incidence of rots.

Disease control

In common with other horticultural crops, the yield, storage potential and effective control of postharvest diseases of yams can be enhanced by sound preharvest cultural practices and effective levels of phytosanitation both in the field and during storage. Traditional inter-cropping of yams with other species together with rotations and patterns of shifting cultivation are strategies believed to help reduce the build up of nematodes and diseases in yam plots. In this regard, the present move to more intensive sedentary farming systems is likely to increase not only the incidence but also the spectrum of diseases that impact on fresh yams.

In the absence of commercial chemical control measures many traditional societies have used and continue to use wood ash and lime (calcium hydroxide) dusts to coat tubers after harvest in order to facilitate wound healing and ameliorate the rate of spread of postharvest rots. Both Coursey (1961) and Thompson (1972a) cite these practices in Nigeria and Jamaica respectively. As a result of a 5 month storage trial, Nnodu and Nwankiti (1986) reported that the use of wood ash slurries or the postharvest dipping of tubers in 10% sodium hypochlorite were as effective as treatments with benomyl or thiabendazole in controlling weight loss and tuber rot. Reports such as these suggest that the traditional methodologies, including the use of indigenous herbal compounds, can be effective, however, there has been little research done to investigate these processes in any great detail or determine to what extent the efficacy of such practices could be increased.

In terms of conventional postharvest chemical control strategies the use of thiabendazole and benomyl (benlate) have been found effective. Dumont (1995) has shown that thiabendazole gave some control of postharvest diseases of yams. Monitoring tubers of *D. alata* he observed that those treated with thiabendazole and an insecticide lost 23% to rots as opposed to the 72% wastage recorded for untreated tubers. Similar trials with *D. cayenensis-rotundata* resulted in losses of 39 and 81% for treated and untreated material respectively. Thompson *et al.* (1977) have also shown that benomyl and thiabendazole reduced storage rots of yams. Anon (1982) recommended the use of benomyl, thiabendazole or captan at concentrations of 500 to 1,000 p.p.m. and Osagie (1992) cites the use of benomyl and thiabendazole at rates of 100 and 250 p.p.m. respectively for the control of rots. Studying the effects of TBTA (n-tributyltin acetate), Olurinola *et al.* (1992) have reported a significant reduction in the rate of growth of 4 yam rot fungal isolates (*Aspergillus niger*, *A. flavus*, *Penicillium citrinum* and *Rhizopus stolonifer*) both *in vitro* and *in vivo* with the *in vitro* toxicity of TBTA being reduced when 2.5% Tween 80 was used.

On occasion, the application of some chemicals has been shown to actually lead to an increase in the level of disease. An example of this is the postharvest application of dichloran to control postharvest diseases of yams (Thompson *et al.* 1977). The reason for the increase (Figure 3) was probably due to synergy between the various organism which were infecting the tuber.

Figure 3. Effects of fungicidal treatment on (a) the weight loss and (b) the level of surface fungi on yams (*Dioscorea rotundata*) (Source: Thompson *et al.* 1977).

Fungicide resistance

The genetic potential of fungi are constantly changing and, where a chemical fungicide is frequently used, strains of fungi do develop which are tolerant to that particular product. This has been observed on a number of occasions and particularly with reference to the benzimidazole group of fungicides. In the past, benomyl, which is a member of the benzimidazole group, has been used extensively to control postharvest diseases of yams (Thompson *et al.* 1977). Following the prolonged commercial application of the chemical, however, a rot caused by infection with *Penicillium sclerotigenum* began to be observed on yam tubers. *In vitro* studies by Plumbley *et al.* (1984 and 1986) identified the emergence of a strain of *P. sclerotigenum* tolerant to benomyl (Figure 4) and this was confirmed by tests *in vivo*. In this particular instance control of the pathogen was achieved by the use of the fungicide imazalil (Table 14) but this example illustrates that resistant forms of many common pathogens are likely to develop in the future and that multiple resistance to the relatively small range of postharvest chemicals now commercially available is a real risk. Further more, increasingly stringent controls on the acceptable levels of fungicide residues on edible products and growing concerns regarding possible long term health hazards associated with the use of chemical are likely to restrict their widespread use even further.

Figure 4. Colony size of *Penicillium sclerotigenum* Yamamoto on potato dextrose agar containing different concentrations of benomyl after 14 days growth at 25 °C (Source: Plumbley *et al.* 1984).

Table 14. Effects of benomyl and imazalil on the growth (in cm) of a benomyl tolerant strain of *Penicillium sclerotigenum* on yam tubers (*Dioscorea cayenensis*) during storage at 20 °C (Source: Plumbley *et al.* 1984).

Treatment	Storage period in days			
	7	14	21	28
Control	1.10	2.20	3.19	3.66
Benomyl (500 p.p.m.)	0.83	1.87	2.05	3.49
Benomyl (1000 p.p.m.)	0.60	1.34	2.35	2.99
Imazalil (500 p.p.m.)	0	0	0	0
LSD (P = 0.05)	0.56			

9. Insects

Insect pest and nematodes may also reduce yields and quality of yams by infesting the aerial sections of the plant, the base of the vine and the tubers. Feeding insects can cause economic losses both in the field and postharvest. The pests most often cited include yam beetles, termites, mealy bugs, scale insects, coffee bean weevils and yam moths.

Emehute (1995) reviewed the species of insects which can attack stored yams in Nigeria and described the types of damage for which they are responsible. Insects of the families *Tineidae* and *Pyralidae* (*Lepidoptera*), *Anthribidae* (*Coleoptera*), *Stratiomyidae* (*Diptera*) and *Chalcididae* (*Hymenoptera*) were all observed to emerge from the pulp of stored tubers of water yam (*D. alata*) with the majority of the damage being incurred by larvae feeding within the tubers. In most cases the early signs of infestation are external holes filled with larval faecal matter (frass) held together by silken threads (Iheagwam and Wojtusiak 1989). Tubers with cut surfaces have been found to be more prone to attack by *Lepidoptera* than those with unbroken skin, possibly because 1st-instar larvae were unable to penetrate the skin of the latter.

In other work, insect pests which were found on, or which emerged from, stored yams in Nigeria included *Dasyses incrustata*, *Setomorpha rutella*, *Aspidiella hartii*, *Planococcus citri*, *Araecerus fasciculatus*, *Tribolium castaneum*, and a number of other species, including braconid parasitoids (Iheagwam 1988). *Dasyses rugosella* has also been reported to be a pest of stored yams in Nigeria by Iheagwam and Ezike (1989) and additional observations by Nwankiti *et al.* (1988) and Plumbley and Rees (1983) respectively also cite *Phenococcus citri* and *Decadarchis minuscula* as probably the cause of problem in fresh yams stored in traditional barns, again in Nigeria.

The percentage of moth larvae infested *D. alata* tubers on sale at Nsukka market, Nigeria were shown to increase continuously from February to reach a peak of 54% in June with an overall average of 12.62% of all tubers that were sampled being infested. Since badly infested tubers are not generally offered for sale on the market, the actual losses incurred on account of the moths must be expected to be much higher than that revealed during the study (Ezike and Iheagwam 1988).

In Barbados, *Opogona sacchari* was found damaging the tubers of the *D. alata* cultivar White Lisbon in store, although tubers of the cultivar 'Oriental' found in the same building were unaffected. White Lisbon tubers with dead skin were preferred by the insect to those of White Lisbon with healthy skin or Oriental tubers. The extent of internal damage by the larvae appeared to influence the degree of tuber sprouting and consequent growth of the shoot. It was recommended that these pest be controlled by dipping tubers in an 85% solution of Sevin (carbonyl) WP at 1 kg per 200 litres of water, or by covering tubers with lime and/or ash (Gibbs 1991). In general, where chemical controls are an option, permethrin and malathion are often used to counter insect infestations while, for yam exports from Ghana, Ghartey (1995) suggested fumigation with methyl bromide at 12 g m^{-3} $hour^{-1}$ for 4 hours at 28 ± 2 °C.

