FINAL TECHNICAL REPORT

Improving the quality and value of non-grain starch staples

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1.0 EXECUTIVE SUMMARY

The objective of the project was to assess quality-value relationships for fresh sweetpotato and dried cassava marketed into the main urban centres. Based on these assessments, the project aimed to determine the causes of the losses and test interventions to improve quality and thus value of the commodity. Development of such improvements to the commodity systems offers the potential to enhance the livelihoods of poor farmers and traders.

Secondary data on marketing systems in urban centres have been reviewed focusing on an analysis of data collected in the fourth phase of the Collaborative Study of Cassava in Africa. Processed cassava products were important in Mtwara and Mwanza and but not Dar es Salaam. Methods for assessing quality/value relationships in urban markets were developed and validated. The level of damage of sweetpotato was high in all centres, but noticeably higher in Dar es Salaam. Market place quality-value assessments for fresh sweetpotato and dried cassava were made. For sweetpotato, weevil damage caused the greatest loss in value (30-40% for surface attack and 50% when deeper). Smaller, but still significant, discounts of 10-30% occurred when roots were shrivelled, cut or broken. For dried cassava, colour is the main determinant of value with whiter products preferred. The impact of different types of mould on value of fermented cassava was quantified.

For sweetpotato, field studies and market chain analyses of losses were conducted. Each time a sack was dropped from heights of 0.5 m, an additional 10% of the roots received major breaks. Analysis of results from an impact sensor indicated that while large drops from 0.5 m or greater caused severe breakage of the sweetpotato roots, skinning injury was associated with many (800-1,200) minor shocks which are possibly caused by vibration during transport. The method of transport (boat or road) produced similar losses in market value. There was no cultivar effect on losses. Losses in market value after 14 days storage were estimated to be as high as 60% which was exacerbated with transport induced damage, in particular skinning injury. Shelf-life could be improved by reducing the number and severity of drops. Extended shelf-life would enhance incomes to retailers and traders and reduce losses for the consumer.

Alternative methods of curing and packaging of roots were investigated. Pre-harvest pruning (18 days before harvest) led to a significant reduction in skinning injury that could extend shelf-life and reduced losses during storage. Alternative methods of packaging were shown to increase the shelf-life and reduce losses. Economic value was however unaffected. Various publications have been produced to disseminate the quality/value assessment methodology and the technical findings of the research work.

Studies on fermented dried cassava were conducted as a postgraduate research project at the University of Reading. The predominant fungi in the cassava fermentations were *Rhizopus stolonifer* and *Neurospora sitophila*. Indications from the quality-value studies were that the colour of *Rhizopus spp.* growth was preferred over that from *Neurospora*. Factors favouring the growth of one over the other were investigated. The highest hyphal extension rate recorded for *Rhizopus stolonifer* was 1.15 mm/h at 25° C, a_w ~1.0, in air. Under the same conditions the hyphal extension rate of *N. sitophila* was 1.2 mm/h. The highest hyphal extension rate recorded for *N. sitophila* was 2.6 mm/h at 30° C, a_w 0.98, in 15% CO_2/85% air. Under the same conditions the hyphal extension rate of *R. stolonifer* was 0.88 mm/h. Between these extremes, conditions were identified (specifically involving lower water activity) where the growth of *R. stolonifer* was greater than that of *N. sitophila*.

2.0 BACKGROUND

Together, cassava and sweetpotato form a very significant component of the staple food supply in Tanzania. However, until recently, they are considered to be of low economic value and very little information has been collected on the consumption patterns and marketing systems of these commodities.

Cassava

Recognising the shortage of data on cassava in Africa, the Collaborative Study of Cassava in Africa was initiated in 1987/88 (Nweke, 1988). Phase I data, collected in a village-level survey, has given an overview of the post-harvest systems for cassava (NRI, 1992). The analysis of Phase I data has also provided a stimulus for the new interest in post-harvest research in Tanzania (Kapinga, *Pers. Comm.*). Cassava is consumed in both fresh and processed forms. The marketing of fresh cassava is limited by its very short shelf-life, and although techniques for extending shelf-life up to one week are being disseminated by NRI through the Regional Africa Technology Transfer project on Non-Grain Starch Staples (Bancroft, 1995), processing is generally used to produce a more storable commodity (Westby, 1991).

There are two principal traditional processed cassava products in Tanzania, *makopa* and *udaga*. Makopa is the major sun-dried product of the Coastal and Southern Zones of the country, whereas *udaga* is a fungally fermented product that is commonly processed in the Lake Zone. Needs assessment surveys undertaken in Dar es Salaam, Tanga Region and Lake Zone under the Regional Africa Project on Non-Grain Starch Staples (Digges *et al,.* 1994; Ndunguru *et al.,* 1995), have shown that the quality of both products is considered variable and unreliable by urban consumers, and that this adds to the low status that cassava holds in the market, compared to commodities such as maize and rice.

An additional potential quality problem was indicated by Crop Post-Harvest Programme funded work in Ghana which demonstrated the potential of slowly sun-dried, or poorly stored, cassava to support mycotoxin formation (Wareing, 1993). Some evidence for similar inefficiencies in the processing, storage and marketing chain have been observed in Tanzania during informal surveys recently conducted by NRI in collaboration with the Tanzanian National Root and Tuber Crops Programme in Lake and Coast Zones (CPHP Project R6314).

