CROP POST HARVEST PROGRAMME

Development of integrated protocols to safeguard the quality of fresh yams

R 7582 (ZB 0234)

FINAL TECHNICAL REPORT

1 February 2000 – 31 March 2003

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ABBREVIATIONS

GEPC: Ghana Export Promotion Council
GPHA: Ghana Ports and Harbours Authority
GYPEA: Ghana Yam Producers and Exporters

ACKNOWLEDGEMENTS

This report is an output from a research project funded by the United Kingdom Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID. R7582 Crop Post-harvest Research Programme.

EXECUTIVE SUMMARY

The overall objective of the project was to improve the system by which yams are marketed in and exported from Ghana. Specific objectives are; to identify the technical and socioeconomic constraints to the system; to improve handling, storage and export protocols; develop recommendations to improve linkages between growers and exporters; to reduce the incidence of chronic rots in yams entering the marketing chain; and devise improved methods for the grading of yams.
Problems of the yam marketing system include lack of competition faced by traders which put producers at a disadvantage and leads to low and fluctuating prices for farmers. Growers lack market information and cannot defer sale during the harvest season when prices are low because of lack of storage facilities and finance. The quality of yams arriving at the markets are compromised due to poor transport infrastructure, poor harvesting practices, and poor storage conditions. There appears to be no premium for the growers for higher quality yams. Growers are persuaded by traders to harvest early in the season, when yam prices are higher, but the immature yams are more perishable. The variety, Pona, preferred for its taste, is one of the more perishable varieties. Losses can account for as much as 50 per cent of production.

Storage trials demonstrated that the optimum storage method depends on tuber maturity; yam barns refined by GTZ for storage of ware yams are less suitable for storage of milk yams than the traditional pit system. Tests were carried out in the field and in the laboratory to determine how curing (promotion of natural wound-healing) might by optimised in the field. The optimum temperature for curing of *Pona* is 32oC, and although it had been assumed that yams cured naturally when stored in pits in the tropics, in many cases the temperatures recorded in trials were lower, and curing apparently ineffective. Temperatures in excess of 34oC inhibit curing, as do high levels of carbon dioxide and low levels of oxygen, underlining the importance of ventilation. Recommendations for curing practices suitable for the range of agroecological zones in Ghanaare being developed.

The organisation and problems of the yam export trade has been determined by surveys covering producers, traders and exporters in Ghana, and importers in the UK, and by assessment of yam quality at various stages in the export process. Yam exports represent less than 0.01% of national yam production, but an expansion would increase foreign exchange earnings for Ghana. The export trade is perceived as highly lucrative, but margins can be squeezed considerably by high cost of tubers and substantial losses due to rejects by importers. Supply uncertainty hampers contract performance by exporters, undermining long-term trade relations with importers.

Even after grading 5-10% tubers were found to have internal rots before leaving Ghana. Although exporters appear unaware, shippers have no active temperature control for the yams, and most the ships used, either have no facilities for temperature control or do not to deploy the systems. Temperatures may rise from 30C to 34C in the first 10-14 days of shipment, and then dip below 15C and even 10oC in European waters (such temperatures are know to induce chilling injury in yams). Surveys of Pona yam exports indicate 30% of the consignments may be rotten by the end of the season in March.

Linkage between exporters and growers could assure more stable supply of high quality tubers at stable prices and improve tuber quality through reducing the supply chain. An instructive model is that of pineapples for the export market. In this model exporters have firm export orders and establish forward supply contracts with producers. In the case of yams, exporters wait for orders before using agents to obtain supplies from wholesale markets in Accra.

Linkage between exporters and producers appears feasible; if the capacity of exporters to absorb suppliers from producers can be enhanced through securing firm export orders and/or being more actively involved in the domestic trade in high quality tubers. Considerable improvement in yam

quality could be obtained if exporters were aware of optimal shipping conditions for yams, and ensured that the shippers complied with these conditions.

The incidence of rots in yams was studied both in the markets, and during storage trials. The most common organisms identified in the two cases was essentially the same. The theory that infections originate from the seed yam in the field is supported by findings of a survey conducted in Brong Ahafo.

Non-invasive methods for assessing rots in yams would improve quality of yams leaving Ghana, and therefore arriving in the UK. Using external visual appearance of yams, the best method so far devised for assessing internal rots (considering %external rots and %gashes) can select/discard yams with an efficiency of 75%.

Initial experiments on a simple gas sensor array has demonstrated that the response of the sensors differed significantly between sound and internally rotten tubers, and also between sound and damaged tubers. Further development of the instrumentation has been more difficult than anticipated, but will continue after the termination of this project.

CONTENTS

BACKGROUND

Information should include a description of the importance of the researchable constraint(s) that the project sought to address and a summary of any significant research previously carried out. Also, some reference to how the demand for the project was identified.

The Importance of Yams

The intensive cultivation of yams (*Dioscorea* spp.) is concentrated in the West African states of Benin, Cameroon, Côte d'Ivoire, Ghana, Nigeria and Togo, which together generate 95-96% of total annual global production (FAO 1994). Over the past 15 years world production of yams has been increasing and this is believed to be due mainly to the expansion of yam production in Africa. Despite this trend, and the fact that the yam crop contributes significantly to the income generating power of the rural producers as well as alleviating food security concerns in West Africa as a whole, support for research into the problems faced by the yam trade is patchy and the latent potential of this commodity is still very far from being fully realised.

General Focus of Research

Until relatively recently, most research initiatives that have focused on yams have attempted to address production problems by considering methods of propagation, production strategies and measures against pre-harvest diseases (Tetteh and Saakwa 1991, and references therein) and relatively few studies have been directed at the post-harvest sector in general (Thompson and Bancroft, 1996). Despite their obvious importance, the economic and social factors that dictate contemporary post-harvest handling and storage practices have remained unresearched and the workings of the marketing systems have been generally ignored. In the future this may change if international research organisations begin to fulfil their stated objective of developing the yam crop more fully. At the time of the start of this project, however, there were currently no other active research projects which shared the specific aim of developing appropriate strategies to safeguard the quality of marketable yams and improve their export potential.

Post-Harvest Losses

Although the need to improve the post-harvest storage, handling and transportation of yams has always been acknowledged, the importance of these issues was brought to the fore by the results of surveys conducted in Ghana in 1994 and 1995 by GTZ and NRI (Kleih *et al.* 1994). Need assessment surveys funded by the DFID Regional Africa Project on Non-Grain Starch Staples (Kleih *et al*., 1994) and carried out by the NRI in collaboration with the Ghanaian National Programmes recorded that considerable losses were inherent in the traditional yam marketing systems but noted that, at that time, there were few reliable data on the extent of such losses or a precise understanding of the nature of the constraints.

An indication of the likely extent of losses encountered by producers alone derives from survey work conducted by the GTZ. Estimates for on-farm losses for yam and cassava together ranged from 4 - 25%, with typical losses of yams during a storage period of 16 weeks accounting for 18% (GTZ, 1995). In formulating the National Agricultural Research Strategy (NARS) Plan for Ghana, well aware of the difficulties faced by the yam trade, policy makers highlighted yam as a priority crop for research and development and particularly identified the need to reduce post-harvest losses which, in 1994, the Ministry of Food and Agriculture estimated at some 20% of production. Internationally research bodies have begun to turn their attention to the constraints evident in the yam production system. In June 1997 francophone agencies (CIRAD, CORAF, INRA, and OSTROM) met with a view to co-ordinating their efforts to define and put in place a global strategy for research and development to promote yams.

The RNRKS project R6505 (‘*Relieving post-harvest constraints and identifying opportunities for improving the marketing of fresh yam in Ghana’)* managed by R. Bancroft, generated more detailed data quantifying the biological and economic loss encountered between the farm gate and the traditional retail market. Pertinent findings generated by that project are that:

a) The most significant consequence of shortcomings in the contemporary marketing systems is the premature degradation of tubers by rots resulting in either partial or absolute biological loss (refer to Figure 1) and price discounting of the order of 35-80% (Crentsil & Danso, 1996, and Crentsil *et al.,* 1997);

b) Of all apparently ‘healthy’ yams sampled in the market system some 20-30% harbour chronic internal rots (Bancroft *et al*., 1997);

c) Combinations of specific ‘curing’ and post-harvest handling/storage protocols have the potential to reduce the extent of rotting after 3-4 months on-farm storage (NRInt., 1999), and

d) To effect any significant diminution and control of the losses identified in the marketing chain in the foreseeable future, specific traditional post-harvest handling and marketing practices will need to be radically altered with the focus of change directed at producers and exporters in particular.

The extent of waste in the export sector had yet to be adequately quantified, a report by Ghartey (1995), however, cited a range of problems and potential deficiencies affecting the yam export trade from Ghana and, not surprisingly, spoilage by rots is cited as a significant area of concern. Discussions with yam importers in the UK suggested that, on arrival, losses of 10% are expected and that it is not uncommon for wastage rates to rise to 50% and even 100% (Bancroft 1996 & 1998 and Crentsil *et al*. 1997). As a consequence of the risks involved in the export of yams neither the exporters themselves nor the importers can rely on consistent quality and both periodically suffer economic loss of consignments and market.

Quality of marketable yams on-farm

As the general level of development in the yam producing areas of West Africa currently precludes the use of biocides (specifically fungicides), sprout suppressants or refrigerated cool stores, it is the judicious use of other alternative forms of intervention that, for the time being at least, may provide some means of mitigating the current levels of post-harvest loss. Of key importance here is the integrated use of ‘curing’ protocols, improved yam-barn designs for storage under ambient conditions and a radical re-assessment of the post-harvest grading and handling of yams.

Over the years a favoured topic for research in West Africa has been the storage of yams, the design of yam barns and the comparative advantage of barns to the pit storage of tubers (Coursey 1967, Coursey and Nwankwo 1968, Demeaux and Vivier 1984, Girardin, O. 1996, GTZ 1995, Henckes *et al*. 1995, Igbeka 1985, IITA [Undated], Nwankiti *et al.* 1987 and Ogundana 1982). Various pre-storage ‘curing’ and ‘lime’ treatments of yams have also been advocated by a number of researchers as a means of diminishing the incidence and forestalling decay and moisture loss in tubers by encouraging the wound-healing of tissues immediately after harvest (Cooke *et al.* 1988, Martin 1974 and Thompson 1972,). As regards the post-harvest management of yams during transportation and export, recommendations for the selection of yams for export have also been produced (Ghartey 1995 and Medlicott - undated) and in Ghana guidance notes for yam exporters are made available by the Federation of Associations of Ghanaian Exporters (FAGE, 1997).

Despite this body of research, its findings and recommendations, there is little evidence to suggest that improved protocols have been deployed effectively on a large scale by those working in the yam trade in West Africa. If concerted efforts have been made to disseminate this information and bring about significant changes in traditional practices and these initiatives have failed, then papers investigating the possible social and economic constraints to the implementing of modified post-harvest strategies are absent. At least in part, therefore, the problem would appear to be that the lessons learned from previous academic research have not been transferred, developed, pilot tested and promoted in communities reliant on the yam trade and hence any of the potential benefits of that may accrue from changes in handling strategies have not yet been realised in practice. It was one of the objectives of the project reported here to take the products of previous research and at least begin the process of developing and testing strategies that are realistic and economically profitable for those involved in the production and trading of yams.

During the last season of trials undertaken as part of the NRI managed project R6505, the adherence to specific curing and post-harvest protocols was found to significantly reduce the weight of rots recovered from tuber samples after three and four months storage (NRInt., 1999). Although research is still required to determine which curing regimes engender an optimal response and which may prove detrimental, the available evidence suggests that the integration of curing protocols together with the storage of yams in improved yam barns similar to those advocated by the GTZ (GTZ, 1995 and Henckes et al. 1995) have the potential to reduce on-farm wastage.

Ultimately, to change the *status quo* it is necessary to work alongside producers to up-grade their existing practices to include curing and also devise strategies by which access to improved storage facilities becomes an affordable option. Success depends on whether protocols can be shown to be consistent, and technically and economically superior to existing practices, whether or not individual farmers can be convinced of the benefits and persuaded to break with tradition, pool their resources and work communally with others to bring about improvements, and whether the new working relationships that may be required to promote changes in post-harvest practice are sustainable over time. A review of literature available in the public domain indicates that initiatives of this nature had not been undertaken previously.

Quality of yams shipped for export

In much the same manner, additional initiatives to upgrade the practice of yam exporters are required to improve the quality of yams exported from Ghana. In the light of observations recorded during project R6505, the areas of specific concern were the need to forge links between producers and exporters; the requirement for producers to select yams specifically for the export market; improved produce grading prior to shipment and improved stowage and handling regimes during shipment by sea. For such recommendations to succeed in invigorating the existing export trade their technical, economic and social veracity needs to be established by studying the quality of out-turns, assessing the economic benefits relative to manpower and resource inputs, and taking due note of the sociological factors that may influence the speed with which such new trading relationships and practices may become established.

Principal Agents of Disease

Of the range of factors that precipitate losses of marketable tubers, rots are the most immediately apparent causing both primary and secondary damage. Published papers indicate that an extensive list of fungal and some bacterial organisms have been isolated from decaying yams (e.g. Coursey 1967, GTZ 1995, Nwankiti *et al.* 1987, Ogundana 1982, Thompson *et al*. 1977) and conventional wisdom suggests that many of these agents gain entry into the cortical tissues of the yam via natural openings, cracks, punctures caused by various insect pests and nematodes and wounds resulting from mechanical damage and poor handling (Thompson and Bancroft, 1996). Observations further suggest that the incidence of rots may be influenced by varietal resistance, the nature of the storage environment and whether tubers have been cured or treated with biocides or lime and/or ash preparations. Specific information regarding which pathogens engender the most damage and why, and how handling protocols may influence the incidence and progression of these diseases remains lacking however. Preliminary studies undertaken during Project R6505 suggested that the spectra of pathogens found degrading yams differed between varieties, their source of production and also may change during the trading/storage season. Destructive analysis of apparently sound yams has also revealed high levels of chronic disease deep within the yam tubers suggesting that a significant proportion of infections may be initiated pre-harvest and may even stem from the original planting material. In seeking to develop strategies to counter the incidence of disease in the post-harvest sector it is imperative to appreciate more precisely where infections arise and how different protocols may be deployed effectively to disrupt the normal epidemiological progression of potentially destructive pathogens.

Curing of fresh produce

Curing was first described for potatoes (Priestley and Woffenden, 1923;Artswager, 1927) and involved exposing the tubers to warm (usually 15-18 ^{o}C) humid conditions for a few days after harvest. Its effect is to encourage rapid wound healing to retard water loss and act as a barrier to invading micro-organisms (Passam *et al*., 1976). Additionally the warm temperatures may stimulate metabolic reactions resulting in the production of toxic or antagonistic chemicals . There are also many reports of curing being effective on fruits (Holmes *et al.*, 1998; Tariq and Thompson, 2001). Artschwager and Starret (1931) distinguished the three stages involved in the physiology of wound healing in sweet potatoes as; 1) The desiccation of several cell layers of parenchyma in the wound; 2) The thickening of cell walls (suberization or lignification) of cells beneath the the desicated cells; 3) The formation of wound periderm (cork or wound phellem) underneath the lignified layer to complete the process of wound healing. Lignification has been observed to be probably the most critical step in the wound healing process since after lignification a wound-periderm is formed underneath the lignified cell layer even if sweet potato roots are removed from curing (Walter and Schadel, 1982; 1983). The wound periderm consists of layers of cells, stacked in a similar way to the native periderm and resembles the natural periderm except that is formed after harvest. It can develop under both curing and cooler conditions, but under curing conditions it develops more quickly (Walter and Schadel, 1982). The factors affecting wound healing in plants include environmental conditions, type of wound, maturity and soil temperature. Wound healing can be measured in several ways. This includes the number of lignified cell layers (Walter and Schadel, 1982), wound phellem layers (Strider and McCombs, 1958), rates of water loss (Lulai and Orr, 1995), ethylene production (Walter and Schadel 1982; St Amand and Randel (1989; 1991) and microbial invasion (Nielsen and Johnson, 1974).

Curing for control of tuber rots of yam (Dioscorea spp.)

Thompson *et al*. (1977) have shown histologically that lignification and the development of wound periderm in yams is similar to that of sweetpotato. This, however, contrasts with the data of Martin (1974) who suggested earlier that periderm formation does not generally occur during curing of yams. Several workers have reported the advantages of storing cured tubers over uncured tubers. Despite its obvious advantages curing is not widely practised in West Africa. In order to reduce its added cost to production and to promote the practice among farmers, curing will have to be made more efficient by optimising the tuber and environmental factors affecting the process. It is therefor important to establish what would be the most appropriate levels of these factors that will condition efficient curing in white yam (*D. rotundata*Poir). To date the limited literature on wound healing in yams is not particularly clear about the nature of the environmental conditions required to initiate the curing process although they all report longer shelf life for cured compared to uncured tubers. Table 1 shows the environmental conditions reported for successful curing of yam tubers. .

Table 1. Environmental conditions for curing of yam (*Dioscorea spp*.) tubers to prolong shelf life.

Species	Temperature (°C)	Humidity (%)	Duration (days)	Reference
D.alata	32	90	4	Gonzalez and Rivera (1972)
D.rotundata	25-30	55-82	5	Adesuyi (1973)
D. esculenta *D. dulbifera*	26-28	high	5-7	Martin (1974)
D.rotundata *D. caynensis*	25-40	95-100	-	Been *et al*. (1976)
D.rotundata	26	92	11-15	Nnodu (1986)
D. caynensis	36-40	91-98	-	Thompson *et al*. (1977)

There seems to be agreement on the use of high humidity (>70°C) but there is still a wide range in suggested optimum curing temperature (25-40°C) and curing duration (2-15 days).

The physiology of curing in yam tubers is under-researched and much is still to be discovered regarding the mechanisms that controls wound healing in yam and how the process may be influenced by other factors such as tuber maturity at harvest and duration of storage of tubers. The optimum age at harvest for tubers to be stored for a long period is an important factor for yam production. The time of maturity varies considerably between cultivars (Okoli *et al*., 1984;Degrass, 1984) but adequate attention has not been paid to its effect on curing and therefore on the storability of yams. It is also important to investigate if yams stored over a period of time but later sustain some damage due to transportation and handling can be cured before export. This is because yam is a seasonal crop and yam export is done throughout the year. The physical effects of curing on tuber skin strength, toughness and fracture (skin strength, skin elasticity and tissue integrity) is also worth studying as this impacts on the level of damage on cured tubers as they are transported or inspected in storage.

Non-Destructive Grading Methods

In response to demands of the fresh produce industry in the developed countries to satisfy quality assurance targets, commercial firms and research organisations have recently begun to develop equipment designed to assess quality indices by non-destructive assays based on the use of sonic probes or sensory arrays. Commercial trials are already underway to determine the feasibility of using sonic probes to grade fruit such as apples, avocados and melons (Bancroft, 1988) and a published example of the successful deployment of another approach is provided by the determination of fruit ripeness of muskmelons. By analysing the aromatic volatiles evolved from the fruit, Benady and his co-workers (1995) have been able to predict the ripeness of melons with a higher degree of accuracy than by all other conventional destructive and non-destructive methods of ripeness evaluation. More recently, researchers have begun to explore the possibility of using sensory array equipment to differentiate between other materials, for example Keshri *et al* (1998) have reported success in using sensory equipment to detect and differentiate the activity of spoilage fungi grown in culture.

At the NRI sensory arrays have been used successfully to determine the internal quality of mangoes and tomatoes (Taylor, 1997a and 1997b) and experimentation indicates that similar techniques have the potential to monitor the quality/maturity of apples (Taylor, 1998a) during storage and differentiate between variously treated samples of groundnuts (Taylor, 1998b).

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PROJECT PURPOSE

The purpose of the project and how it addressed the identified development opportunity or identified constraint to development.

The overall objective of the project is to improve the system by which yams are marketed in Ghana, and also exported from Ghana to Europe (specifically the UK). In order to achieve this, the specific project objectives are; to identify the technical and socioeconomic constraints to the system; to improve handling, storage and export protocols; develop recommendations to improve linkages between growers and exporters; to reduce the incidence of chronic rots in yams entering the marketing chain; and devise improved methods for the grading of yams.

Improvement of yam handling and storage will have a direct impact on Food Security, while improvement in their market potential will increase their contribution to rural livelihoods

In the 'Yam Belt' of West Africa, resource-poor peasant farmers are responsible for the cultivation of yams, but there are indications that they have the potential to scale up production. For the majority, the crop represents both food security and, due to its enduring popularity, an important source of income. Projected population growth, urbanisation and the further development of local, regional and overseas markets suggest that the demand for yams will increase. If producers and traders were able to respond effectively to these marketing opportunities, the contribution to rural livelihoods made by the yam trade would expand, and the income generating potential of the crop would be more fully realised. Presently, the more effective exploitation of yams is constrained by high costs of production in terms of manpower inputs and very considerable pre- and post-harvest losses. This project sought to: develop and test integrated technical, socially and ecologically acceptable protocols that are able to reduce the absolute biological and economic losses inherent in the current system; improve the quality of yams destined for both local and overseas markets; and strengthen the links between yam producers and exporters.

Although the majority of the field work was conducted in Ghana, the findings will be pertinent to the other yam-trading systems operating in West Africa.

RESEARCH ACTIVITIES

This section should include detailed descriptions of all the research activities (research studies, surveys etc.) conducted to achieve the outputs of the project. Information on any facilities, expertise and special resources used to implement the project should also be included. Indicate any modification to the proposed research activities, and whether planned inputs were achieved.

Changes to project management and personnel.

A full list of the institutions and staff members that contributed to this project is given on page i.

The project was developed and initiated by Dr. Roger Bancroft. However, in 2001 Dr Bancroft ceased to be a full-time member of staff at the Natural Resources Institute, although continuing as an associate staff member. From this time administrative management of the project was taken over by Dr. Debbie Rees. However, management of all of the technical activities within Ghana, and many of those in the UK remained the responsibility of Dr Bancroft.
Day-to-day management of project activities in Ghana was undertaken by David Crentsil of the Ministry of Agriculture.

Changes to Outputs and Activities.

During the course of the project certain alterations were made to the Outputs and activities in discussion with the Programme Manager. These are summarised in the Logframe shown on the following pages.

Compilation of this report

This report was compiled primarily by D. Rees, from data and reports on the individual project activities supplied by the project participants. The following sections were written by G.Omumah: Activities 2.1, Outputs 2.1

Note: The logframe is in a separate file: Logframe.doc

Output 1: Improved post-harvest handling and storage protocols developed, integrated and validated in collaboration with yam producers for deployment in-country.

1.1 Socioeconomic aspects of the marketing system

Further information can be obtained from Greenhalgh (2001) and Agbodza (2002)

A range of data sources were used in compiling this study, including existing reports and grey literature. Additional statistical data was also obtained from government production and marketing statistics. Another important source has been interviews with yam producers, and the data from these interviews were supplemented with interviews with other persons knowledgeable about post harvest yam production practices including traders, government officers, exporters and consumers. Through these sources detailed data were collected on the range of factors influencing post harvest yam handling and storage practices. In the remainder of this section the nature and sources of data employed are discussed in more detail.

Interviews were undertaken with 66 farmers in the Brong Ahafo Region – the largest yam-producing region in Ghana. In addition, as part of Phase 1 of the project some twenty yam traders in the Techiman, Kintampo and Atebubu markets were interviewed along with 20 traders each from the Basere and Konkongo markets in Accra. 53 traders were interviewed. 4 Ghanaian exporters were interviewed along with six UK yam importers.

Structured questionnaires were used in conducting the interviews. The aim was to collect data from producers on all the socio-economic factors that dictate the kinds of post-harvest handling and storage practices of yams and how these affect quality and price. Information is also being collected on quality including variety of yam being produced, aroma and taste, physical appearance of tubers and grade of yam. Information being collected from yam traders included grade/size, place of storage, type of storage structures, types of vehicles used in conveying yams to the market. Some of the general questions that the research endeavoured to provide answers to include:

- What are the post-harvest handling and storage practices by farmers?
- What are the socio-economic factors that determine the choice of post-harvest handling and storage practices by farmers?
- How are the costs and returns of yam farmers' post-harvest handling and storage practices determined?
- What is the relationship between the quality of yam and its economic value?
- Are there any regulations or standards that producers follow in order to produce good quality yam?

1.2 Storage and handling trials.

Further details can be obtained from Bancroft *et al.* (2003)

For this output handling/storage trials were conducted over three seasons in order to investigate the strengths and weaknesses of the existing methods, and to identify improvements. The locations and treatments varied depending on the findings of the previous years trials. The trials were supported by laboratory experiments conducted in parallel.

The improvement of handling and storage is important for the export as well as marketing in-country, so that these activities are also of relevance to Output 2.

1.2.1 Storage and handling trials: Year 1

In the first year of the project (2000-2001) a trial was established in the village of Fiaso in the Techiman District of Brong Ahafo Region, during which the shelf-life potential of three varieties of White Yam (*Dioscorea rotundata* var. Pona, Lili and Zoan) stored under a range of conditions (traditional and recently introduced) were studied. An important aspect of the treatments used was the introduction of a prestorage treatment designed to allow "curing" of the tubers (see Background). The tubers used were milk yams i.e. were relatively immature (harvested approximately 6 months from planting).

Yam supply

Yam tubers of three varieties: Pona, Lili and Zoan were harvested from separate farms. Sound tubers from each variety of yam were divided into four groups of 100 tubers, which were exposed to four pre-storage/storage treatments as shown below.

Pre-storage/storage treatments

	Prestorage treatment	**Storage treatment**
Treatment a	Improved yam barn	
Treatment b	2 weeks of "curing" in a humidified clamp at ambient temp.	Improved yam barn
Treatment c	2 weeks of "curing" in sealed plastic bags at ambient temp.	Improved yam barn
Treatment d	Traditional storage pit	

The *improved yam barn* was based on traditional designs with improvements defined by GTZ (GTZ (1995) Market orientated storage of yams - a case study in Northern Ghana. GTZ Internal report. Henckes, C., Fuseini, H.A. and Nicol, K. 1995. Market-orientated yam storage: a key to increase the profit of yam production. *International Conference, Postharvest technology and Commodity Marketing* 27-29 November 1995, Accra Ghana.). The tubers were stored on open shelves.

The *humidified clamp* was a structure built in the open in which a circular pile of yams bedded on straw were covered with a polypropylene sheet. To enhance the humidity within the clamp, a bucket of water was placed at the centre of the pile.

For *curing* in treatment (c) tubers were placed in plastic bags (900 x 600 mm, gauge 350) which were then closed and tied with string.

The traditional storage pit was the control treatment, as this was the most common storage structure founding the region. Yams were placed in a shallow pit which was then covered with a mound of earth and shaded by palm fronds.

Trial design

Immediately after harvest, a quality assessment of both obviously sound, and diseased tubers was conducted. Subsequently 400 sound tubers of each of the three varieties were selected for the trial. 100 tubers of each variety were exposed to the pre-storage treatments for each of the 4 treatments. To allow for mis-hap, only 60 tubers of each variety (3 replicates of 4 tubers to be sampled at 5 time points) were carried forward to the storage phase for each of the 4 treatments. Tubers were selected from the remaining tubers for quality assessment. All tubers for treatments a,b and c were stored in a single barn.
Tubers for treatment d were stored in 15 pits, each of which contained 4 tubers of each variety (12 tubers). Thus 3 pits were sampled at each time point.

Tubers were assessed for quality at monthly intervals for 5 months. Due to time constraints, the 3 replicates were assessed on consecutive days. Thus for treatment d, one pit was opened on each day of assessment

Tuber Assessment
The monthly assessment of yams during storage were conducted as follows.
Firstly, intact tubers were inspected and data was recorded describing length, weight and internal and external temperature.
Tubers were cut into five portions. The ‘head’ and ‘tail’ portions were cut at points 1/8th the length of the tuber from the head and the tail respectively, and the remaining cylindrical trunk of the yam was cut into three segments of equal length. These segments were referred to as the ‘top’, ‘middle’ and ‘bottom’ portions of the tuber. For each of the five dissected portions of yam an entire series of observations were made as listed in Table 1.1

Table 1.1 Data obtained during assessment of yam tubers: year 1

Characteristics of whole yams	**Characteristics of each portion**		
	By number	By area	By weight
Total length of tuber (mm) Total weight of tuber (g) Surface Temperature (°C) Internal Temperature (°C)	Sprouting (Y/N) Harvest cut (Y/N) No. of cuts No. of splits/cracks No. of breakages No. of termite holes No. of spear grass holes No. of beetle holes No. of millipede holes No. of other holes	Total skin surface area (mm^2) Area of grazes Area of gashes Area of pest eaten portions Area of heat stressed portions Area of cuts Area of splits/cracks Area of rough skin Area of visible rots	Wt of yam portion Wt of heat stressed portions Wt of termite damage Wt of spear grass damage Wt of beetle damage Wt of millipede damage Wt of internal brown spots Wt of external rot damage Wt of internal rot damage

1.2.2 Storage and handling trials: Year 2

1.2.2.1 Main trial on Pona

For the second year of trials, due to its economic importance, the main trial concentrated on the variety Pona. The main purpose of this trial was to determine whether storage could be improved by a curing treatment. As for year 1, the tubers were relatively immature (8-9 months from planting). The trial was conducted at Nyomoase in the Atebubu district of the Brong Ahafo region

Yam supply

Yams were provided by two farmers on adjacent farms. Planting was done about the same time by both farmers. Two days were taken to harvest the tubers used for the trial. 800 tubers were provided by one farmer, while the other supplied 300. These tubers were mixed thoroughly out of the 1100 tubers 900 were selected for the trial.

During harvesting information on the two farms was obtained from the farmers through discussions using the participatory approach.

Storage treatments

	Pre-storage treatment	**Storage treatment**
Treatment a	Improved yam barn	
Treatment b	4 days of “curing” in a “curing room”	Improved yam barn
Treatment c	Traditional storage pit	

Traditional storage pit
For the pre-storage treatment a pit (length: 2.5m; width: 1.8m; depth: 0.5m) large enough to contain 300 tubers was dug. The tubers were then arranged in it with the tail end down, after which they were covered with earth. A shade was then erected over it to protect the arrangement from rain and the sun. The tubers were kept in the pit for four days after which they were removed.
For the storage treatment tubers were stored in 5 pits of 46 tubers each..
For security purposes the storage pits were dug in the village and not on the farm.

Improved yam barn.
The improved yam barn was built to the same specifications and dimensions as that built at Fiaso in year 1 (1.1).

Curing room
The room used for curing was built of earth but cemented inside and outside. It was roofed with aluminium sheet and had internal dimensions; Length:- 4.20m, Width:- 3.40m, Height:- centre: - 2.75m; sides: – 2.20m

Before the curing process all openings on the door and window of the room were sealed by covering them with black polythene sheets. Some boards were then arranged on the floor to serve as pallets on which the tubers were arranged. Two trays each having a surface area of about 1800cm² (60cm x 30cm) and a depth of 10cm were filled with water and placed together in the centre of the pallet. The 300 tubers were then arranged around the trays and the whole arrangement covered with a polythene sheet. Temperature and humidity was assessed using ‘Tiny Tag’ monitoring equipment.

Six small holes, each of an area of about $4cm^2$ were made at selected points on the sheet to improve aeration within the pile. Five 100-watts bulbs were hung evenly-spaced over the covered pile of tubers. The space between the polythene sheet and the bulbs was about 30cm. Four wet jute sacks were also hung in the room 'enclosing' the arrangement. The lower ends of the sacks were dipped in trays (with the same dimensions as those mentioned above) of water throughout the curing period. Through capillarity force water from the trays always rose to significant heights on the hanging sacks. Apart from this two more of such trays were filled with water and placed in the room.

To get a reasonable temperature and humidity even before the tubers were arranged in the room, some water was boiled in a big bowl at one corner of the room and all the lights switched on. This activity continued throughout the curing period.

Trial design

900 tubers were selected for the trial. 300 tubers were exposed to the pre-storage conditions for each of the 3 treatments. Only 230 tubers (46 tubers to be sampled at 5 time points) were carried forward to the storage phase for each of the 3 treatments. Of the tubers remaining after the prestorage treatment 10 sound and 10 unsound (where available) were selected and assessed in detail for quality. All tubers for treatments a,b were stored in a single barn. Tubers for treatment c were stored in 5 pits, each containing 46 tubers.

Tuber assessments

Of the 46 tubers assessed each month 16 tubers were randomly selected for destructive assessment.