10. Nematodes

Nematode diseases caused by *Scutellonema bradys, Meloidogyne incognita* and *Pratylenchus spp.* adversely affect the surface tissues of yam tubers both during the development of the crop in the soil and later during postharvest storage. A correlation has also been observed between nematode damage and the incidence of postharvest rots, for once micro-organisms have gained access to the cortical tissues of the yam the latter provide a particularly favourable substrate for further development.

In West Africa, as a general rule, FAO (1985) claimed that storage losses of yams in the savannah zone were fewer than in those experienced in a forest environment. This has been attributed to the lower incidence of the *Scutellonema* nematode and to the tendency for yams grown in drier environments to have a higher dry-matter content. This may be an important consideration as regards the choice of yam producing areas in the future.

In their own right, field infestations by nematodes can cause a hard and dry necrosis in yam tubers during storage that is quite distinct from and not a consequence of fungal or bacterial spoilage (Thompson *et al.* 1973). Assessments of such damage can be used to determine the level of activity of nematode populations. Another method that has been used experimentally by Fawole and Evans (1989) is to monitor the oxygen uptake of yams during storage. Working with *D. rotundata* cultivars Nwopoko and Obioturugo: and *D. cayenensis* cultivar Ukom Manu, they observed that the oxygen consumption of tubers heavily infected with root-knot nematodes was significantly higher than those that had not been infected. As a consequence, they postulated that there might be a correlation between the rate of oxygen consumption and the level of damage being caused to the tubers as a result of the feeding activity of the nematodes.

The severity of damage caused by parasitic nematodes in yam tubers has been shown to be temperature dependant with greater levels of damage resulting when tubers were stored under tropical ambient conditions. In contrast, when tubers were maintained at
13 °C there was no increase in nematode populations in the tubers and, as a result no increase in necrosis (Thompson *et al.* 1973).

Different measures have been advocated for the direct control of nematodes. Chemical treatments are available but carry with them the danger of persistent toxic contamination of the tubers. Hot water treatments have also been tested experimentally particularly as a means of generating disease-free seed yams but, to date, this technology does not appear to have been widely disseminated.

Onyenobi (1987) studied the effectiveness of the nematocide Vydate L (oxamyl) in controlling the damage caused by root-knot nematodes (*Meloidogyne* spp.). In this work infested tubers of *D. rotundata* were dipped in different concentrations of Vydate L for various periods of time with and without the use of hot water. Over a time span of 5 months, sprouting, weight loss, rotting and the loss of edible portions of tubers were monitored. To conclude, Vydate L was found to be an economical and safe method of controlling postharvest nematode damage in ware tubers.

The compounds phorate and thionazin have also been assessed for their efficacy in suppressing *S. bradys*. During the storage of tubers of *D. alata*, in contrast to the controls, concentrations of 1000 and 2500 p.p.m. of phorate and thionazin were observed to completely suppress nematode activity in yams some 3 and 5 weeks after treatment. As regards the level of residues remaining on the tubers, no appreciable (*sic*) amounts of thionazin were found but varying concentrations of phorate and its degradation products were detected (Adesiyan 1981).

11. Sprouting

A major feature of yams is a natural period of dormancy between harvest and the sprouting of new vines with the length of such dormancy being characteristic of each variety. At the termination of dormancy, the tempo of respiration and metabolic activity within tubers increases and tissues become more prone to physiological deterioration and decay as the resistance of their tissues to microbial attack diminishes.

The pre-harvest nutrition of the yam crop has been shown to influence the propensity of yams to sprout. Kpeglo *et al.* (1980) showed that high levels of nitrogen (90 kg hectare^{-1}) increased percentage sprouting in *D. rotundata* during subsequent storage while the application of potassium and phosphorus tended to delay sprouting and increase the storage life of yams by approximately 3 to 5 months. Time of harvesting may also effect the dormancy period with delays in harvesting invariably resulting in a decrease in the potential dormancy period. In an attempt to extend dormancy premature harvesting may sometimes be practised, however, this in itself may not only diminish the yield of the crop but also have an adverse effect of the culinary quality of the tubers.

Different authorities cite different nominal dormancy periods. Thompson (pers. comm. 1996) suggests that the longest dormancy periods may be in excess of 7 months whereas Hahn *et al.* (1993) claimed that under normal circumstances tubers may remain dormant for some 10 to 15 weeks. Mozie (1986) study the dormancy of tubers held in a conventional barn maintained at 20 and 25 °C could only report an unsynchronised pattern of germination while Muzac-Tucker *et al.* (1993) working with 11 cultivars derived from tubers of *D. alata, D. cayenensis, D. esculenta, D. rotundata* and *D. trifida* grown in Jamaica found that these remained dormant for 5-8 weeks when stored on shelves indoors at 27 °C and 11 weeks if held at 20 °C in the dark when storage followed postharvest washing and sun-drying. It is likely that a number of factors together influence the dormancy potential of any particular crop although genetic disposition will be by far the most important. During observations in Jamaica it was found that *D. cayenensis* had a consistently shorter dormancy period than *D. rotundata* (Thompson unpublished data) despite the fact that the rate of oxygen uptake in stored *D. rotundata* was significantly higher than in *D. cayenensis* (Fawole and Evans 1989) which would appear to contradict the observation.

Temperature.

Pre-harvest and storage temperatures are considered to have a very significant impact on the dormancy potential of yams. It has already been mentioned that, although not extensively researched, FAO (1985) have suggested that yam cultivars grown in the savannah zones of West Africa suffer lower postharvest losses than those of the forested regions. This response to the hotter and drier conditions characteristic of the savannah may also be related to the longer endogenous dormancy associated with the yams grown in these areas quite apart from the reduced incidence of nematode infestations.

A number of studies have been conducted to determine the impact of controlled temperature regimes on the storage potential and length of dormancy of yams. In comparison to tubers maintained at 30 ± 2 °C, those held at 20 ± 2 °C have been observed to remain dormant for an additional 5 months. At the lower temperature of 13 °C no sprouting was observed in tubers of *D. rotundata* during 5 months storage, but sprouting did occur in produce held at 15 °C and above (Thompson 1973). In later work Mozie (1986) observed that storage at 15 °C suppressed the appearance of fructose in *D. rotundata* tissues and also delayed sprouting for over 9 months after harvest. Similar results have been published by IITA(1989-1993) where, in comparison to those yams stored under Nigerian ambient temperatures, the maintenance of tubers at 15 °C resulted in the suppression of sprouting and weight loss regardless of variety, tuber source, size or duration of storage. Commercially, Anon (1982) has recommended yam storage at 14 to 18 °C and 65 to 75 % RH to maintain the culinary quality and inhibited the sprouting of tubers for up to 6 months.

Although the suggested optimal storage temperature for yams is of the order of 15C, in practical terms this cannot be achieved in the yam production areas without recourse to refrigerated storage facilities. Throughout many of the yam growing regions this is unlikely to be an economic option in the near future. In the absence of temperature controlled storage facilities various designs for improved yam barns have been promoted to ameliorate post-harvest losses associated with high temperatures and elevated humidity (refer to Section 14).

Sprout removal.

Traditionally, in many yam producing areas, attempts are made to prolong the storage of yams by careful pruning away of vine cormlets, cormbuds and emergent vines in an attempt to extend the storage life of the tubers. Research conducted in Côte d'Ivoire, observed that the persistent removal of yam sprouts throughout the storage season helped to reduce gross weight loss from tubers in comparison to those that were not de-sprouted (Girardin pers. comm. 1996).