The key quality criteria of cassava products considered by consumers have not been well defined, although some initial information has been collected during the surveys described above. Little is known about the quality/value relationships that exist for these processed products. Fungal fermentation (Westby, 1991) is the key to the processing of many of these products but little is known about the process or the possibilities for improving it. It is hypothesised that if significant higher prices are to be gained from improved quality products, the incomes of the people living in marginal areas can be improved.

Sweetpotato

Although processed sweetpotato products exist, fresh roots are preferred. As with cassava, precise information on the marketing system is scarce, although it is clear that the perishability of the fresh root is a major constraint to the marketing of the commodity. A

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survey of farmers undertaken by the Tanzanian National Root and Tuber Crops Programme has drawn attention to the importance of minimising losses by improving post-harvest handling systems (Kapinga *et al.* 1995). The existing marketing systems for sweetpotato are considered poorly developed with high levels of root damage during transportation. However, the true extent of both biological and economic losses is not known and the relationship between cultivars, marketing systems and quality depreciation is inadequately understood. The Tanzanian National Root and Tuber Crop Programme consider improvements to sweetpotato handling a high priority.

References for background section

BANCROFT, R.D. (1995) An assessment of post-harvest losses of fresh cassava in Dar es Salaam and recommendations on how best to extend the storage life of roots. NRI Report.

DIGGES, P., NDUNGURU, G., HAMED, L., LASWAI, H., MBIHA, E., MWAMANGA, G. Report on a visit to Tanga Region, Tanzania to validate needs assessment methodologies for non-grain starch staple food crops (24 January - 12 February 1994) R 2094(R). Chatham: Natural Resources Institute.

KAPINGA, R., EWELL, P., JEREMIAH, S. and KILEO, R. (1995) Farmers perspectives on sweetpotato and implications for research in Tanzania. A case study.(To be published jointly by the Tanzanian Ministry of Agriculture and the International Potato Center).

NATURAL RESOURCES INSTITUTE (1992). COSCA Phase I Processing Component. COSCA Working Paper Number 7. Chatham, United Kingdom.

NWEKE, F.I. (1988) COSCA Project Description. COSCA Working Paper No. 1. International Institute of Tropical Agriculture, Ibadan, Nigeria.

WAREING, P. (1993) Report on a visit to Ghana to determine the incidence and extent of mould and mycotoxin contamination in cassava products. 6 June - 2 July 1993. NRI Report.

WESTBY, A. (1991) Importance of microorganisms in cassava processing. In *Tropical Root Crops in a Developing Economy Proceeding of the 9th Symposium of the International Society for Tropical Root Crops 20-26 October 1991, Accra, Ghana* ed. Ofori, F. and Hahn, S.K. pp 249-255. International Society of tropical Root Crops: ISHS-Secretariat, Wageningen.

3.0 PROJECT PURPOSE

The purpose of the project when initiated was "Improved quality and handling systems developed and promoted" (see Project Logical Framework in Annex 1). Following revision of the Crop Post-Harvest Programme logframes the purpose of the project is "Strategies developed which improve food security of poor households through increased availability and improved quality of root crop and horticultural foods and better access to markets."

The relationships between quality and value for non-grain starch staples entering urban centres are not well understood and so the relative benefits of improving quality are difficult to determine. This project focuses understanding these relationships for fresh sweetpotato and dried cassava products entering the main urban markets in of Tanzania. Improvements to the quality of these products that increases their value has the potential to enhance the incomes of poor rural producers and traders. Enhanced incomes will make a positive contribution to the livelihoods of these poor people.

The objectives of the project to make a contribution towards the purpose were:

  (i)   to assess the fresh sweetpotato and dried cassava product marketing systems and quality-value relationships, and

  (ii)   to investigate the factors associated with quality deterioration and develop technical improvements. Such improvements would make a direct contribution to the project goal of "Non-grain starch staple handling, marketing and credit systems improved".

4.0 RESEARCH ACTIVITIES AND OUTPUTS

This report summarises the activities and outputs of the project. Project publications and technical reports are listed in Section 5 of this report. A number of the outputs are available on CD-ROM and these are listed in Annex 2. The project logical framework is given in Annex 1.

This section of the report is organised according to the outputs of the project, sub-divided according to commodity.

Output 1: Assessment of fresh sweetpotato and dried cassava product marketing systems and quality/value relationships

The main collaborators for this output were the Natural Resources Institute, Tanzania Food and Nutrition Centre and ARI-Ukiriguru. Inputs were also made by Sokoine University of Agriculture and the Marketing Development Bureau of the Ministry of Agriculture.

<u>Development of methodologies and their application to determining quality-value relationships for fresh sweetpotato in Tanzania</u>

In most urban markets in Tanzania sweetpotatoes are purchased in sacks or bamboo baskets and then sold to consumers in heaps. Heaps are sold at fixed prices which differ in total weight depending on factors such as the size (small, medium, large) and quality of the roots. The actual price of the roots is further complicated by a "top up" of additional roots, which is given as part of the sale negotiation process. With respect to quality, sweetpotatoes within each heap may be undamaged or they may have cuts or breaks, be shrivelled or suffer from weevil damage.

Two complementary methodological approaches for assessing the relationship between quality and economic value of fresh sweetpotato are described. The first approach used a range of participatory ranking and valuation exercises to gain an impression of the major quality issues, seasonality of marketing and the impact of specific types of quality deterioration on retail value. This was supported by a statistical analysis of heaps of produce being retailed in the market. This second approach allowed the impact of different quality characteristics to be quantified.