The destructive assessment was similar to that used in year 1, except that the tubers were cut finally into 40 pieces rather than 5 . Three main assessment stages were employed. The first one involved assessing the whole tuber, the second involved cutting the tuber into five sections. For the third stage the five sections were further cut into eight different pieces (bits) and assessed. Parameters used for the assessments are presented below:

Table 1.2 Data obtained during assessment of yam tubers: year 2.

	Tuber form	Parameters assessed
First stage	Full	Weight and length of tuber
Second stage	Five sections	Weight of section, number of cuts, number of splits/cracks, number of termite and spear grass holes and number of gashes on each section
Third stage	Eight pieces (bits)	Weight and surface area of each piece, surface area of rough skin (nematode infection) and weight of rot on each piece.

1.2.2.2 Storage and handling trial year 2: Comparison of varieties Pona and Onumo (Aboagye-Nuamah and Offei (2002).

During year 2, two white yam varieties, Pona and Onumo were compared in a parallel trial to that described in 1.2, using essentially the same methods. A total of 200 commercially sound tubers of each variety were selected for the experiment. Each selected tuber was labelled and weighed. 10 tubers of each variety were randomly selected and assessed to determine the quality status of the yam tubers. The remaining tubers were then divided into three groups of 60 tubers and subjected to the three post-harvest treatments as described above.

1.2.3 Storage and handling trial year 3

The results of the first two years of trials suggested that the maturity of yams had a very significant effect on their storability, and optimum storage conditions. In the third year, therefore, two sets of trials were conducted, firstly on immature "milk" yams, and secondly on the more mature "ware" yams.

1.2.3.1 Storage and handling trial year 3: Milk yams

The trials were conducted at Yomoase, Brong Ahafo Region. Previous trials had indicated that Milk yams stored better in pits than in barns. The trials were therefore designed to determined whether improvements could be made to pit storage.

Yam supply

700 Pona tubers were harvested over two and a half days from one farmer's farm.
Information on the growing practices used at the farm was collected at the time of harvest.

Storage treatments

	Prestorage treatment		Storage treatment
Treatment NP	No chemical treatment	4 days stored in pit	Stored in pit
Treatment TP	0.4% Thiabendazole	4 days stored in pit	Stored in pit
Treatment NC	No chemical treatment	4 days in "curing room"	Stored in pit
Treatment TC	0.4% Thiabendazole	4 days in "curing room"	Stored in pit

Pit storage
For the prestorage treatment a single pit large enough to contain 300 tubers was dug. A 'Tiny Tag' electronic monitoring devise was placed in the pit to monitor the temperature and relative humidity throughout the period. The pit was covered with earth and a shade erected.
For the storage treatment 5 pits, each with a capacity of 100 tubers, were constructed.

Curing room
The room used for curing was built of earth but cemented inside and outside. It was roofed with aluminium sheet and had the following internal dimensions: Length:- 4.20 m, Width:- 3.40 m, Height:- centre: - 2.75 m; sides: – 2.20 m. Before the curing process all openings on the door and window of the room were sealed by covering them with black polythene sheets. Pallets were then arranged on the floor. Two trays each having a surface area of about 1800 cm^2 (60 cm x 30 cm) and a depth of 10 cm were placed together on the centre of the pallet. A wooden frame (length – 70 cm; width – 55 cm; height – 75 cm) was erected around the trays. Two jute sacks were cut into four along their longitudinal sides, soaked with water and hung on the wooden frame with their lower ends lying in the trays. The trays were then filled with hot water, after which the whole arrangement was covered with a plastic sheet. The wet jute sacks and the hot water were used to generate the relatively high temperature and humidity needed for curing. Small holes were made on the plastic sheet at convenient locations to facilitate gas exchanges. To facilitate increase in temperature and relative humidity water was heated at one corner of the room with a gas stove. For the same purpose two 100-watt bulbs were

hung on the covered arrangement. To ensure that the temperature did not go beyond the recommended level two temperature probes were used. When the temperature was found to be going higher than the recommended, either the bulbs or stove or both were put off. The curing process lasted for four days.

Trial design

Out of 700 harvested tubers 610 good tubers were selected for the trial. Ten of these were assessed to determine initial quality prior to any subsequent handling. 150 tubers (separated into 6 replicates of 25 tubers) were then assigned to each of the four treatments. Yams designated to treatment TP and TC were then dipped in 0.4% thiabendazole. A single pit containing 300 tubers was used for pre-storage pit treatment involved in two of the treatments (NP and TP). Similarly curing of the remaining 300 tubers (treatments NC and TC) was conducted in the "curing room" as one batch.
For logistical reasons, only 5 of the 6 replicates were used during the subsequent stages of the trial. Immediately after the 'curing' protocol was completed and prior to the next phase of the experiment, 25 samples of each of the yams of treatments NP, TP, NC and TC were destructively analysed. This left a total of 125 yams for each treatment combination to pass into storage. In this trial storage was arranged in a series of 5 pits. In each pit, each treatment combination was represented by 5 blocks, each containing 5 individual tubers. Hence each pit contained 5x5x4 = 100 tubers.

Assessment of tubers.

Yams were assessed after 1 and 2 months of storage. On each occasion one pit was assessed for quality, while a second was used to select good quality yams for transport to the UK and further assessment.
Assessment of tubers involved two stages. In the first stage all 25 tubers from each treatment were first weighed and their status recorded. The status of each tuber was described as good, compromised or poor depending on its wholesomeness. During the second stage 16 tubers were randomly selected from the 25 for detailed assessment. In this assessment each tuber was cut into eight equal pieces along the length of the yam and each piece weighed. Every piece was then further assessed using for a wide range of parameters as indicated in Table 1.1.

1.2.3.2 Storage and handling trial year 3: Ware yams

This trial was conducted at Dogoketewa, in the Nkwanta district of the Volta region. Previous trials had indicated that ware yams stored well in barns. The trials were therefore designed to determine whether improvements could be made to barn storage.

The design of the trial, and the methods used were essentially the same as for milk yams (1.4.1) except where described below.

Yam supply

700 Pona tubers were harvested over two days from one farmer's farm.

Storage treatments

	Prestorage treatment		Storage treatment
Treatment NP	No chemical treatment	4 days stored in barn	Stored in barn
Treatment TP	0.4% Thiabendazole	4 days stored in barn	Stored in barn
Treatment NC	No chemical treatment	4 days in "curing room"	Stored in barn
Treatment TC	0.4% Thiabendazole	4 days in "curing room"	Stored in barn

Storage barn
Before harvesting of the tubers a barn was constructed by the farmer on his farm under a tree with local materials (poles and palm fronds). The dimensions of the barn were as follows:
Length: 4.30 m; width: 4.00 m and height: 1.90 m. To prevent entry of rodents into the barn, the inside of the walls as well as the roof were lined and protected with hexagonal wire netting of 1.5cm 'gauge'. The space between the wall and the floor was also filled with firmed earth.

Curing room
A curing chamber was built in a room for the curing process. This was very similar to the one used for milk yams. The room used for curing is built of earth and roofed with aluminium sheet and had the following internal dimensions: Length:- 3.20m, Width:- 2.80m, Height:- centre: - 2.80m; sides: – 2.20m. The chamber consisted of wooden frame mounted on a wooden pallet. The frame was then covered with a plastic (polyethylene) sheet. Four small and one relatively bigger vents were made on the plastic sheet to facilitate gas exchange during curing. In the middle of the pallet were placed together two rectangular shaped bowls, each with dimensions of length 60cm, width 30cm and depth 10cm.
The curing procedure used was as described in 1.4.1.

Trial design

Trial design was the same as that used for milk yams.

Tuber assessment

During storage period five assessments were carried out. At each assessment one of the five lots in the barn was assessed. Three lots were subjected to the two stages of assessment while the other two went through only the first stage. The two lots that went through only the first stage of assessment were used for shipment (export) trials from Ghana to the UK.

1.3 Studies on the environmental effects on wound-healing in yams.

In order to facilitate the interpretation of the field trial results, and to optimise storage conditions in the field, a set of experiments was conducted to define the environmental effects on wound-healing in yams. Initial experiments were conducted at the Department of Crop Sciences, University of Ghana, and later experiments were conducted at the NRI in UK. The data presented is from the later experiments.

The specific objectives of the experiments were:

- To investigate the effect of temperature, time and CO_2/O_2 concentration on the extent of wound lignification in white yam.

- To investigate the effect of CO_2/O_2 concentration during curing on the subsequent internal colour of tubers after cutting.

1.3.1. To investigate the effect of temperature, time and CO_2/O_2 concentration on the extent of wound lignification in white yam.

Yam tubers of variety Pona were air freighted from Ghana to NRI. 192 sound tubers were selected for the experiment. The experiment was conducted twice at 8 day intervals.

Four shallow wounds were cut around the central portion of each tuber using a potato peeler. Twenty-four tubers (3 replicates of 8 tubers) were placed in each of 4 incubators set to 30 ^{o}C, 32 ^{o}C, 34 ^{o}C and 36 ^{o}C. Within each incubators, the tubers were placed in 3 plastic boxes (8 tubers per box) on racks placed above a layer of water, through which air was bubbled. Thus a high humidity was maintained with sufficient ventilation to prevent an increase in CO_2 levels or a decrease in O_2 levels. The temperature and relative humidity in the incubators were monitored using Tinytalk miniature data loggers.

Two tubers from each replicate were removed at 3, 4, 5 and 6 days for assessment of lignification.

As it was not possible to assess all tubers on the day of removal, tissue samples were cut from the wound and fixed in FAA solution (Ethanol 70%, Formalin 5%, Acetic Acid 5%). In order to assess thickness of the lignified layer, and the number of lignified cell layers, samples were then stained with phloroglucinol (1% in 95% ethanol) for 2 minutes, transferred to concentrated HC1 for 30 s and rinsed with water for 30s. The number and thickness of the lignified layer was assessed at x100 enlargement using a microscope equipped with a graticule.

1.3.2 To investigate the effect of CO_2/O_2 concentration during curing on the subsequent internal colour of tubers after cutting.

Six artificially wounded tubers were placed in each of two plastic boxes within an incubator set at ?, arranged as described above, except that the containers were tightly sealed with plasticine.

One box was ventilated with air, while the other was supplied with a gas mix of ?% CO_2 and ?% O_2.

Tubers were removed after the fourth day and cut for observation of internal tissue colour lignification as described above.

Output 2: Improved post-harvest handling and shipping protocols for the export market identified and recommendations developed in collaboration with joint yam producer/exporter associations.

2.1 Socioeconomic aspects of the Ghanaian yam export trade

The aim of the socio-economic research activities included:

- Identifying the main economic and marketing factors affecting the viability of fresh yam exports from Ghana into the UK market, including competition from other Yam exporting countries;
- Determining the technical and socio-economic constraints hindering the development of effective yam producer/exporter linkages and possible strategies to foster successful collaborations; and
- Assessing the feasibility of introducing improved handling, storage and shipping protocols to reduce biological and economic losses, thereby improving the quality of yams delivered to the export destinations, especially the UK market; and

Methodologies adopted by the Socio-economic Team

2.1.1 Ghanaian Yam exports to the UK: economic and marketing influences and sources of competition

A range of data sources have been used in compiling this study, including trade and production statistics, existing reports and grey literature, along with interviews with commercial contacts and traders. The Bibliography and References (Appendix I) provides details of the principal documents consulted; many of which have not been published officially[1].

Various quantitative data (e.g. market size, prices, origin of imports) as well as qualitative (market requirements, quality, constraints to trade) were collected. A series of unstructured and semi-structured interviews with UK yam importers and Ghanaian exporters was supplemented with interviews with other persons knowledgeable about the yam trade including government officers, representatives of the Ghana Yam Producers and Exporters (GYPEA) and the Ghana Export Promotion Council (GEPC). Researchers, academics and consumers were also consulted.

Data on the volume, value and destination of yam exports as well as details of company exports were obtained from the GEPC. As with all trade data there is a degree of mis-recording and discrepancies in the data. In contrast, such detailed data was difficult to obtain in the UK, where data on yam imports is not disaggregated within the category of “other root vegetables with a large starch content”. Only qualitative information was available on such aspects as the quality, grades and size of yams exported, physical characteristics, taste and aroma, sources of production, storage methods, packaging and shipping methods, as well as types of transport used.

2.1.2 Development of effective yam producer/exporter linkages

The study employed both semi-structured and structured questionnaire interviews to collect both quantitative and qualitative information, including yam farming practices, marketing (sales points) of farmers’ yams. Other information collected includes types of buyers of farmers’ yams, farmers and

[1] The authors are grateful to those who were kind enough to provide these documents.

traders needs, and reasons for going into marketing linkage arrangements, and market actors opinions on yam marketing linkages. Information collected from exporters includes current yam marketing and supply systems, rejects and tuber rot levels associated with such supply systems, and the profitability of the yam export business.

The study area was selected to cover the three regions in the country where yams are grown in large quantities, and which also happen to have been part of the previous phase[2] of the current yam project. Sampling was somewhat purposive, selected to include villages from which yam exporters indicated they obtained their yam consignments. Other villages were also selected on the advice of the District Agricultural Development Officers, in terms of their relative importance in the district as far as yam production is concerned. This approach was adopted to cover farmers who may already have dealt with yam exporters or who at least have some market orientation in production. This purposive sampling approach ensured that commercial yam producers were adequately covered. It is envisaged that commercial orientation will stimulate yam farmers to want to establish market linkages, hence the choice.

The target populations from which samples were drawn include yam exporters, yam farmers and traders (in selected districts), and yam exporter associations. Some officials of the Ghana Export Promotion Council (GEPC) and participants of the defunct Yam Export Production Villages concept were also interviewed. Discussions were also held with officials of the Ghana Ports and Harbours Authority (GPHA) and the Ghana Shippers Council.

The project team held focus group discussions with farmers and traders using the semi-structured questionnaires in five selected yam-producing districts: four villages in the Nkwanta district; one in the Kete-Krachi district of the Volta region; two villages in Salaga district of the Northern region; two in the Sene district and one in the Atebubu district of the Brong-Ahafo region. These discussions were intended to provide the team with first hand information on the nature of existing marketing linkages and the perceived effectiveness or otherwise of those systems, as well as possible interventions needed. The results of the above discussions were used in designing questionnaire for structured interviews involving individuals.

A total of 66 yam farmers and 18 exporters were interviewed. The exporters were made to self-complete the questionnaire after the Project Team had explained the questions, but the response rate was rather discouraging as most of them were reluctant to divulge information.

2.1.3 Profitability of yam exports

Based on primary data collected through structured and semi-structured interviews, and supplemented with information from secondary sources, the study analysed the profitability of yam exports, employing marginal analysis.

In the analysis exporter margins are estimated as the difference between the total revenue and total variable cost, expressed as a percent of the value of the exports, i.e.

EM = (TR – TVC) x 100/ total value of exports, where EM is exporter margin; TVC is total variable cost, and TR is total revenue.

The total cost was calculated by summing up all relevant cost items including the cost of tubers purchased, transport cost, cost of packaging (including labour cost for packaging), port charges,

[2] The phase that tried on-farm to develop and standardize a curing system for yam

shipping and handling costs, and cost of freight. Data on administrative cost and wages for permanent staff were not allocated.

The total revenue was estimated as the product of the number of cartons exported (less the quantity rejected) and the price per carton in foreign currency. Reject losses were valued at the selling price of a 25kg box of yam in a particular consignment. The arrangement with importers is that a maximum level of rejects (due to rots), ranging between 3% and 10%, is agreed upon. Any rots above the agreed limit is counted as a cost to the exporter and therefore not paid for. Data on this was also obtained from exporters.

2.2 Assessment/improvement of post-harvest and shipping protocols.

Further details can be obtained from Panni *et al.* (2002), Bancroft *et al.* (2002)

Effective protocols for yam export require good storage conditions in Ghana, followed by appropriate handling and storage during export. The former is addressed within the activities of Output 1. In addition to this, export trials were conducted during the second and third year of the project. The objectives of these trials were both to examine the quality of yams after various storage treatments, and to obtain information on the actual conditions during export, and how these could be improved.

The trials were carried out with the help of K. Laast Company, a yam exporting company.

2.2.1 Export trials year 2

As part of the (Pona) Yam Handling and Storage trial conducted at Nyomoase in the Atebubu district of the Brong Ahafo region (see activities 1.2.2), samples of tubers recovered from the three treatments were exported to the United Kingdom and their qualities assessed there to ascertain how the differently treated tubers could withstand the rigours of export handling. The tubers were compared with tubers purchased from elsewhere by an exporter and exported under the same export handling procedure. At the same time the conditions (temperature and relative humidity) under which the tubers were kept at the warehouses and exported were monitored. Two export shipments were carried out.

Sampling for export

During the storage trial assessment of tubers from the three treatments was carried out monthly. Of the 46 tubers from each treatment sampled each month, 16 were randomly selected and assessed. A careful selection of all bad (not sound for export) tubers was then made out of the remaining 30. The good tubers were then returned to their original storage structures until it was time for export.

Approximately three days before the arrival date of the ship, the consignments meant for export were brought down to Accra and given to an exporter who packaged them in the same way that he packaged his consignments for export. During selection of the trial tubers for export, all the tubers kept after the monthly assessment were brought out of storage. The best 16 tubers from each treatment were selected and sent to the exporter.

The first consignment was exported after about three months in storage while the second export was carried out after tubers had been stored for about four and a half months.

Packaging for export

Packaging was done by the exporter. This was to ensure uniformity of all activities since the performance of the trial tubers during shipment was to be compared to that of the exporter's consignment.

Four telescopic cartons were used for packaging of the tubers. Where possible, four tubers from each of the three storage treatments were placed in each carton. (In the first consignment one tubers was found to be 'unexportable' and was removed. In the second consignment also, only 14 of the PT tubers were found to be exportable. Two of the cartons therefore contained 15 instead of the proposed 16 tubers. To make up the required export weight of 25kg per box, some Pona tubers were purchased from the exporter and added to the trial tubers.

2.2.2 Export trials Year 3

2.2.2.1 Milk yams

As part of the milk Pona Yam Handling and Storage trial conducted at Yomoase (see activities 1.2.3.1), samples of tubers recovered from the four treatments were exported to the United Kingdom and their qualities assessed there to ascertain how the differently treated tubers could withstand the rigours of export handling. The tubers were compared with tubers purchased from elsewhere by an exporter and exported under the same export handling procedure. At the same time the conditions (temperature and relative humidity) under which the tubers were kept at the warehouses and exported were monitored. Two export shipments were carried out.

For the first shipment 100 tubers consisting of 25 tubers from each of the four treatments used in the storage trial were dug from their storage pit and assessed after 37 days of storage. For easy identification of the tubers, they were washed and dried under a shade. The very good and exportable tubers were then brought down to Accra and kept in the exporter's ware house. These were later sent to UK for further assessment.

The second export trial was conducted with tubers removed from the trial after 64 days of storage. Due to partial flooding of the area where the tubers were stored, the tubers were found covered with wet soil and had to be washed to make identification of the individual tubers possible. They were then dried under shade and initial assessment made. The good (exportable) tubers were identified and sent down to Accra for preparation for shipment to UK . The tubers were first kept in a box (with vents) in an appropriate place at the premises of the Agricultural Engineering Services Directorate for three days and later sent to the Exporter's (K. Laast's) warehouse, where they were prepared and made ready for shipment.

Preparation of tubers for UK.

Of the 25 tubers from each treatment brought down for export to UK for further assessment, the following were found to be suitable for shipment for the two trials:

Trial 1	Trial 2
NP 16 tubers	NP 11 tubers
NC 9 tubers	NC 1 tuber
TP 7 tubers	TP 15 tubers
TC 9 tubers	TC 4 tubers.

(See Activities 1.2.3.1 for a description of the treatments.)

These were shared among 8 telescopic boxes that were used for the shipment.
The eight boxes were topped up with Pona tubers bought from the exporter to make up the required weight of about 25kg per box. The individual tubers were wrapped in newsprint before they were packed in the boxes. A ‘Tiny Tag’ electronic monitoring equipment was placed in one of the boxes to monitor the temperature and relative humidity of the environment in which the tubers were kept. The individual boxes were then strapped and made ready for transportation to the Tema harbour.

Four more boxes of exportable Pona tubers were purchased from the exporter. Two of these were treated with 0.4% Thiabendazole while the tubers in the other two were not treated. The top part and head of tubers to be treated were dipped in the Thiabendazole solution for 1 minute. The tubers were then allowed to dry and packaged after they had been wrapped individually in newsprint. All packaging was carried out on 4 October 2002.

The four boxes and the eight used for the tubers from the storage trial were palletised together and loaded into the ship.

To get an idea of the quality of the exportable tubers shipped by the exporter, 30 of such tubers were purchased by sampling from the export consignment and assessed in Ghana. At the same time 20 ‘rejected’ tubers were purchased from the exporter and assessed to ascertain why they were rejected.

According to the exporter the Pona exported were purchased from Techiman. The time of harvesting could not, however, be known by the exporter.

2.2.2.2 Ware yams

In much the same manner as described above for the ‘Milk Yams’ (Section 2.2.2.1), trial shipments of ‘Ware’ Yams were prepared and dispatched to the UK. Unhappily, of the two consignments sent to the UK, the first was never recovered from the vessel and may be assumed to have been subject to pedial larceny. On the second attempt, again some of the cargo disappeared before discharge in the UK but some data was recovered. In both cases, the temperature and humidity recorders were never found.

Tubers used for these two trials were obtained from the handling and storage experiment established at Dogoketewa in the Nkwanta district of the Volta region and also from Pona consignment purchased by the exporter for export. (The latter was grown in a village in Northern Ghana).

On each occasion 100 yams from the handling and storage trial (consisting of 25 tubers from each of the four treatments) were removed from the storage barn and assessed for their export potential. They were then brought to Accra and kept in the exporter’s warehouse until time for shipment to UK.

Preparation of tubers for shipment.
Of the 25 tubers from each treatment kept at the exporter’s warehouse 16 sound ones were selected for shipment. Eight telescopic boxes purchased from the exporter were used for packaging. Every box therefore contained two tubers from each of the four treatments. To obtain the required shipping weight of 25kg per box, Every box was then ‘topped up’ with Pona purchased from the exporter’s consignment.

Tubers were individually wrapped with newsprint before they were packaged. The boxes were left uncovered until time for carting to the Tema harbour, when they were covered and strapped.

Two types of 'Tiny Tag' electronic monitoring equipment were placed in one of the boxes. One was programmed to monitor the temperature and relative humidity of the environment in which the tubers were kept. The other was to record the vibrations, to which the tubers were subjected.

As in the case of 'Milk Yams', the 'export' grade tubers dispatched with the produce recovered from the storage trial were either treated with TBZ or remained untreated as controls.

To get an idea of the quality of the Pona tubers shipped by the exporter, 30 of such tubers were purchased and assessed. The 30 tubers were selected randomly from the consignment set aside for export. Thirty 'rejected' tubers were also purchased (by random sampling from the rejected lot) from the exporter and assessed to ascertain why they were rejected.

Output 3. Principal disease agents responsible for post-harvest loss in quality of yams identified, source of infections determined and counter measures verified.

3.1 Investigating the source of seed yam infection

Further information is given in Ametepe (2003)

Studies were undertaken in Atebubu, Kintampo and Techiman Districts of the Brong Ahafo Region to identify the sources of pre-harvest infections of seed yams associated with the loss of quality in seed yam tubers of *Dioscorea rotundata, Poir, var*. Lili and Pona. The studies were conducted on 450 tubers each of Lili and Pona, which were obtained from 6 farmers each in two villages randomly selected from each of the three districts. The farmers stored the seed yam tubers in four traditional storage systems. The seed yams were assessed externally and internally at three different sampling times corresponding to 0 days post-harvest, 60 days post-harvest and 120 days post-harvest.

The objectives of this study were to:

1. Determine the health quality status of farmers' seed yams,
2. Identify the rot causing pathogens of seed yams of two white yam varieties,
3. Determine the sources of the rot causing pathogens and
4. Investigate traditional storage barns as possible sources of seed yam infections by micro-organisms.

3.1.1 Survey of practices relating to seed yam production and storage

A survey was carried out in the Brong Ahafo Region to derive information from yam producers on the traditional methods of seed yam production, agronomic practices, storage methods, extent of pests and diseases and methods of pre- and post-harvest seed yam management.
The questionnaires were designed, pre-tested and administered between November and December 2000 to producers from Akokoa and Nyomoase in Atebubu district, Bawakura and Suronuase in Kintampo district and Asantanso and Fiaso in Techiman district all in Brong Ahafo Region of Ghana. Six producers were randomly selected in each town..

3.1.2 Idenfication of pests and diseases and assessment of variety effect on quality of seed yams

Seed yams of two varieties, Lili and Pona, were obtained from thirty-six farmers in six villages of three yam producing districts in the Brong Ahafo Region based on the intensity of yam production. From each of the selected villages, three farmers each were selected for each of the yam varieties. Twenty-five freshly harvested seed yams of each variety were obtained from each producer. Soil was removed from the seed yams with a shoe brush and the roots on them were clipped with a pair of scissors. They were then labelled according to the district, village, farmer, variety and serial number of tuber, and the fresh weight of each seed yam was measured using a weighing scale. Five seed yams from each farmer were assessed at the start and after 60 days. Although the original plan was to assess five further yams from each farmer at 60 day intervals up to 240 days, the remaining 15 yams were assessed after 120 days storage due to rapid deterioration of the seed yams and increased rodent consumption. The experimental design used was the Completely Randomised Design (CRD).

During assessments, the following parameters were recorded:
Surface area of bruising
Surface area of sharp cuts
Weight loss
% rotten tissue (by weight)

Micro-organisms were isolated and identified..
The presence or absence and weight of internal brown spots, indicating *Dioscorea Mosaic Virus (DMV*).
The number and length and weight of sprouts.
The presence or absence of nematode galls, and surface area of nematode damage
Nematodes were extracted from the tissues and identified
Presence (number) or absence of mealy bugs,
Presence or absence of scale insects.
Presence or absence, number and diameter of termite holes
Rodent damage
The presence or absence of spear grass damage

Isolation and identification of rots

Tissues from the diseased samples were cultured within five days of recovery from the diseased seed yam. Isolation of fungi was done first on water agar (WA) and later transferred to potato dextrose agar (PDA). Small portions of seed yam tissue from the advancing edge of the infected tissue were removed with flamed scalpel and surface sterilised in 1% sodium hypo chlorite solution for two minutes to disinfect the tissue surface of any contaminant micro-organism. The tissue was removed with forceps and rinsed in sterile distilled water for three minutes and blotted on sterilised filter paper. Three pieces of the surface sterilised diseased tissues were placed on one WA plate for culturing incubated at ambient temperatures of 20 –30°C. Pure cultures were sub-cultured from the advancing edge of each of the growing micro-organism on PDA plates

The PDA colonies of the fungi, which did not sporulate, were kept in disinfected improvised wooden incubation chambers with light provided by a two feet 18 watt Tungstram fluorescent tube to provide a near ultraviolet light continuously for seven days (Johnson and Booth, 1968; Tuite, 1969; Neegaard, 1977).

To identify the pathogens, mycelia bits were taken from pure cultures of the pathogens, Identification was according to the cultural characteristics on PDA, rate of growth, pigmentation, morphological features of the mycelium and conidia and the sporulating characteristics of the fungi.

Isolation and identification of bacterium:

To isolate and identify the bacterial species, a small amount of tissue was removed from the advanced edge of the diseased tissue with a heat-sterilised knife and surface sterilised in 1% sodium hypochlorite for three minutes. The tissue was then rinsed in sterile distilled water for three minutes. The tissue was then chopped with a flamed scalpel into small pieces in a drop of sterile distilled water in a petri dish, incubated for two to three minutes at ambient temperature, and streaked into nutrient agar (NA) plates. The plates were incubated under ambient room temperature for three to four days in wooden incubation chambers. Sub cultures from well-spaced single colonies were streaked into new NA plates. Identification involved a motility test, gram staining, spore characteristics, and tests for anaerobic growth. *Pseudomonas sp.* was identified by plating on *Pseudomonas*-Agar F (Mikrobiologie). Further identification was done using API 20E, Enterobacteriaceae identification kits (bioMérieux)

Extraction of nematodes from seed yams and soils.

Samples taken from infected seed yams were thoroughly washed under running tap water to remove all soil particles. A thin slice of six to ten millimetres of seed yam tissue was cut into bits placed in a petri dish and twenty millilitres of water added. The petri dish was left for twenty-four hours after which drops of water were taken from it into a grooved slide and observed under the microscope for nematodes. Freshwater was added to the pieces of tuber in the container each day for three days to improve aeration. Identification of the nematodes was based on their morphological features.

About 750g each of soil from mounds in the fields where the seed yams were produced were also taken for analysis for nematodes. A sub-sample of 200g was taken from each 750g soil sample and put into facial tissue paper supported on a 1 mm-mesh sieve in a plastic funnel with a flexible hose and a clamp attached to the funnel. Nematodes were extracted from soil samples, using the method described by Dropkin (1989). Water was poured down the side of the funnel until it covered the lower surface of the soil. After twenty-four hours, the clamp was opened to draw about twenty millilitres of water into a smaller beaker. Drops of water from the beaker were observed in a grooved slide, first under the light microscope and further under the compound microscope.

3.1.3 Effect of traditional storage systems on quality of seed yams of two white yam varieties (Lili and Pona).

Seed yams of two white yam varieties (Lili, 450 and Pona, 450) were stored by six farmers each at Akokoa, Nyomoase, Bawakura, Suronuase, Asantanso and Fiaso in Brong Ahafo Region from November 2000 to April 2001. The storage systems were; (i) storage in thatch farm huts with one side opened,, (ii) storage in dried millet stalk farm hut,, (iii) storage in heap under shade trees covered with dried palm leaves, and (iv) storage in the thatch roof of farmer's house.
Twenty-five seed yams of each farmer's consignment were divided into five replicate groups of five to constitute a treatment. Each replicate of five seed yams was assessed at 0, 60 and 120 days after storage to determine the influence of the storage systems on their quality. Weighing the seed yams at 0, 60 and 120 days after storage weight loss in each seed yam in the storage systems was monitored.

The seed yams were further examined to determine the presence or absence of rots, which were categorised into external or internal rot. The seed yams were also inspected for the presence or absence of Internal Brown Spots. The weights of the rots of external or internal origin and Internal Brown Spot were also monitored. The incidence, weight and thickness of wound periderm on the seed yams of the two varieties stored in the four storage systems were measured.

To further determine the types of micro-organisms associated with the yam barns, water agar plates were prepared and used to trap pathogen spores in the selected traditional storage systems at Atebubu, Kintampo and Techiman districts. One plate of water agar was used per system at harvest before the tubers of yam were packed into them and at 120 days after storage. The uncovered water agar plate was held vertically in the right hand and waved overhead six times in the storage system. The plate was left uncovered on the floor of the storage system and recovered after 2 hours. The plate was kept in an ice chest. Bits of WA were cut from the advancing margins of the growing micro-organism with a cork borer and sub cultured on PDA. The pure cultures were later identified using methods described in 3.1.2.

3.2 Assessing the incidence of major rot pathogens that compromise the quality of yams in selected markets In Accra

Further information is given in Aboagye-Nuamah, Oduro and Offei (2003)

A total of 113 yam tubers with rots arising from natural infections were obtained from four selected sources. These were the Accra, Agbogbloshie (Kokomba yam market), and Madina markets, and from a Yam Barn in the Crop Science Department of the University of Ghana, Legon. Samples were taken from the advancing ends of the each rotten yam tuber and were individually wrapped in plain polythene bags and sent into the laboratory. Samples were then conserved in a refrigerator at 5 - 10^{o}C until isolation and identification of the organisms were done. The methods of identification were as described in Activities 3.1

3.3 Association between tuber damage and rot causing organisms on the incidence of rots among two varieties of white yam (*Dioscorea rotundata* Poir *var. Pona and Onumo*)

Further information is given in Aboagye-Nuamah and Offei (2003)

The experiment was conducted between October 2001 and June 2002 at the Post-harvest Division of the Ministry of Food and Agriculture (MoFA), Sunyani and the Pathology Laboratory of the Department of Crop Science, University of Ghana, Legon.

Two white yam varieties, Pona and Onumo , at different physiological maturity, immature "milked" yam" and mature "ware" yams were used for the experiment. The experiment covered two periods: from October to February for the Milk yam and February to June for the Ware yams.