The effects of sprout removal from stored tubers of *D. alata* cultivar Um 680 and *D. rotundata* cultivar Obiaoturugo on subsequent yam growth were investigated by Nwankiti (1988) in trials at Makurdi in 1985 and 1986. Sprouts were either left intact, continuously removed from the yams or removed between 1 to 5 times throughout the storage period. Results indicated that the highest weight loss was associated with those tubers left with their sprouts intact during storage. Following storage, minisetts weighing 25g were taken from the stored tubers and subsequently grown in the field. Sprout removal was shown to have a significant effect on yam emergence at 31 and 38 days after planting in 1985 and 30 days after planting in 1986. At 105 days after planting the leaf area index of the vines derived from those tubers that had undergone sprout removal was significantly greater than the controls, however, no significant differences were observed between the various treatments 120 days after planting. All sprout removal treatments gave a higher percentages of microtubers (weighing less than 200 g) and continuous sprout-removal gave significantly higher total tuber yields than all other treatments. In both years *D. alata* out yielded *D. rotundata*. In conclusion, it is suggested that sprouts should not be left on stored tubers for more than 2 months and if the tubers are to be used as planting material then sprout suppressant chemicals which may delay field emergence should not be used.

Chemicals treatments

Various chemicals have been shown to be effective in preventing sprouting in potato tubers and such observations have naturally stimulated researchers to seek a similar response in yams. To date the results have been somewhat mixed. For example, when used, many of these same chemicals proved to be generally ineffective when applied to *D. rotundata* (see review by Cooke *et al.* 1988). Studying the potential effects of a preharvest foliar application of maleic hydrazide (a preparation which successfully suppresses sprouting in onions and potatoes) on the storage response of yams, Hayward and Walker (1961) reported no effects. In Trinidad, Campbell *et al.* (1962) also studied the effects of maleic hydrazide and compared them with foliar applications and postharvest treatments of 1,2,4,5-tetrachloro-3-nitrobenzene (TCNB), pentachloronitrobenzene (PCNB), isopropyl carbanilate (IIPC), the sodium salt of 2,4-dichlorophenoxy acetic acid and the methyl ester of α naphthalene acetic acid (MENA) on the *D. alata* cultivar White Lisbon. During subsequent storage, all treatments with the exception of MENA were shown to have little or no effect on the sprouting of the tubers. In later work these researchers were able to show that the postharvest application of MENA, when incorporated upon a paper carrier and placed among the stored tubers, markedly reduced sprouting which was said to normally start about the fourth month after harvest. Experimental tubers treated in this manner were found to be still palatable after 6 to 7 months storage compared to non-treated tubers which remained palatable for only 4 to 5 months.

Passam (1982) and Wickham *et al.* (1984) appear to be amongst the first to show that the postharvest treatment of *D. alata* and *D. esculenta* with giberellins can delay sprouting and Rao and George (1990) demonstrated that treatment of harvested tubers with 100 p.p.m. giberellic acid for 2 hours was effective in extending the dormancy of yams by over 4 months in comparison to untreated tubers. When studying the effects of giberellic acid on *D. rotundata* and *D. alata*, Igwilo *et al.* (1988) reported a delay in sprouting of, on average, 56 and 75 days respectively for tubers held under ambient conditions in Nigeria. It also became apparent that giberellic acid could suppress sprouting completely for, following treatment, some tubers of *D. rotundata* variety Um 680 did not sprout at all during 9 months storage. The results of a more detailed investigation have been published more recently by Nnodu and Alozie (1992). These researchers described experiments where freshly harvested *D. rotundata* tubers were immersed in a solution containing 150 p.p.m. giberellic acid for periods from 2 to 24 hours (at increments of 2 hours). After 1 month, 24% of the untreated (control) tubers sprouted in comparison to (usually) none of the treated tubers. After storage for 2 months, 95% of the untreated tubers sprouted in comparison to 76 and 38% for those immersed for 2 and 4 hours respectively. By this stage between 5% and 19% of the tubers immersed for 6-24 hours had also begun to sprout. In a second experiment 6 batches of freshly harvested *D. rotundata* tubers were immersed for 1 to 6 times in a solution containing 150 p.p.m. giberellic acid. After 45 days all of the untreated tubers sprouted compared with between 9 and 14% for the treated batches.

Akoroda (1995) has described experiments where giberellic acid, ethephon, CCC (chlormeqat), BA (benzyladenine), NAA (naphthalene acetic acid), chloram-phenicol and cyclo-heximide were sprayed on the foliage of *D. rotundata* 9 days before harvesting. Most treatments had inconsistent effects although there was some indication that giberellic acid at 4 p.p.m., BA/NAA at 50/10 p.p.m. delayed sprouting and other chemicals showed some suppression during the early part of storage.

In Côte d'Ivoire (Girardin pers. comm. 1996) the postharvest treatment of tubers with giberellic acid (i.e. dipping of tuber apex in 150 p.p.m. solution for 2 hr) has been shown to extend the period of dormancy for 5 to 6 weeks, thereafter the rate of growth of emerging sprouts was equivalent to that of untreated tubers. The researchers involved in this latter experiment suggests that the more circumspect use of giberellic acid solutions applied to the proximal growing points of tubers postharvest may prove to be an economic and commercially viable means of controlling the dormancy of tubers in comparison to preharvest foliar treatments and full postharvest dips both of which are intrinsically expensive operations. Certainly, as is the case with other protocols reliant on the availability of particular chemicals, given the economic constraints facing most yam producers unless a treatment can demonstrate significant commercial benefits it will not be adopted.

Interesting observations have been made by Nindjin (1995) as a result of Quantitative Descriptive Analysis (QDA) of the yam varieties - Bètè bètè and Krenglé recovered from the various storage trials undertaken by Girardin (in press 1996). Sensory evaluation scores obtained from taste panels assessing the quality of *foutou* (a boiled and pounded yam paste) suggested that freshly harvested yams of *D. alata* yams had not yet developed the culinary qualities sought by the general public and only attained these attributes after a period of storage. In contrast, varieties of *D. cayenensis-rotundata* commanded a ready market as soon as they were harvested. Both the varieties of yam studied could be stored for a longer period as a consequence of treatment with giberellic acid, however, the combination of pit storage and hormone treatment on the variety Bètè bètè resulted in the maintenance of unfavourable organoleptic characteristics. In parallel to these observations an analysis of starch and sugar profiles of the same yam tissues suggested that hormone treatment possibly retarded the conversion of starch to sugars. Poor taste and texture of prepared yam was also reported as a consequence of infestation of yam stores by scale insects.

Irradiation.

Osagie (1992) has reviewed the literature on the effects of irradiation on storage of yams and found that in addition to delaying or eliminating sprouting in *D. alata*, *D. cayenensis* and *D. rotundata* tubers, irradiation also reduced weight loss, rotting, and had variable effects on starch and sugar contents of *D. rotundata* tubers.

Exposure of yams to 50 Grays radiation was shown by Adesuyi (1973) to be effective in inhibiting the sprouting of tubers during 3 months storage in comparison to untreated yams all of which were observed to sprout during the same period. In order to inhibited sprouting for up to 8 months Anon (1982) has recommended 7.5 to 12.5 krad of gamma irradiation prior to storage in yam barns. It appears that exposure to irradiation doses of 7.5 krad and above are necessary to inhibit sprouting although the nature of the response is cultivar dependent Adesuyi (1976, 1978 and 1982). Doses higher than 15 or 20 krad have a diminished impact on postharvest rotting and may also adversely affect the internal tissues of the yams. The manner in which radiation interferes with the mechanism of sprout germination has not yet been elucidated but Osagie (1992) suggests that it may result from modifications to nucleic acid metabolism in meristematic tissues.