Various participatory ranking and valuation exercises were performed in different markets within Mwanza town and at different times of the year. The experiments show that both traders and customers consistently place lower valuations on damaged sweetpotatoes than on undamaged ones. Evidence of weevil attack leads to the greatest reduction in value, with average discounts of around 30 - 40% for surface attack and over 50% for deeper attack. Smaller but still significant discounts of between 10 - 30% occur if a potato is shrivelled, cut or broken.

An analysis of sweetpotato heaps on sale in the markets showed that a high proportion of sweetpotato entering the marketplace is damaged in some way. The results also suggest that overall there is a significant reduction in the value of sweetpotato if they are damaged. This reduction varies according to the type of damage with cuts and weevil attack having the

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largest impact on value, indicating that measures to reduce these types of damage will be most appreciated in the market place.

There is also evidence to suggest that there is significant variation in the value of sweetpotato by variety. Results show that yellow skinned varieties are preferred and sell at an average premium of 10% above the price of reddish purple skinned ones. This suggests that farmers should attempt to supply more of the Njano variety of sweetpotato to the Mwanza markets.

Overall, the results suggest that efforts to improve the quality of sweetpotato should focus firstly on reducing the number of weevil damaged potatoes entering the market, especially deep burrowing weevil. A second priority area should be to reduce breaks, cuts and shrivelling. However, any post-harvest intervention that reduces sweetpotato damage will have a significant positive impact on quality perceptions in the market place.

These studies were summarised in a technical report (Thomson *et al.* 1997) that is available on the CD-ROM (File 15). Elements of the work were summarised in Annex 3 which is a paper presented at the 9th Symposium of the International Society for Tropical Root and Tuber Crops and subsequently published in the Tropical Agriculture (Trinidad).

Estimation of the importance of different types of sweetpotato damage in sweet potato entering the main urban markets

To complement the work on quality-value relationships for fresh sweetpotato, some collaborative work was done with project R6507. The level of damage of sweetpotato was high in all urban centres, but noticeably higher in Dar es Salaam (45%, 49% and 75% damaged roots in Mwanza, Morogoro and Dar es Salaam, respectively). These studies are summarised in the paper by Rees *et al.* (2001) that has been accepted for publication (Annex 4).

Analysis of data from the urban study of the Collaborative Study of Cassava in Africa

As proposed in the initial project proposal, data collected by the national root and tuber crops programme as part of the fourth phase of the Collaborative Study of Cassava in Africa was analysed. The data analysis provided useful background on the marketing of cassava and cassava products in the main urban centres of Tanzania.

The work has been written up for publication (Ndunguru *et al.* 1999a, draft as File 8 CD-ROM). It was found that different forms of cassava were important in different locations: Dar-es-Salaam (fresh cassava), Mwanza (dried fermented cassava) and Mtwara (dried cassava, fermented and non-fermented). Traders of fresh cassava generally procure larger and more regular consignments than those dealing in dried cassava products and, because fresh roots are perishable, also store their products for shorter periods. In Dar-es-Salaam, peak market volumes occur between January and April (wet season). In the other two markets, peak volumes occur between May and October (dry season). Differences in these peak periods occur because fresh cassava is easier to harvest during the rainy season, and dried cassava products are easier to process during the dry season. Price and volume generally had an inverse relationship. However a positive relationship existed for fresh cassava in Dar-es-Salaam during January to March, a period that clashes with peak demand during Ramadan. Increasing numbers of traders are entering cassava markets, suggesting that barriers to entry

are not significant. In all three markets, a large proportion of roots had recently been unsellable due to deterioration. Most fresh cassava traders in Dar-es-Salaam and Mwanza preferred sweet varieties, whereas Mtwara traders preferred bitter varieties. The desirable characteristics of fresh roots were taste (which should be sweet), starch content (measured as hard texture) and outer skin colour (which should be reddish brown).

Quality-value relationships in cassava

Dried cassava products are important commodities in the urban markets of Mwanza in northwest Tanzania. Participatory methodologies mentioned above were used to gauge relationships between quality and value of the marketed produce. The two major dried cassava products marketed in Mwanza are *udaga* (a heap fermented product) and *makopa* (a non-fermented product). In both cases, traders and customers prefer a white product because this gives better tasting and more visually appealing *ugali* flour. Perceived valuations show a 30 - 50% discount for dark *udaga* compared with white *udaga*. *Makopa* is valued approximately 10% below *udaga* of similar colour and piece size. Moulds of various colours appear on *udaga* during the rainy months. No visible mould is liked, but some types are disliked more than others are. Average valuation discounts are 10 - 15% for orange coloured mould, 20 - 25% for green coloured mould and 35 - 40% for black coloured mould. Consequently, product values might increase if mould was scraped off the roots after prior to sale. Produce is usually ungraded in the markets. The results suggest that if *udaga* was well graded when it entered the market, improved price differentiation could occur. Consumers who prefer better quality could fulfil their requirements by paying more, while those who are satisfied with (or could only afford) poorer quality could pay less.

This work was published as a paper presented at a SARRNET regional workshop (Ndunguru *et al.* 1999b). The text of this document is presented in Annex 5 and File 9 on the CD-ROM. Data on differences in value associated with different colours of mould group formed the basis of PhD studies at the University of Reading (Output 2).

Output 2: Investigation of the factors associated with quality deterioration and development of technical improvements.

The main collaborators for work on sweetpotato for this output were the Natural Resources Institute, Tanzania Food and Nutrition Centre and ARI-Ukiriguru. Sokoine University of Agriculture and the Marketing Development Bureau of the Ministry of Agriculture also made inputs.

Work on cassava was mainly conducted by a PhD student at The University of Reading.