The Yams were separated into five groups depending on naturally occurring wounds - cuts, gashes, breakage and insect holes (as defined below)- and undamaged controls.

- ***Cuts***: These are sharp excisions made on the tuber surface by farm tools either during harvesting or cultural practices.
- ***Holes***: These are tunnels or small openings in the tubers, which are visible outside. They may be as a result of termite damage or spear grass growing into the tuber.
- ***Gashes***: Any damage on the tuber surface, which results in the destruction of the tissue of a particular segment of the tuber other than a cut, or hole.
- ***Breakage***: This is where a particular portion or segment of the tuber has been broken off or removed.
- ***Control***: The control was made up of commercially sound tubers with no visible quality defect.

The yam tubers were then stored in a raised well ventilated improved yam barn built to the specification of GTZ (GTZ, 1995) in a completely randomised design (CRD) with 4 replicates. Routine monthly assessments were carried out on the yams over the four months storage period for each season. At each assessment time, four replicate tuber samples with rots were selected from each treatment and assessed for rots. Representative samples of rots arising from a particular wound from these treatments were taken and returned to the laboratory for isolation and identification of pathogens associated with the rots. In each instance, the recovered disease samples were individually wrapped in polythene bags and transported from the field to the laboratory in an ice chest. Samples were then kept in a refrigerator at 0 – 5^{o}C until isolation of pathogens were done as described in 3.1.

The quality of yams was assessed using the methods described in activities 1.2.2.2.

3.4 Isolation of rotting pathogens from storage trials.

Further information can be obtained from Cornelius (2002)

Output 4: Grading protocols capable of identifying and excluding chronic quality defects in yam investigated and tested.

4.1 Comparing methods for non-destructive visual assessment and destructive assessment for grading yams for levels of rot.

During the Handling/Storage trials described for Output 1, very detailed and labour intensive methods were used to assess tuber quality as accurately as possible. These methods are not practical for standard use within the yam marketing system. The objectives of this trial were:

- To determine the best methods for non-destructive visual assessment of yams, and their accuracy.
- To determine the most efficient destructive methods for assessing yam quality so that these could be used where destructive sampling of yams is practical.

The trial involved selecting 50 yams of variable quality, and assessing them both by external appearance and by a detailed destructive method. The destructive method used was as described in Activities 1.2.2.1. It involved cutting the yam into 80 pieces (8 longitudinal sections, each cut into 10 radial pieces), each of which was assessed for forms of internal damage. This allowed us to simulate the observations which would have been made had the yam been cut in various ways.

4.2 Determine the practicality of using sensory arrays to grade yams.

The fact that yam tubers can have significant internal rotting without any externally visible signs makes grading for export very difficult. A study was conducted to determine whether sensory arrays (see Scientific background) could provide a practical means for assessing yam quality non-destructively.

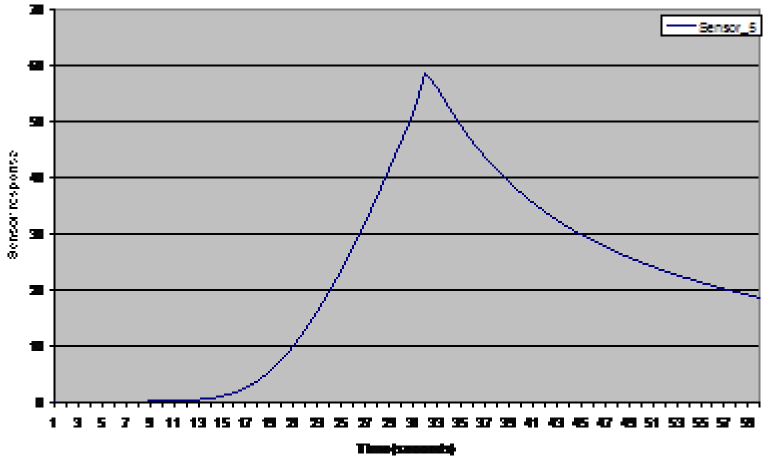
4.2.1 Gas Sensor Array equipment

The gas sensor array apparatus deployed during the present study was designed and built by NRI in collaboration with ???. The main components of the system are shown in Fig. 4.1 b)
The apparatus consisted of a delivery system (funnel and two pumps) to take volatiles from the sample to the electronic sensor array of six metal oxide gas sensors (obtained from Capteur Sensor and Analysis Ltd., Oxfordshire) a data pre-processor and a laptop computer for data handling. The details of the sensors are shown in Table 4.1. A typical time response trace from a sensor is shown in Figure 4.1a.

Table 4.1 Details of sensitivities of sensors to gas species

Sensor number	Gas species	Gas concentration range (ppm)	Operational temperature (°C)
1	Ethanol	1000	-
2	Propane	300 - 10000	503
3	Ethylene	250 - 1000	104
4	Ethanol	250 - 1000	422
5	Hydrogen sulphide	25 - 100	431
6	Carbon monoxide	100 - 400	439

(a)



(b)

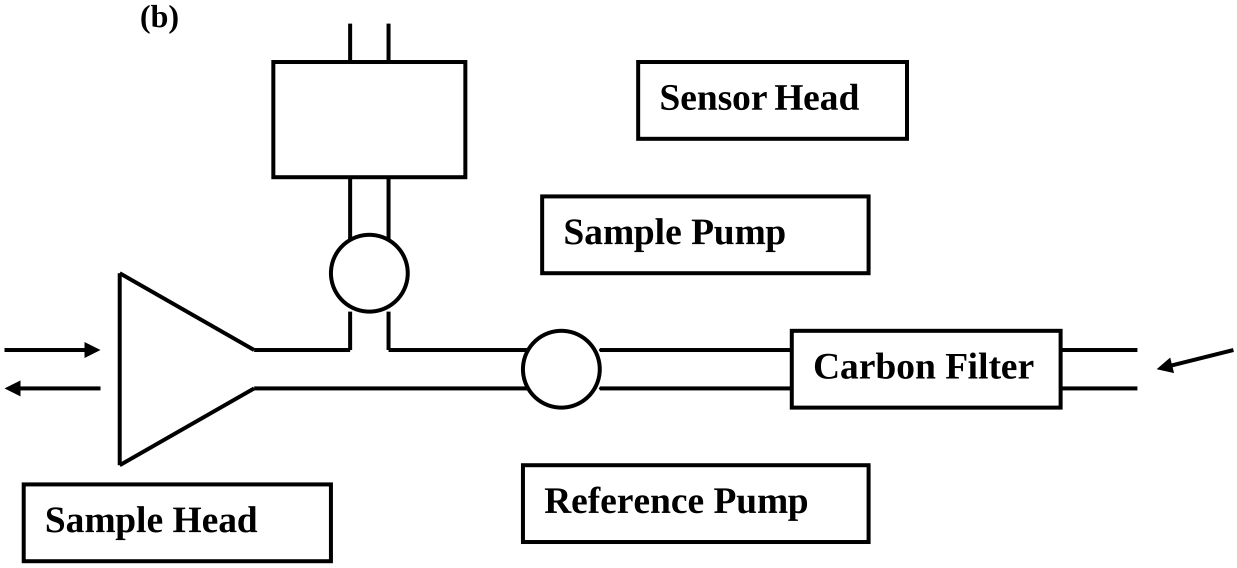


Fig. 4.1(a) Change in resistance of sensor five to aroma volatiles from a yam tuber during a volatile measurement period(0-30 seconds) and fall-off in response to sensor cleaning period (30-60 seconds). (b) Essential components of the gas sensor array.

An analysis involves five stages It begins with the warm up phase in which the sensors are brought up to their specified operational temperature (see Table 4.1). During “purge 1” the reference pump runs for 30 seconds to purge the previous sample. During “purge 2” the sample pump and reference pump are run together for 180 seconds to purge the sensor head of the previous sample and to keep the sample funnel clear. During the “measure” phase the reference pump is stopped and the sample pump only draws sample gas for 30 seconds in through the funnel into the sensor chamber. Finally, during the “cleaning” phase, the reference pump blows air for 30 seconds through the sample funnel and sensor head prior to the sensors being shut down. This phase can be extended to allow contamination of the sensors to be blown off. It therefore takes 5 minutes and 30 seconds to analyse a sample and 15 minutes resting interval between measurements. Data from the sensors are logged from the start of purge 1 until the end of the cleaning phase. The instrument provides access to various control and calibration functions for editing profile phases and sensor temperatures. The flow rate of the pumps is 120 ml per minute.

During analysis of a gas sample, the components of the gas interact with the surface of the sensors (oxidation reduction reaction) resulting in a change in electrical resistance of the sensors. The change in resistance of Sensor 5 for volatiles derived from yam, is shown in Fig. 4.1a.

Resistance impulses from all six sensors are individually interpreted. The data for a particular sample can be interpreted as a pattern of responses or a“fingerprint” representative of that sample. A library of patterns can be stored in a computer database, such that data from test samples can be compared to this library and classified accordingly.

In order to evaluate the ability of the gas sensor array to distinguish between different groups of treatments, Discriminant Analysis is usually undertaken. Discriminant analysis is a generic name for a group of methods used for treating multiple -group classification problems. They include linear discriminant analysis (LDA) and canonical variate analysis (CVA). Linear discriminant analysis comprises a number of steps. It defines the proposed group structure, by allocating observations to one of a minimum of two groups. It then calculates the group centre, (mean of the observations in each group) and the distance of each observation from a group centre. Finally, the analysis records which group centre is nearest to each observation and compares this with the group definitions made earlier to determine the number of correct matches. The analysis of such data is complicated and beyond the scope of this report but involves the transformation and interpretation of group characteristics by Principal Component Analysis (PCA).

4.2.2 Preliminary evaluation of the ability of a gas sensor array to detect internal rotting in yam tubers.

White yam tubers of ‘Asana’ variety were bought from Spitalfields market in London on 7th November 2000. The yams were imported to UK from Ghana with unknown pre-history and were packed in ventilated cardboard boxes. Export yams from Ghana are usually bought from yam markets in Accra and shipped to the UK. The voyage takes about two weeks.

The yams were transported to a laboratory in the Natural Resources Institute in Chatham the same day and placed at random on shelves in a controlled environment room. The following day the tubers were cleaned of surface soil using a soft brush, numbered and their lengths and weights measured. Twenty sound tubers, and twenty tubers suspected of having some form of internal rots were selected, mixed, replaced in boxes to be used for the experiment. The weights of the tubers ranged between 1.8 and 3.6 Kg and their lengths ranged from 30 -61 cm. The suspected internal rot test was done by visual inspection, feeling the skin of tubers with the fingers and sniffing of tubers. The temperature and

relative humidity of the controlled environment room laboratory used for the experiment were monitored daily.
The samples used for the experiment were as summarised below:

- Sound tuber
- Sound tuber with artificial wound created using 5mm cork borer (wound depth 3mm)
- Tuber suspected of having internal rot

The NRI gas sensor array (GSA) was used to analyse aroma volatiles. Samples were taken from the middle portion of sound tubers and from the position of the wound for wounded tubers. Five measurements were taken from the same position on each tuber. The order of measurements was randomised among the tubers.

The aroma volatiles were drawn into a sampling head consisting of a 150ml plastic funnel joined to a 44cm plastic tube of 0.70cm internal diameter attached to the GSA

The tubers were cut open after the experiment to inspect the internal tissue and any rot found was removed and weighed.

4.2.3 Evaluation of gas sensor array for discriminating between varieties of white yam

The yams used for the experiment were part of a batch of tubers harvested in July 2000 at Fiaso in the Techiman district of Ghana and stored in a yam barn at 28°C and 69 %RH. Two ventilated cartons each of 'Lily' and 'Zoan' white yam varieties and three cartons of 'Pona' variety were shipped from Ghana and arrived at the NRI on 26th January 2001. Yams shipped from Ghana normally take about two weeks to arrive in the UK. There were 16 to 31 tubers in each carton depending on tuber size. The tubers were removed from the cartons, numbered, weighed and their lengths measured. External tuber quality was assessed and tubers found to be rotten discarded. The sound tubers were mixed up in cartons and arranged randomly on shelves in a storage facility where they were kept until needed for experiments. The temperature and humidity of the store was observed daily.

The experiment was conducted on two sound tubers each of 'Lily', 'Pona' and 'Zoan' varieties of white yam. Their identification and quality assessment was done by visual inspection, feeling with the finger and smelling of the tubers. The yams had been stored in NRI for 11 days on the day of the experiment.

The NRI gas sensor array (GSA) was used to analyse aroma volatiles from the outer middle third portion of the tubers. Five measurements were taken from the same position on each tuber. The order of measurements was randomised among the tubers. The sampling system was as described in 4.2.2.

The tubers were cut opened after the experiment to observe the internal tissue and any rot found was removed and weighed.

4.2.4 Further work using gas sensory arrays.

The work on gas sensor arrays was delayed due to equipment problems.
Hand-held portable sensor had problems with stability of readings. Therefore redesigned, and in process of being rebuilt.
NRI has purchased more complex commercial version that allows further work to be conducted on potential of GSA.
Recently arrived. Experiments planned for after end of project.

Experiment 1: detection of rots.
Artificially infect tubers (agar plug), and take measurements on opposite side of tuber

Experiment 2: can GSA distinguish between rotting pathogens
Compare profiles of pathogens grown on agar.
Artificially infect tubers with different pathogens, and take measurements from opposite side of tuber.
Penicillium brevicompactum
Rhizopus stolonifer
Aspergillus niger
Fusarium oxysporum
Botryodiploidea theobromae.

Experiment 3: Can GSA determine age of tuber
Compare tubers of difference age.

4.3 Preliminary evaluation of the ability of an X-ray metal detector to detect internal tuber rots in white yam.

An X-ray metal detector (for detecting metals in passenger luggage at the Kotoka International Airport in Accra, Ghana) was assessed on 20/12/01for its ability to detect internal tuber rots in four rotten and four sound white yam tubers of 'Pona' variety.

Output 5: Knowledge exchanged and information disseminated

During the course of the project five workshops have been held to disseminate information to yam traders, exporters, and scientists, and proceedings are being prepared for distribution .
At the end of the project a CD of all the publication outputs is being produced for distribution to stakeholders. Recommendations to improve the marketing system including a list of best practices for each stage of the system will be distributed to yam traders and exporters in Ghana and to importers in the UK.

OUTPUTS

The research results and products achieved by the project. Were all the anticipated outputs achieved and if not what were the reasons? Research results should be presented as tables, graphs or sketches rather than lengthy writing, and provided in as quantitative a form as far as is possible.

Output 1: Improved post-harvest handling and storage protocols developed, integrated and validated in collaboration with yam producers for deployment in-country.

Overview of Output 1

Objectively verifiable indicators
1.1 Technical, economic and social investigations completed by December 2002.
1.2 On-farm pilot scale trials completed by March 2002.
1.3 Impact assessment of on-farm protocols completed by March 2003

The project was successful in that it identified the socioeconomic and technical constraints for the yam production and marketing system within Ghana (OVI 1.1). Recommendations have also been developed for the improvement of the management of the system, and improvement of technical aspects of the post-harvest handling of yams. One of the main technical recommendations is the introduction of a curing process for yams immediately after harvest, during which the tubers should be placed in an environment to promote natural healing of wounds inflicted during harvested. However, trials to test the curing protocols took longer than anticipated (OVI 1.2), so that it was not possible to conduct farmer managed trials, or an impact assessment (OVI 1.3).

1.1 Socioeconomic aspects of the marketing system.

Further information can be obtained from Greenhalgh (2001) and Agbodza (2002)

Note: following the initial survey work on the yam marketing system within Ghana, subsequent work concentrated on the supply of yams for export. The following is a summary of the early conclusions. The main findings are therefore addressed under Output 2, but are of relevance to both the internal and export markets.

Survey work involving interviews of growers and traders identified several problems of the yam marketing system in Ghana. Lack of competition faced by traders in some areas puts producers at a disadvantage and can lead to relatively low and fluctuating prices for farmers. Growers are unable to counteract this, as they lack reliable market information and are unable to defer sale during the harvest season when prices are low because of lack of storage facilities and finance. The quality of yams arriving at the markets may be compromised for several reasonspoor transport infrastructure, poor harvesting practices (such as the use of cutlasses) which result in damage, and poor storage conditions. There appears to be no premium for the growers for higher quality yams, and thus little incentive to improve practices. The poor quality of yams is further exacerbated when growers are persuaded by traders to harvest early in the season, when yam prices are higher, but the immature yams are more perishable. The variety, Pona, which is preferred for its taste, is one of the more perishable varieties. This combination of factors contributes to substantial losses, which cumulatively over time can account for as much as 50 per cent of production.

To address these problems recommendations have been developed for improvements in the organisation of the marketing system.

1.2 Storage and handling trials.

Further details can be obtained from Bancroft *et al.* (2003)

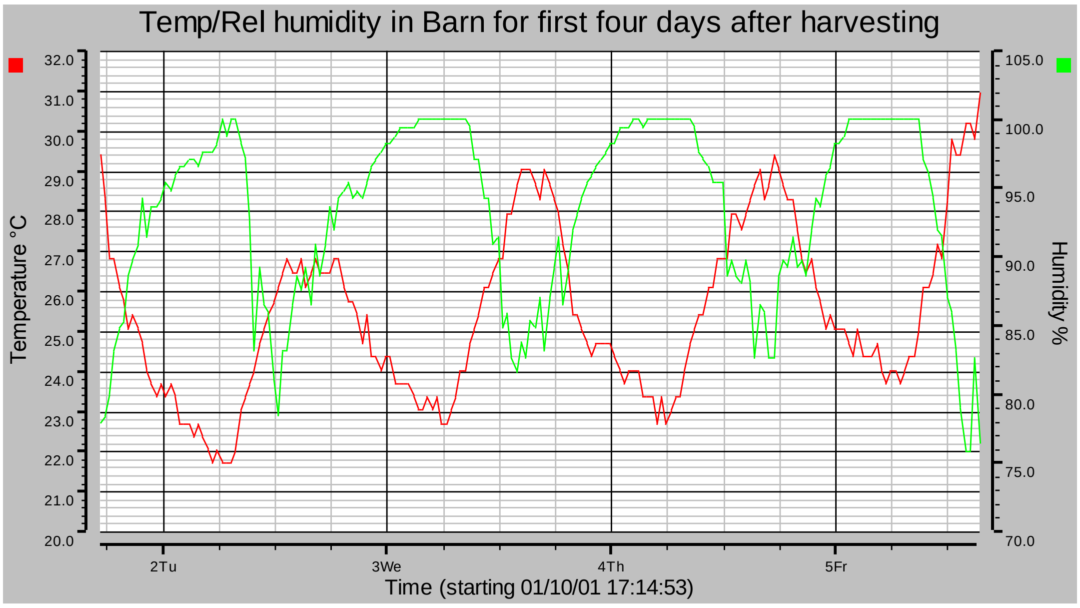
To improve storage protocols for yam tubers, especially for the variety *Pona*, storage trials were conducted over three seasons.

1.2.1 Storage and handling trials: Year 1

During the first year of trials, the effect of four storage protocols on the quality of three white yam varieties were compared. The storage treatments included traditional pit storage and storage barns, and also considered the effect of pre-storage treatments that could promote natural healing (curing) of tubers. For practical reasons, the tubers used were immature "milk" yams. Temperature and relative humidity conditions in the storage barn throughout the trial were recorded with data loggers. The data is shown in Figure 1.1. During the first 4 days, the temperature ranged from 22 - 30ºC, while the humidity was maintained between 75 and 100%. Later on in the trial, the temperature rose, and the humidity fell.

After 5 months of storage, considerable rotting was observed in all treatments for the trial. The upper top half of tubers appeared more prone to rots ($P < 0.001$) (Fig 1.2). Careful handling at harvest can reduce incidence of rots entering tubers at the tail end. The harvest cut, in particular, and insect holes and abrasions towards the head of the tuber appear to facilitate the entry of pathogenic organisms and so engender a higher frequency and greater severity of rots.

a)



b)

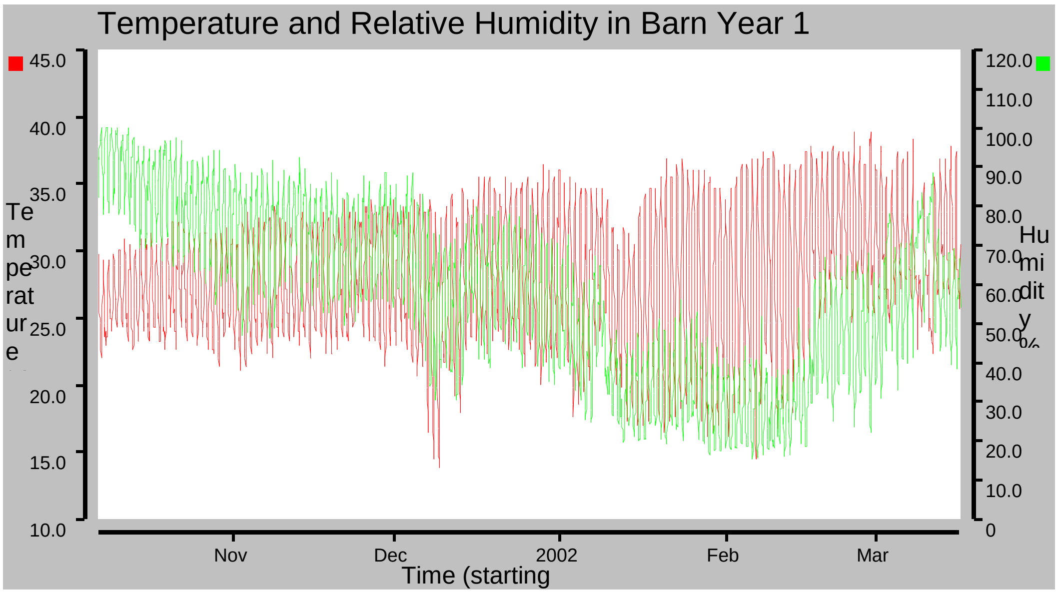


Figure 1.1 Temperature and humidity recorded in the storage barn
a) during the first four days of storage
b) during the whole period of the trial.

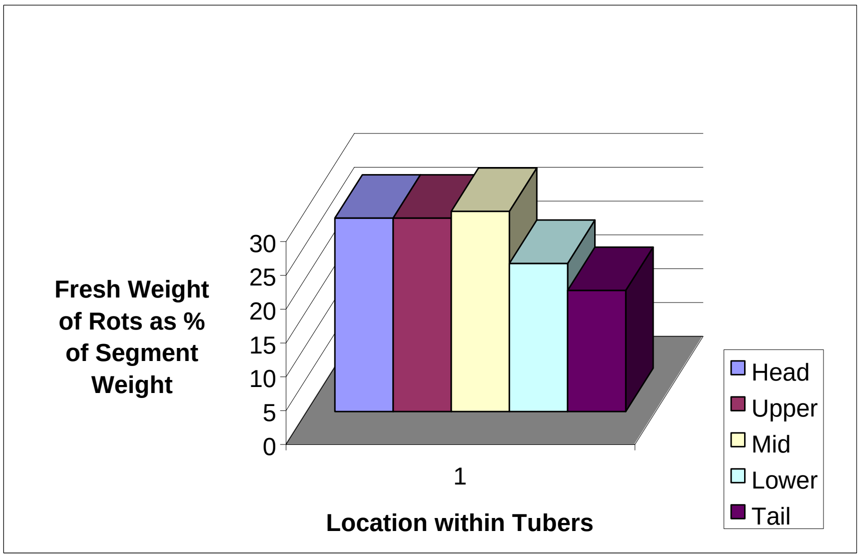


Figure 1.2 Distribution of rots within yam tubers

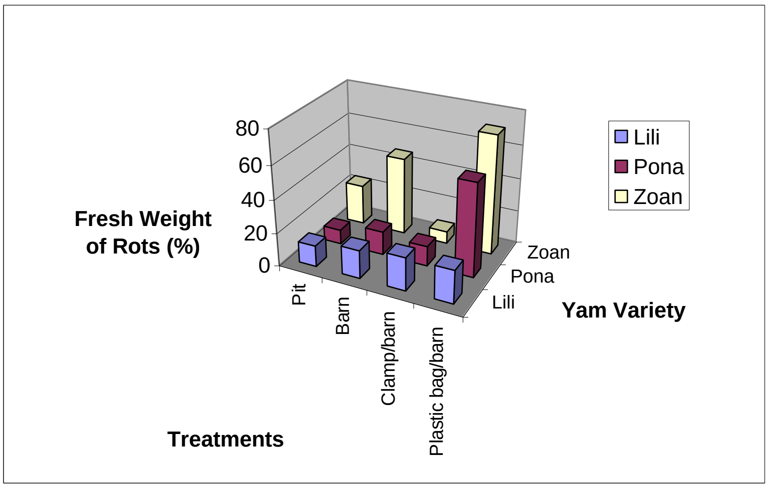


Figure 1.3 The effect of pre-storage/storage treatment and variety on rotting of tubers

Figure 1.3 indicates the extent of tuber rotting (expressed as % fresh weight of the whole tuber) for the four treatments after five months. Both cultivar and storage effects were highly significant ($P < 0.001$). Very similar results were obtained when rot was expressed as % surface area. For these yams, apart from the variety Zoan, the traditional pit storage resulted in less rotting than barn storage. The purpose of putting yams in plastic bags or in clamps for 2 weeks prior to barn storage was to expose yams to an environment that would promote natural wound-healing (curing), and thereby increase resistance to rots. In the case of plastic bags, this was clearly not successful. Considerable condensation was seen during the trial, indicating that there was insufficient ventilation for efficient curing (see Outputs 1.2.4), while the accumulation of moisture would have encouraged the growth of rots. Thus it is not surprising that this treatment resulted in the highest levels of rot. The effect of clamp pre-storage is ambiguous, but appears to have reduced rotting for Zoan.

Table 1.2. The impact of post-harvest treatments on the weight loss of fresh tubers after 5 months storage.

Variety	Treatment	Barn	Clamp/ barn	Pit	Bagged/ barn	Overall
	Original Average Weight (g)	Weight Loss (%)				
Lili	1788	21.7	33.3	8.9	14.7	19.7
Pona	1645	5.3	22.7	17.4	57.9	25.8
Zoan	1748	47.0	37.5	4.2	56.1	36.2
Overall		24.6	31.2	10.2	42.9	

Table 1.3. The impact of post-harvest treatments on sprouting of tubers after 5 months.

Treatment	Barn storage	Clamp/Barn	Bagged/barn	Pit	Significance
Units of Sprout Length	0.160	0.049	0.007	**0.292**	P = 0.044
Weight of Sprouts	0.150	0.060	0.010	**0.910**	P = 0.006

Tuber weight loss and sprouting over 5 months are summarised in Tables 1.2 and 1.3. Overall, the lowest weight loss was observed in pit storage. Weight loss appears to relate reasonably well with rotting, such that those treatments which result in the highest rotting are also associated with high weight loss. This probably indicates that these treatments are not efficient at promoting wound-healing. Overall pit storage still appears to be the best form of storage, except that it promoted considerably greater sprouting of tubers than the other treatments (Table 1.3).

With respect to cultivar effects, the cultivar Lili is the least susceptible to rotting overall, and also shows lower rates of weight loss. Interestingly, Lili shows particular resistance to rotting after being placed in plastic bags. From the data obtained we cannot tell whether this is a result of a high intrinsic resistance to rotting, or a lower respiration rate, resulting in less condensation.

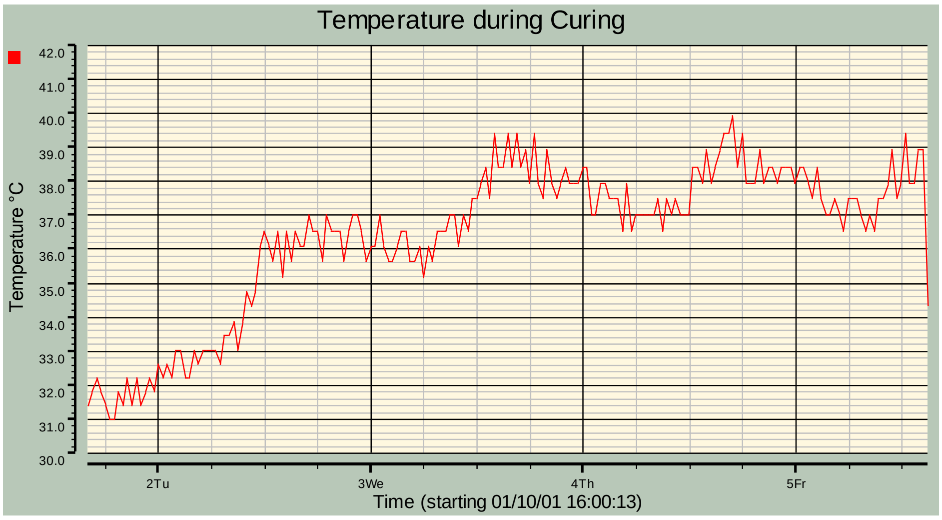
Unfortunately, although Lili is much easier to store than the other two varieties, Pona is preferred for marketing due to its superior sensory properties. Trials in subsequent years therefore concentrated on improving storage of this variety.

1.2.2 Storage and handling trials: year 2

In the second year of trials, there was an attempt to introduce a curing treatment that could be better controlled in terms of temperature and humidity, by constructing a "curing room". The time of curing was also reduced from 2 weeks to 4 days. As for the first year of trials, the tubers used were immature "milk" yams.

The conditions achieved during the curing process are shown in Figures 1.4 a and b. Apart from the first day, the temperature ranged between 36 and 39°C, while the humidity was maintained above 85% for the whole curing period.

a)



b)

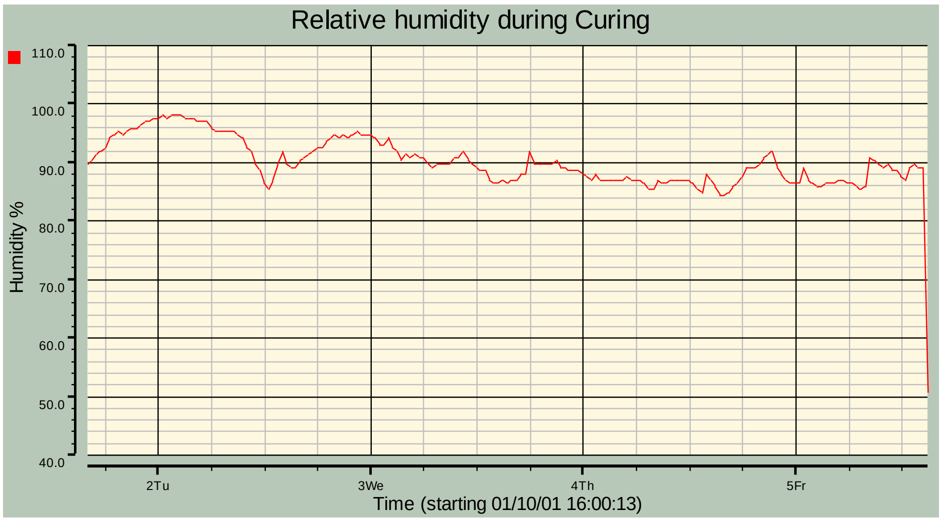


Figure 1.4: Temperature and humidity during the curing process.

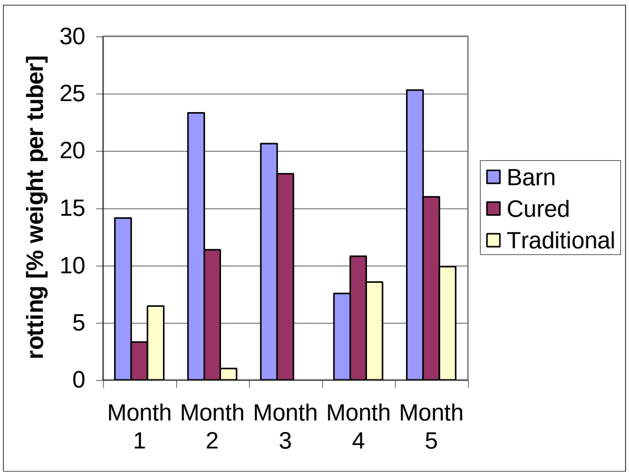


Figure 1.5: The effect of pre-storage/storage treatment on % rotting of yam tubers in storage and handling trial: year 2. The treatments used are described in Activities 1.2.2.1.