12. Chemical Changes During Storage

Immediately following harvest, yams enter a dormant or resting phase the successful manipulation and extension of which permits the effective conservation of the tubers for weeks or months. Although relatively quiescent, chemical changes do occur during storage the study of which may ultimately provide insights into how it may be possible to control the processes that lead to the termination of dormancy, the loss of culinary quality and finally tissue senescence.

Soon after harvest metabolic activity in yam tubers declines markedly and remains low until just before sprout germination. Daudet (1980) monitored the rates of respiration and transpiration of various cultivars of *D. alata* and *D. trifida* both pre- and postharvest. At 2 to 3 months after planting he recorded hourly respiration rates of

150-200 mg/CO_2/kg. By the time the tubers had entered dormancy, the levels of respiration had declined to 5-10 mg CO_2/kg. Results published by Passam and Noon (1977) indicate the typical rates of respiration of various sections of yam tubers of *D. rotundata* held at 25°C during the postharvest phase (Table 15) which ends with the termination of dormancy and the production of sprouts. Other work by Passam *et al.* (1976) relates the impact of mechanical damage and microbial decay on the internal metabolism of tubers leading to increased rates of respiration and the consequent loss of moisture content and premature loss in quality.

Table 15. The respiratory activity of tubers of yam (*Dioscorea rotundata*) during storage at 25°C (Source: After Passam and Noon 1977)

Date of measurement	*Condition of tuber*	*Respiration rate ml CO_2 kg fresh weight^{-1} hour^{-1}*
July 1974	After harvest (tail of tuber)	19
	After harvest (head of tuber)	4
	8 days after harvest (entire tuber)	15
September	Dormant (entire tuber)	3
November	Dormant (entire tuber)	5
	Dormant (tail of tuber)	7
	Dormant (head of tuber)	4
February 1975	Sprouts appearing	18
March	Sprouting (tail of tuber)	14
	Sprouting (head of tuber)	44
	Sprouts developed (entire tuber)	34

Studying the physiological changes in tubers of *D. alata* and *D. esculenta* stored for 150 days as thin layers on the floor of a well ventilated room at 24 to 28 °C and 70-90% RH., Ravindran and Wanasundera (1993) observed that the tubers of *D. alata* began to sprout after 60-90 days while in *D. esculenta* sprouting only occurred after 120 days. In both species the moisture content of stored tubers decreased throughout the storage period, resulting in losses in tuber fresh weight. Crude protein, starch, vitamin C, oxalates and some minerals all decreased significantly during the first 60 days of storage, but thereafter any further decrease became more gradual. These results suggested that, from the point of view of food value, yam tubers should be used within 60 days of harvest. However, despite these changes it was found that the tubers remained acceptable even after 150 days of storage.

Monitoring the amino acid and fatty acid content of tuber of *D. rotundata* stored for 1, 5 and 8 months after harvest, Kouassi *et al.* (1988) reported that although the total amino acid content decreased slightly and fatty acid content increased during the storage period, there was no significant change in the composition of total amino acids and fatty acids derived from yam tubers stored at 25 °C.

Rather more pronounced changes have been shown to occur to the levels of various carbohydrates during the storage period which is indicative of a starch-sucrose interconversion. Studies of the hexose, sucrose and maltose contents of stored tubers of 6 cultivars of *D. alata*, and 4 cultivars of *D. rotundata* (Kouassi *et al.* 1990) indicated a pronounced increase in these sugars during the rest period. More so than during subsequent sprouting. In a review of the chemical changes occurring during the storage of *D. cayenensis* and *D. rotundata* tubers under ambient conditions in Nigeria, Osagie (1992) cites a decline in crude protein and ascorbic acid levels, a rise in reducing sugars and an increase, not only in the levels polyphenolic and glycoalkaloid substances in the stored tubers, but also the concentration of such compounds in the head regions of the tubers during the first 120 days of storage. Not-with-standing the this latter trend, the rise in the concentrations of reducing sugars in the tubers appeared to correlate well with the improved taste of cooked yam that had been stored for a period as compared with freshly harvested tubers (Onayemi and Idowu 1988). An observation which probably also accounts for the improved acceptability of the *D. alata* variety Bètè bètè to consumers in Côte d'Ivoire following a period in store (Girardin pers. comm. 1996).

Similar changes in sugar levels are reported in Chinese yams (*D. batatas*) by Hironaka and Ishibashi (1991) who observed that, after approximately 58 days in store, the surface of the tubers gradually turn yellow and after 60 days both the glucose and fructose contents of the tubers increased markedly resulting in an increase in sweetness. Such changes did not, however, appear to influence the viscosity of a ground solution of the yams which was shown to decrease progressively throughout storage.

Comparing the trends over a range of yam species, Sundaresan *et al.* (1991) has shown a decline in the starch, protein and moisture contents of *D. alata*, *D. esculenta* and *D. rotundata* tubers during storage while observing that the total free sugars remained almost constant in *D. esculenta* and *D. alata* but increased two fold in *D. rotundata*. In contrast the polyphenolic content of *D. rotundata* remained the same while that of the other two species increased. It would of interest to determine to what extent these changes in sugar and polyphenol content over time might be correlated with the perceptions of consumer acceptability.

13. Storage Conditions

A review of previous research conducted on the storage of *Dioscorea* spp. was published by Cooke *et al.* in 1988. In general terms, if required, the tubers of *Dioscorea* spp. can be left in the ground under ambient conditions and harvested piecemeal. Indeed this system probably still remains the tradition in a certain proportion of communities. However, although ostensibly a simple and inexpensive option, in-ground storage precludes the use of the land for alternative cropping and, left in this manner, the tubers are susceptible to the natural processes of physiological deterioration and exposed to attacked by moulds, insects, termites and other pests including rodents and other animals. As a consequence, in-ground storage is not generally recommended (Burden and Wills

1989) and producers have often sought alternative strategies to conserve their yam stocks. In the absence of more sophisticated technical interventions, a number of different storage structures have been developed and advocated over the years (see Section 14) principally, it must be acknowledged, for use in domestic yam marketing systems. With a view to determining the optimum environmental conditions necessary to extend the shelf-life of yams destined for export, researchers have tended to investigate the impact of different levels of temperature, relative humidity and gas atmospheres on the keeping quality of yams when held under in controlled environments.

Controlled Temperatures

As with the majority of perishable produce, the control of the storage temperatures to which yam tubers are exposed is the main tool by which horticultural technologists have sought to influence the postharvest shelf-life of the commodity. With this concept in mind Ezeike (1989), drawing on the evidence of empirical observations, has sought to develop models to try and predict the impact of both ambient and refrigerated temperatures on the likely storage life of yam tubers. To a point such information provides useful guidelines to those involved in the commercial trading of yams but the modelling of biological systems is not an exact science and different species and cultivars of yams may not necessarily react in a consistent manner to different low temperature storage regimes. The differences in response that may result from the different genetic potential of the material and preharvest conditions of production are often observed in terms of the extent to which reduced temperatures may influence sprouting, weight loss, physiological degeneration (chilling injury) and culinary quality. Given that published results of particular investigations only provide limited information, research into the effects of temperature on the postharvest response of yams has highlighted the importance of certain, apparently critical, temperature ranges.

With respect to the sprouting potential of yams, observations suggest that moderately low temperatures have the effect of delaying the onset sprout germination and rather more severe reductions in temperature are necessary to inhibit sprouting altogether. As exemplified in the work conducted by Hironaka and Ishibashi (1991) with the Chinese yam (*D. batatas*). These researchers observed that when stored at 7 and 10 °C, the yams began to sprout after 33 days of storage but that no sprouting was seen in the yams stored at 1 or 3 °C.