Studies on sweetpotato marketing systems

Analysis of the causes of loss in quality during marketing

Commercial consignments of sacks of sweetpotatoes were monitored from harvest to markets in Mwanza or Dar es Salaam. Overall the handling and transport system could result in up to 20 per cent of roots in a sack with severe breaks and between 35 per cent and 86 per cent with severe skinning injury. Using the method for relating quality to value developed by in the

project (Ndunguru *et al.* 1998; Annex 3), the loss in market value could be as high as 13 per cent per sack.

Impact loggers located at the centre of sacks provided an objective method for continuously monitoring the handling of the produce. The most severe handling occurred during unloading and loading. Sacks transported in the Lake Zone received an of average to two impacts of 20g or greater, which is equivalent to a drop from 0.5 m. Sacks transported to Dar es Salaam received an average of one impact of 20 g or greater. Multiple regression analysis indicated that skinning injury and broken roots correlated with minor impacts between 0.2g and 2g.

These studies using impact loggers also provide a useful means of comparing varieties. Regression analysis indicated that for roots handled and transported in 100 kg sacks, both cultivars tested (Polista and SPN/0) were equally susceptible to skinning injury and broken roots and that this was not affected by season. This technique could be used for evaluating other cultivars or alternative packaging systems.

In the project work the major causes of loss in quality of sweetpotato during handling and transport were identified. Overcoming problems associated with severe handling requires a combination of education of the handlers and in some cases, redesigning of the unloading areas. The effect of minor impacts may be reduced by improved vehicle suspension, improved road conditions, reduction in weight of roots in a sack or changes in packaging material (for example, from polypropylene sacks to cardboard boxes). Changes in practice that are within the financial means of those involved need to be evaluated technically and economically. The data obtained in this study should assist this process.

These studies have been published (Tomlins *et al.* 2000) and the text of the paper is attached at Annex 6. This is file 18 on the CD-ROM.

Influence of post-harvest handling on the quality and shelf-life of sweetpotato

Previous research in the project indicated that handling and transport of sweetpotato can lead to reduced market value. F for example, in Tanzania losses were (13%) where up to 20% and 86% of roots were severely broken and skinned respectively (Tomlins *et al.* 2000; Annex 6). The most severe handling occurred during unloading and loading from road vehicles and ships, where porters dropped the sacks from shoulder height. A follow-up study was done to shows the effect of handling of sacks of sweetpotato on quality by varying sack weight, height of drop and the number of impacts received. After damage, the roots were subsequently stored at ambient conditions to determine how handling influenced shelf life.

The height and number of drops reduced the quality of sweetpotato (SPN/0 cultivar). The occurrence of broken roots increased with both height and number of times a sack was dropped while skinning injury increased with height. The weight of the sack (50 or 100 kg) had no influence of quality. The shelf-life, indicated by weight loss, was most influenced by the height that a sack was dropped and to a lesser extent the number of drops. Of the classes of injury (weevil, cuts, skinning, breaks, shrivelling) sustained by sweetpotatoes during handling, skinning injury, and to a lesser degree broken roots, correlated most with weight loss.

Reduced handling of sacks of sweetpotato will improve their marketability and returns to farmers and extend the shelf life by reducing skinning injury and broken roots. A simple intervention by reducing the weight from the current 100 kg to 50 kg did not reduce damage. The use of alternative methods of packaging (cardboard and wooden boxes) may lead to improved quality; this needs to be investigated under actual conditions. Furthermore, pre-harvest curing of the roots by pruning the plant canopy up to 14 days before harvest has been reported to reduce the injury to roots during handling and transport by facilitating wound healing. Pruning is not widely practised in Tanzania and East Africa and may offer a simple and low-cost technique for reducing susceptibility to injury. These interventions were investigated in subsequent studies.

This work has been submitted for publication (Ndunguru *et al*. 2000a) and a copy of the manuscript with the detailed results is given at Annex 7. This is file 11 on the CD-ROM.

Methods for reducing post-harvest losses in sweetpotato

Cardboard boxes filled with 20 kg of sweetpotato and pre-harvest pruning of 14 days or more improved quality by reducing skinning injury. This did not lead to improved market value at auction because traders do not consider roots with skinning injury to be unacceptable (Ndunguru *et al*. 1998) and the presentation in cardboard boxes was new to them. An advantage of roots with reduced skinning injury is an extended shelf life (Ndunguru *et al*. 2000a) but traders are unaware of this. Education of traders, wholesalers and auction agents of the advantages of extended shelf life may lead to improve market value for roots with reduced skinning injury and a demand for roots transported in cardboard cartons and pre-harvest pruning.

This work has been submitted for publication (Ndunguru *et al*. 2000b) and a copy of the manuscript with the detailed results is given at Annex 8. This is file 10 on the CD-ROM.

Collaboration with DFID Regional Africa Project on Non-Grain Starch Staples

The project interfaced in a very minor way with a DFID Regional Africa project working in the Lake Zone of Tanzania. From the perspective of this project the main interest was on the methods for disseminating new information to target groups. In the case of the new cassava products, a cautious approach to the dissemination of information was adopted. This involved the following stages: (i) identification of the initial need to diversify cassava utilisation, (ii) a feasibility study; (iii) an interactive pilot phase where information was obtained on the factors that would facilitate sustainable uptake of the technology; and (iv) a wider dissemination phase. This approach was found to be successful. The work resulted in two publications (Kapinga *et al.* 1998 [File 3 on the CD-ROM]; Kapinga *et al.* 1999 [File 4 on the CD-ROM]).