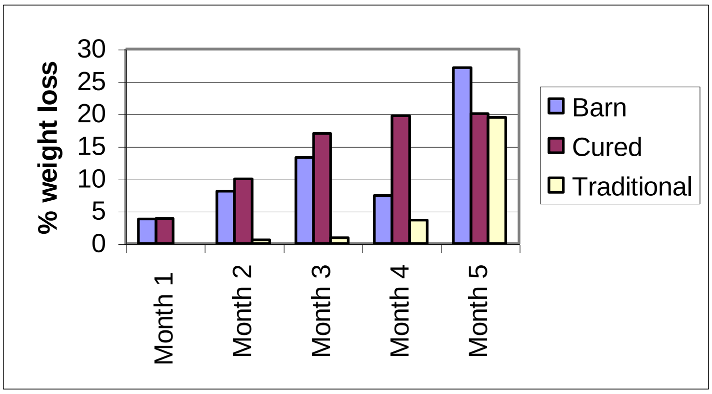


Figure 1.6: The effect of pre-storage/storage treatment on % fresh weight loss of yam tubers in storage and handling trial: year 2. The treatments used are described in Activities 1.2.2.1.

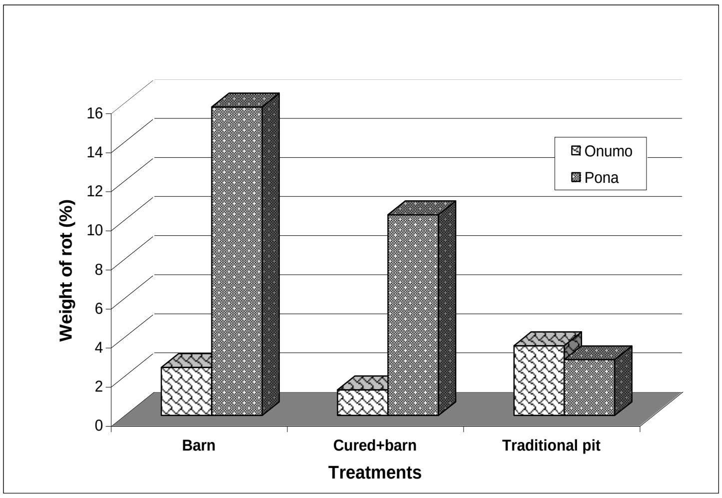


Figure 1.7: The effect of pre-storage/storage treatment on % rotting of two varieties of yam tubers in storage and handling trials: year 2. The treatments used are described in Activities 1.2.2.2

The effect of pre-storage/storage treatments on tuber quality are illustrated in Figures 1.5-1.7, and Tables 1.4 and 1.5.

For the Pona tubers used (immature milk yams), the results quite clearly show that traditional pit storage retains quality better than barn storage. Thus % rotting is less (Figures 1.5, 1.7), and % weight loss is less (Figure 1.6) than for the other two treatments. However, the practice of curing does appear to improve barn storage to some extent, in that it reduces rotting in the barns (Figures 1.5 and 1.7), although interestingly, it does not appear to reduce fresh weight loss (Figure 1.6).

Samples of tubers were selected from the Pona trial and exported to the UK using the normal shipping routes. The observations of tuber quality for two such export trials are summarised in Tables 1.4 and 1.5. In this case, although traditional pits are again shown to provide better quality tubers, the benefits of curing for barn storage are less clear.

Table 1.4 Rotting observed in Pona yams imported to the UK in March 2002. Standard export yams were selected randomly from commercial consignments, while the other treatments refer to the pre-storage/storage treatments described in Activities 1.2.1

Yam Source	Standard Export	Barn	Cured + barn	Traditional pit
No. tubers with no rotting	44	11	10	10
No. tubers with >10% rotting.	20	5	7	4
% tubers with >10% rotting.	31.25	31.25	41.18	28.57

Table 1.5 Rotting observed in Pona yams imported to the UK in April 2002. Treatments refer to the pre-storage/storage treatments described in Activities 1.2.1

Yam Source		Barn	Cured + barn	Traditional pit
% tubers with rots		56	59	35
% tubers with > 10% rot		18	29	21
% tubers with < 10% rot		37	30	14

The results shown in Figure 1.7 were obtained from the trial described in Activities 1.2.2.2 and are interesting in another context, as they compare the behaviour of two varieties; Pona and Onumo. They indicate that although the traditional pit system is better than barn storage for Pona milk yams, this is not the case for the variety Onumo. This variety is more resistant to rots, and appears to store better in barns.

One important issue is whether the finding that immature (milk) tubers of Pona store better in pits than barns can be extrapolated to mature (ware) yams. Trials were conducted by Aboagye-Nuamah and Offei (2003) to compare the behaviour of milk and ware yams in storage barns. They also looked at the effect of tuber damage on rates of deterioration by rotting. Table 1.6 summarises the rates of rotting observed after one month of storage in a barn. Overall there was no significant difference in the rate of rotting for milk and ware yams (results not shown), although there is some indication that damage has a more significant effect on milk yams than on ware yams.

Table 1.6: Percentage rot of tubers after one month storage in a barn as influenced by maturity and damage.

Season	Breakage	Cuts	Gashes	Holes	Sound
Early	55.1	77.8	70.6	27.4	0.0
Late	40.0	100.0c	55.8	15.0	2.1

1.2.3 Storage and handling trials: year 3

In the third year of trials, as it was seen to be very important to understand the effect of tuber maturity on post-harvest behaviour, and to develop storage protocols for mature yams, trials were conducted separately on milk and ware yams. Comparison of early results from this project with those of previous projects run by GTZ, suggested that whereas ware yams stored better in barns, milk yams kept better in traditional pits. For this reason the milk yam trials aimed to test improvements to pit storage, while the ware yam trials aimed to test improvements to barn storage.

1.2.3.1 Milk yams

Figures 1.8 a and b indicate the environmental conditions maintained in the traditional pit during the first four days of storage, and in a purpose built "curing room", respectively.

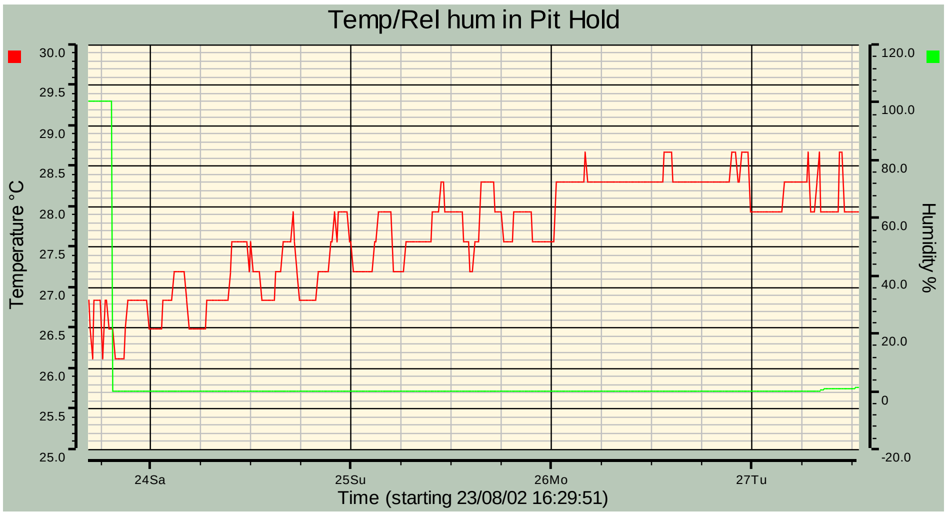


Figure 1.8a Temperature and relative humidity recorded in pit. We believe that the relative humidity was very close to 100%, resulting in condensation on the probe causing it to fail.

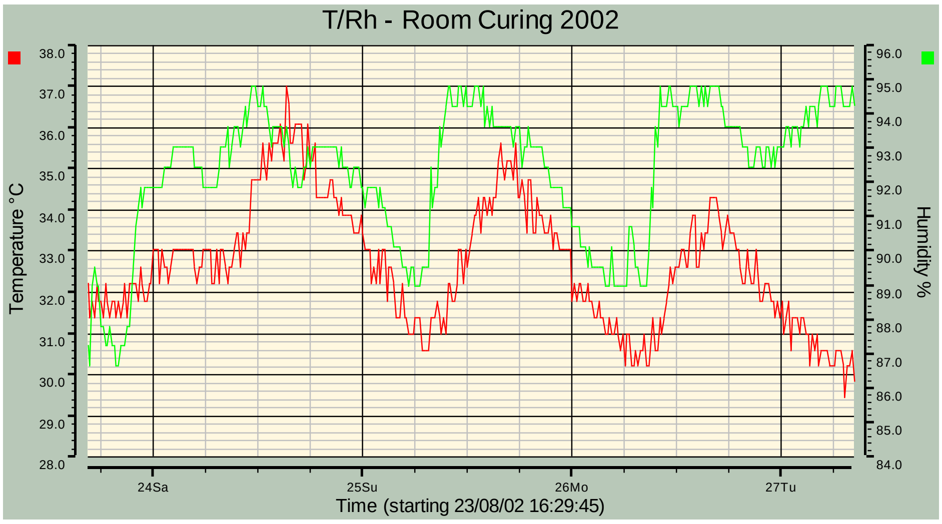


Figure 1.8b Temperature and relative humidity recorded in the curing room.

Whereas the temperature in the pit rose from 26.5 to 28.5°C over the initial four days of storage, the temperature in the curing room was increased by the use of lights and hot water up to 30 - 37°C. The humidity probe in the pit ceased to function during the measurements. This behaviour is often caused by very high humidities resulting in condensation on the probe. We believe this to be the case here, suggesting that the humidity in the pit was very high, close to 100%, whereas in the curing room it ranged between 87 – 95%. The curing room showed a marked daily cycle in conditions, whereas the pit had a much more consistent environment.

In addition to testing the effect of curing, this trial also considered the effect of dipping tubers in thiabendazole. (This chemical is shortly to be approved by the EU for use on imported yam tubers).

Table 1.7 summarises the rotting observed over 37 days of storage in terms of number of rotten tubers (from a total of 16) for each treatment. Unfortunately in this trial the storage pits flooded in the second month of storage, so that data beyond 37 days is unreliable. More detail on the level of rotting per tuber is given in Figure 1.9.

Table 1.7 number of rotting tubers after storage of milk Pona yams under four treatments. 16 tubers were included in each assessment.

	Cured		Prestorage in pit	
Days of storage	No chemical treatment [NC]	+Thiabendazole [TC]	No chemical treatment [NP]	+Thiabendazole [TP]
6	1	0	0	0
37	1	0	2	1

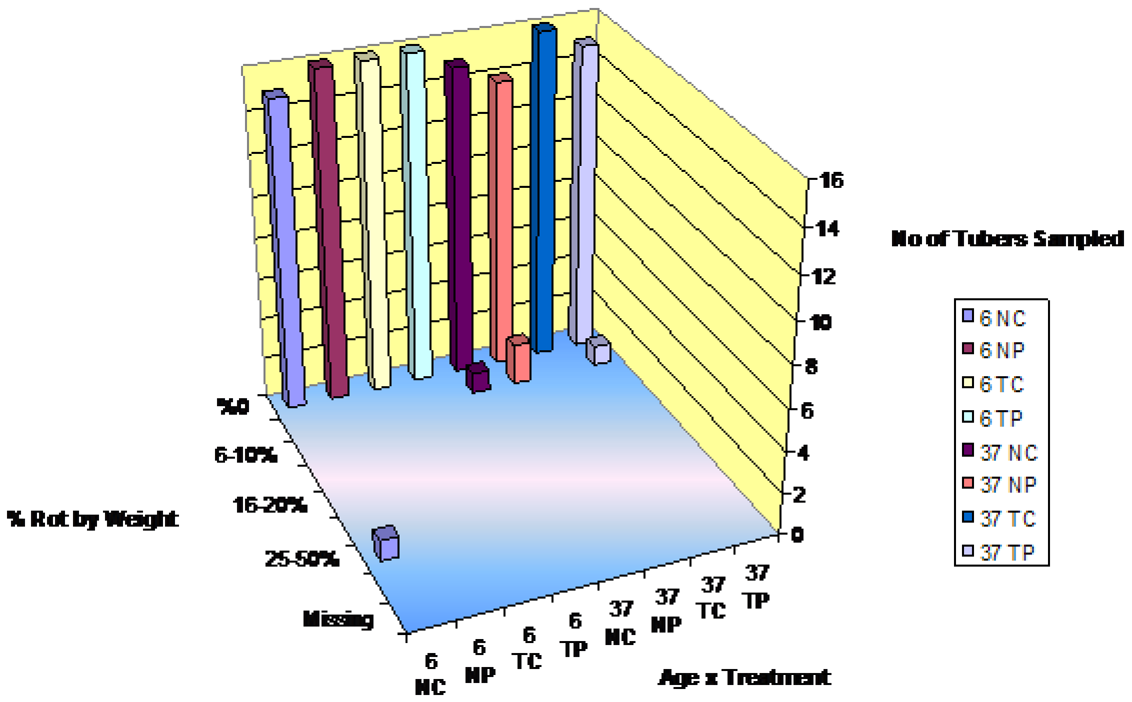


Figure 1.9 levels of rotting observed in tubers after storage of milk Pona yams under four treatments. The treatments are as indicated in Table 1.7.

Over the time-scale of the trial the level of rotting was very low, so that no clear effects of either curing or thiabendazole on rotting could be detected. Such low levels of rotting were not expected, and we believe that they are due to very efficient selection of clean tubers at the start of the trial. Although this does not allow us to assess the storage treatments, it does serve to underline the importance of good tuber selection, and to show with experience very effective tuber selection can be achieved.

An important and unexpected observation, however, was that during assessment at six days the cut surfaces of tubers that had been cured turned brownish after a few minutes. The cut surfaces of those that were kept in the pit remained whitish throughout the assessment period and beyond. During assessment of the tubers after 37 days, it was again observed that cut surfaces of tubers that were cured before storage showed brownish colouration while those that were not cured remained white. However, when the pieces were kept under water, they maintained their ‘whitish’ surfaces

1.2.3.2 Ware yams

Figures 1.10 and 1.11 indicate the environmental conditions maintained in the barn during the first four days of storage, and in a purpose built "curing room", respectively.

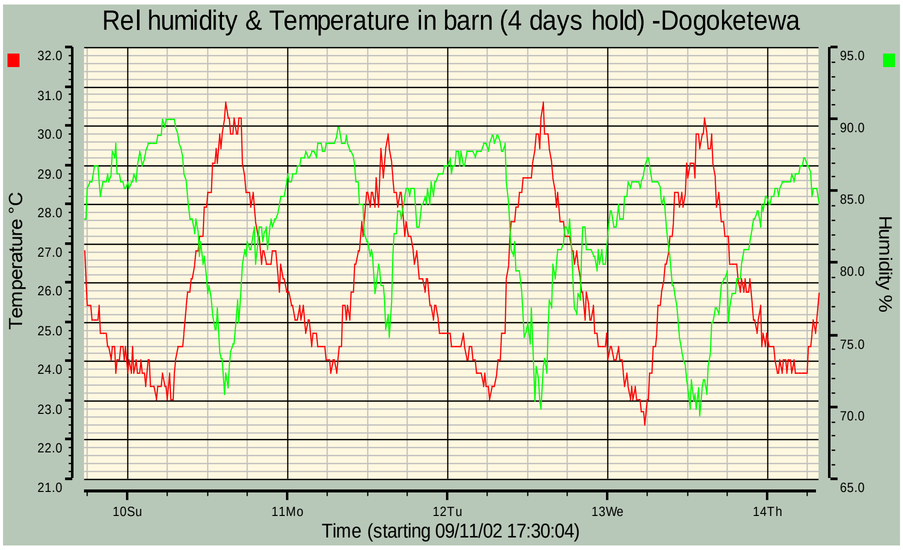


Figure 1.10 Temperature and relative humidity observed in barn.

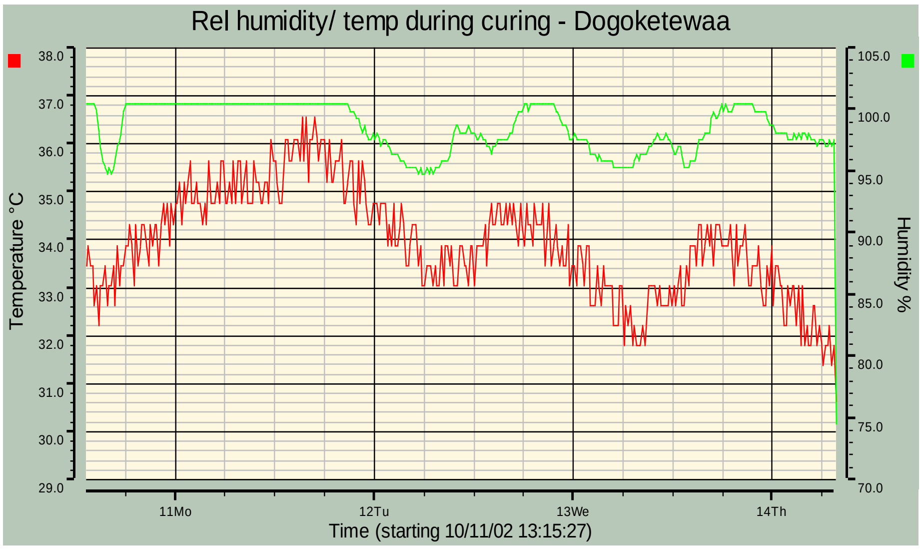


Figure 1.11 Temperature and relative humidity observed in curing room

The humidity in the barn was lower (ranging from 90% down to 70%) than the traditional pit used in the earlier trial, with temperatures ranging from 23 to 30°C. The curing room had higher temperatures (32-36) and higher humidity (95-100%) than for the milk yam trial.

Table 1.8 summarises the rotting observed over the 3.5 months of storage in terms of number of rotten tubers (from a total of 16) for each treatment. More detail on the level of rotting per tuber is given in Fig 1.12.

Table 1.8 number of rotting tubers after storage of ware Pona yams under four treatments. 16 tubers were included in each assessment.

	Cured		Prestorage in barn	
Days of storage	No chemical treatment (NC)	+Thiabendazole (TC)	No chemical treatment (NB)	+Thiabendazole (TB)
7	1	0	0	0
25	4	2	0	0
74	1	6	0	0
105	4	2	2	1

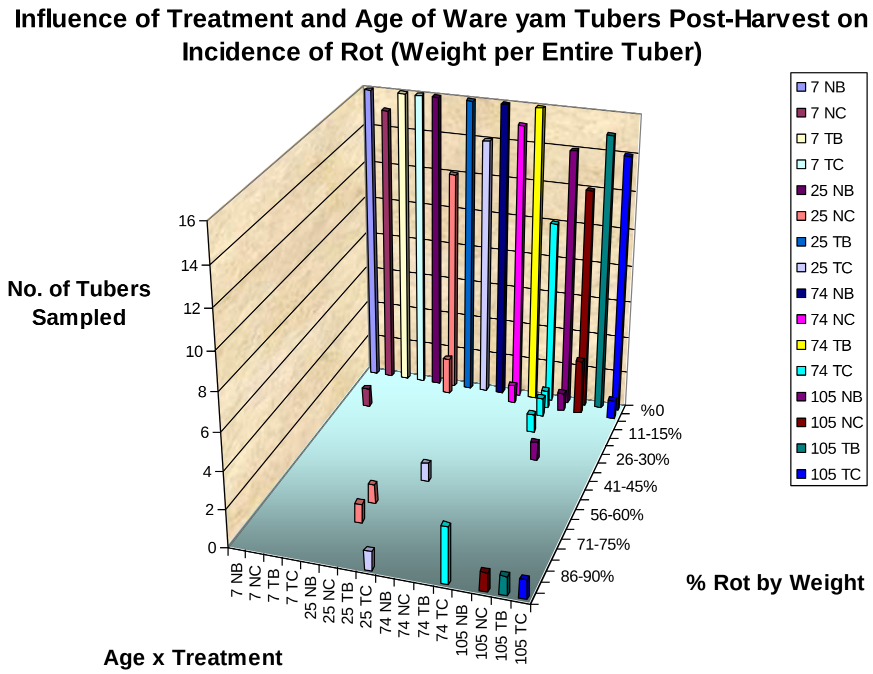


Figure 1.12 Levels of rotting observed in tubers after storage of milk Pona yams under four treatments. The treatments are as indicated in Table 1.8.

In these trials although the levels of rotting were not high, it appears that curing might have increased levels of rotting. As for the milk yams, it was observed during assessments that for all tubers that were cured, their cut surfaces turned brownish after a few minutes exposure to the atmosphere, while cut surfaces of uncured tubers remained white. No significant effect of thiabendazole treatment was observed.

The results were supported by export trials. Figure 1.13 illustrates the incidence of rots in Ware yams imported in March 2003 to the UK. The tubers assessed included samples from the four treatments described above, and also commercial export yams (controls) with and without thiabendazole treatment immediately prior to shipping. The overall level of rot in all the variously treated yams was 14.8%. None of the treatments, however, had a demonstrable affect. On arrival in the UK the non-treated controls were found to have 8.7% rots whereas the thiabendazole treated material had 8.2% rots. The difference was not significant.

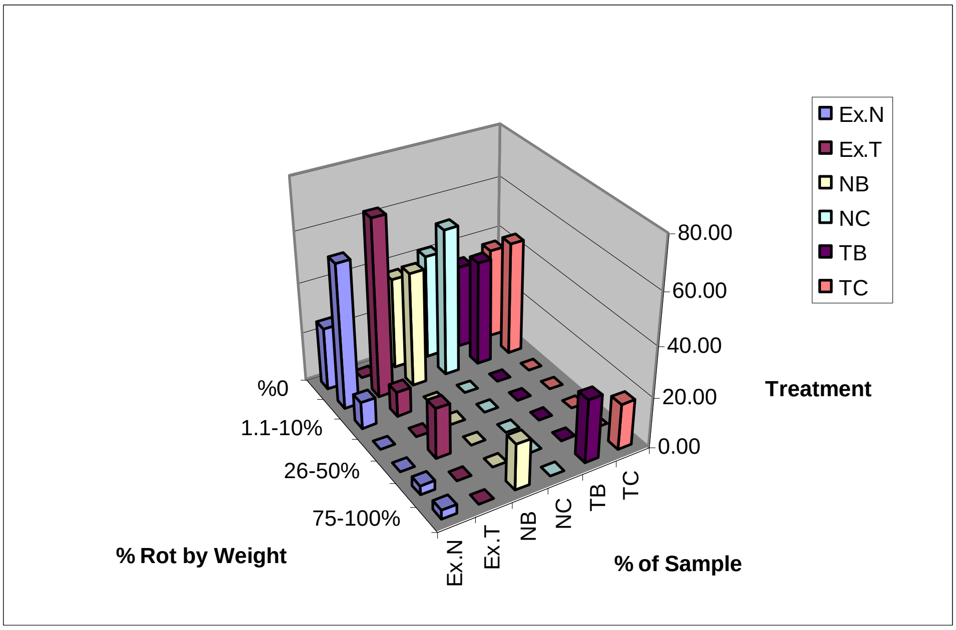


Figure 1.13 Levels of rots observed in ware Pona yams after importation to the UK. Ex N: untreated standard export tubers, Ex.T: standard export tubers dipped in thiabendazole immediately before shipping. Other treatments are as indicated in Table 1.8.

There is an indication that curing might reduce sprouting (Figure 1.14).

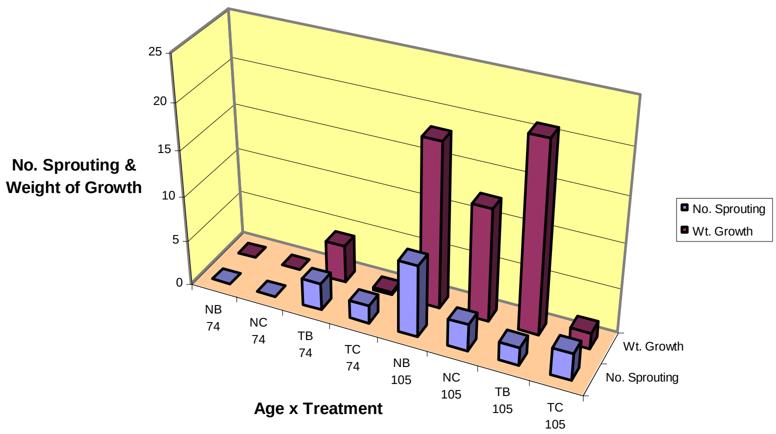


Figure 1.14: The effect of storage treatment and storage time on tuber sprouting.

1.3 Studies on the environmental effects on wound-healing in yams.

Further details can be obtained from Cornelius (2003)

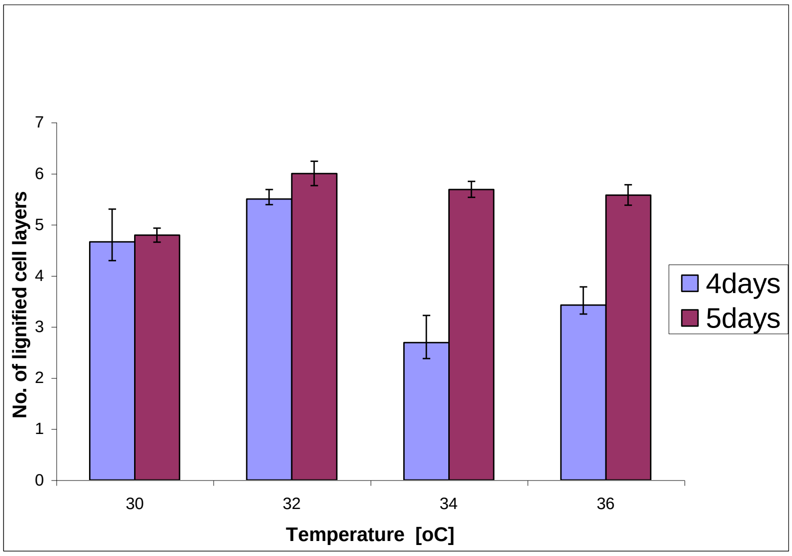


Figure 1.15 The effect of temperature on the number of lignified cell layers formed in Pona milk yams after curing for 4 and 5 days. Vertical bars represent standard error.

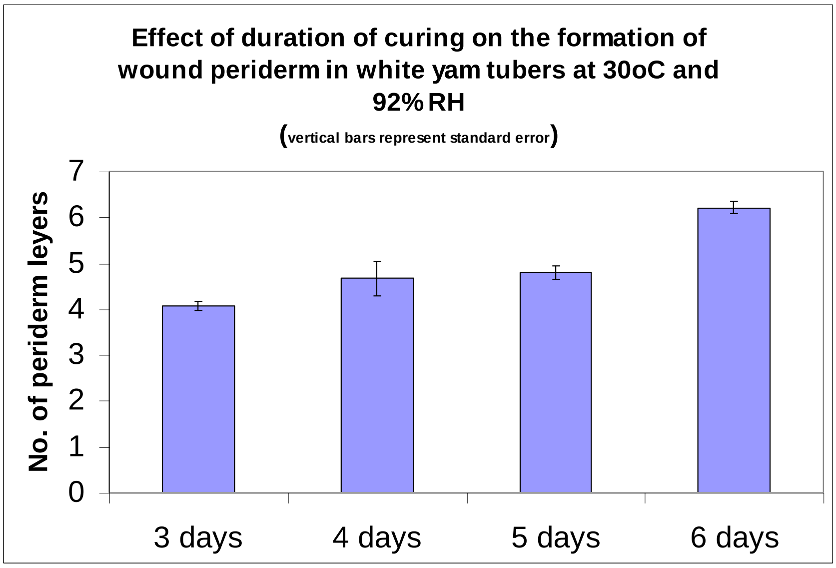


Figure 1.16 the effect of curing time on the number of lignified cell layers in Pona milk yams maintained at 30°C and 92% RH

Key results obtained in a laboratory study on the effect of curing environment on rate of curing in Pona milk yams are illustrated in Figures 1.15 and 1.16. The rate of curing is determined by the lignification of cell layers which is an essential part of curing. The optimum temperature for curing was found to be

32°C, while the thickness of the lignified layer continues to increase at least up to six days. Although this experiment has been repeated for ware yams, the microscopic samples are yet to be fully analysed.

The yams used for the experiments of Figures 1.15 and 1.16 showed no tissue browning, as observed in the third year of field trials. In an attempt to understand why this phenomenon was observed in the field, the effect of atmospheric modification (increase in CO_2 and decrease in O_2) as would be observed if ventilation were not sufficient, was studied. The conditions used and the results obtained are summarised in Tables 1.9 and 1.10. Generally the modified atmosphere decreased the rate of lignification, indicating the importance of ventilation, but did not cause browning of tuber tissue. Insufficient ventilation in the field would allow build up of the plant hormone, ethylene. The effect of ethylene was not tested in this experiment, but may be responsible for the browning effect.

Table 1.9. Atmospheric composition and temperature recorded during curing of yam tubers.

Duration of curing (days)	% CO_2	%O_2	Temperature (°C)
1	24.0	0.02	34.0
2	23.8	0.03	34.5
3	24.0	0.03	34.5
4	24.0	1.50	34.0

Table 1.10. Comparison of various wound periderm characteristics during curing of yam tubers at 34 °C and 91% RH in air and modified atmosphere (23%CO_2 and 0.035%O_2)

Tuber number	No. of periderm layers		Thickness of periderm layers		Score for colour of stain in periderm	
	control	Modified atmosphere	control	Modified atmosphere	control	Modified atmosphere
1	4.50	2.75	9.50	10.75	1.0	0.190
2	4.0	3.25	15.75	16.67	1.0	0.13
3	4.25	3.75	9.50	21.25	1.0	0.190
4	3.75	2.25	14.99	12.00	1.0	0.250
5	5.00	3.25	14.00	12.75	1.0	0.19
6	4.00	2.75	16.00	17.25	1.0	9.13
Mean	4.25±0.	3.00±0.23	13.12±1	15.11±1.8	1.0±0.0	0.18±0.02

1.4 Summary and discussion of key technical findings for Output 1

Early on in the project trials were conducted in which the post-harvest behaviour of different varieties of white yam were compared. Pona, is the preferred variety for marketing due to its superior sensory and culinary characteristics, but is significantly more perishable and susceptible to rotting than other varieties such as Onumo. Although outside the scope of this project, there might be great potential for breeding for better storing cultivars, as long as good sensory characteristics can be maintained.

The results from the first two years of field trials indicated that, at least for Pona milk yams, pit storage is better than barn storage. Given that extensive trials conducted by GTZ using ware yams indicated that barn storage was an improvement on pit storage, the assumption must be that tuber maturity has a very significant effect on optimum storage conditions. Thus pit storage should be used for immature yams, while barn storage should be used for mature yams.

Within our trials, a major objective was to refine curing in order to improve storability. The studies on the effect of environment on the process of curing conducted in the laboratory (1.3) are very important in helping us to interpret the findings of the field handling and storage trials (1.2). In particular, it will be very important to know if the optimum curing conditions for ware yams differ significantly from those of milk yams, and it is unfortunate that it was not possible to complete this study before the end of this project. Indeed, in retrospect it would have been better to carry out a series of laboratory studies before planning the field trials.

The curing protocols used in the first year were not very successful. However, the second year of trials was very encouraging. The curing treatment improved barn storage, even though comparison with the laboratory experiments indicates that the curing temperature (36-39°C) was considerably above the optimum of 32°C, and the time of curing (4 days) was not long enough to complete the process (at least 6 days needed). It was unfortunate that in the final year of trials on milk yams, in which the curing conditions were much closer to optimum (30 - 37°C, high humidity, although still only 4 days), the levels of rotting were not sufficient to assess the impact of curing.

In the final year, the effect of curing on ware yams was not very positive, but as yet we do not have completed laboratory studies to help us to interpret this data.

Once the laboratory studies on ware yams are complete, the knowledge gained of optimum curing conditions, and of the environmental conditions that can be maintained within various designs of curing room, will enable us to provide recommendations to improve storage both of milk and ware yams.

Output 2: Improved post-harvest handling and shipping protocols developed for the export market and validated in collaboration with joint yam producer/exporter associations.

Overview of Output 2

Objectively verifiable indicators
2.1 Technical, economic and social investigations completed by March 2003.
2.2 Recommendations developed by March 2003.

The OVIs of this Output were adapted during the course of the project (see Activities). The revised OVIs were achieved.
Technical work on the improvement of post-harvest handling of tubers in Ghana for export is described under Output 1, as it is also relevant to tubers destined for markets within Ghana. The main recommendations however, refer to the treatment of yams during shipment to Europe, during which very serious problems have been identified.