Although such reduced temperatures may be shown experimentally to control sprouting, somewhat higher temperatures are necessary to ensure yams retain their quality. Medlicott (undated) has argued that a storage regime of 12° to 13°C is required in order to maximise the marketing period of tubers with lower temperatures resulting in chilling injury and sprouting becoming problematic at higher temperatures. Osuji (1984) has also drawn attention to the impact of storage temperatures on the rate of moisture loss in yams and cautions that, to counteract the excesses of weight loss associated with the rapid removal of tubers from one temperature environment to another, the temperature of the stored yams should be allowed to increase slowly and progressively throughout the storage period and that temperatures should neither be held constant nor be reduced.

The exposure of yam tubers to much reduced temperatures invariably proves counter-productive and leads to the destruction of consignments. Mozie (1986) citing research conducted on *D. rotundata*, reported that after 3 months storage at 5 °C all the tubers exhibited putrefaction and soft rots. Such observations obviously highlight the extreme damage that results from chilling the tissues of yams at too low a temperature for too long a period. Views differ, however, as to what temperatures will result in chilling injury. Anon (1986) stated that "refrigerated storage at temperatures below 10 to 20 °C is not feasible as chilling injury occurs", whereas Osuji (1984) has shown that the membrane of the cells within a tuber may be damaged at 15 °C. In their turn Coursey (1968) and Thompson (1973a) have reported that chilling injury in *D. rotundata* occurs below 12.5°C and, working again with *D. rotundata*, Thompson *et al.* (1973) showed that yams exposed to 11.5 to 12 °C presented symptoms of chilling injury after 8 days and that the intensity of such damage increased as the time of exposure increased. Kay (1987) has provided an even lower estimate concluding that, with the exception of *D. trifida*, most yams were subject to chilling injury when stored below 12 °C.

Although published papers may differ over the precise point at which chilling injury begins to become manifest, it appears relatively safe to assume that storage at temperatures below 12-15°C may very well result in chilling injury. The most obvious signs of which are internal browning and the softening of tissues, leading very quickly to fungal infection and decay (Burton 1970, Medlicott undated and Noon and Colhoun, 1981). The link between chilling injury and increased spoilage by micro-organisms has been documented by Burton (1970) and IITA (1989-1993) with both authorities reporting an increase in tuber decay in material held at 15 °C in comparison to that held at higher temperatures. Given the threat to stored merchandise of losses to fungal agents, Demfaux and Vivier (1984) advocated the use of fungicides in such circumstances and reported a 5-10% reduction in losses over a period of six months when fungicides were used in conjunction with storage at 12-15°C.

Not-with-standing the threat posed by reduce temperatures to the internal integrity of yam tissues and subsequent spoilage, Thompson, A.K. and Vernall E.E. 1986 (unpublished) working with *D. rotundata* that had been stored for 155 days in either 13, 15, 17 or 19 °C observed that a sensory evaluation panel was unable to identify differences between any of the treatments in terms of flavour, bitterness, dryness, waxyness or fibrousness of the tubers. They concluded, therefore, that in this particular trial and in comparison to freshly harvested tubers from the same source, the refrigerated storage of tubers did not adversely affect the organoleptic properties of the yams.

Humidity

The level of humidity prevalent in atmosphere in the immediate vacinity of yam tubers may influence the storage potential of the crop in a number of ways. Over time, a relatively moist environment is likely to reduce the rate of moisture loss from the tubers and thereby help to maintain their fresh weight and texture, whereas a drying atmosphere will lead to dehydration and loss in quality. As already mentioned, humidity also plays a pivotal rôle in the curing process of yams and is a major factor in determining the incidence and rate of development of spoilage rots.

Studying the impact of storage structures on the postharvest characteristics of *D. Cayenensis*, Ajay and Madueke (1990) reported the manner in which elevated levels of ventilation within a store resulted in increased weight loss from tubers and how both shade and protection from the rain reduced both weight loss and the spoilage of tubers by rotting organisms. The influence of humidity on the rate of fungal growth on yams has also been investigated by Martin (1972)

The weight loss of yams under specified conditions has been documented by Thompson (1972a). When exposed to tropical ambient temperatures of approximately 28 °C at 90-94% RH, yams were observed to loose 13% of their weight. This was significantly less than the 26% observed in a corresponding environment maintained at 54-68% RH. The rate of weight loss from living tissues such as yams is not, however, merely a function of the vapour pressure deficit that is engendered between the tissues of the tuber and the surrounding atmosphere. Working with *D. rotundata*, Noon and Colhoun (1979) showed that, irrespective of the prevailing level of RH, the weight loss of yams held at 35 °C (and 30% RH) was considerably greater than that 20 °C (at 40% RH) on account on the greater rate of tissue respiration in the former.

Working at a somewhat lower temperatures Gonzales and de Rivera (1972) and Noon (1978) recommended storage conditions for yams of 16 °C and 70% RH. Rivera *et al.* (1974) compared the storage potential of yams maintained at 16 °C at both 70 and 80% RH and found that although tubers were apt to loose weight, organoleptically, they were still found to be of an acceptable quality after 200 days in store.

Thompson, A.K. and Vernall E.E. 1986 (unpublished) have shown that *D. rotundata* stored at 13 to 14 °C for 24 weeks in 90% RH lost 9% in weight while those in held at the same temperatures but at 73% RH lost 28% in weight. The tissues of the yams sampled showed signs of internal necrosis (which was probably the result of chilling injury), however, the prevalence of these symptoms were related to the level of atmospheric RH such that those tubers exposed to 90% RH had 37% compared to 70% for those which had been stored in 73% RH.

As a result of investigating the effects of RH on *D. rotundata*, Passam (1977) reported that the exposure of yams to a saturated humidity caused sprout initiation after 20 days whereas in an environment of 60-70% RH tubers only sprouted after 40 days. Passam also reported that 80% of tubers stored at 90% RH produced rootlets over their surface compared to none for those stored at 50% RH. This effect had previously been reported by Thompson (1972a) where tubers kept in high humidity showed parenchymatous cell proliferation over the surface often associated with rootlets. This effect was reversed when the tubers were returned to a lower humidity.

Gaseous atmosphere

A reduction in oxygen and a moderate increase in carbon dioxide levels afforded by either controlled- (CA) or modified atmosphere (MA) storage environments may well help to retard the postharvest physiological changes in yam tissues. As yet, however, there has not been any systematic analysis of the response of yams to different gas concentrations and the available literature provides scant reference to the impact of gas atmospheres on the storage potential of yams.

Medlicott (undated) mentions that yams can be stored with other products with no detrimental effects and this suggests that yams do not generate appreciable quantities of ethylene or drastically modify the gas composition of storage areas. Another reference by Hironaka and Ishibashi (1991) reports the successful storage of tubers of *D. batatas* in polyethylene film packaging at 3°C and that this method was effective in preventing weight loss during storage. Perhaps more informative are certain experiments by Osuji (1987) on tubers of a cultivar of *D. rotundata* called 'Nwopolo'. Osuji observed the rate of weight loss of two groups of tubers both stored for 18 weeks. The control group were maintained under aerobic conditions throughout, while the second group was exposed alternately to
10 days of aerobic storage and 7 days of anaerobic storage (an adiabatic environment). By the termination of the experiment, the control tubers were reported to have lost a total of 15% of their weight, while the adiabatic tubers had lost only 3%. A result that suggests that the adiabatic storage environment had exerted a significant effect on the respiratory activity of the tubers.