Strategic research on improving the quality of fungally fermented cassava

Studies on quality-value relationships for fermented cassava indicated the importance of different types of mould group (see Ndunguru *et al.* 1999; Annex 5). Studies on fermented dried cassava were conducted as a postgraduate research project at The University of Reading.

The mycofloras of four samples of dried fermented cassava pieces (makopa) and 3 samples of fermented cassava flour (udaga) from Tanzania were examined. Eighteen moulds and 6 yeasts were isolated, including 6 types of *Rhizopus stolonifera*, 8 of *Neurospora sitophila*, 2 if *Penicillium* sp. and 2 unidentified white moulds.

Heap fermentations of cassava were observed in Tanzania. It was noted that peeled cassava was sun dried before being placed in a heap to ferment. The heaps were only partially covered and, consequently, the gas composition inside the heaps was measured to be similar to air. The temperature in the heaps rose to about 5°C above the ambient temperature (30°C) during the fermentation. Microbial cultures, including 44 bacteria, 27 moulds/mycelial yeasts and 6 budding yeasts were isolated from cassava fermentations in Tanzania. The predominant fungus in the cassava fermentations was *Rhizopus stolonifera*, which was present in all 6 heaps investigated. *Neurospora sitophila* was seen in two heaps, *Pichia anomalia* was found in one heap and budding yeasts were found in two heaps.

Rhizopus stolonifera, *Neurospora sitophila* and *Pichia anomalia* were previously isolated from samples of dry fermented cassava pieces (makopa) and dry fermented cassava flour (udaga) and finding the same moulds in fresh fermenting cassava heaps serves to confirm that these are among the prevalent organisms involved in fermentation. Bacterial populations 10^7 cells g^{-1} (determined microscopically) in fermenting cassava, although substantial, do not appear to be large enough to be important in the fermentation.

A preliminary surface response study on the effect of environmental conditions (water activity, 0.98, 0.99, ~1.0; pH, 5, 6, 7; temperature, 25, 30, 37°C; carbon dioxide, 0.03, 25, 50 [v/v %]; and oxygen, 2, 10, 20 [v/v%]) on the rate of hyphal extension of selected moulds was done. Good data was obtained for *Rhizopus stolonifera* C5 (from udaga) and for *R. oligosporus* (NRRL 2710, a tempe strain). *R. stolonifera* grew fastest at 31°C and at water activity close to 1.0. Oxygen and carbon dioxide concentrations and pH value had little effect on hyphal extension rate over the ranges of values investigated.

The water activity of slices of cassava cut from dried cassava roots was measured. Values ranged from 0.91 - 0.95 at the surface to 0.97 - 0.98 in the centre. Water contents ranged from 39% to 81% (w/w) but did not correlate well with the water activities. The use of cellophane disks of growing mycelium as inoculum was shown to give reliable results and was preferable to the use of spore suspensions. The effect of water activity of the inoculum medium showed that this had little effect on the subsequent growth of *Rhizopus stolonifera*, *Rhizopus oligosporus*, *Neurospora sitophila* or *Pichia* sp. but in the case of *Penicillium chrysogenum*, inoculum grown on medium with water a_w 0.98 was more tolerant of low water activity than inoculum grown at a_w ~1.00.

Data has been collected on the effects of environmental conditions on the rate of hyphal extension of *Rhizopus oligosporus* NRRL 2710 (Sparringa *et al.* 2001; Annex 9; File 14 on the CD-ROM). Although *R. oligosporus* NRRL 2710 is not from udaga, it is a well characterised mould and was used to develop methods for investigating the effects of environmental conditions on the growth of udaga moulds using response surface methodology. The conditions supporting the fastest rate of hyphal extension (1.5 mm h^{-1}) were at 39 – 42 °C, pH 5.8, water activity ~1.0, in air.

The highest hyphal extension rate recorded for *R. stolonifera* was 1.15 mm/h at 25° C, a_w ~1.0, in air. Under the same conditions the hyphal extension rate of *N. sitophila* was 1.2 mm/h. The highest hyphal extension rate recorded for *N. sitophila* was 2.6 mm/h at 30° C, a_w 0.98, in15% CO_2 /85% air. Under the same conditions the hyphal extension rate of *R. stolonifer* was 0.88 mm/h. Between these extremes, conditions were identified (specifically involving lower water activity) where the growth of *R. stolonifer* was greater than that of *N. sitophila*. It is suggested that adequate surface drying of cassava roots before making the heap fermentation may be an important factor in promoting growth of *Rhyizopus* spp. over that of *N. sitophila*.

5.0 CONTRIBUTION OF OUTPUTS

Contribution towards DFID's developmental goals

The project has made a significant contribution to the project's purpose of "Improved quality and handling systems developed" with an OVI of "Strategies for optimising quality of 2 NGSS developed and promoted in 2 target countries by March 1999". This particular project developed strategies for the improved handling of sweetpotato in urban markets in Tanzania. These outputs have been promoted through regional and international conference presentations.

Adoption of the improved handling procedures as part of a package of improvements to the sweetpotato post-harvest system are likely to improve the livelihoods of poor people through enhanced incomes.