2.1 Socioeconomic aspects of the Ghanaian Yam export trade

The defined outputs of the socio-economic research were to have:

i. Identified the economic and marketing factors affecting the viability of fresh yam exports from Ghana into the UK (and other European and American) markets, including competition from other Yam exporting countries.

ii. Identified the technical and socio-economic constraints hindering the development of effective yam producer/exporter linkages as well as devised possible strategies to foster successful collaborations.

iii. Assessed the feasibility of introducing improved handling, storage and shipping protocols to reduce biological and economic losses, thereby improving the quality of exported yams.

2.1.1 Summary of Significant Results

- The study revealed yam export has potential in Ghana. Gross margins – difference between wholesale prices in UK markets and local wholesale prices plus direct shipping costs – exceed 75% of the domestic price, making the trade look quite lucrative. In terms of output, Ghana ranks second only to Nigeria enjoys very strong price competitiveness. Furthermore, there is evidence that consumers in the UK market, to which over 50% Ghanaian exports are destined, prefer the white yam varieties from Ghana because of the taste.

- Although it is considered as a high-value tuber crop, it is grown mainly by smallholders using simple tools like cutlasses and hoes and own tubers as planting material, but making very little use of modern inputs like fertiliser and pesticides. Hence, smallholders could benefit from improved marketing and prices due to increased exports. The volume of exports, both formal and informal, represent less than 0.01% of national output of the crop and does not therefore pose any threat to household food security, in terms of the contribution of the crop to meeting the calorie needs of the average Ghanaian.

- Exports of yams from Ghana have doubled since the mid-1990s, but further expansion is limited by the factors summarised below.

- Yam has not crossed the ethnic barrier in the UK market, which has either stagnated or grown only marginally. The growth in Ghanaian exports therefore represents more of displacement of imports from other origins. The main competition is from Caribbean and Brazilian supplies, but these tend to be significant mainly during the period when supplies from Ghana appear to dry up. Disputes over quality are frequent and it costs an additional $0.80 to dispose of rotten yams in the UK. Frequent unscheduled exports from Ghana also depress prices, leading to considerable losses by exporters. New entrant exporters are less able to cope with such losses than the experienced ones. Quite often, instability in the export market is attributed in the media to the activities of rogue traders engaged in drug trafficking using yams, but a number of exporters have realised that the root cause is lack of professionalism in the trade.

- The existing marketing system contributes to the poor quality of Ghanaian yams. The crop goes through multiple handling as it is transported from the surplus-producing areas to the main urban markets from which exporters source their consignment. The trade is highly informal with no enforced standards regarding weight and quality. Storage is largely on-farm, and in efficient facilities, as farmers cannot afford modern storage facilities – the technical component of the project examined the technical feasibility of adopting various protocols to reduce post-harvest losses. Packaging in the domestic system is based on traditional systems which fail to reduce losses in transit. Domestic transport is a problem, though it is less so from the point of export. Direct linkage between exporters and farmers to shorten this chain and reduce such losses was explored in another study and is reported on later. Poor shipping conditions contribute in small measure to losses in transit. Though the Ghana Shippers Council is well-placed to initiate dialogue between exporters and shippers to improve this situation, the yam exporters had never used this channel, due mainly to lack of knowledge.

- Entry barriers to the trade were observed to be low, contributing the lack of professionalism in the trade, with attendant frequent occurrence of disputes related to unscheduled exports and poor quality tubers.

- The study shows that if Ghana is to enjoy growth in yam exports, the focus should be on improving the internal marketing system. There is some indication from exporters of their preparedness to adopt technical protocols and other market interventions that will assure the supply of quality produce in a stable manner. It is also apparent that UK importers will more than welcome such improvement, which are likely to be beyond the life of this project.

<u>Specific Outputs of the Research</u>

2.1.2 Yam exports from Ghana: economic and marketing factors affecting viability, including competition from other yam exporting countries.

This section reports on the yam supply and distribution system, within Ghana and the UK markets, identifying opportunities and constraints in the chain, and what is needed to enhance prospects for exporters and producers.

2.1.2.1 Ghana yam: production and export

Ghana ranks second to Nigeria in terms of global yam production, with annual output estimated officially at 3.5 million tonnes[3] (compared with Nigeria's output of 37.8 million tonnes). The crop is an important part of Ghana's food economy, being second in importance (in tonnage terms) only to cassava in meeting the calorie needs of the average Ghanaian (Fowler, 2000). Yam production has been rising since the 1990s, from 1.7 million tonnes in 1994 to 3.25 million tonnes in 1999. Output growth is attributed to increased area under cultivation as well as improved productivity (with yield per hectare rising from 7.4 tonnes in 1990 to 12.9 tonnes in 2000[4].

Yam production is concentrated in Ghana's interior savannah (northern parts of the Brong Ahafo, Ashanti, Eastern and Volta Regions as well as the Northern and Upper Regions). Many varieties of the crop are well adapted to the climatic conditions and light sandy soils in this area. Although it is considered a relatively high-value tuber crop, it is grown mainly by smallholders making very little use of modern inputs like fertiliser and pesticides. The main purchased inputs are simple tools like cutlasses and hoes; and farmers usually use their own tubers as planting material. Availability of farm labour is seen by farmers as one of the main factors limiting expansion of area under cultivation, though land is also becoming an increasingly important constraint in some yam growing areas. Asuming-Brempong et al. (2003) estimated the average farm size at 5.5 hectares – which is well above the national average for staple crops (officially estimated at 1.5 hectares) – an indication that its production is more commercially oriented than most other food crops in Ghana. In the Northern Region it is inter-cropped with other staples such as maize and millet, but in the other regions it is generally harvested before other crops are planted.

According to the FAO, Ghana enjoys a strong comparative advantage in yam production (FAO 1998). As Table 2.1 illustrates, formal yam exports have risen significantly over the past decade, rising from 2,100 tonnes in 1990 to a record of 12,463 tonnes in 2000[5]. With foreign exchange revenues estimated at over US $7 million per year, yam is the second most important non-traditional agricultural export after pineapple[6]. The quantity exported through formal channels represents less than 0.01% of national output; but it is estimated that unrecorded, overland shipments to sub-regional markets (including Burkina Faso, Côte d'Ivoire, Mali and Togo) could be between 25,000 to 30,000 (FAO, 1998)[7].

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[3] Source: Ministry of Agriculture and Food (MoFA) data quoted in ISSER (2002).

[4] Official production data need to be treated with some degree of caution as the collection of statistical data on smallholder crops, which is a very difficult task, has been affected by the restructuring of the Ministry of Agriculture and Food (MoFA) (Centre for Policy Analysis, 1999).

[5] Source: ISSER (2002).

[6] Its status was recently changed by legislation (LI 1709) to a traditional export, apparently to create controls intended to improve the trade.

[7] No sources for the estimates is provided in the FAO publication

Table 2.1: Ghana yam exports (1994-2001)

Year	Volume Exported (tonnes)
1994	5,323
1995	6,866
1996	8,086
1997	7,018
1998	7,421
1999	9,763
2000	12,463
2001	9,629

Source: Ghana Export Promotion Council **(**GEPC).

Destination markets for exported Ghana yams

About 50% of the Ghanaian yam exports are destined for the UK market. Other destinations include continental Europe, (namely Germany, Italy, Netherlands and France) and North America. In recent years, shipments to the USA have increased, and in 1999, accounted for almost one-quarter of exports by value[8]. The UK market is dominated by 10 wholesalers, most (7) of whom have been in the business for over 15 years. The market is small and growing slowly, as reported by Otoo (2003)[9]. , This is in part due to the observation that the principal consumers in the overseas markets are "West African and other yam-eating 'diaspora' communities" (FAO 1998), although migrants from the Caribbean and South American countries are also consumers. As yet, yams (in contrast to some other tropical products, such as bananas and mango) do not appear to have "crossed over", witnessing significant consumption by the indigenous rather than the ethnic population. It is also reported that second generation immigrants consume less yam than their parents (reports Otoo, 2003 from survey of wholesalers).

Yam imports into UK is estimated at about 11,000 tonnes per year[10]. Nigeria used to be the major supplier of yams to UK, but lack of competitiveness and an official ban on exports following food shortages, led to supplies from this source becoming insignificant. Ghana accounts for 50-60% of yam imports into UK, with other suppliers being Côte d'Ivoire, Brazil, Columbia, Jamaica (and other Caribbean countries) and Cameroon (which is reported to produce high quality yams but has insufficient for exports). Ghanaian yam exports have increased in the past decade as a result of the competitiveness of Ghanaian exports and their replacement of yams from other origins than because of a rapid expansion of the market.

In the 1970s, two species predominated in the UK market: the White or West African or Negro or Guinea yam (*Dioscorea rotundata* Poir), imported from West Africa and Jamaica; and the Lisbon yam or water yam (*D. alata* L.) - imported mainly from Barbados. Currently, however, consumers appear to have a preference for Ghanaian yams (Greenhalgh, 2001)[11]. Taste is an important factor cited for the preference of Ghana yams over other origins. Whereas larger yam tubers are preferred in

[8] As yet for 1999 only the value of yam exports to various destinations are available and they should exports to the UK accounted for 48%, USA 24%, Netherlands 11%, Germany 8% and Italy 3%.

[9] A recent survey of UK yam wholesalers carried out by Otoo (2003) revealed that that yam consumption in the UK had either been stagnant or grown only marginally. Consistent with this, only one out of eight respondents reported increased margins, with the rest indicating that margins had stagnated or declined.

[10] The UK does not separately specify yam imports, but these are grouped under "Other Root Vegetables with a high starch content"- HCDCS Code 0714 90 110. Nevertheless, based on an interpretation of the data, trade discussions, previous analysis and origin export data it is possible to provide some estimates of overall imports.

[11] This is, however, not based on a detailed consumer survey.

Ghana, there is a reported preference for smaller tubers in both the UK and Continental European countries. It has also been noted that, in Nigeria and Benin, the urban population is increasingly demanding competitively priced smaller tubers (weighing 1-2 kg), rather than the typical tuber that weighs between 3 and 5 kg. This is beginning to influence production techniques in both countries (Fowler 2000).

There is no reference to similar changes having taken place in Ghana. Indeed, field studies conducted in several wholesale and retail markets showed that large tubers attract a significant price premium over smaller ones (Kleih et al, 1994). However, such a change may not be far away, given the rapid growth in the country's urban population.

Table 2.2: Varieties of Yams Exported by Sample Yam Exporters

Yam variety	Frequency	Percent
Puna	7	53.8
Asana	2	15.4
Dente (Punjo)	1	7.7
Other white yam	3	23.1
Total	**13**	**100.0**

Source: Jatoe and Tweneboah-Koduah (2003)

White yams are the preferred and most widely cultivated varieties in Ghana due to the economic value, accounting for about 80 percent of the country's total production (Tetteh and Saakwa, 1991). The *puna*, *larbeko* and *lorbayi* white yam varieties command higher market prices and are therefore largely favoured by farmers despite their higher susceptibility to spoilage. *Puna* and *larbeko* yams have a maximum storage life of three months whereas other white yam varieties can be stored for six to twelve months.

Supply of yam to the UK market is seasonal. The bulk of yam sales (about 65% of the total marketed) in the UK market occurs in August-December, when wholesalers on the average sell about 185 tonnes of yam each per month (Otoo, 2003). The period coincides with the yam season in Ghana: planting normally occurs in September-November and the harvest usually begins in July. The first shipments, which occur in July, tend to be made by air, as the relatively higher prices during that period compensate for the higher cost of transport. Some yams, stored in West Africa, may be available until April, but the main supplies from February to June are from the West Indies and Brazil. To some extent, the situation in the UK market contrasts with the US market, which is relatively uniform year round, in terms of volumes. According to Amex (1993), the US market is supplied predominantly by Latin America and the Caribbean producers.

Yam is usually shipped by sea to the ports of Felixstowe, Tilbury and Teesport (in north east England), but is sometimes air freighted into the UK (British Airways opened a new terminal at Heathrow to handle fruit and vegetable in 2000). The major wholesale markets are Spitalfields market in East London, the Western Market in London and the markets for "ethnic produce" in Birmingham, Manchester and Bradford. Yam is retailed through many small markets and a large number of fruit and vegetable shops and stalls, most of which cater to the immigrant population in urban areas. The supermarkets are not known to retail significant volumes of yam, though a few of them sell mainly small Central American yams (the larger 2-3 kg tubers are not preferred). In contrast, yam is available through retail chain outlets in the US. The two major importing areas in the USA are the New York/New Jersey and South Florida areas, and in the early 1990s they accounted for over 90% of yam imports.

2.1.2.2 Yam supply and distribution system

Only a small number of exporters produce yams, and most of them rely on the domestic distribution system to procure yams for export, usually using agents to buy from the main wholesale markets in Accra (especially the Konkomba and Basare yam markets). With production concentrated in the central and northern parts of Ghana, and the major consumer markets in the south, the direction of the yam trade tends to be southwards. Yam is marketed fresh throughout the country, with little or no trade in stable processed products with a prolonged shelf life. Processing through roasting, frying or for fufu preparation is generally done by final consumers or food outlets.

Domestic marketing chain

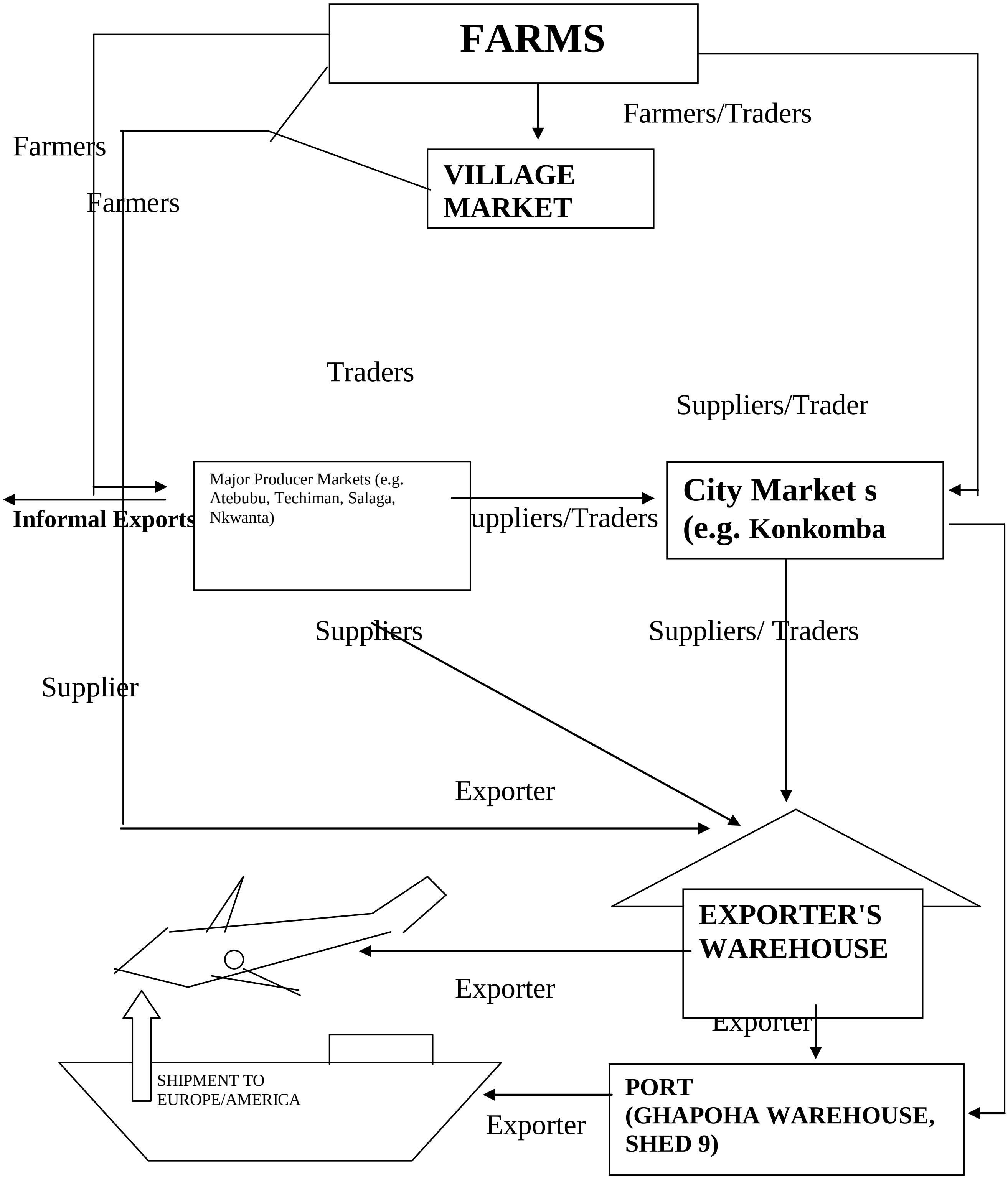
A very simplified version of the main marketing channel, illustrated in Figure 2.1, shows producers selling at the farm gate or in assembly markets in villages and rural towns. Assembling is usually undertaken by itinerant traders, who sometimes work through agents. After bulking, the traders transport the yams to wholesale markets in urban centres, renting large trucks for this purpose, either individually or in groups. There, yams are sold to sedentary wholesalers and retailers. Many retail markets exist in each urban centre. Direct trading links between farmers and urban wholesalers or exporters are not common (NRI, 2000; Asuming-Brempong et al, 2003). However, close ethnic ties appear to exist between traders and producers[12], which allows wholesalers to either buy yams on credit or to assist producers sell in the wholesale market.

Assembling of produce takes between 10 and 21 days, depending on the season and availability of supplies. This is due mainly to farms being small and widely dispersed as well as difficulty in getting suitable transport to move the crop from the farm to villages or the assembly markets. Lack of reliable market information and the absence of quality and weight standards means that the buyer has to be physically present in the producing areas to ensure that they get the right yams for the right price. The time and financial cost involved in the process is one factor that discourages direct sourcing of produce from farmers by exporters.

Yams are transported over distances of more than 500 km (Gray, 1996), and multiple handling occurs along the chain, including re-stacking, loading and off-loading at several points. Together, or in isolation, these activities lead to significant quality deterioration and losses. The principal quality problems cited by traders are rotting, breakage, surface damage, bruises, termite damage, nematode damage, cooked spots and sprouting (Gray, 1996).

[12] A study by Asuming-Brempong et al (2003) found over 75% of yam producers and about 65% of the traders shared common ethnic origins (mainly from the northern tribes). Only 15% of exporters sampled share similar ethnic background.

FIGURE 2.1: MARKETING CHANNELS FOR YAMS IN GHANA'S EXPORT TRADE



Trading Arrangements

Women dominate the yam trade in some markets, especially in the assembly and retail markets. However, men dominate the urban wholesale trade. The traders generally lack access to bank credit, but traders are often required to extend credit to farmers to assure supply during the harvest (NRI, 2000). Apart from self-finance, traders often resort to informal finance in the form of trade credit and loans from other traders, friends and relations) exists. Most urban retailers depend on credit extended by the wholesalers, allowing them to pay after the sale of yams. These trade financing constraints impose significant limitations on capacity expansion by traders. Trade credit is often not extended to exporters, who tend to relatively bigger operators, with more formal education and long history of dealing with banks.

Different trading arrangements are negotiated between exporters and importers, depending on the degree of familiarity and trust developed through repeat transactions. Yams are often shipped on a consignment basis and the final price is worked out when the yams have been sold – a practice which is discouraged in the US market. There are several reasons why consignment basis dominates the current trade, including the high losses through rot during shipment; substantial price volatility in the market and considerable uncertainty in the trade. There have been a number of disputes, especially when the UK is flooded and prices collapse.

Importers usually pay for freight charges and are responsible for clearing the consignment. In addition, they have to obtain the necessary import licence from the UK Ministry of Agriculture's (MAFF) Intervention Board. There is a ceiling on the level of imports and a licence is required to import. As yet, it is thought that since import volumes are relatively small – and present no threat to UK animal feed supplies - there has been no import licence refusal. While Brazil pays a small levy on its exports to the EU (about £1 per tonne) but the levy is waived on ACP origins.

Trade standards and quality

Standard weights are not applied within the trade, except at the point of export. Within the domestic trade sale is often in heaps of tubers, the standard number of tubers in a heap differing in different markets. At the assembly markets yams are sold in heaps of 110 tubers; the 10 tubers being an addition to compensate for losses and other costs incurred during the marketing process (including bribes paid at various police barriers in transit). At the major wholesale markets, wholesalers add 3 tubers to the 100 sold to retailers to cover losses and other transfers. The heaps contain tubers of different sizes and quality – this variability makes it difficult for trade by description to occur (i.e. without requiring the trader to physically sample the commodity).

In contrast with what prevails in the domestic trade, yams are sorted, washed and dried before being packaged for export. Though formal quality standards exist[13], they are generally not applied when exporters do sorting. The preferred yams are the relatively smaller tubers weighing 2 kg on average and with a low water content, allowing the tubers to store better (FAO, 1998). There is no evidence of formal quality inspection at the Ghana ports. Tubers rejected by exporters are usually re-sold in the domestic market, with some retailers buying these directly from the exporters' warehouses.

Despite the sorting, there are frequent complaints from UK importers about the high level of losses, usually of rotten yams, upon arrival at the ports. The most popular variety exported by Ghana, *Puna*, has a relatively short shelf life (can be stored for only 3-4 months) compared to Brazilian varieties that

[13] "Standard Specification for Fresh Yams" produced by the Ghana Standards Board.

can store for 6 months, and the Costa Rican “cush-cush” yams which are reputed to have a much longer shelf life. A recent informal survey in London’s Spitalfields market[14] showed that:

- Losses averaged between 5-10% per container, and could even be as high as 25% towards the end of the season (June/July when the new harvest is yet to come in);
- The losses could be due to:
    - undetected internal rot;
    - poor shipping conditions, allowing the package to get wet or getting the yams “cooked” in transit by keeping them in very hot places in the ship;
    - off-loading;
    - poor quality cartons
    - sharp variations in shipping conditions – microbiological rotting occurs during shipment as a result of very high temperatures followed by rapid cooling

Quite often, import contracts allow for exporters to replace “rejected” yams in subsequent shipments. However, the cost of disposing rotten yams is quite high in the UK – about £5 per 25kg box of rotten yams. Assuming a reject rate of 10%, this translates into an additional cost of £20 per tonne or £0.50 per 25kg box of yams shipped.

Storage and transport of yams

Post-harvest losses for yams are very high (Marfo et al, 1998) and can be attributed to poor harvesting and handling practices as well as lack of efficient storage facilities. Most storage occurs on-farm, and resource-poor farmers cannot afford the available improved storage technologies (NRI, 2000). The result is substantial losses through weight loss, rots, sprouts and attacks by termites and rodents. Hence, the longer the yams are kept in store the greater the decline in their market value.

Transporting yams to the major markets is severely hampered by lack of a well-maintained network of primary, secondary and feeder roads in the rural areas results. Reliable cargo transport is often unavailable – bicycles, hired tractors and *old* taxis are the main means of transport used by itinerant traders in assembling the crop in the surplus-producing communities. Traders use hired cargo trucks to transport yams from the assembly villages to wholesale and other major markets. Transport costs are very high, can represent “up to 50 per cent of the marketing margin” (IECT, 1999)[15]. These transport constraints also limit sub-regional trade in yams, but are less of a problem from the point of export.

Export of yams is mainly by sea, through the Tema and Takoradi ports. Air-freighting occurs, usually during the beginning of the harvest, when “milked yams” are exported. Shipments often take 14 to 25 days between Ghana and the UK. Shipping companies from Ghana include Ro-Ro, Grimaldi/OTAL (African Liners) and Maersk, which appears to be mainly involved in shipments to the USA. Ghana has an advantage regarding the distance the yams have to be shipped to the UK compared with Brazil, Costa Rica and Caribbean and costs can range between £600-£900 per container (i.e. between £48 and £72 per tonne or £1.20 and £1.80 per box of 25kg). Clearing costs approximately £50 per container.

Air freighting is substantially more expensive, raising the retail price of air freighted yams in UK retail to between at £28-30 per 25-kg box, compared to average price per 25-kg box of sea-freighted yams of between £8-£18. Air freighted yams can be in UK shops within 2-3 days of leaving the producing country. From the UK ports (Felixstowe, Tilbury and Teesport) the yams are transported by road to wholesalers, at an average cost of £1.12 per 25kg[16].

[14] NRI (2000).

[15] Gray (1996) estimates that three-quarters of “marketing costs” are accounted for by transport.

[16] The estimated cost from Teesport to Spitalfields is £560 per container.

Yams for export are packed in 25-kg cardboard boxes, which may be telescopic or ordinary. No such packaging is used in the domestic trade. The packaged yams are shipped in containers holding 500 boxes (12.5 tonnes) or put on pallets containing 40 boxes (10 tonne). Palletisation of the consignment is undertaken by the port authorities (the Ghana Harbours and Ports Authority – GPHA), which also provide temporary warehousing facilities when shipping is delayed. The pallets, which are placed on flat racks, are preferred because they permit circulation of air and tend to be cheaper than container shipment[17]. Shipping conditions, particular temperature, tend vary significantly during transit and is known to adversely affect the quality of yams[18] **(see Outputs 2.2)**.

Yam Prices

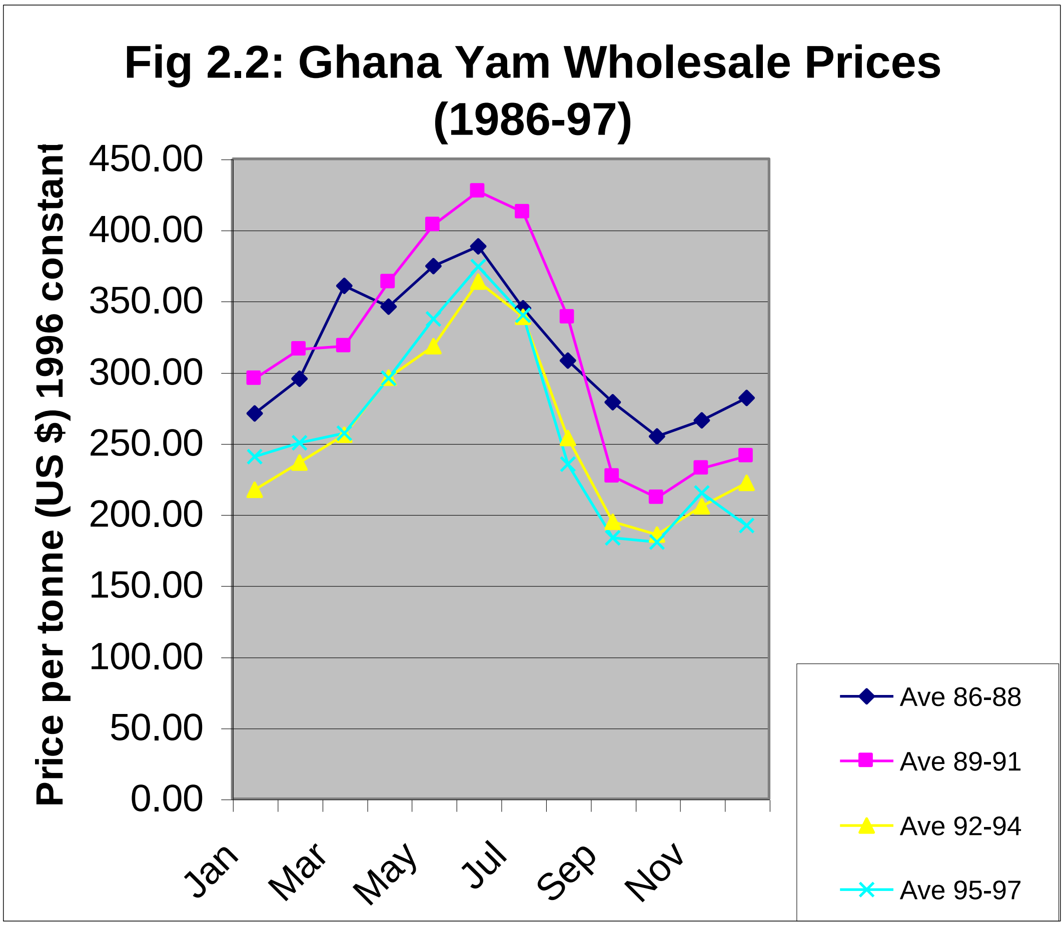
Yams are a relatively high cost starchy food in comparison with its major competitors, namely cassava in West Africa and potatoes and rice in Europe. Like most agricultural products, yam prices show wide seasonal variation, as illustrated in Fig 2.2 below. Yam prices are usually lowest in October and peak in June (just before the early harvest in July). Between 1986 and 1997, the average October wholesale price was $208.24 per tonne, the comparative figure for June being $388.39 per tonne; implying an average seasonal price rise of over 85% in real terms (that is after taking into account the effects of inflation and currency depreciation on domestic prices). It is not uncommon for prices to double during the season as occurred in the periods 1992-94 and 1995-97 (Fig 4.2).

Real wholesale prices have been declining, partly because of increased output, falling by almost 20% between 1986 and 1997. However, while wholesale prices in October fell by nearly 30% in real terms over the period, the corresponding fall in prices during the lean season (April to June) is about 15%. Falling real wholesale prices imply improved price competitiveness of the yam sub-sector in Ghana – in the 1986-88 period, the wholesale price per 25kg box of yams (cost of tubers alone) was $6.37, but by the 1995-97 period this had fallen to $4.52.

This situation is due in part to poor storage, making it difficult to better manage the supply of the crop to match demand – a reflection of an under-developed marketing system (GTZ, 1999). Lack of access to credit for consumption smoothing by farmers, and the pressing liquidity constraints this creates, necessitates sale during the harvest season, leading to depressed producer prices.

[17] Grimaldi Line which is provides pallet shipment offers a lower tariff than container shipments.

[18] The Ghana Shippers Council organises educational programmes for exporters and can intervene in shipping related disputes. Though exporters pay a levy to the Council, none of them had used their services in seeking a claim against a shipper because of losses in transit due to poor shipping conditions.



Source: Historical price data from Ministry of Food and Agriculture (MoFA)

Entry barriers to yam export

With domestic wholesale prices ranging between $5.2 and $9.7 per 25kg box (i.e. between October and June respectively), and wholesale price in UK of between $12.0 and $20 (based on data collected by Otoo, 2003), yam exports appear very lucrative[19]. Barriers to entry into the yam trade are low; one reason being ease of access to produce during the harvest season, when there is usually a glut and prices are very low. As part of efforts to promote non-traditional exports, Government lowered regulatory barriers to the trade in the early 1990s with the revocation of the legislative instrument (LI 1354), which governed yam exports, and required irrevocable letters of credit before exports would be authorised. No official quality control system is enforced at the ports, except for phytosanitary inspections by the Plant Protection and Regulatory Services Directorate (PPRSD) of MoFA.

The inspectors look for:

- cuts and other forms of injuries. This measure ensures that all ‘entry points’ for disease causing organisms are closed thus prolonging the shelf life of the tuber.

[19] With gross margins – difference between wholesale prices in UK markets and local wholesale prices plus direct shipping costs – in excess of 75% of the domestic price, many traders find it an attractive enterprise. In the words of one of the exporters, yam export is “more than a goldmine”. A group of wholesalers turned exporters shared similar perceptions of the yam export trade.

- soil and soil particles on produce. This ensures that soil borne diseases are not carried to other countries.
- deformation, 'branches' or grooves on the tuber. Branched tubers or those with grooves may have soil particles hidden in certain parts.
- insects and insect holes.

sprouts. All sprouts, where possible are broken off otherwise such tubers are replaced.

There is a core of about one dozen companies with long experience in the trade and which accounts for a major proportion of the exports, but there usually tends to be a large number of new exporters in the business and turnover of exporters is high. This is mainly the result of the low entry barriers and the relative attractiveness of the trade. Inexperienced exporters often lack knowledge of both trading and the sector, particularly conditions in the export destination markets. UK importers tend to be well informed about price-sensitive developments in the yam market in Ghana (Otoo, 2003), including information on local prices, shipments schedules as well as expected volumes to be landed in any particular week and what effect it will have on prices. This is, however, not the case with most exporters in Ghana – they have little or no idea about the size of the UK yam market, suppliers and volumes shipped into the market (J. Danquah, 2003 *pers. comm*.).