14. Simple Storage Structures

Throughout the yam growing regions communities have traditionally resorted to a variety of measures to conserve harvested yam tubers. The details of these particular methods vary but in general terms there appear to be 5 main options (see also FAO 1985):

a) The heaping of yams in the field often under the shade of trees;
b) Burial in pits;
c) Storage of tubers on raised wooden platforms;
d) Storage of tubers in various types of enclosed huts made of various materials and often thatched, and
e) Tubers tied to a vertical framework under shade (a structure often referred to as a traditional 'Yam-barn'.

Survey work undertaken by Anamoh and Bach (1994) in Ghana reveals that local farmers have a precise and detailed knowledge of both the advantages and disadvantages of all the different storage options available to them. Their perceptions are summarised in Table 16. Given any particular set of circumstances the choice of which storage structure to adopt was reliant on the following considerations: the season, the number of yams to store, ease of construction, cost of construction, efficiency of structure, durability of structure, and other potential uses. In the Ghanaian context some 73% of interviewees resorted to the storage of yams in the field under shade for at least some period whereas only a minority of 28% stored their crop under shelter provided by huts, yams vines or woven mats etc.

Various authors have describe in detail the construction of different storage structures. Mück (1994), for instance, has compiled drawings and photographs of a range of simple yam stores and Wilson (undated) provided an account of barn construction.

Ezeike (1985) has also described the type of yam barns used in rural areas in Nigeria. The precise design of these latter structures varies but they usually consist of live stakes (approx. dimensions 5-10 cm in diameter and 1 to 2 m high) driven into the ground at 1 m

Table 16. Types of yam storage structures, advantages and disadvantages as perceived by farmers interviewed in Kintampo, Bole and Tamale Districts, Ghana (Source: Anoamoh and Bacho 1994)

Type of Storage Structure	Brief Description	Advantages	Disadvantages
Burying	A pit dug knee deep and yams arranged inside and covered back with soil.	-Curing of yam wounds; -Prevents rodent, bush fire and animal damage.	-Shorter length of storage (1 to 2 weeks); -Cannot be used in dry season; -Stores relatively smaller quantities (1-200 yams).
Zanamat	Stakes are pegged in either circular or rectangular form and grass mats used to cover the sides and the top. Yam vines are then put around the entire structure and on the top. The yams are arranged on raised platforms in side the structure or just on the ground.	-Can be constructed to accommodate large quantities of yam (up to 20,000); -Aeration is much better than in other methods; -Sprouting can be easily monitored; -Yams can be stored longer than in other structures.	-Costly to construct; Rodents attack cannot be prevented; -Prone to attack by animals; -Yams can be stolen easily; -Bush fire; -Can be stolen easily; -Prone to termites.
Sigu (Millet/Guinea stalk structure)	Poles are pegged in either conical or rectangular form and sorghum/millet stalks used to fence around. Yam vines are put around to act as protection against animal destruction.	-Due to better ventilation yam rot due to heat and wounds are reduced; Can be constructed to store large quantities of yam; -Cost less than the Zanamat to construct; -Protects yam against animal attack better; -Sprouting can be monitored easily.	-Prone to bush fires; -Yams can be stolen easily; Prone to rodent attack; Prone to termite infestation.
Under Shade	Yams are arranged under large shady trees and yam vines used to cover them.	-Aeration is increased, thus reducing the problem of rot due to heat and wounds; -Very little cost involved; -Sprouting can be monitored easily.	-Prone to: Rodents, stealing, bush fire and termites.
Farm Hut	Mud walls are erected in either circular or rectangular form and roofed with grass. Yams are arranged inside.	-Has a longer life span; -Used for habitation during off season; -Prevent animal damage better; -Sprouting is easily monitored; -Termite attack are reduced.	-Stores relatively smaller quantities of yam and generates more heat.

intervals from which tubers may be suspended by vines. The live stakes produce foliage which may be supplemented with palm leaves and thatch to shade the tubers from the sun and rain and provide a cool moist environment.

Information generated by Ezeike *et al.* 1989 suggested that a modified underground pit structure for yam tuber storage maintained a lower and more constant temperature (21 to 24 °C) than a traditional barn, with relative humidities of the order of 84-93% RH. By controlling the relative magnitudes of the inlet and outlet air velocities, they argued that the temperature within the pit could be manipulated. The advantage of this form of storage was seen in the influence that the background level of relative humidity appeared to have on the weight loss of tubers. Over a 5 month period yams conserved in a traditional barn were observed to loose 60% by weight whereas the weight loss of tubers held in the pit was found to be only 15 to 25%.

A number of different research organisations have advocated the construction and use of modified yam barns and Anon (1982) has provided drawings and photographs of open sided shelves and improved barns designed for the more efficient storage of yams.

Nwankiti *et al.* (1988) compared the quality of tubers recovered from a traditional open barn and a modified covered barn. In the former they observed mean temperatures of 34 °C and a relative humidity of 60% whereas the average temperature and RH in the covered barn was 26.5 °C and 78.5% respectively. After storage for 6 months they noted a weight loss of 40% in those tubers recovered from the traditional barn in comparison to 10-13% in the modified structure. They also indicated that the quality of the flour made from those tubers held in the traditional barn was inferior to that from tubers which had been stored in covered barn. One draw back that they did notice with the covered barn , however, was and increased problem with insects particularly *Aracerus fasciculatus*, *Aspidiella hartii* and *Phenococcus citri*. Studying the influence of barn construction of fungal rots, George (1990) reported that the *D. alata* cultivar Sree Roopa showed better storability when placed on racks in a covered barn, compared with an open barn and various pit treatments. Damage due to *Fusarium* sp. being shown to be higher in the open barn structure.

In another more recent study, Okwuowulu (1995) again sought to compare the impact of two different storage structures on the storage potential of a range of yam cultivars. In this experiment tubers of *D. rotundata* cultivar Obiaoturugo and Nwopoko, cayenensis type *D. rotundata* (*D. cayenensis*) cultivar Abi, *D. alata* cultivar Ominelu and Um 680, and *D. bulbifera* cultivar Adu-Olode were harvested 6-8 months after planting and stored in either a traditional barn or a modified indoor store. The traditional barn consisted of a framework of raffia palm poles supported by erect stems of Newbouldia leaves, with the live plants providing shade and shelter. The modified store was constructed with a roof of galvanised iron sheets, a layer of woven mats as a ceiling to absorb heat, and walls of 1 m high iron sheets topped by wire netting to exclude rodents while still allowing for air flow.

It was observed that the weight losses from yam tubers, sprouting and the level of rotting during storage all differed significantly between the six cultivars. Neither fertiliser applications (recommended levels of N. P. K.) nor its timing (6, 8 or 10 weeks after planting) were seen to significantly influence the extent of weight loss or the degree of spoilage of tubers during storage but sprouting was affected by the timing of fertiliser applications. Age at harvest did significantly affected storability with those tubers harvested 6 or 7 months after planting remaining of a higher quality. In this particular trial the weight losses were observed to be lower in the traditional barn than in the modified store which may have been a consequence of the ambient heat generated by the metal sheets used in the construction of the modified storage structure.

Investigating the influence of the degree of ventilation on the sprouting potential of yams, Mozie (1981/1982b) monitored the response of tubers of *D. rotundata* held in a conventional barn and exposed to either continuous ventilation, intermittent ventilation by a fan for 6 hourly intervals or no assisted ventilation (the conventional practice). He observed that tubers held in the intermittent air flow had a lower weight loss than those with continuos air flow and that the tubers in the store which had no fan had in fact lost the most weight of all. Dormancy was broken earlier in the ventilated stores but after 16 weeks storage these sprouts died and were not regenerated even after 44 weeks in store.