Promotion pathways to target institutions and beneficiaries

The project was conducted as a collaboration between the Natural Resources Institute, the Tanzania Food and Nutrition Centre and National Root and Tuber Crops Programme based at ARI-Ukiriguru. These two organisations are key target institutions for further promotion of the project outputs within Tanzania. The National Coordinator for Root and Tuber Crops is based at ARI Ukiriguru. The results of the project and the related project R6507 "The extension of storage life and improvement of quality in fresh sweetpotato through selection of appropriate cultivars and handling conditions" have been promoted at national coordinating meetings of the national root crops programme. The Tanzania Food and Nutrition Centre holds the national mandate for working on post-harvest issues. These two organisations will be responsible for promoting the outputs of the project more widely through their normal work programmes and linkages with extension services.

Outputs of the research have been promoted through presentations at regional workshops such as the African Potato Association (Ndunguru *et al.* 2000; File 12 on CD-ROM) and the Southern Africa Regional Root Crops Network (SARRNET) (Ndunguru *et al.* 1999b, File 9 on CD-ROM; Kapinga *et al.* 1999, File 4 on CD-ROM). Presentations have also been made at the triennial symposia of the International Society for Tropical Root and Tuber Crops (Kapinga *et al.* 1998, File 3 on CD-ROM; Ndunguru *et al.* 1998, File 5 on CD-ROM; Kapinga *et al.* 2000, Files 1 and 2 on CD-ROM).

In order to disseminate project findings to a wider scientific audience, a number of papers have been submitted to international peer-reviewed scientific journals (see list below).

Follow up action/research necessary to promote the findings of the work to achieve their development benefit

In the case of sweetpotato, the project identified the potential to market sweetpotato out of season by using some form of appropriate storage. This has been developed into a follow-on research project with the same project team (Crop Post-Harvest Programme R7498: "Maximising incomes from sweetpotato production as a contribution to rural livelihoods". The use of storage and improved handling procedures (developed in this project) offer the

potential to improve financial returns to poor farmers living in marginal areas and so enhance their livelihoods.

In the case of the work on cassava, additional strategic research will be required to adapt the findings to cassava based systems.

Publications, plans for further dissemination

Outputs from the project are listed below. Where possible these have been stored on CD-ROM and passed to the Programme Manager. A list of the documents on CD-ROM are contained in Annex 2.

Publications:

KAPINGA, R.E., REES, D., WESTBY, A., NDUNGURU, G.T., RWIZA, E., TOMLINS, K.I., STATHERS, T., JEREMIAH, S. and MBILINYI, L. (2000) Increasing the contribution of sweetpotato to sustainable rural livelihoods in Tanzania. Paper presented at the Triennial Symposium of the International Society for Tropical Root Crops, Japan, 10-16 September 2000.

KAPINGA, R., WESTBY, A., RWIZA, E. BAINBRIDGE, Z. and NSANZUGWANKO, A. (1998) Diversification of cassava utilisation in the Lake Zone of Tanzania: a case study. *Tropical Agriculture (Trinidad)* **75**: 125-128.

KAPINGA, R., WESTBY, A., RWIZA, E., BAINBRIDGE, Z.A., and AMOUR, R. (1999) Stakeholder participation in technology testing and dissemination of cassava diversification in the Lake Zone of Tanzania. In Food Security and crop diversification in SADC countries the role of cassava and sweetpotato. Pp 90-99. Edited by M.O. Akoroda and J. Terri, SARRNET, Malawi. (Peer reviewed conference proceedings)

KENDALL, M., OWENS, J.D. and WESTBY, A. (1998) Cassava solid substrate fermentation. Poster presented at the Society for General Microbiology Meeting, University of East Anglia, 8 September 1998. (Conference poster)

NDUNGURU, G., THOMSON, M., WAIDA, R., RWIZA, E. and WESTBY, A. (1998) Methods for examining the relationship between quality characteristics and economic value of marketed fresh sweetpotato. *Tropical Agriculture (Trinidad)* **75**: 129-133.

NDUNGURU, G.T., THOMSON, M., WAIDA, T.D.R., RWIZA, E., JEREMIAH, S. and WESTBY, A. (1999b) Relationship between quality and economic value of dried cassava products in Mwanza, Tanzania. In Food Security and crop diversification in SADC countries the role of cassava and sweetpotato. Pp 408-414. Edited by M.O. Akoroda and J. Terri, SARRNET, Malawi. (Peer reviewed conference proceedings)

NDUNGURU, G.T., WESTBY, A., GIDAMIS, A. and TOMLINS, K.I. (2000) Losses in sweetpotato quality during post-harvest handling in Tanzania. Presented at the Fifth Triennial Congress of the African Potato Association. Kampala, Uganda May 29 – June 2 2000.

TOMLINS, K.I., NDUNGURU, G., RWIZA, E. and WESTBY, A. (2000). Post-harvest handling and transport of sweetpotatoes and their influence on quality in Tanzania. *Journal of Horticultural Science and Biotechnology* **75**, 586-590.

WESTBY, A. (1999) *Getting to the Roots (and Tubers) of Development.* Inaugural Professorial Lecture. Publisher: University of Greenwich Press (ISBN 1 86166 114 2), Greenwich, UK.

WESTBY, A., REILLY, P.J.A. and BAINBRIDGE, Z.A. (1997) Review of the effect of fermentation on naturally occurring toxins. *Food Control.* **8,** 329-339.

The following are Journal publications that have been submitted or will shortly be submitted, but not yet published.

NDUNGURU, G.T., GRAY, A., KAPINGA, R.E., WESTBY, A. MASHAMBA, F. and KAMALA, R. (1999a) The urban marketing of cassava and cassava products in Tanzania. *African Journal of Root and Tuber Crops* Submitted.