Information asymmetry between importers and exporters tends to weaken the bargaining position of the latter, especially when contract settlement is after sale of the commodity in the export destination market. This undermines trust between the counter-parties, compounding difficulties created by quality uncertainty. Unscheduled exports by uninformed traders is a frequent occurrence[20]. One effect is deepen uncertainty about prices in the UK market, leading to losses by some exporters. It is quite common for many in the export trade to attribute price collapse in the UK market due to excess supply to the activities of rogue traders engaged in drug trafficking[21]. It is, however, becoming quite apparent to some in the trade that the problem is due more to the activities of uninformed exporters (K. Baah, 2003 pers. comm.).

Not surprisingly, there have been calls for tightening controls in the export trade, but initiatives like the introduction of a quota system failed to work. The executives of the Ghana Yam Exporters Association (GYEA) are doubtful that the recent change of status of yam (to a traditional export that requires new documentation prior to export)[22] will fail to achieve its aim of regulating the trade because it does not re-impose the requirement that shipment should be against irrevocable letters of credit only.

2.1.3 Promoting linkage between yam producers and exporters to improve the competitiveness of yam exports.

In the section on Ghana yam export marketing, we reported many supply-side problems in the trade, including low quality tubers and a high degree of deterioration of yams at the final port of destination, as well as supply and price variability. These were attributed to inefficiencies in the marketing system, which is rather long and entails considerable multiple handling that contributes to spoilage of tubers in transit. It has been suggested that some of these problems can be reduced with the development of mutually advantageous linkages between exporters and farmers.

[20] Wholesale traders surveyed by Otoo (2003) reported very frequent unscheduled imports, ranging between 6 to 10 cases in the season.

[21] There have been several media reports in the Ghanaian press alleging that drug dealers are destroying the yam trade, but there is no corroborative evidence to confirm this is happening.

[22] The new legislation is LI 1709.

No viable linkages between exporters and producers have been observed in the yam trade in Ghana. In this section we report on technical and socio-economic constraints hindering their development and what needs to be done to foster them.

2.1.3.1 The case and conditions for effective producer/trader (exporter) linkage

Vertical integration schemes linking exporters or processors and growers through contractual relations for input and technical advise provision and output marketing have been developed in several parts of Sub-Saharan Africa for horticultural crops, tropical fruits, tea, sugar cane and other crops (Stringfellow, 1995; Little and Watts, 1994). This type of relation enables smallholder farmers to produce for higher value, higher growth markets that would be otherwise difficult to reach due to a lack of critical marketing and other agricultural services. For the processor or exporter such schemes assure timely supplies of produce at an agreed price and some form of control over specific aspects of the production process, including the type of variety grown, the inputs used and other agronomic practices. The alternative of operating a large farm would not only imply high investment and labour costs, but it would also increase the firm's exposure to production and marketing risks.

Based on experience from Sub-Saharan Africa and other developing countries, it has been suggested by Stringfellow (1995) and others that successful contract farming arrangements between growers and exporters need to meet the following conditions:

- First, production of the commodity should require significant amounts of productivity-enhancing inputs like fertiliser and pesticides[23]. Because such inputs are expensive and often unavailable in rural areas, cash-constrained farmers need a reliable source of supply, especially if this same source is willing to provide the inputs on credit. Farmers may also require access to complementary technical information, particularly in cases where they are being introduced to a new crop, a new technology or a new and more demanding market with specific quality requirements.

- Second, the crop in question does not have well-established multiple marketing channels[24]. If farmers have limited opportunity for side-selling, they are less likely to breach interlinked contracts involving input supply on credit and crop marketing. Farmers also have little incentive to participate in such arrangements if it does not offer access to more rewarding markets.

- Third, unless the targeted export markets are relatively attractive to the farmer as well as to the exporter, there will be no interest on both sides to invest in direct contractual relations.

2.1.3.2 Experience in promoting farmer/exporter linkages

The failed yam linkage scheme

Yam does not seem to fulfil any of the conditions mentioned above. It is traditionally grown using simple, low-technology inputs. Being a major staple food, multiple marketing opportunities exist for producers, increasing the risk of contract non-performance by farmers and discouraging exporters from investing in service provision. The export market is also not only thin, but has not exhibited strong growth and has been quite unstable. Uncertainty about export orders and future prices deter exporters from investing in the establishment of direct linkages with farmers. In particular, they are

[23] In peasant farming systems, input use is a function of factors such as the level development of input markets, the susceptibility of a certain crop to pests and diseases, its yield response to fertilizer use or irrigation, and the quality requirements of final consumer markets.

[24] Crops that enjoy high consumption levels within the region or country of production are normally characterised by well-established spot markets.

unable to guarantee purchase of deliveries from farmers since they lack the capacity to store the produce beyond a few weeks and have not developed alternative marketing channels should they fail to secure export orders.

As a result of these factors, farmers and exporters have both not been enthusiastic about developing linkages. Farmers scepticism is also in part due to a failed attempt to promote such a linkage in the past as reported below based on the study by Asuming-Brempong et al (2003). The arrangement involved the Ghana Yam Producers and Exporters Association (GYPEA) and farmers in the Nkwanta and Kete-Krachi districts of the Volta region. A co-ordinator was identified to assemble produce from various farmers in the area for the exporters. It did not involve any formal agreements, being based on trust between the parties.

The exporters failed to take delivery of a consignment of about 150 tonnes of yam supplied by the participating farmers and also failed to communicate their inability to buy the consignment to the farmers. Hence, the trust upon which the scheme was built, was lost leading to the collapse of the linkage arrangement. The other major factor that militated against the programme was the involvement of politicians. The linkage system was developed around the District Chief Executive (DCE)[25], who appointed an official of the National Mobilization Programme[26] to co-ordinate activities by farmers and liase with exporters. According to the farmers, the co-ordinator was selective in dealing with farmer groups and was far from transparent in his dealings with the parties in the linkage. For example, farmers reported that he quoted prices to the exporters above what he paid to the yam farmers, denying the farmers of one essential ingredient - remunerative market.

The pineapple export linkage model: a success story in Ghana

The model has been developed by Farmapine, a private company engaged in fresh pineapple export. Pineapple is the leading non-traditional agricultural export. The crop meets at least one of the conditions for successful contract farming – its production requires significant use of productivity-enhancing inputs as well as extension in agronomic practices. However, like yam, it has multiple marketing channels. Seini (2002) reports that only about 37% of Ghana's pineapple output is exported. The rest is marketed locally through the informal fruits and vegetables market, to supermarkets and hotels, and to fruit processing companies of various sizes. Hence, the risk of side-selling is quite high. The production of pineapple is also concentrated geographically, even more so than is the case for yams.

The exporter (Farmapine) works with farmers who are organised into 5 co-operative groups, and who are also shareholders of the company. The company provides technical support and credit to the farmers, who have to demonstrate commercial orientation. The farmers are given codes for identification and traceability and production is confined to the "pineapple belt[27]". Farmapine regulates quantities produced at any given time, to match output with export orders. It is responsible for transporting the crop from the farms, using specialised trucks.

Prior to entering into supply agreements with the farmers, Farmapine secures firm forward contracts, guaranteeing volumes to be supplied and agreed minimum price for fresh pineapples with each of its trading partners (10 importers). Farmers are paid after the crop is exported, with the cost of inputs and services provided being deducted from what is due to them. The system is well-policed by the company, and its staff are sometimes used in harvesting the crop to assure delivery of quality pineapples and on schedule.

[25] Political head of the local government system.

[26] A political organisation created by the past NDC government, which was responsible for relief and mass mobilisation programmes.

[27] A contiguous geographical area within the Akuapim South district.

The experience of Farmapine indicates that, even in the face of the risk of side-selling, a successful linkage arrangement can be developed if farmers are well organised, and the arrangement well monitored within a limited geographically-defined production area. The key factor, however, seems to be the exporters' capacity to absorb volumes delivered by producers and to effect prompt settlement in accordance with agreed terms. The price offered should also be competitive. Farmapine is able to do this on the basis of the forward contracts with importers.

2.1.3.3 Prospects for replicating the pineapple farmer/exporter linkage

Expectations from linkage schemes

Asuming-Brempong et al (2003) observed that farmers they surveyed were interested in linkage schemes with exporters. The farmers ranked market access for a good price as their top priority in participating in any linkage scheme, followed by access to production credit.

For exporters, the main objective was to assure timely delivery of quality fresh tubers and at stable prices. Some exporters view the development of linkages with producers as potentially more beneficial than existing informal arrangements with agents in the major urban yam markets. These agents usually procure supplies for the exporters when the latter has an order. They charge a commission of between $18 and $30 per tonne of yams supplied. Where the agent operates on a non-commission basis, he/she may actually buy and sell the consignments to the exporter, in which case they are commonly classified as "suppliers". In both cases, the agents transport the yams to the exporter's warehouse and the yams are sorted before payment.

Characteristics of participants

Of the farmers surveyed (Tables 2.3 and 2.4), 42% are aged 50 years and over, indicating that promoters will be dealing with an ageing population. More than 62% of them have no formal education and nearly 50% of them farm on communal land. The land tenure system involves non-cash payments to chiefs (with payment in the form of alcoholic beverages and tubers of yams. These characteristics suggest that the commercial orientation of the farmers may be doubtful. However, the average farm size of over 5 hectares is indicative that some of the producers may be gravitating towards commercial production.

Table 2.3: Age Distribution of Sample Yam Farmers

Age Range	Frequency	Percent
up to20	10	15.2
21-29	6	9.1
30-39	8	12.1
40-49	14	21.2
50-59	7	10.6
60 and above	21	31.8
Total	**66**	**100.0**

Source: Asuming-Brempong et al (2003).

Table 2.4: Educational Status of Sample Yam Farmers

Level	Frequency	Percent
No formal education	41	62.1
Primary	7	10.6
Middle school	12	18.2
Secondary school	3	4.5
Vocational school	2	3.0
Arabic school	1	1.5
Total	**66**	**100.0**

It is also evident from data collected by Asuming-Brempong et al (2003), that few exporters (only 15%) share common ethnic background with yam farmers, whereas over 65% of the yam traders share similar ethnicity with the farmers. Since ethnic ties appear to have played an important part in the development of linkages between traders and farmers, the commercial and economic benefits of any other arrangement has to be clearly demonstrated to attract participation by farmers. In this context, the desire by the Konkomba Yam Farmers and Exporters Association[28] to develop such a linkage may be worth further consideration.

Unlike Farmapine, most yam exporters have difficulty assuring farmers of a stable and remunerative market. This problem is due to their difficulty in securing firm forward contracts, partly as a result of the supply and quality uncertainty that characterises the yam export trade *(discussed in the preceding section)*. The Farmapine model illustrates how important it is for exporters, seeking to benefit from developing such linkages, to enhance their capacity to take delivery of produce contracted for. One such option, which may be considered but has not been explored to any significant extent by exporters, is that of developing alternative domestic distribution channels for export grade tubers.

[28] The Association brings together a group of farmers (based in the northern savannah and traders based in the Konkomba Yam Market in Accra). They share strong ethnic ties. The Association has only recently entered the export trade.

2.1.4 Examining economic basis for introducing improved handling, storage and shipping protocols in the yam export trade.

In the section we review the profitability of yam exports to the UK market and examine the case for introducing improved handling, storage and shipping protocols to reduce biological and economic losses, thereby improving the quality of exported yams.

2.1.4.1 Yam exports: is it really a goldmine undermined by drug dealers?

The perception is strong among yam exporters and traders that yam exports is a very lucrative business. The executives of one of the Exporters Associations[29] explained that they entered the export trade, after years of being mainly wholesalers, because they saw it as highly profitable. In the words of one of the exporters, yam export is “more than a goldmine”.

This perception seems to be based on the assumed high gross margins, defined here as the difference between wholesale prices in UK markets and local wholesale prices plus direct shipping costs. Based on data collected by Asuming-Brempong et al (2003), these margins exceed 75% of the domestic wholesale price. As a result a number of new exporters enter the trade, but many often fail leading a high turnover of participants in the export trade. The profitability of yam exports was therefore examined to provide some understanding of why some exporters fail.

The study employed marginal analysis in estimating the profitability yam exports. In the analysis exporter margins are estimated as the difference between the total revenue and total variable cost expressed as a percent of the value of the exports. Thus if TVC = total variable cost, TR = total revenue, then Exporter Gross Margin EGM is given by

$$EM = (TR - TVC) \times 100 / \text{total value of exports}$$

The total revenue is estimated as the gross earnings per 25kg box of yams. Due to difficulty in obtaining reliable data from both exporters and importers, the price per box paid to exporters was estimated using wholesale prices in the UK market[30], less an assumed importer margin of 12% of the wholesale price.

The total cost was calculated by summing up all relevant cost items including cost of tubers purchased, transport cost, material cost on packaging, casual labour for packaging, port charges, shipping and handling costs, and cost of freight. Data onadministrative cost and wages for permanent staff were not allocated. The cost thus captured is variable cost and the computed exporter margins cannot be regarded as profit. Also included are reject losses, which was based on estimates provided by exporters. Most export contracts allow for a maximum percentage rejects (due to rots), ranging between 3% and 10%. Any rejects over and above the agreed limit is counted as a cost to the exporter.

Based on historical data from MOFA on domestic wholesale prices and data on exporters’ operating costs collected by Jatoe and Tweneboah-Koduah (2003), the cost structure for exporters is as shown below:

[29] The Konkomba Yam Farmers and Exporters Association interviewed on 05/04/03.
[30] This is based on data collected by Otoo (2003).

Table 2.5: Estimated cost structure of Ghana Yam Exporters

Particulars	**October average (US $)**	**June average (US $)**
Wholesale price per 25kg box (Ghana)	4.52	9.35
Packaging materials	2.16	2.16
Labour	0.21	0.21
Local transport	0.57	0.57
Freight	1.80	1.80
Reject losses (external)[31]	1.10	1.65
Total variable cost	10.36	15.74

Source: MOFA and Jatoe and Tweneboah-Kodua (2003).

Table 2.6: Revenue and margins of Ghana Yam Exporters

Particulars	**October average (US $)**	**June average (US $)**
Wholesale price per 25kg box (UK)	12.40	21.70
Estimated price paid to exporter (25kg box)	11.07	19.38
Less total variable cost (Table 2.5)	10.36	15.74
Exporter gross margin (EGM)	0.71	3.64
EGM as percent of domestic price	15.7%	38.9%
EGM as percent of total variable cost	6.8%	23.1%

Source: Otoo (2003), MOFA and Jatoe and Tweneboah-Kodua (2003).

Margins are tight and strategic management is critical to business success

The above estimates indicate that yam exports are indeed profitable, the margins can be very tight, especially during the immediate post-harvest period (till about October when domestic prices bottom out). Risk of business failure, therefore appear to be quite high for exporters engaged in shipments during the immediate post-harvest period. This will particularly be the case for new entrants doing small volumes. For larger operators, the lower margins may be sufficient to keep them in the business till export market prices adjust upwards later.

It is also apparent from the above that the scope exporters have for increasing margins lie mainly in the following areas:

- Reducing costs of rejects at destination markets, implying the need for technical interventions and protocols that assure minimum spoilage during transit;
- Reducing the cost of yams - possibly through direct linkage with producers and/or stockpiling during the harvest season; and
- Timing shipments right, to avoid the period when a glut in the export market depresses prices and substantially squeeze margins. This may mean intra-season stockholding to assure supply of quality yams at stable prices.

Intra-season stockholding of yams appear financially feasible. Figure 2.2 shows that domestic wholesale prices have, during the latter part of the 1990s, risen by about 85% over the 7-month period of October to May. The cost of carrying the stocks over this period can be estimated – including the cost of storage (assumed to be about 2% of the value of the crop per month[32]) plus the financing

[31] It is assumed that the reject rate will rise by about 50% (the caveat here is that the estimate is not based on a scientific survey).

[32] No reliable estimates of storage costs for yams in Ghana has been sighted; but the estimate is based on storage costs for maize. Storage costs include rental for warehouse space, which is likely to be constant for both crops, and the services and inputs required to maintain the quality of the commodity.

cost[33]. Even using the rather high domestic interest rates, the total carrying cost is about 45% of the value of the commodity (in October). That leaves potential gross margins of about 42% from stockholding.

The economic incentives for stockholding therefore exist, what is required is to make information on its technical feasibility to entrepreneurs to encourage uptake. Similar analysis was expected to be undertaken for other technical interventions intended to prolong the shelf-life of yams, including curing. This could not be done because the technical investigations are not complete. However, so long as the cost of adopting any such technology is lower than the estimated reject costs, it can be said that the economic justification for adoption can be made.

Similarly, the use modern technology to detect internal rot and improve pre-shipment sorting can lower the cost of rejects[34]. It goes without saying, however, the cost of such a service has to be lower than current estimated reject losses.

[33] The interest rate used is the market interest rate compounded – about 45%, which is quite high.

[34] Rejects are not a problem in the domestic market because the tubers can be sold. However, in the UK market, it is not only difficult to sell partly rotten tubers but a high expense is incurred in disposing off rejects (the nominal figure is £5.00 per box of rotten yams, which could translate into $0.50 per box shipped if a reject rate of 10% is assumed).

2.2 Assessment/improvement of post-harvest and shipping protocols.

Further details can be obtained from Panni *et al.* (2002), Bancroft *et al.* (2002)

2.2.1. Effectiveness of grading at point of export

In February and March 2002 destructive assessments were carried out on yams at the point of export to determine how effective the grading process was. In February, samples of 'export grade' yams revealed 6% of all yams had evidence of some rots greater than 10% by weight of the tubers. Whereas in March the mean total weight of rots found in a sample of yams assessed to be of export quality (i.e. rot free) was 2.5% in comparison to the rejects with 19.10% rots. These results suggest that grading is reasonably effective, but improved methods would be very valuable (see Output 4).

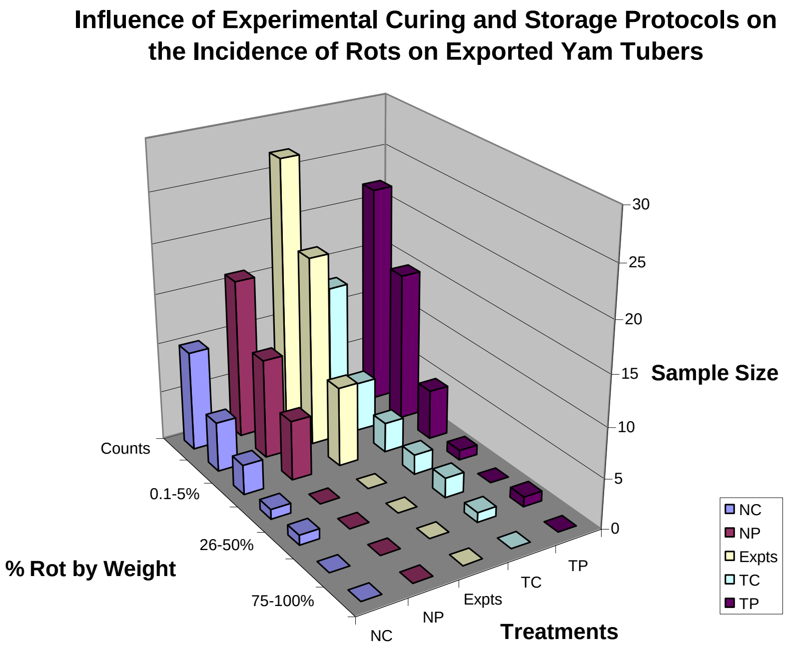
2.2.2 Export trials

The export trials included yams from the Handling and Storage trials described in Output 1, and yams selected from commercial consignments. In both cases care was taken to ensure that only yams showing no external signs of rotting prior to shipment were included in the trials. Despite this, assessments of yams on arrival in the UK indicated considerable rotting.

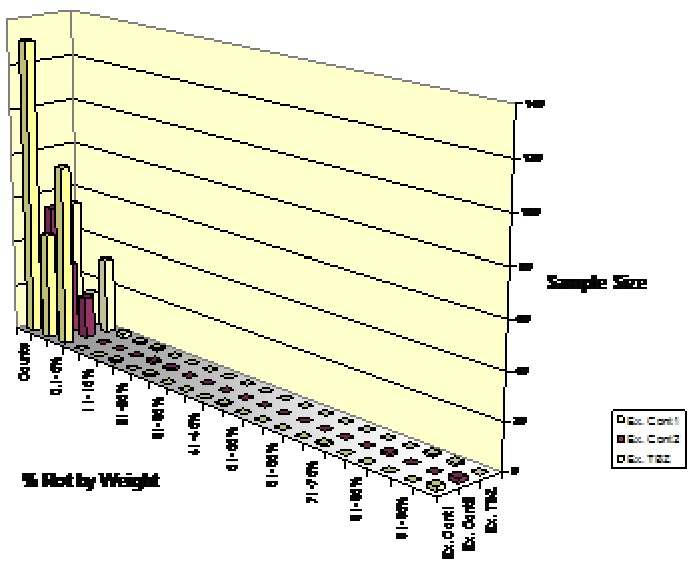
Data from the first year of export trials is summarised under Output 1, in Tables 1.4 and 1.5. In this case between 30 and 60% yams showed more than 10% rotting by weight for all the storage treatments, and the standard export yams. (The effect of different storage treatments is discussed in Output 1.)

The quality of the first export consignment in the third year of trials is shown in Figure 2.3a and b. It can be seen that in all cases more than 50% yams showed rotting. Similar results were obtained for the other export trials.

The poor quality of the yams is probably a result of inappropriate storage conditions on board ships. Figure 2.4 a and b, shows the readouts from temperature/humidity loggers sent with two of the export consignments. The first record is particularly bad, with temperatures rising to 30°C for several weeks, which would lead to high rates of metabolism and therefore deterioration, and then dropping to 10°C which would result in chilling damage to yams. The low humidities observed in this case would also encourage desiccation of the tubers. Although exporters appear to be unaware of the fact, shippers appear to carry out no active temperature control for the yams, and most the ships used, either would appear to have no facilities for temperature control or, alternatively, choose not to deploy the systems that they do have.



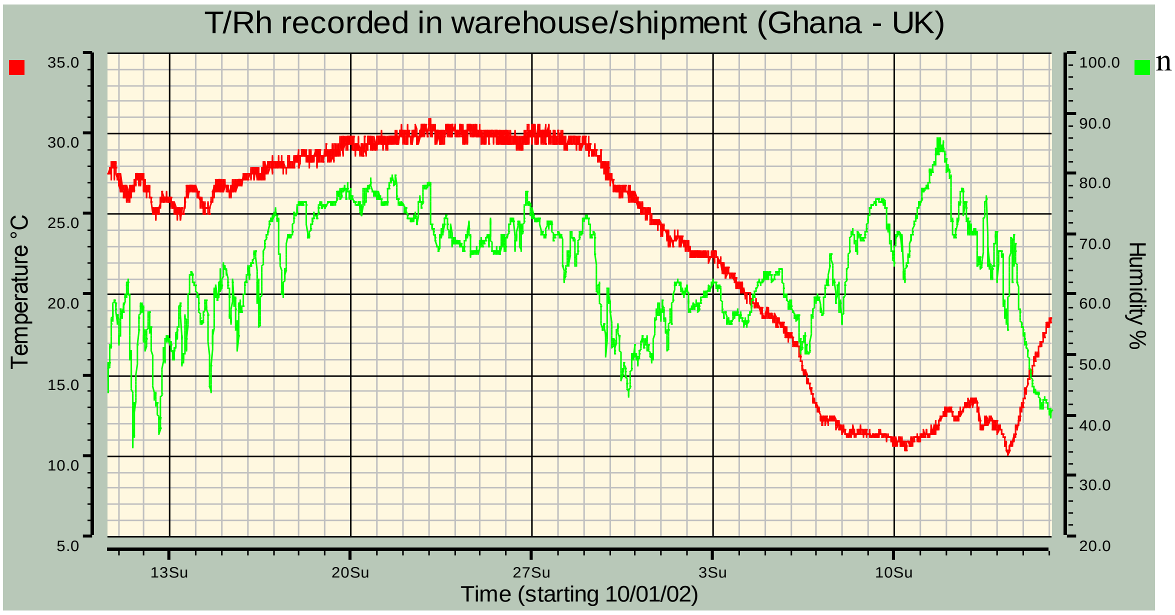
a)



b)

Figure 2.3 Levels of rotting in yams on arrival in the UK. a) Yams slected from Handling/storage trials. b) Yams from commercial export consignments. Ex cont1 and Ex cont 2 are from separate containers, while Ex/TBZ were treated with Thiabendazole immediately before export.

a)



b)

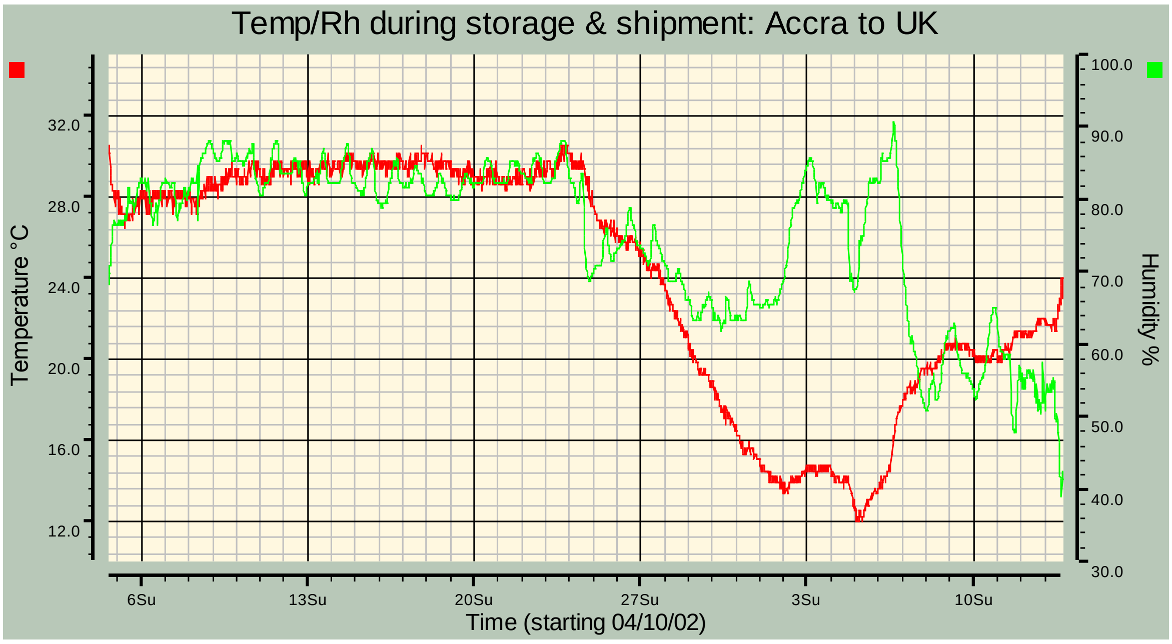


Figure 2.4 Temperature and humidity recorded during the export of yams during the second season.

2.3 Summary and discussion of key technical findings for Output 2

The quality of yams arriving in the UK after export from Ghana is poor, with high levels of rotting. Our observations suggest that the main reason for this is the inappropriate storage conditions to which yams are exposed during shipping. Shippers appear to carry out no active temperature control for the yams, and most the ships used, either would appear to have no facilities for temperature control or, alternatively, choose not to deploy the systems that they do have. In order to improve this situation, we believe that it is very important that exporters are aware of the optimum storage conditions for yams, and that they have an explicit agreement with the shippers to maintain these conditions. This is included in our "Recommendations for good practice for yam exporters" set out below.

There is still room for improvement of the quality of yams leaving Ghana. Although we found that the grading of tubers was reasonably good, it could be immediately improved if exporters took more note of levels/types of visible damage as well as visible signs of rotting (see Output 4). However, optimisation of export quality would very much benefit from the non-invasive grading methods as investigated in Output 4.

Excerpt from "Recommendations for good practice for yam exporters" (Still under development)

Grading at point of export
Discard all tubers that show any external signs of rotting, and also those which have external gashes. Clean cuts are less serious, as they can heal more rapidly.

Maintenance of good storage conditions during shipping
Ideal storage conditions for white yam tubers during shipping are as follows:
Temperature 15ºC - 20ºC
Humidity 80-95%.
Ensure that the shipping company responsible for your yams is aware of this, and has agreed with you to maintain these conditions. Ask the shipping company to show you the control systems that they use to maintain the environmental conditions within the hold.

Checking the storage conditions during shipping
To check that the correct storage conditions are maintained, and to help you to resolve any disputes, include temperature/humidity probes with each consignment of yams. Ideally you should include three probes with each consignment, so that if a probe malfunctions you can detect this. However, this may not be practical for financial reasons. If finances do not allow the purchase of temperature/humidity probes, the use of a probe that measures temperature alone would, nevertheless be very useful.
The probe(s) should be retrieved and checked by your agent in the UK, and then returned to you for subsequent shipments.

Output 3. Principal disease agents responsible for post-harvest loss in quality of yams identified, source of infections determined and counter measures verified.

Overview of Output 3

Objectively Verifiable Indicators
3.1 Disease organisms of significance and their source ranked by December 2002.
3.2 Disease counter measures verified by March 2003.

This Output has been successfully achieved, in that the main rotting pathogens both for seed yams and during yam storage and marketing have been identified. As it is believed that many infections in the field originate from the seed yams, the pracites relating to seed yam production and storage were considered in details. The main counter measures investigated are improvement of seed yam handling and curing and dipping with thiabendazole for the main crop. The latter two are both discussed within output 1.

3.1.1 Survey of practices relating to seed yam production and storage

Further details are given in Ametepe (2003).

Results obtained from the survey on see yam production and storage indicate that the only method of seed yam production practised by the farmers was the traditional method of pricking the first harvest. This method allows the formation of new but smaller tubers under the vine after two months and this reduced considerably the length of time needed to produce seed yams under the mini sett technique. Out of the thirty-six farmers interviewed, 84% obtained their seed yams from their own farms, 7% from other farmers and 10% from market traders in the yam markets at Atebubu, Kintampo and Techiman in Brong Ahafo Region. The quantity of seed yams produced by each farmer is however limited and does not allow for specialisation in seed yam production.

The majority, 72% of the farmers store their seed yams on the ground in heaps under shade trees. Each heap of seed yams is then covered with dried yam vines or dried palm leaves. 16.7% stored their seed yams in farm huts built with dried millet stalks. 6% kept their seed yams in thatch huts built on their farms. These huts had only a side opened. The storage of seed yams in the thatch roofs of farmers' houses was practised only by 6% of the interviewees.

More than half of the farmers interviewed, 53%, store their seed yams up to 90 days before planting them and the rest, 47%, keep them up to 30 days. Seed yams were stored to break tuber dormancy and also to allow farmers to clear their new fields and prepare mounds. The use of pesticides in yam production and treatment in storage is practically non-existent.

Farmers reported high losses of seed yams during storage, due to a variety of reasons. Termite infestation was mentioned by 40% of the farmers as being responsible for deterioration in seed yams. Damage caused by mice to seed yams was mentioned by 30% of the respondents, whilst 17% attributed seed yam deterioration to rots. Nematode galls (rough skin) caused by nematode infection was described by 13% of the farmers as responsible for seed yam deterioration. The extent of rotting losses recorded by farmers is given in Table 3.1.

Table 3.1.Annual percentage of seed yam rotting recorded by farmers in Brong Ahafo Region.

Number of seed yams inspected.	Rots (%).	Percentage respondents involved.
100 seed yams.	1 – 5	2.6
100 seed yams.	6 – 10	36.2
100 seed yams.	11 –15	27.7
100 seed yams.	>15	33.5

3.1.2 Idenfication of pests and diseases and assessment of variety effect on quality of seed yams

Seed yam tubers are infested with many organisms in the field and handling practices expose the tubers to rot diseases during storage. The study revealed that 19% of the seed yams were infested by mealy bugs with the infestation as high as 70 mealy bugs per tuber, 42% of all the seed yams examined were infested with termite, 24% were partially eaten by rodent and 52% of all the tubers examined had rots. Nematode galls were found in 24% of all the seed yams. The dominant infection courts for rot causing pathogens were the superficial bruises and cuts that were sustained by the seed yams at harvest.
The frequency of occurrence of rotting pathogens is shown in Table 3.2.