In recent years work has been undertaken in Ghana to encourage producers to adopt modifications to their traditional storage practices (Henckes *et al.* 1995. In this instance, developmental researchers are not simply advocating the use of a particular storage structure but also a modified approach to yam conservation. The market orientated yam storage protocol that is being disseminated seeks to encourage the grading and curing of yam tubers immediately after harvest followed by the application of wood ash to held wound healing and moisture conservation. All procedures that are already familiar to the yam farmers. To bring about improved yam storage the project also recommends the use of a raised hut structure that may be made from local materials. Analysis conducted to date suggests that the higher quality of yams and increased sales associated with the successful use of these storage methods may improve the gross margin or profit of producers by as much as 30-40%.

RESEARCHABLE ISSUES IN POSTHARVEST OF YAMS

Background

In the past, in comparison to many traditional cash crops and the major grain staples in particular, the principal non-grain starch staple crops grown in the developing countries of the lowland tropics (aroids, cassava, sweet potato and yams) have attracted little attention and sustained research funding. In common with other commodities, of the work that has been undertaken and published on yams, much of the emphasis has been related to pre-harvest concerns. The current review cites examples of the work undertaken by a relatively small number of researchers that have sought to investigate the factors that impinge on the postharvest quality of yams. As a consequence of this exercise it is quite apparent that much of our present knowledge is based on a relatively small selection of discrete empirical observations and that our true level of understanding of the biochemical and biophysical mechanisms that direct and influence the postharvest storage potential of various forms of yam remains superficial and incomplete. It is the contention of the authors that if communities within the major yam producing areas are to benefit more fully from the enhanced efficient utilisation of such an indigenous resource, at some point, such deficiencies will need to be addressed and pertinent technical interventions developed and disseminated within the yam production and marketing systems.

In past years various researchers and authorities have voiced different opinions about the possible way forward and the need or otherwise for research on yams. The ideas presented have often reflected the perception, discipline and interest of an individual exponent or the experience of a particular research group or donor agency. At times, when priorities and funding have permitted, research on yams has attracted attention, however for much of the last decade or so, investigations into the postharvest constraints affecting yams has been relatively low key. For instance, in a somewhat different era, Coursey (1983) undertook a detailed review of the work carried out by the Tropical Products Institute (TPI now NRI) on tropical root crops, and reported and discussed the technical findings to that date but did not take the lead and advance the debate further to consider the possible future general research needs of yams. During much the same period and now almost a decade ago, following a survey of postharvest problems in Cameroon, Numfor and Ay (1987) were unable to identify any researchable issues associated with fresh yams. The low profile afforded yam research at this time is exemplified by the attitude adopted by the FAO (1985) who, despite the fact that the storage of yams was acknowledged to be a principal constraint to the realisation of the production potential of such crops world-wide, concluded that in comparison to the best traditional storage methods used by producers at that time, there was no practical advantage to be gained by advocating the use of more technically advanced storage protocols that, although considered effective, could not be sustained by the indigenous industries. The debate has continued into the 1990s. As a result of studying yam and cassava in south-eastern Nigeria, Nweke *et al.* (1991) proposed that there was indeed a pressing need for post- as opposed to preharvest research but that, in his view, as more research had been carried out on yams in the past, in future the emphasis should be focused on cassava. From the perspective of Ghana, Alhassan (1994) has also argued the case for more postharvest research but in the context of a different country and a different economy he advocated that work needed to be conducted on yam.

Although in broad terms it is still true to say that the conditions do not yet exist in many of the yam producing communities to support the wholesale introduction of technical interventions of a more technically sophisticated (and expensive) nature, worthwhile benefits are still likely to accrue from judicious modifications to different elements of existing pre-and postharvest practices and research is still required to understand the mechanisms by which constraints impact on the storage and marketing of yams and how both biological and economic losses may be reduced.

For many years researchers have discussed the potential of improving the characteristics of edible yams by germplasm selection. In 1979 Wilson saw the future for the development of yams in West Africa as being in some manner dependant on the breeder's ability to produce improved cultivars. While she considered that most of the requirements of such material would be related to agronomic production factors, she also recognised that storage and culinary qualities would also become relevant. The exploitation of the potential of germplasm to demonstrate tolerance or resistance to pests and diseases has long been a principal objective of plant breeding and, more latterly, genetic manipulation which has a direct relevance to the postharvest potential of the crop, however over time, it has become increasing evident that selection criteria need to be expanded to include other major postharvest characteristics of tubers such as size, shape and ease of harvesting and postharvest handling (both manual and/or mechanised), and storage potential (Orkworand and Asiedu, 1995). In this regard Onwueme (1980) has advocated the selection of cultivars with more robust periderm tissues to diminish susceptibility to bruising and for a tolerance to potential storage temperatures of 0 to 10°C, a suggestion reiterated by Osagie (1992). Organoleptic attributes, dry matter content and dormancy period are also characteristics cited by Asiedu (1994) as requiring formal inclusion in germplasm selection protocols. Such good intentions are in accordance with comments made by Ghartey (1995) who, in a review of the research and development needs of the fledgling yam export industry Ghana, suggested that geneticists should work towards reducing the perishability and improving the shelf life and pest resistance of yams while still maintaining the fragrance and good taste of the product.

In an evaluation of the technical problems facing the Jamaican export industry in 1979, Thompson *et al.* cited three areas where research and modifications to existing practices would be likely to result in significant benefits. In each instance their recommendations related to measures that would ameliorate the postharvest damage of tubers and consequent loss due to spoilage. These researchers argued that alternative methods of propagation of (in this instance) *D. cayenensis* should be sought so that entire tubers could be collected for the export trade rather than continue with the traditional system of harvesting whereby the proximal 'head' portion of the tuber was left in the ground to generate seed material while the distal portion was offered for marketing and sale. Inherent to such a process are the not inconsiderable losses sustained by the harvested tubers that, once cut from the vine, become particularly susceptible to colonisation by postharvest rots. Although such a recommendation was made in the context of the Jamaican export trade, the observation still remains pertinent not only in the Caribbean but also in other yam producing areas. Their other concerns were for the improved design of cartons for export packaging and more effective protocols for the control of postharvest diseases. The need to continue research with respect to the latter and especially with reference to the development of new fungicide treatments with low mammalian toxicity was one of the recommendations presented by a committee on postharvest technology and economics to a seminar on yams in 1982 (see Miège and Lyonga 1982). If anything this issue is of even greater import today than previously with the heightened awareness of environmental concerns coupled with more rigorous controls on the use of treatments that involve the use of, for example, benzimidazole based chemicals.

Commenting on the present role and future prospects for yams, Hahn *et al.* (1993) again drew attention to the importance of mechanical damage and diseases as major contributing factors leading to the loss of quality in tubers. Other areas of concern being the depreciation that results from premature sprouting of tubers and the direct effects of pests and nematodes. In this regard, the call for basic research made in the early 1980s (Miège and Lyonga 1982) to increase our understanding of the biochemistry and physiology of the yam and the principles involved in the control of both the initiation and breakage of dormancy and the loss of resistance to pathogenic invasion that occurs after the breakage of dormancy remains to be addressed and is as pertinent now as then.

In 1995, cognisant of the importance of yams in the domestic economies of several states in West Africa and the as yet unrealised future potential of the crop, the Plant Health Management Division of the International Institute of Tropical Agriculture (IITA) hosted a workshop to review the present status of knowledge of the pests and pathogens considered to be major constraints to yam production in the region. As a consequence of this meeting various working groups were established with a mandate to discuss deficiencies in past and the present research, to develop cross-institutional linkages between scientists and to formulate joint initiatives for future research proposals. A summary of the researchable issues considered important by the participants of the workshop and pertinent to the postharvest storage of yams are summarised in Table 17. Other suggestions observed within the literature have included investigations into the preservation of yams by novel technical interventions and the production of stable products from yam, possibly following fermentation (Degras, 1993).