NDUNGURU, G.T., TOMLINS, K.I., RWIZA, E. and WESTBY, A. (2000) Evaluation of methods for reducing postharvest handling losses in sweetpotato in Tanzania. *Tropical Science (submitted)*

NDUNGURU, G.T., TOMLINS, K.I., RWIZA, E. and WESTBY, A. (2000) Post harvest handling and its influence on the quality and shelf life of sweetpotatoes in Tanzania *Tropical Science (submitted)*

SPARRINGA, R.A., KENDALL, M., WESTBY, A. and OWENS, J.D. (2001) Effect of temperature, pH, water activity and carbon dioxide concentration on growth and sporulation. *Rhyzopus oligosporus* NRRL 2710. To be submitted to *Journal of Applied Microbiology* – 25 pp. in manscript.

The following are internal reports

KAPINGA, R.E., JEREMIAH, S.C., RWIZA, E.J. MAYONA, C., MTUNDA, K. and KILIMA, M. (1996). Sweetpotato and cassava post-harvest: In: 1996 Annual Report of the Tanzanian National Root and Tuber Crops Programme. TNRCP Report.

KENDALL, M. (1997) "Improving the quality of fungally fermented cassava" Literature review, University of Reading. 18pp.

KENDALL, M. (2000) Use of response surface methodology to identify environmental conditions favouring the growth of *Rhizopus stolonifera* over that of *Neurospora sitophila*. Technical Report No. 19, The University of Reading. 14 pp.

KENDALL, M., MSABAHA, R., NDUNGURU, G.T. and OWENS, J.D. (1998) Field studies on udaga fermentation in Tanzania. Technical Report, University of Reading. 16pp.

KENDALL, M.N. (1998) Changes in water activity and moisture content of cassava during simulated sun drying. Project Report. Reading: University of Reading. 6pp.

KENDALL, M.N. and OWENS, J.D. (1998) Effects of environmental conditions on the growth of udaga moulds assessed by response surface methodology. Report No. 17. Reading: University of Reading. 22pp.

KENDALL, M.N., MSABAHA, R. NDUNGURU, G.T. and OWENS, J.D. (1998) Microbial flora of fermented cassava. Report No. 15. Reading: University of Reading. 27pp.

NDUNGURU, G.T, KAPINGA, R., MTUNDA, K. and WESTBY, A. (1997) Analysis of urban market component of the Collaborative Study of Cassava in Africa. TFNC/TNRCP/NRI Report. 17pp.

SPARRINGA, R.A., KENDALL, M.N. and OWENS, J.D. (1999) Effects of temperature, pH, water activity and carbon dioxide on growth and sporulation of *Rhyzopus oligosporus*. Technical Report No. 18. The University of Reading, Reading. 17 pp.

THOMPSON, M., NDUNGURU, G.T. and RWIZA, E. (1996) Development of methodologies for testing the relationship between quality and economic value for fresh sweetpotato and dried cassava products based on fieldwork performed in Mwanza, Tanzania. NRI/TFNC/TNRCP Report.

THOMSON, M., NDUNGURU, G.T., WAIDA, T.D.R., RWIZA, E. and JEREMIAH, S. (1997) The relationship between quality and economic value of fresh sweetpotato and dried cassava products in Mwanza, Tanzania. NRI/TFNC/MoA, Tanzania, Technical Report.44pp.

TOMLINS, K.I., and NDUNGURU, G.T. (1999) Losses in sweetpotato quality at harvest and during the post-harvest handling and transport. Studies in the Dar es Salaam region (low season). Technical Report R2404. Chatham: Natural Resources Institute. 22pp.

TOMLINS, K.I., NDUNGURU, G.T. and RWIZA, E. (1998) Losses in sweetpotato quality at harvest and during the post-harvest handling in the Mwanza Region of Tanzania. Technical Report R2375(S). Chatham: Natural Resources Institute. 16pp.

Other dissemination of results:

KENDALL, M. (1999) *Fungal fermentation of cassava.* MPhil/PhD Transfer Report, University of Reading. 76 pp. (Thesis)

KENDALL, M. (In preparation) *Fungal fermentation of cassava. PhD Thesis, University of Reading.*

NDUNGURU, G.T. (In preparation) Improving the quality and value of marketed fresh sweetpotato roots and processed cassava products (makopa and udaga) (Working title – thesis awaiting final comment from supervisors at Sokoine University)., Sokoine University of Agriculture, Morogoro, Tanzania.

Follow-up dissemination planned

A number of scientific papers have been submitted. It is hoped that these will be published in the near future.

The project collaborators will promote the outputs of the project where possible through their normal activities. Additional promotion of the project activities will be possible through Project R7498.

Annex 1. Project memorandum - Improving the quality and value of non-grain starch staples