Table 3.2 Frequency of occurrence of rot causing pathogens in partially rotten seed yams of Lili and Pona in Brong Ahafo Region

Micro-organisms	Lili	Pona	Mean*
Aspergillus flavus	19.9[a]	8.3[a]	13.7
Aspergillus niger	6.8	8.3	7.6
Asperg*illus ochraceous*	1.2	1.7	1.5
Botryodiplodia theobromae	3.7	6.6	5.3
Fusarium oxysporum	5.1	5.5	5.3
Fusarium sp.1	0.0	2.8	1.5
Fusarium sp.2	8.7	10.5	9.6
Fusarium verticilloides	20.5	8.8	14.3
Penicillium brevi-compactum	1.9	4.4	3.2
Penicillium citrinum	13.0	8.3	10.5
Penicillium sp.	8.7	3.3	5.8
Rhizopus stolonifer	9.3	26.0	18.1
Pseudomonas 1	1.2	0.0	0.7
Pseudomonas 2	0.0	5.5	2.9
Mean	11.5*	12.9*	

[a] Figures represent frequency of occurrence given as a percentage of the total isolations.
*Figures represent mean frequency of occurrence.

3.1.3 Effect of traditional storage systems on quality of seed yams of two white yam varieties (Lili and Pona).

In this trial, both the effect of different storage systems, and variety on seed yam quality were investigated.

A high level of rotting was observed in seed yams during this trial. More than 60% tubers had rots after 60 days of storage (Figure 3.1). No significant difference in rotting was seen between the two varieties, despite the fact that in trials presented in Output 1 milk yams of variety Lili were found to be more resistant to rots. However, assessment of the level of bruising for the two varieties (Figure 3.2) suggested that farmers handled Pona much more carefully. If this is the reason why Pona is not showing its expect high susceptibility to rots, it indicates the importance of careful handling.

Twelve fungal species, two bacteria and a nematode were consistently isolated from 900 seed yams stored under four storage methods at six locations from November 2000 to April 2001. The twelve fungal species were *Aspergillus flavus* Link., *Aspergillus niger* van Tieghem., *Aspergillus ochraceous* Wilhelm., *Botryodiplodia theobromae* Pat., *Fusarium oxysporum* Schlechtend., *Fusarium verticilloides* (Sacc) Nirenb., *Fusarium sp.1*, *Fusarium sp.2*, *Penicillium brevi-compactum* Dierckx., *Penicillium citrinum*, *Penicillium sp.*, and *Rhizopus stolonifer* (Ehrenb.: Fr.) Lind. Their frequency of occurrence in the four storage methods are summarised in Table 3.3.

Table 3.3 Frequency of occurrence of rot causing pathogens in seed yams stored under four traditional storage-systems, in Brong Ahafo Region.

Micro-organism	System 1	System 2	System 3	System 4	Mean
Aspergillus flavus.†	0.0[a]	14.6[a]	15.1	7.4[a]	9.3*
Aspergillus niger.†	0.0	10.4	6.0	22.2	9.7
Aspergillus ochraceous.†	0.0	6.3	0.8	0.0	1.8
Botryodiplodia theobromae†	0.0	0.0	7.1	0.0	1.8
Fusarium oxysporum	0.0	12.5	4.8	0.0	4.3
Fusarium sp.1	0.0	0.0	2.0	0.0	0.5
Fusarium sp.2 †	20.0	12.5	6.3	29.6	17.1
Fusarium verticilloides	20.0	12.5	15.9	0.0	12.1
Penicillium brevi-compactum	0.0	0.0	4.3	0.0	1.1
Penicillium citrinum	40.0	6.3	10.7	0.0	14.3
Penicillium sp.	0.0	0.0	7.9	0.0	2.0
Rhizopus stolonifer †	0.0	20.8	16.3	40.7	19.5
Pseudomonas 1	0.0	0.0	0.0	0.0	1.0
Pseudomonas 2	20.0	4.1	2.8	0.0	5.7

System 1: storage in thatch farm huts with one side opened.
System 2: storage in dried millet stalk farm hut.
System 3: storage in heap under shade trees covered with dried palm leaves.
System 4: storage in the thatch roof of farmer's house.
[a] Figures represent frequency of occurrence given as a percentage of the total isolations.
† Isolated from air in traditional storage systems.

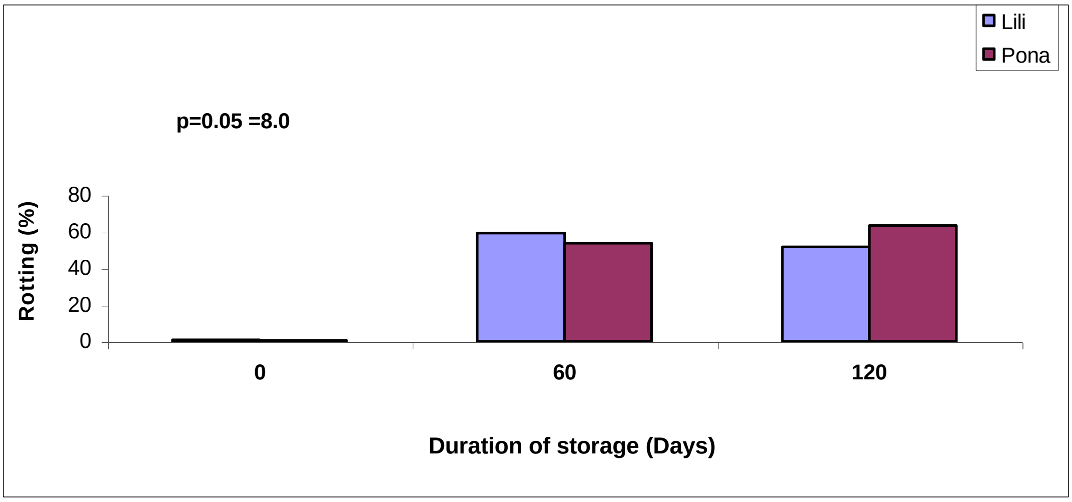


Figure 3.1 The percentage of seed yams of Lili and Pona with rots after 60 days of storage

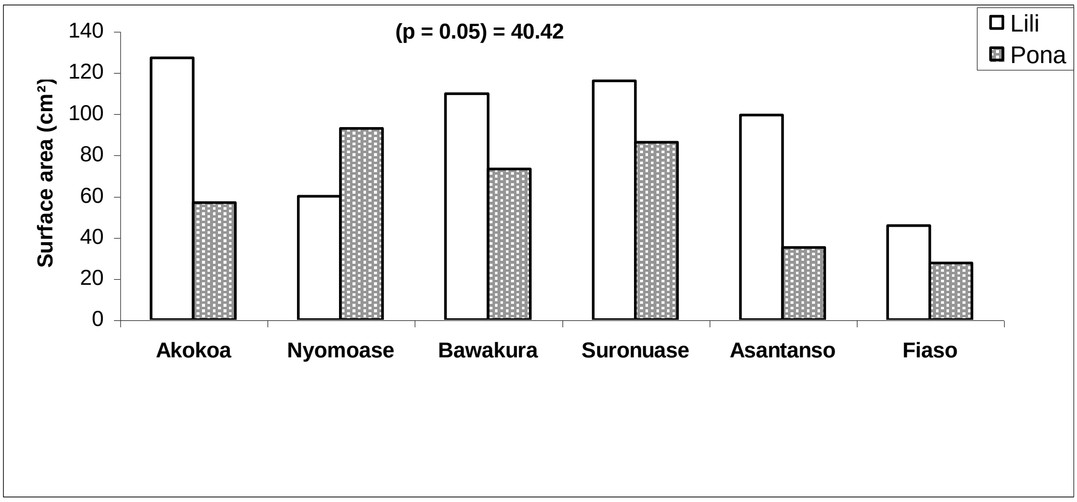


Figure 3.2 Levels of bruising observed in varieties Pona and Lili.

A certain amount of information can be obtained about the behaviour of a pathogen, depending on its location and on the pattern of infection.

For example, *Aspergillus flavus*, which was the third most frequently, encountered fungus during the study was isolated from all parts (the proximal, lateral and distal sections) of seed yams of Lili and Pona. It was also isolated from the air in dried millet stalk farm hut, thatch roof of farmer's house and from seed yams stored in heap under shade trees covered with dried palm leaves. It was further isolated from soil samples but not from thatch farm hut with one side opened. The non isolation of this fungus from the atmosphere in thatch farm hut with one side opened suggest that the pathogen may also be soil borne and that the spores were present on the seed yams before they were stored.

Aspergillus niger was usually isolated from the lateral and distal sections of seed yams, dried millet stalk farm hut, thatch roof of farmer's house and in seed yams stored in heap under shade trees covered with dried palm leaves at Nyomoase, Bawakura, Suronuase, Asantanso and Fiaso. It was however not isolated from the proximal section of seed yams, thatch farm hut with one side opened and at Akokoa. It was also not found in soil samples. It implies that the fungus was not soil borne and occurs in the atmosphere in the storage systems.

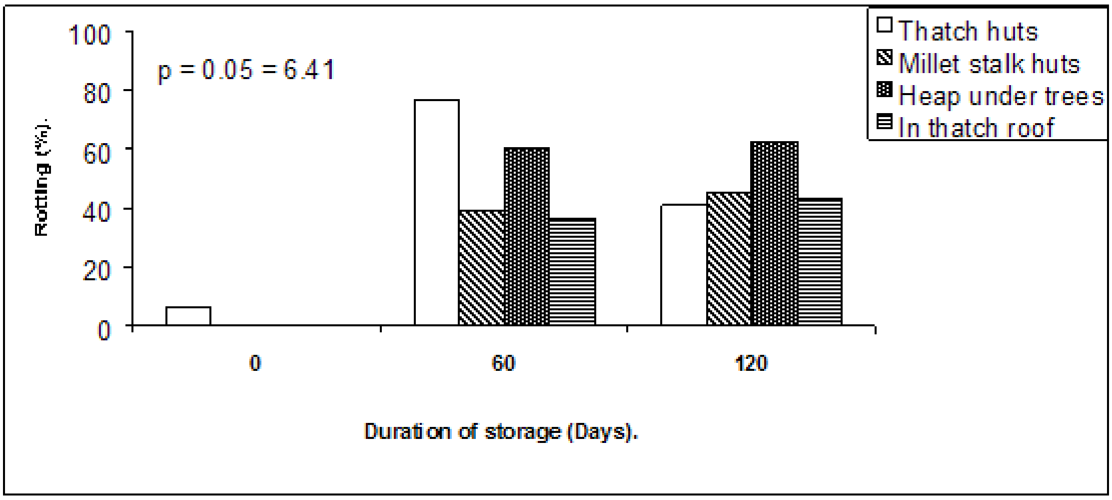


Figure 3.3 Incidence of external rots in seed yams stored in four storage systems in Brong Ahafo Region.

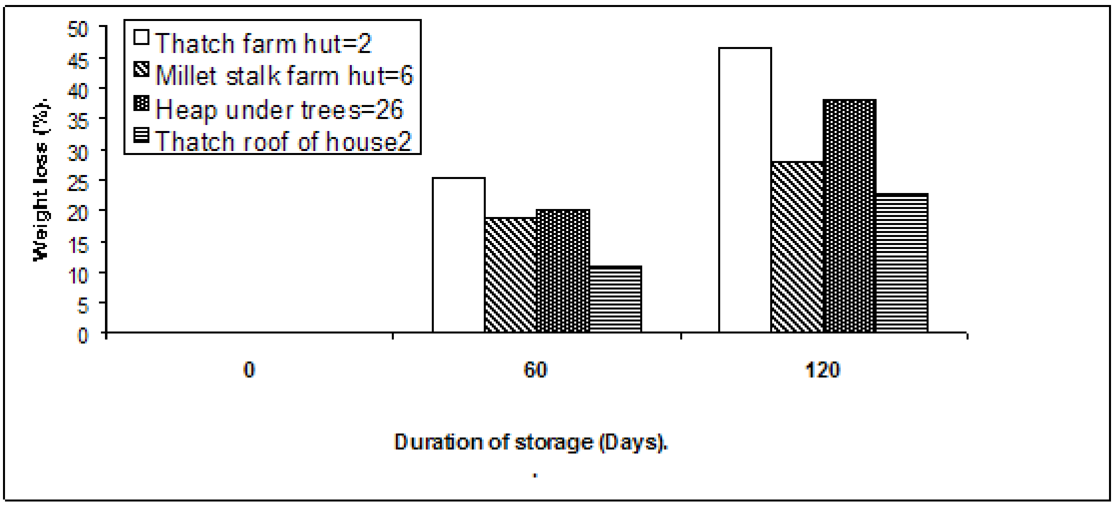


Figure 3.4 Fresh weight loss in seed yams stored in four storage systems in Brong Ahafo Regions

Figures 3.3 and 3.4 show the effect of storage method on rotting and yam weight loss. The two methods which show consistently better results for both parameters are storage in dried millet stalk farm huts, and storage in the thatch roof of the farmer's house. The most common method is to store as a heap under the trees, but this method promotes both high rotting and high weight loss.

The greatest cause of losses recorded by farmers (section 3.1.1) was termites. Figure 3.5 indicates that storage in dried millet stalk farm huts leads to very high termite losses, whereas both thatched farm huts (open on one side) and thatched roof storage show consistently low damage.

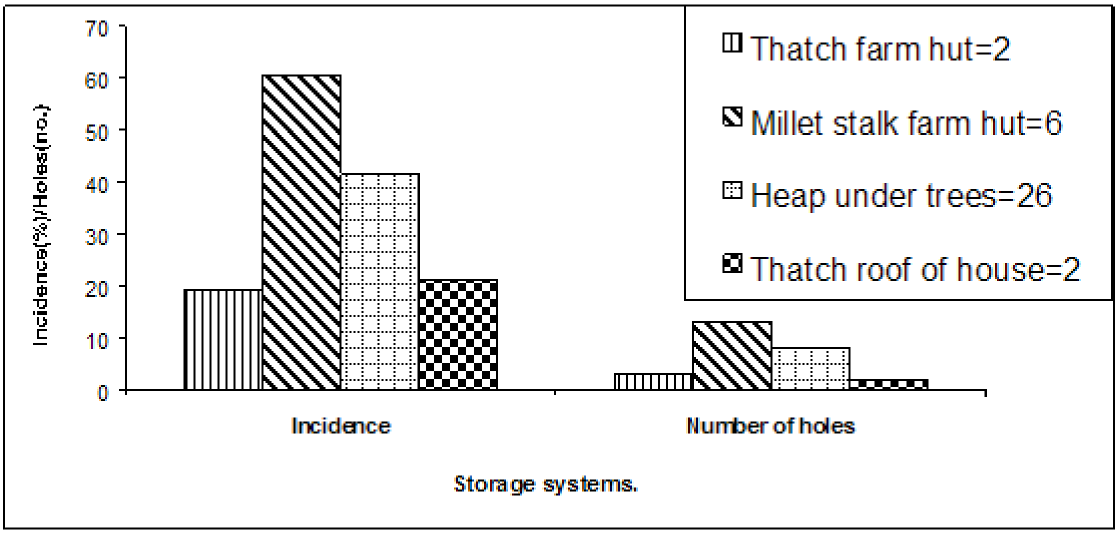


Figure 3.5 Termite infestation on seed yams stored in four storage systems.

Very high levels of mealy bug survival was observed after 120 days storage, which is an indication that these seed yams could become possible sources of infestation in new yam fields.

In summary, seed yams were most frequently stored in heaps under shade trees covered with dried palm leaves. This method leads to high losses, and probably predisposed the seed yams to physiological damage resulting from accumulated heat within the heap accentuated by their direct exposure to direct sunlight. It also predisposed the seed yams to damage by field mice, termites, rotting and weight loss.

Overall the best method observed was the thatched roof of a house. However, it should be noted that the number of examples of this form of storage was very low, so that the results would need to be confirmed.

3.2 Incidence of major rot pathogens that compromise the quality of yams in selected markets in Accra

Further information is given in Aboagye-Nuamah, Oduro and Offei (2003)

In order to identify the most important rotting pathogens during marketing of yams in Ghana, samples were taken from three markets (Figures 3.6-3.8). These were compared with samples from a storage barn (Figure 3.9).

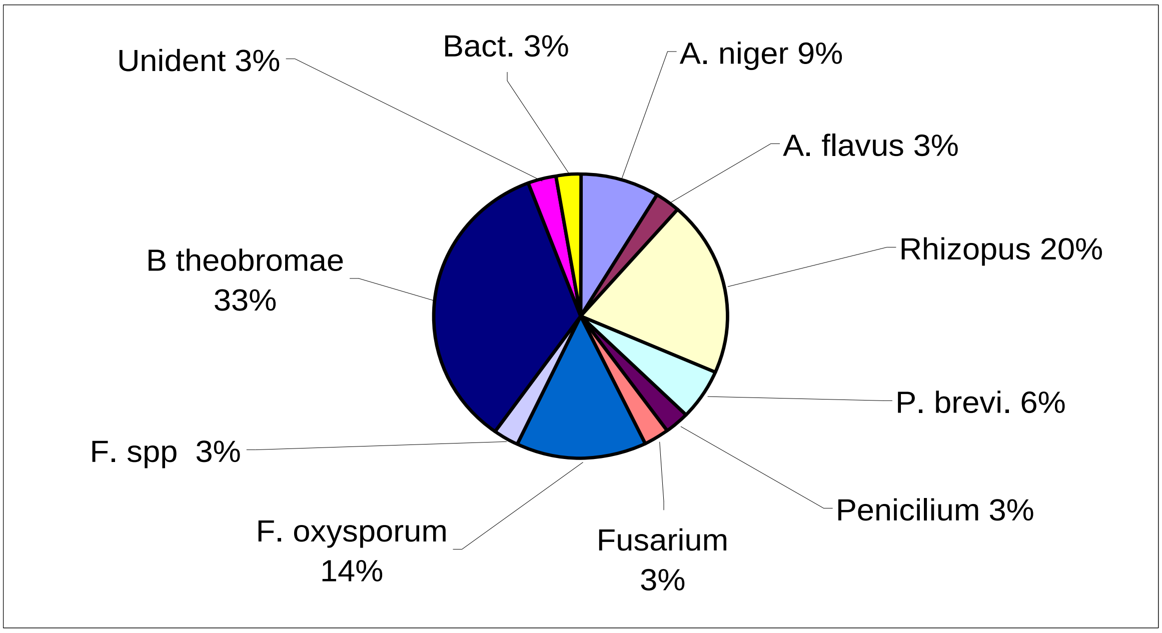


Figure 3.6 Incidence of pathogens isolated from samples taken in Accra market

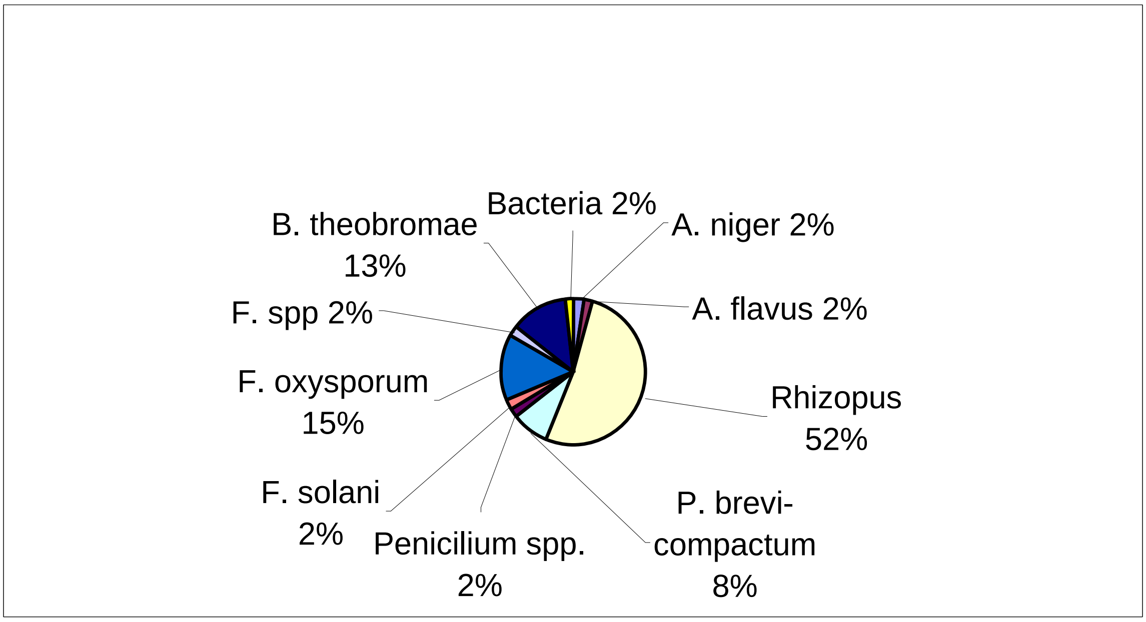


Figure 3.7 Incidence of pathogens isolated from samples taken in Kokomba market.

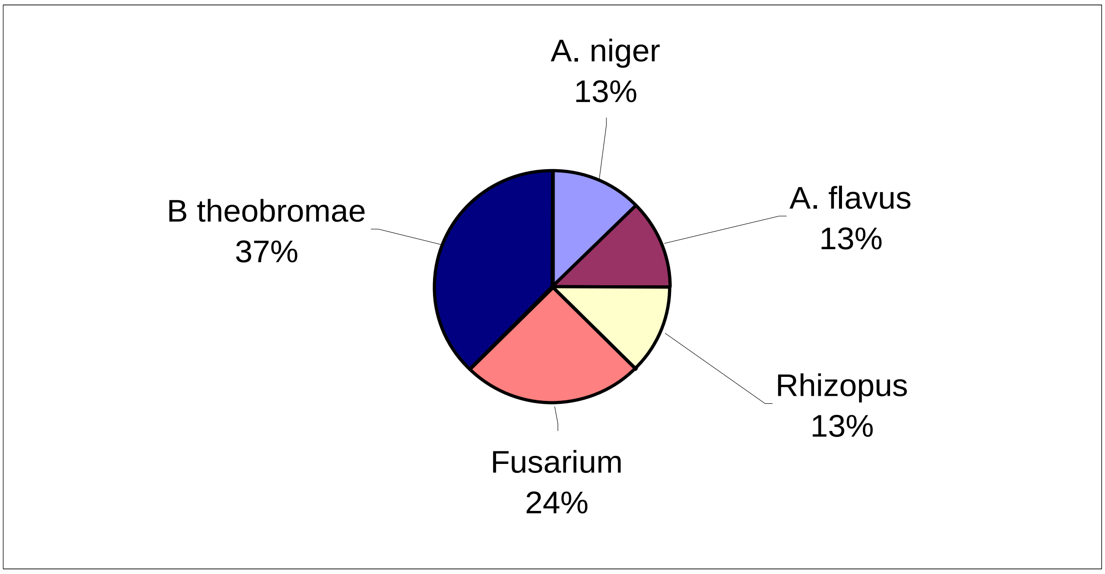


Figure 3.8 Incidence of pathogens isolated from samples taken in Madina market.

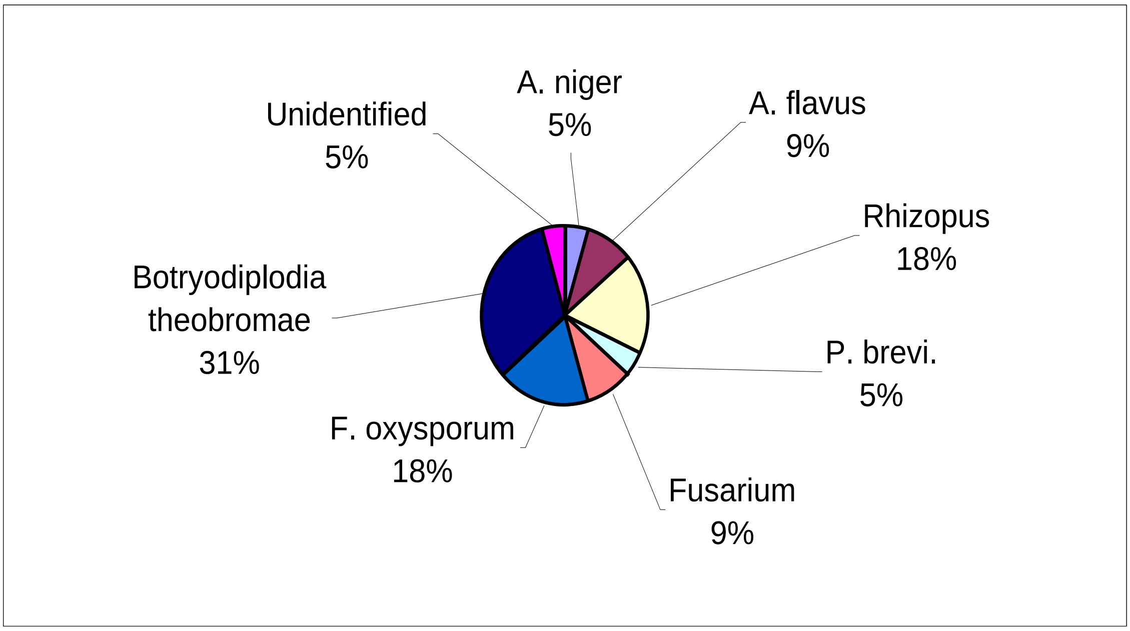


Figure 3.9 Incidence of pathogens isolated from samples taken in a yam barn at Legon.

The results present a fairly consistent picture. There are three pathogens which are among the most common in all three markets and in the yam barn. These are Botryodiploidia theobromae, Rhizopus spp. And Fusarium Oxysporum.

3.3 Association between tuber damage and rot causing organisms on the incidence of rots among two varieties of white yam (*Dioscorea rotundata* Poir *var. Pona and Onumo*)
Further information is given in Aboagye-Nuamah and Offei (2003).

This study was conducted primarily to determine the effect of tuber damage on susceptibility to rotting, and to determine which rotting pathogens were particularly associated with the different forms of damage. Two varieties, Pona and Onumo were used in the study. As has been noted previously, Pona is much more susceptible to rots (Figure 3.10)

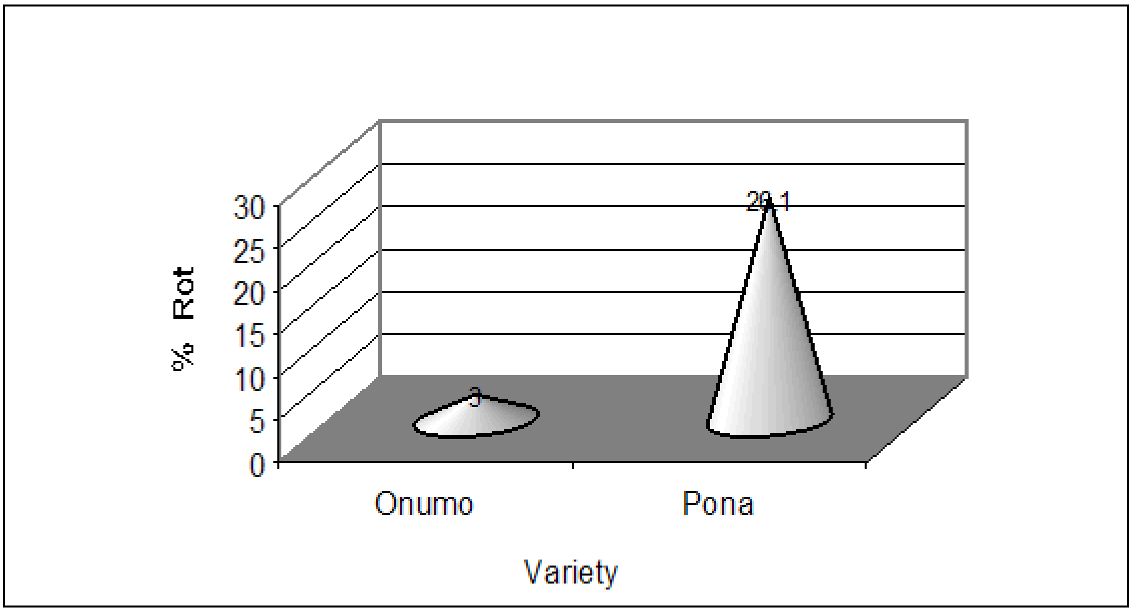


Figure 3.10 the incidence of rots in yam tubers of two varieties.

As Onumo is so resistant to rots, no significant effect of damage was seen on the level of rotting. For Pona, however, damage had a very important effect as illustrated in Figure 3.11.

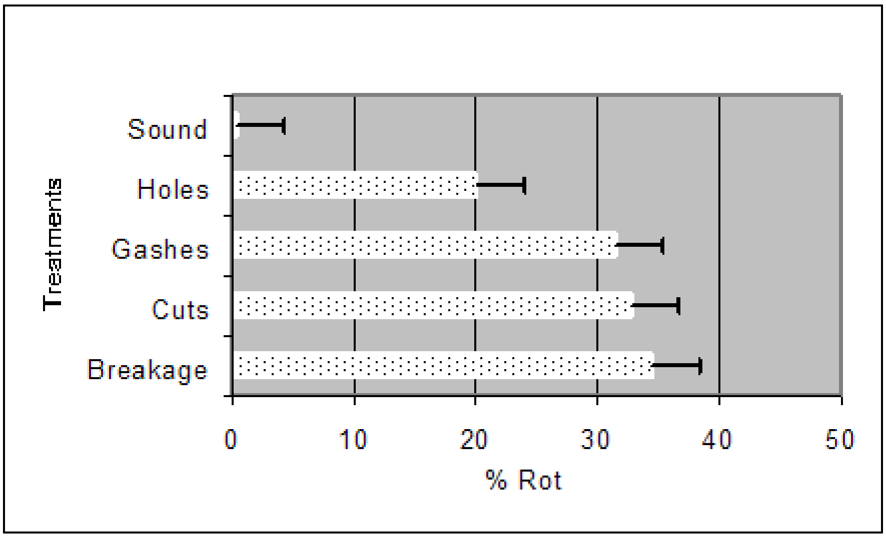


Figure 3.11 The effect of tuber damage on levels of rotting during storage.

Insect holes appear to be associated with slightly less rotting than gashes cuts and breakages. This may be because the tubers produce toxic compounds (phytoalexins) as a response to insect attack, and that these inhibit fungal growth.

Seven micro-organisms were isolated from the wounded yams. These included *Aspergillus niger, A. flavus,* Bacterium, *Botryodiplodia theobromae, Fusarium solani,, Penicillium brevi-compactum* and *Rhizopus stolonifer.* The occurrence of these organisms as influenced by the various types of tuber damage is presented in table 3.4.

Table 3.4: Mean % incidence of Organisms as influenced by the forms of tuber damage

Damage form	*A. flavus*	*A. niger*	Bacteria	*B. theobrmae*	*Fusarium*	*Penicilium*	*Rhizopus*
Breakage	6.5a	29.2	6.9	0.0a	1.9	24.1ab	24.7
Cuts	3.6a	19.0	13.9	7.29b	14.2	26.4b	13.3
Gashes	19.4b	53.2	6.8	1.92a	10.3	18.6ab	2.3
Holes	0.0a	18.7	9.1	0.0a	0.0	0.0a	12.5
Sound	0.0a	27.4 NS	0.0 NS	0.0a	16.6 NS	0.0a	4.2 NS

NS = No significant difference between the means in the column
Means with common letters in a column are not significantly different from each other.

Aspergillus niger, A. flavus, Botryodiplodia theobromae, Fusarium solani,, Penicillium brevi-compactum and *Rhizopus stolonifer* have been found by many authors to be associated with post-harvest rots of yams. In this studiy *Rhizopus stolonifer and Aspergillus niger* were isolated from rots coming from all the various kinds of wounds whilst *Botryodiplodia theobromae* was isolated from rots associated with only cuts and gashes. The results suggest significant differences in the incidence of some pathogens among the various types of tuber damage. This observation however does not follow a particular trend for easy interpretation.

Rhizopus stolonifer, which was the most frequently observed species in the genus, has been considered as a saprophyte in the post harvest decay of yam. Thus although *R. stolonifer* was isolated from most of the rots, it shows the least ability to cause rot. The potential of *R. stolonifer* to cause rot increases in combination with other fungi such as *F. oxysporium,* and *F. solani.* No correlation was, however, observed in this study between the occurrence of the various pathogens isolated from the rotten tissues. *Botryodiplodia theobromae* which was recorded in only two types of wounds in the present study has been reported to be a major cause of decay of yams in West Africa. Identification of the bacterium was not done to genus and species level. However, the bacterium, which has been found to be associated with yam decay, is *Erwinia spp.*

Two species of *Aspergillus - Aspergillus niger and A. flavus* were identified to be associated with some of the rots. In common with other authors, these two species have been identified to be agents causing yam decay (Cornelius, 1998; Noon and Colhoun, 1979). *A. niger* which recorded the highest incidence among the other organisms in this research have been found to be a serious rot causing organism of yam tubers, and is the most widely reported and important within the genera (Ogundana *et al.,* 1970; Adeniji, 1970a). *Penicillium* sp. was isolated only on tubers with wounds (cuts, gashes and breakage) in the present study. This confirms the report that the organism is a wound pathogen and have been found to be a serious pathogen of yam (Adeniji, 1970a; Noon and Calhoun, 1981; Rucci *et al.,* 1979).