Post-Harvest Research Opportunities

The overall objectives of any future research initiatives should ultimately seek to develop effective and economic strategies to reduce post-harvest losses of yams and extend the productive use of the crop. It is probable that every facet of commercial and domestic yam production, post-harvest conservation, processing and marketing would accrue tangible practical benefits from the findings of a series of well focused and directed research initiatives. However, in a world where securing funding to pursue any particular line of research is becoming an increasingly competitive exercise, one of the leading questions to be considered is what areas of endeavour are likely to succeed both in terms of attracting finance and generating useful outputs.

Table 17. Postharvest Yam Issues Requiring Further Research

1) *Characterisation of Pest and Diseases Problems and Traditional Management Associated with Yam Storage*

   a) Characterise yam storage systems
   b) Identify nature and quantify impact of pest and diseases on deterioration of yams during storage
   c) Investigate farmer, trader and consumer perceptions of yam spoilage and loss
   d) Record indigenous technical knowledge

2) *The Influence of Calcium on the Incidence and Development of Yam Rots*

   a) Study the influence of nature and level of calcium balance on host-pathogen relations in yams
   b) Determine nature and active levels of calcium that confer increased resistance to yam tuber spoilage
   c) Determine efficacy of preharvest foliar and soil calcium applications and postharvest soaking and infiltration in the management of yam tuber spoilage

3) *Gall Development*

   a) Monitor the interaction of phytohormones (indole-acetic acid and giberellic acid) in the initiation and development of galls during preharvest growth and postharvest storage
   b) Study the impact of pre- and postharvest application of growth regulators on the initiation and development of galls
   c) Investigate heretability of gall formation

Although discussed, there has never yet been a systematic attempt to collect either qualitative or quantitative data in the principal yam producing areas to describe the extent to which either identified or assumed constraints impinge on the potential of the yam crop. In the absence of such intelligence it will remain difficult to identify which areas of research are likely to prove to be the most pertinent and immediately utilitarian. Hence when considering potential areas of for future research logically at least some resources will have to be made available to define the nature and extent of the problems encountered by those actively engaged in the production, transport and marketing of yams. An appreciation of such realities would then facilitate the prioritisation of other research initiatives.

Table 16. Postharvest Yam Issues Requiring Further Research (Cont...)

4) *Enzyme Activity*

a) Study starch and sugar metabolism during storage
b) Investigate biochemical basis of enzyme activity
c) Investigate inheritance of key enzyme systems

5) *Physiology and Biochemistry*

a) Investigate the influence of environmental factors (temperature and relative humidity etc.) and location on postharvest yam physiology and susceptibility to spoilage

b) Study the balance of hormones in yam tubers during dormancy and sprout germination
c) Model the dormancy and the sprouting process and determine methods to control tuber dormancy
d) Investigate biochemical basis of dormancy
e) Determine storage potential of miniaturised yam tubers during storage and shipment

Building on the published information presently available there would appear to be five main areas where our knowledge and experience remain deficient. In broad terms these may be described as follows:

a) Inadequate knowledge of the extent and intensity of the problems;

b) Poor understanding of the range of existing pre- and postharvest practices and sustainable options;

c) Fundamental lack of knowledge of the biochemistry and physiology of the crop and how varietal differences and physiological status precisely influence the postharvest potential of fresh yams;

d) No appreciable understanding of the processes involved in postharvest deterioration and maintenance of disease resistance in fresh yam tubers, and

e) Little documented evidence of how shelf-life potential, consumer acceptability and market value of yams relate to the physiological condition, disease status and nutritional composition of fresh or processed tubers.

To address these deficiencies the following principle areas of research are suggested:

a) Document and characterise the current distribution of yam production, species and product preferences, seasonal utilisation patterns, marketing systems and their potential for expansion.

b) Study the incidence, characterise the cause and quantify both the biological and economic losses of yams to identify constraints of major significance throughout the production, storage and marketing chains extant in the major yam producing areas;

c) Identify and evaluate existing pre- and postharvest strategies for the conservation of both fresh and processed yams both in terms of technical and economic efficacy and research means of enhancing these systems and, where appropriate develop and test novel forms of intervention and possible new product types.

Of particular importance in this regard is the influence of temperature and humidity on the storage potential and quality of the yams. During the transport of tubers for export various temperatures have been shown to engender symptoms of chilling injury on different species of *Dioscorea* but more information is required on exposure times, varietal differences and the interactions of temperature and water-stress with other storage factors on the post-harvest physiology of tubers.

In many countries packaging also remains an area where relatively simple changes in traditional practice may reap significant benefits. The packing of yams for export in coir dust has been used for several decades in Jamaica. This has not only proved environmentally friendly but has also provided an outlet for a by-product of the coconut industry. Further research into the use of coir dust and other materials, both for export and rural storage, could lead to reductions in the postharvest losses of yams and a better and more consistent quality of product, especially if the process could be combined with a non-chemical method of sprout suppression such as the manipulation of gases within the storage environment.

Controlled and modified atmosphere storage are increasingly being shown to be a commercially viable and environmental friendly method of increasing the storage life of many crops. To date, the effects of gases in the storage atmosphere on the shelf-life and quality of the different *Dioscorea* species does not appear to have attracted much attention. The manipulation of levels of CO_2 and O_2 within a storage environment may be relevant to sprout and disease control in yams.

d) Investigate more fully the organoleptic properties of both fresh and processed yam products, how these relate to consumer acceptability and how product quality ultimately derives from the genetic potential of different yam varieties. Although present day consumer preferences in many communities demand that research should seek to address issues related to the provision of fresh yams, there would appear to be considerable scope to investigate the potential for developing new and improved processed yam products and the transfer of processing technology from tradition to another.

e) Study the post-harvest physiology of fresh yam tubers particularly the hormonal and biochemical mechanisms governing dormancy and sprouting, starch metabolism, cell structure and integrity, resistance to infection and the development of disease. Determine how these systems may be influenced by the innate genetic potential of the crop, the size and maturity of tubers at harvest, possible postharvest curing regimes and the nature of postharvest storage environments.

The facility to manipulate tuber dormancy and control sprouting (possibly by means of the pre- or postharvest application of chemicals) would enhance the storage potential of yams for the benefit of those involved in the storage, transportation and marketing of fresh tubers while also providing producers and breeders with the means to control the time of sprout germination and planting.

Also, where such products are available, the current reliance on chemical methods to control postharvest disease of yams invariably proves costly, often leaves a residue on the tubers and shows increasing signs of failing due to the development of resistant stains of micro-organism. The process of curing may represent another means by which postharvest infection of tubers may be controlled or diminished at least to some extent. A more complete understanding of the process of curing is needed especially details of the most effective temperature and humidity regimes required by different species of yam to optimise the process.

Observations of particular researchers suggest that two other areas of special interest may lead relatively rapidly to improved cultural interventions of benefit to yam producers. One is to investigate the possible use of increased levels of calcium ions to reduce the rate of cell wall degradation in nematode and microbially infected tissues of yam tubers and relate this to calcium applications to the standing crop and the use of lime-washes and ash slurries on harvested tubers (Mr Afalabi, NSPRI, 1996 pers. comm.). The second area is that of determining the technical and economic feasibility of using hot water treatments to control nematode infestations on tubers.

As in the case of the other staples of world-wide importance, an increased understanding of the basic bio-physiological characteristics of the yam will permit more focused and sophisticated germplasm selection and possibly the genetic manipulation of the *Dioscorea* genome to counter some of the constraints which presently hamper the more efficient exploitation of the crop. Of particular benefit would be the enhanced resistance to preharvest diseases that impinge on postharvest yam quality.

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