3.4 Identification of rots from the first year of storage trials.
Further information is given in Cornelius (???)

Pathogens isolated during the first year of Handling/storage trials are shown in Figure 3.12, while their distribution between different storage treatments are shown in Figure 3.13.

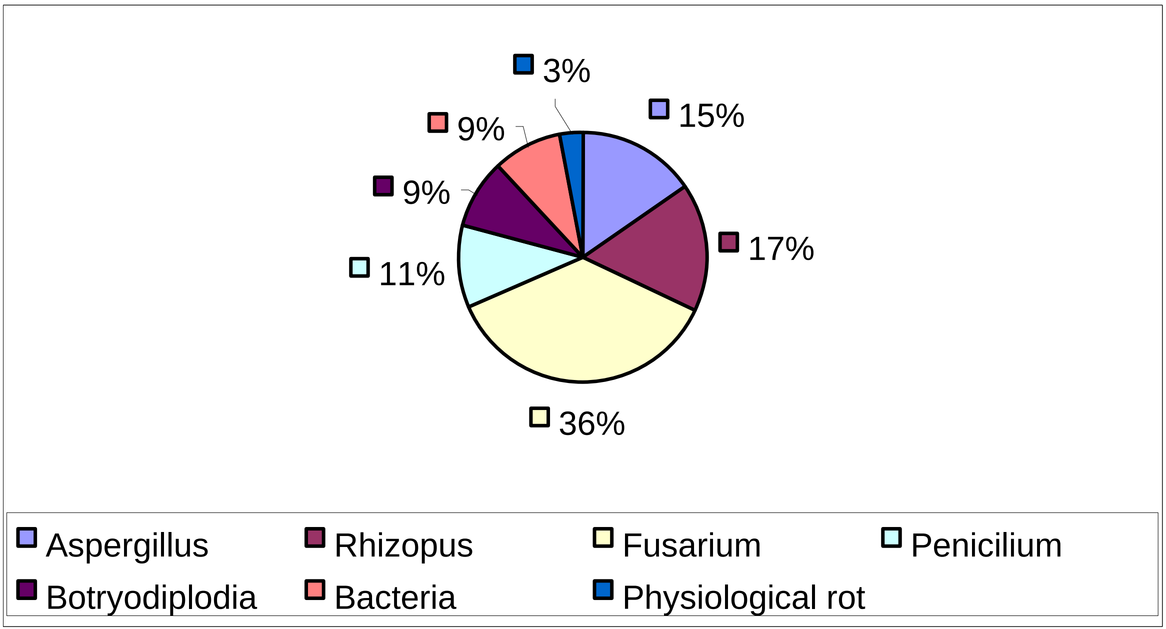


Figure 3.12 The frequency of pathogens isolated from tubers included in the Handling/Storage trials of year 1.

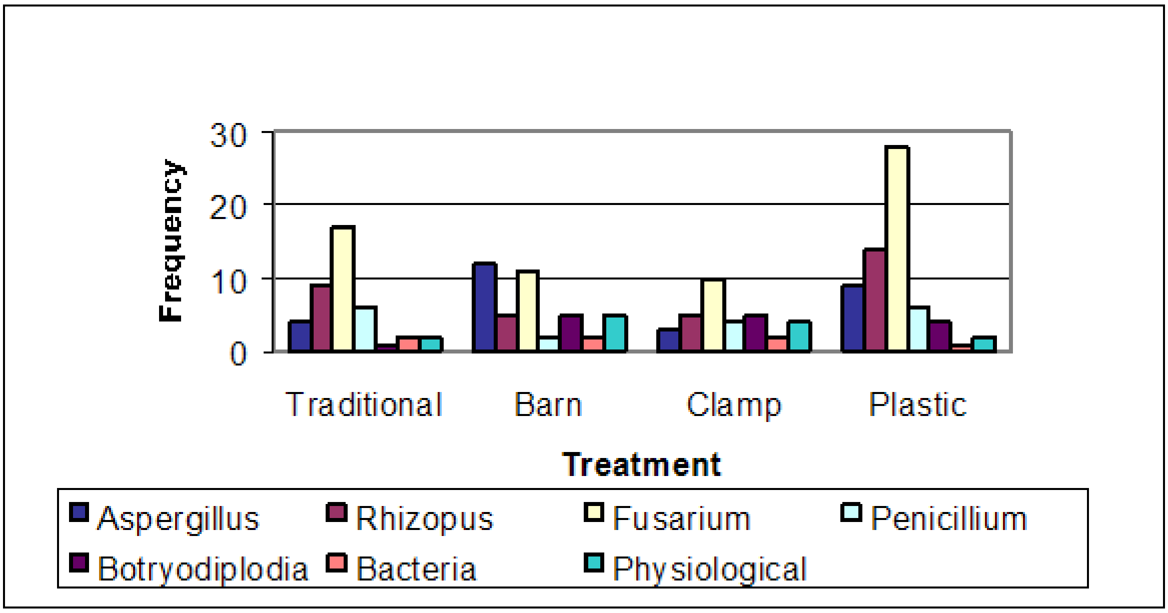


Figure 3.13 The frequency of pathogens isolated from tubers stored in four treatments in the Handling/Storage trials of year 1.

Essentially the same pattern of pathogens was observed as in the markets (Outputs 3.2).

3.5 Summary and discussion of key findings for Output 3

The incidence of rots in yams was studied both in the markets, and during storage trials. The most common organisms identified in the two cases was essentially the same (including *Aspergillus flavus, A. niger, Botryodiplodia theobromae, Bacterium spp., Fusarium oxysporum, F. culmorum, Fusarium spp, Penicillium brevi-compactum, Penicillium spp.* and *Rhizopus stolonifer*.). Not unexpectedly it was found that damage, especially breaks cuts and gashes greatly increased the incidence of rots. Rots tend to be located towards the head of the tuber.

One theory is that infections originate from the seed yam in the field. This was supported by the findings of a survey of seed yam storage conducted in Brong Ahafo. Seed yams were stored for one to three months, almost always with no fungicidal treatment. Isolations from 900 seed yam tubers revealed that mealy bugs infestation can be as high as 70 per tuber, termite infestation affected 36% of all tubers examined, 24% were partially eaten by rodent and 60% of all the tubers examined had rots. The direct transfer of pathogens from seed yam to ware yam still needs to be conclusively confirmed, but nevertheless there is strong evidence that practices to improve seed yam sanitation would be beneficial to ware yam quality.

The main practice considered within this project to reduce infections are improved handling/storage of seed yams, curing and treatment with thiabendazole. The latter two are discussed under Output 1. Despite the fact that the conditions had not been optimised, during trials in 2001/2 curing significantly reduced rotting in Barn stored milk yams (5.8% compared to 9.1%). Towards to the end of the project, when it became clear that the fungicide Thiabendazole was to be approved for yam importation to Europe, the dipping of tuber heads was tested, but at this time the results are ambiguous.

With respect to handling/storage of seed yams, the data produced in Outputs 3.1.3, comparing Pona and Lili clearly show that more careful handling can reduce the extent of rotting. This is true for both seed yams and the main crop, as underlined by the effect of damage on rotting (Figure 3.11). Of the four storage methods for seed yam investigated, storage in a thatched roof appears to best for many criteria (rotting, weight loss, termite damage). However, given the small number of farmers presently using this method, this result needs to be confirmed.

Output 4: Grading protocols capable of identifying and excluding chronic quality defects in yam investigated and tested.

Overview of Output 4

Objectively Verifiable Indicators
4.1 Feasibility of electronic sensor techniques assessed by March 2001
4.2 Available techniques reviewed and recommendations developed by March 2003.

The work on this Output has focused on the use of gas sensor array (GSA) technology to detect internal rots within yam tubers. The Output has been moderately successful in that we have found that GSA technology has potential to be useful. No other more suitable technology has been identified. However, although extensive work has been conducted to develop the instrument into a practical version, work is still on-going and will continue after the termination of this project.

4.1 Comparing methods for non-destructive visual assessment and destructive assessment for grading yams for levels of rot.

4.1.1 To determine the most efficient destructive methods for assessing yam quality so that these could be used where destructive sampling of yams is practical.

The rot within a yam tuber can be assessed by cutting the yam into portions, cutting out the rotten parts, weighing them and calculating the percentage of the total weight. This is very time consuming. Several more rapid methods for assessment of rotting in yams were tested. Figures 4.1 and 4.2 summarise the results obtained for two of these. In the first case, the rot in the head 1/8 section of the tuber was compared to the total % weight of rot. In the second case the % weight of rot in a central strip of the tubers was compared to the total % weight of rot. In the latter case we were simulating a situation where the yam might be cut along its length, and the % rot assessed visually.

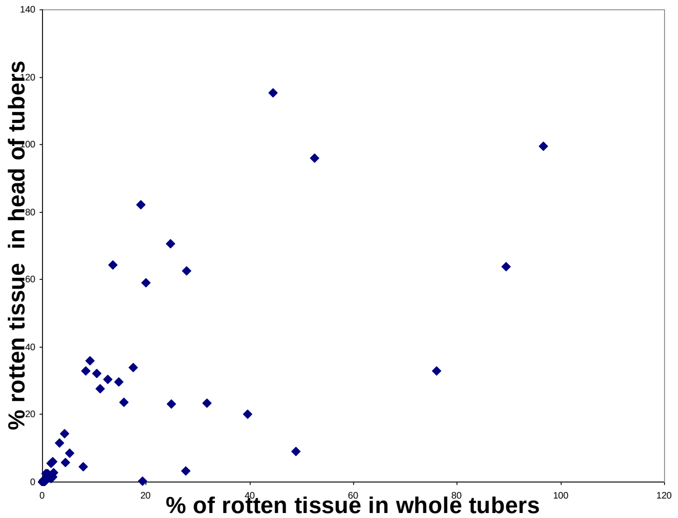


Figure 4.1 the relationship between rot in the tuber head, and % weight rot in the whole tuber.

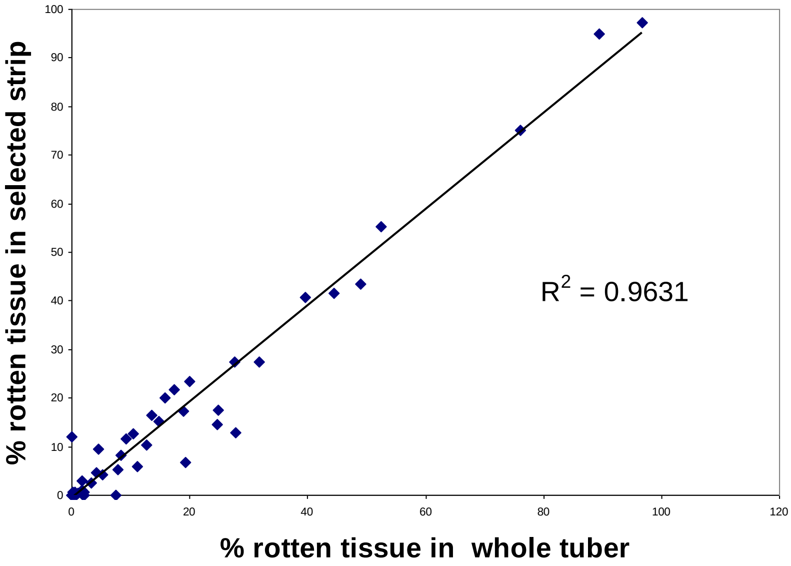


Figure 4.2 Relationship between % weight rot in a central longitudinal strip and % weight total rot

The assumption is that methods such as these would be used to assess a sample of yams in order to check the quality of yam consignments for export. It is therefore important to determine how accurate these methods would be to determine whether a tuber is acceptable or not acceptable. On the random assumption that the cut-off for acceptability might be 10% rot, we can check the success rate of each method. The way in which this was done in this trial is illustrated in figure 4.3. The percentage of rot in the tuber head taken to indicate greater than 10% rot in the whole tuber (i.e. that the tuber was unacceptable) was varied, and for each value the number of tubers correctly and incorrectly defined was counted. If the cut-off point was taken to be 20% rot in the head, then 90% tubers were correctly defined.

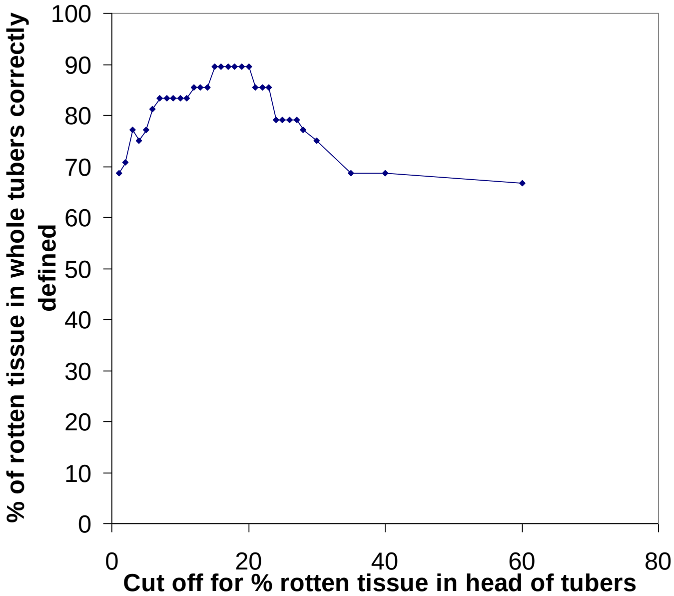


Figure 4.3 Success rate for assessment of tuber quality using rot within the head.

Assessment of total rotting using a longitudinal strip was more accurate, giving an accuaracy of 93%.

4.1.2. To determine the best methods for non-destructive visual assessment of yams, and their accuracy.

Assessment of yam rotting by observation of the externally visible rotting was found to be extremely inaccurate, and in fact only very slightly better than completely random. 52% yams could be correctly defined. However, if yams were assessed also in terms of externally visible damage, a much better assessment could be made. Multiple linear regression modelling of internal rotting in terms of externally visible parameters gave a best model %wt rot=8.64+0.83%visible rot+7.17%gashes. Figure 4.4 shows this model value for each tuber plotted against the actual measured % weight rot. 73% tubers could be correctly defined.

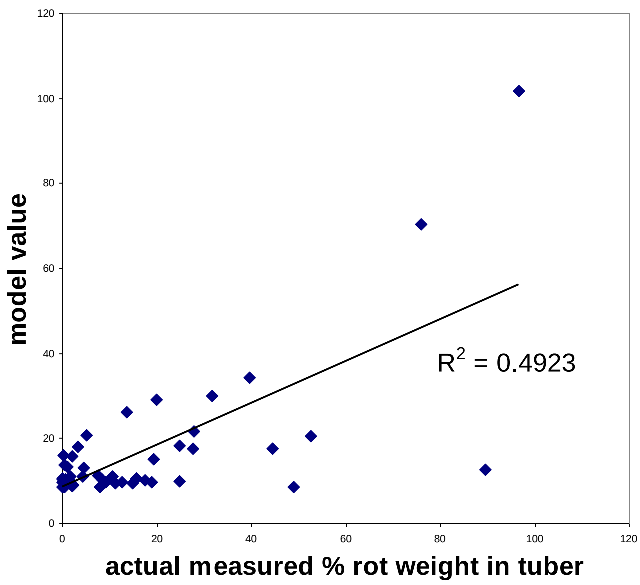


Figure 4.4 The relationship between the predictive model for internal rotting and actual measured rot for 50 yam tubers.

4.2 To determine the practicality of using sensory arrays to grade yams.

4.2.2 Preliminary evaluation of the ability of a gas sensor array to detect internal rotting in yam tubers.

In the first experiment a comparison was made between a sound tuber, an artificially damaged tuber, and one suspected of containing internal rots. The latter tuber was subsequently found to have 8% rotting internally. The sensor responses obtained are shown in Figures 4.6 and 4.7.

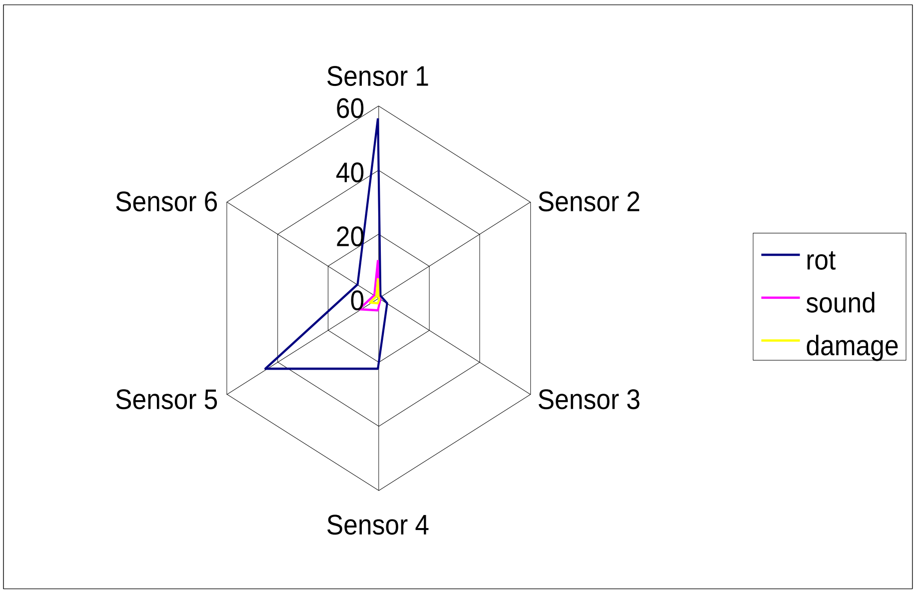


Figure 4.6 A radar plot of maximum sensor response to aroma volatiles from a sound, damaged and internally infected tuber. The values are means of five replicates.

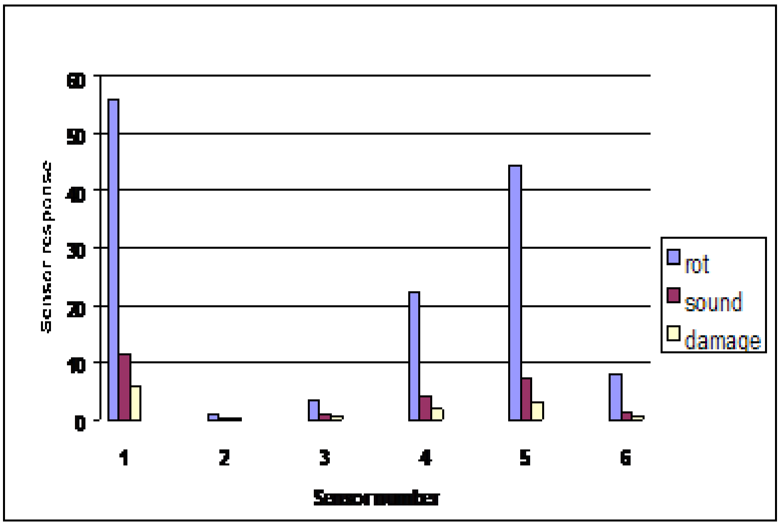


Figure 4.7 Maximum responses of six metal oxide sensors to aroma volatiles derived from sound, damaged and internally infected yam tubers. The values are means of five replicates. Vertical bars represent LSDs at P ≤ 0.05

Using disciminant function analysis for pattern recognition, the canonical variables for the yam analysis shows that at 95% tolerance ,the canonical variate No 2 can discriminate between rotten yam on one hand and sound and damaged yam on another with one borderline decision. Deploying canonical variate No 1 suggests that this analysis is able to discriminate between the sound and damaged tuber.

4.2.3 Evaluation of gas sensor array for discriminating between varieties of white yam

The weights and volumes of the tubers used for the study are shown in Table 4.2. The tubers were stored at 22.5 °C and 44%RH.

Table 4.2. Weights of individual tubers and description of internal rots of three white yam (*D. rotundata*) varieties

Variety of tuber	Weight of tuber (kg)	Weight of rot in tuber(g)	Description of internal tuber tissue
Lily	1.160	0.0	sound
Lily	1.063	13.3	slight traces of dry rot under tuber skin
Pona	0.417	0.0	sound
Pona	0.555	5.1	dry rot from harvest cut area
Zoan	1.147	0.0	slight traces of dry rot under tuber skin
Zoan	0.897	0.0	slight traces of dry rot under tuber skin

There was variation in tuber weight used for the study. Generally tubers of the Lily and Zoan varieties were considered to be medium weight in terms of export while Pona tubers were small in size and about half the weight of the other tubers. Though the tubers were considered to be sound from visual observation and feeling with the fingers, all the tubers had some dry rot under the tuber skin except one tuber each of Lily and Pona varieties which were sound.

To be able to determine whether the gas sensor array is able to discriminate between the white yam varieties, principal component analysis [PCA (correlation method)] was undertaken. This procedure generates a number of PC scores which extracts all the useful contributions to the discrimination of the treatments from among all six sensors. The contributions made by PC score 1 to 5 in distinguishing between the three white yam varieties on the basis of the gas sensor data are presented in Table 4.3. The first three PC scores accounted for 77% of the variance in the data while the percentage variance explained by the subsequent PC scores were smaller. The first PC scores accounted for 92.29% of the variance in the data.

Table 4.3. The percentage variance of the first five Principal Component scores of gas sensor readings made on each of two tubers of three white yam (*Dioscorea rotundata*) varieties.

Scores	1	2	3	4	5
%variance	77.56	10.60	4.12	3.18	1.62
Cumulative % variance	77.56	88.17	92.29	95.47	97.09

In order to see more clearly the ability of the gas sensor array to discriminate between the three white yam varieties Linear Discriminant analysis was undertaken using the first three PC scores obtained and Squared Mahalanobis distance metric. The result is shown in Table 4.4.

Table 4.4. Classification of three white yam (*Dioscorea rotundata*) varieties by Linear Discriminant analysis using Principal Component scores (correlation method) and Squared Mahalanobis distance metric. The replicates are from four readings made on each of two tubers of the three varieties.

	Predicted group membership		
Actual group	Group 1	Group 2	Group 3
Group 1 Lily (5 reps)	60%	40%	
Group 2 Pona (7 reps)	14%	57%	29%
Group 3 Zoan (6 reps)	17%	17%	66%

The PC functions were able to give a classification success rate of 61.11% i.e. the gas sensor measurements were able to successfully classify 61.1% of the yam samples.

The results obtained in this study indicate that the gas sensor array had difficulties in successfully classifying the three white yam varieties. This is not very encouraging when compared to the few works on the application of GSA technology for the discrimination of cultivars of tomato, blueberries, and apples. However, these studies were dealing with fruits where varietal difference very often mean very different flavours as compared to root and tubers such as yam which does not normally show strong aroma differences between fresh tubers of different varieties. There was also rots under the yam tubers skin which was suspected to be caused by nematode activities over the six months between the time of harvesting the tubers and the studies. This may have masked the aroma differences between the yam varieties the method of aroma sampling used for the yam tubers where the sampler (funnel) was not closely attached to the surface of the tuber during aroma measurement may also have introduced variability within the sample acquisition process. There is therefore the need to repeat the study using fresh and sound yam tubers (no internal rots) and measure the aroma using a sampler which ensures high reproducibility within the sample acquisition process. Conducting polymer sensors and other metal oxide sensors may also be used to determine whether these offer improved discrimination between the yam varieties. Furthermore the number of tubers per yam variety and the number of gas sensor measurements per tuber may have to be increased.

4.3 Preliminary evaluation of the ability of an X-ray metal detector to detect internal tuber rots in white yam.

An X-ray metal detector (for detecting metals in passenger luggage at the Kotoka International Airport in Accra, Ghana) was assessed on 20/12/01for its ability to detect internal tuber rots in four rotten and four sound white yam tubers of 'Pona' variety. Five photographs taken for each of the yam tubers placed at different positions on the conveyor belt attached to the detector revealed a comparatively light black colour for internally rotten areas and a darker colour for sound areas in the tubers. (The pictures on the screen were in black and white).
It was, however, not very easy to distinguish between the two colours for tiny spots of rots in the tubers for some positions of the yam tubers on the conveyor belt. Optimisation of sample presentation, manipulations of the intensity and wavelength of the X-ray, the speed of the conveyor belt attached to the detector, the species and varieties of yam, the magnitude of rots in the tubers among others could help in calibrating the detector for fast detection of internal tuber rots in a large quantity of yams.

4.4 Summary and discussion of key findings for Output 4

The results from Output 2 underline how important it is to be able to grade yams for export, and to be able to remove any yams with internal rots. However, our findings here indicate thatit is not possible to detect internal rotting through external signs of rotting. We can however, grad reasonably well if yams with external damage, and particularly gashes, are removed. It is desirable that quality of export yams should be checked by random sampling, and then destructive assessment. We have demonstrated that a very effective and rapid destructive method for assessing extent of rotting, is simply by cutting a yam lengthwise and assessing the % rot at the cut surface.

Ideally, however, yams should be routinely assessed for internal rots using non-destructive methods. Our data has indicated that gas sensor array technology has the potential for grading yams. At this time, the development of a cheap, handheld device that could practically be used for the Ghanaian yam export has been delayed due to technical problems in reproducible sampling. However, we still believe that the technology is suitable, and that there are no more suitable alternatives. Work will continue at NRI after the completion of this project.

Output 5: Knowledge exchanged and information disseminated

Overview of Output 5

Objectively Verifiable Indicators
5.1 Workshops and liaison meetings held to schedule.
5.2 Information disseminated to growers, extension workers and traders in the form of leaflets and posters.
5.3 Information disseminated to relevant scientists and extension workers as report collection on CD.

Frequent workshops and liaison meetings were held throughout the project. The dissemination outputs for growers, extension workers, traders and scientists will be developed from this final report for circulation. Recommendations to improve the marketing system including a list of best practices for each stage of the system will be distributed to yam traders and exporters in Ghana and to importers in the UK.

CONTRIBUTION OF OUTPUTS

The problems both in the yam marketing system within Ghana and the export system have been identified, and the scientific/socioeconomic information necessary for the development of recommendations to solve these problems has been obtained. The time necessary to investigate solutions was longer than anticipated, so that it has not been possible within the timescale of the project to initiate the changes and assess their impact.

Nevertheless, we believe that storage of yams will be improved as a result of improved curing practices, and the understanding that has been developed on the differences in storage behaviour of milk and ware yams. This will improve food security as well as impacting on the marketing system.

Where our recommendations for best practices for yam marketing are taken up we believe that the quality of yams, and therefore their income generating potential will be significantly increased. In the case of export, definition of shipping conditions should have a very significant impact. We hope that an instrument for the non-invasive assessment of internal rots, using gas sensory array technology will be available to yam exporters within 5 years.

PUBLICATIONS

* indicates electronic version included with final report

Activity 1.1

AGBODZA., S. (2001) Effects of Post-Harvest Handling Practices on the Quality and Price of Yam in Ghana: A Case Study of the Brong-Ahafo Region. (Paper presented at project workshop July 2001) Dept. Agricultural Economics, University of Ghana, at Legon. (B)

*AGBODZA, S. (2002) Post-Harvest Handling Practices for Yam in Ghana and Yam Quality-Price Relationship: A Case Study of the Brong-Ahafo Region (M.Phil. Thesis).Dept. Agricultural Economics, University of Ghana, at Legon) (F).

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*CORNELIUS, E. (2003) Effect of temperature, duration of curing and Concentration of Oxygen and Carbondioxide on the Rate of Wound Periderm Formation in White Yam (*Dioscorea rotundata* Poir)Tubers. (Paper presented at project workshop, March 2003) Dept Crop Sci., University of Gahan, Legon. (B)

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Activity 4.1

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Yam Quality Project, Workshop No. 4, Second Meeting With Yam Exporters 18th January 2003 (Proceedings)

Yam Quality Project, Workshop No. 5, Progress During, Third Year, 18th & 19th March 2003 (Proceedings)

Various 'Proposals' prepared by university students in anticipation of their project activities:

Activity 1.1

Post- Harvest Handling and Storage Practices of Yam and Their Impact on its Quality and Price: A Case Study of Brong Ahafo Region M.Phil (Project Proposal, **Nov. 2000).** S. AGBODZA (M.Phil. student, Dept. Agricultural Economics, University of Ghana, at Legon)

Analysis of the Costs and Returns Implications of Yam Production and its Post-Harvest Handling in Ghana: The Case of Producers of Brong-Ahafo Region and Exporters of Greater Accra Region (Internal Project Proposal, 2001). S. AGBODZA (Post-Graduate)

Analysis of Efficiency of Cost of Production for Fresh Yams: A Case Study of Growers, Producer-Exporters and Exporter Firms in the Yam Industry (Internal Project Proposal, Jan. 2002). R. TWENEBOAH-KODUA (Graduate).

Activity 1.3

Ascertaining the Costs and Returns from Curing of Farms in Ghana (Workshop Proposal Paper, July 2002).R. TWENEBOAH-KODUA (Graduate)

Activity 2.1

The Post-Harvest Handling of Yam and its Effect on Ghana's Exports (M.Phil. Project Proposal, Nov. 2000). H. A. ASANTE (M.Phil. student, Dept. Agricultural Economics, University of Ghana, at Legon)

Proposal to Quantify the Extent of Economic Loss of Exported Yams and Identify the Main Economic Deficiencies that Adversely Affect the Existing Export Trade to the UK (Dept. of Agricultural Economic, University of Ghana at Legon) (Workshop Proposal July 2002).

Activity 2.2

The Demand and Marketing of Yams (in the UK) and its Place in Food Security (M.A. Project Proposal, Sept. 2001).S. OTOO (M.A. Student, University of Greenwich, UK)

Activity 2.3

Proposal to Investigate Particular Constraints to the Development of Effective Producer/Exporter Links (Workshop Proposal, July 2002). JOHN JATOE (Post-Graduate Assistant, Dept. of Agricultural Economic, University of Ghana at Legon).

Activity 3.3

Influence of Curing and Handling Practices on the Incidence and Prevalence of Post-Harvest Rots in White Yams (*Dioscorea rotundata*, Poir) (Internal ProposalAug. 2001).F. NUAMAH (Graduate-Assistant, Dept. Crop Science, University of Ghana, at Legon)

Influence of Curing and the Role of Rot Causing Organisms on the Incidence and Prevalence of Post-Harvest Rots in White Yams (*Dioscorea rotundata*, Poir) (Workshop Proposal Paper, July 2002).F. NUAMAH (Graduate-Assistant, Dept. Crop Science, University of Ghana, at Legon)

Curing Efficiency of White Yam (*Dioscorea rotundata* Poir) Tubers as Affected by Temperature, Duration of Curing, Tuber Maturity at Harvest and Duration of Storage (Internal Proposal Aug. 2001).E. CORNELIUS (PhD. student, Dept. Crop Science, University of Ghana, at Legon),

Further Investigations to Determine the Efficiency of Wound Healing in White Yam (*Dioscorea rotundata*, Poir) Tubers as Affected by Temperature, duration of Curing, Age at Harvest and duration of Storage (Workshop Proposal Paper, July 2002).E. CORNELIUS (PhD. student, Dept. Crop Science, University of Ghana, at Legon).

Curing Efficiency of White Yam (*Dioscorea Rotundata* Poir Tubers as Affected by Temperature and Length of Curing (Internal Proposal, July 2002).E. CORNELIUS (PhD. student, Dept. Crop Science, University of Ghana, at Legon).

Activity 4.1

Electronic Sensing of Volatiles for Quality Assessment of White Yam (*Dioscorea rotundata*) Tubers (PhD Project Proposal, Oct. 2000). E. CORNELIUS (PhD. student, Dept. Crop Science, University of Ghana, at Legon).

Electronic Sensing of Aroma Volatiles for Early Detection of Internal Rots in White Yam (*Dioscorea rotundata* Poir) Tubers. Internal ProposalJuly 2002E. CORNELIUS (PhD. student, Dept. Crop Science, University of Ghana, at Legon)

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