Narrative Summary (NS)	Measurable Indicators (OVI)	Means of Verification (MOV)	Assumptions
Goal 1. Non-grain starch staple handling, marketing and credit systems improved	1. - CIP, CIAT, INIBAP and/or IITA utilising research outputs in core programmes by 2000. - By 2005 at least one NGO project in an NRD core country using technologies generated. - Value of commodities increased in target areas of NRD core countries by 10% by 2005.	1 - Reports of target institutions. - National production statistics. - Evaluation of Crops Post Harvest Programme. - Research programme reports. - Monitoring against baseline data.	1 Enabling environment (policies, institutions, markets, incentives) for widespread adoption of new technologies and strategies exists.
Purpose 1. Improved quality and handling systems developed and promoted. (Also with relevance to "New market opportunities exploited")	1. - Strategies for optimising quality of 2 NGSS developed and promoted in 2 target countries by March 1999.	1. - Research Programme reports. - Dissemination publications. - Reports of target institutions.	1. - Target institutions invest in uptake of research results. - Quality assurance is an integral part of all parts of Purposes 3 and 4 of the Crop Post-Harvest Programme and will be treated as such.
Outputs 1. Root and tuber crop commodity systems assessed with respect to quality /value relationships and likely changes in demand	1. Marketing systems characterised and nature of quality-value relationships established by March 1997.	1. Reports and publications in the scientific literature.	1. - Quality-value relationships exist and are significant.
2. Factors associated with quality deterioration studied and technical improvements tested and disseminated.	2.1 Effects of fungal fermentation on consumer perceived quality characteristics established by March 1998. 2.2 Means of achieving desired quality factors during fermentation determined by December 1998. 2.3 Optimal handling practises for sweetpotato established December 1998. 2.4 Sweetpotato handling technologies tested by December 1998. 2.5 Opportunities to address other constraints defined by December 1997.	2. Reports and publications in the scientific literature. PhD thesis.	2. - Cost-benefit analyses of new technologies favourable. - New technologies socially acceptable

Activities			Assumptions
Phase I			
1.1 Secondary data on root crop marketing systems including recent COSCA Phase IV reviewed.			1 weather conditions and other external variables are typical of production system -COSCA data and other data made available. Consensus views from consumers on quality criteria
1.2 Major root crop marketing systems characterised using informal survey techniques.			
1.3 Quality criteria considered by consumers for the major commodities identified.			
1.4 Develop an objective grading system for each commodity to relate quality to economic value			
1.5 Identify points in marketing system where loss in quality and hence value occur.			
1.6 Assess market opportunities and constraints that will emerge in the future as a result of changes in demand.			
<u>Factors controlling the quality of fungally fermented cassava products and possible means of improvement defined.</u>			
2.1 Identify the causes of the changes in quality characteristics associated with fungal fermentation.			
2.2 Optimise fermentation conditions to ensure desired quality changes occur.			
Phase II			
<u>Improved sweetpotato handling techniques developed and tested.</u>			
2.3 Identify optimal handling practice and storage conditions for fresh sweetpotato,			
2.4 Test and disseminate recommendations.			
<u>Technical solution to other constraints identified in output 1 evaluated.</u>			
2.5. Investigate technical solutions for identified constraints.			

Annex 2: List of files on CD ROM

The following appendices are on CD-ROM. This is not a complete list of project outputs as some outputs are not available in an electronic format. All of the project outputs are listed in Report and hard copies are available on request from the project leader. Some of the papers are as submitted to the Journal and may not be exactly as printed because of later editorial adjustments.

Reports on sweetpotato work: copies available from Professor Andrew Westby

File 1: KAPINGA, R,E, REES, D., WESTBY, A., NDUNGURU, G.T., RWIZA, E., TOMLINS, K.I., STATHERS, T., JEREMIAH, S. and MBILINYI, L. (2000a) Increasing the contribution of sweetpotato to sustainable rural livelihoods in Tanzania. Paper presented at the Triennial Symposium of the International Society for Tropical Root Crops, Japan, 10-16 September 2000. Submitted paper.

File 2:: KAPINGA, R,E, REES, D., WESTBY, A., NDUNGURU, G.T., RWIZA, E., TOMLINS, K.I., STATHERS, T., JEREMIAH, S. and MBILINYI, L. (2000b) Increasing the contribution of sweetpotato to sustainable rural livelihoods in Tanzania. Paper presented at the Triennial Symposium of the International Society for Tropical Root Crops, Japan, 10-16 September 2000. Powerpoint presentation.

File 3:: KAPINGA, R., WESTBY, A., RWIZA, E. BAINBRIDGE, Z. and NSANZUGWANKO, A. (1998) Diversification of cassava utilisation in the Lake Zone of Tanzania: a case study. *Tropical Agriculture (Trinidad)* **75**: 125-128.

File 4: KAPINGA, R., WESTBY, A., RWIZA, E., BAINBRIDGE, Z.A., and AMOUR, R. (1999) Stakeholder participation in technology testing and dissemination of cassava diversification in the Lake Zone of Tanzania. In Food Security and crop diversification in SADC countries the role of cassava and sweetpotato. Pp 90-99. Edited by M.O. Akoroda and J,J, Terri, SARRNET, Malawi. Powerpoint presentation.

File 5: NDUNGURU, G., THOMSON, M., WAIDA, R., RWIZA, E. and WESTBY, A.. (1998) Methods for examining the relationship between quality characteristics and economic value of marketed fresh sweetpotato. *Tropical Agriculture (Trinidad)* **75**: 129-133.

File 6: NDUNGURU, G., THOMSON, M., WAIDA, R., RWIZA, E. and WESTBY, A.. (1998) Methods for examining the relationship between quality characteristics and economic value of marketed fresh sweetpotato. *Tropical Agriculture (Trinidad)* **75**: 129-133. Powerpoint presentation

File 7: NDUNGURU, G.T, KAPINGA, R., MTUNDA, K. and WESTBY, A. (1997) Analysis of urban market component of the Collaborative Study of Cassava in Africa. TFNC/TNRCP/NRI Report.

File 8: NDUNGURU, G.T., GRAY, A., KAPINGA, R.E., WESTBY, A. MASHAMBA, F. and KAMALA, R. (1999a) The urban marketing of cassava and cassava products in Tanzania. *African Journal of Root and Tuber Crops* Submitted. (Late draft of paper).

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File 9: NDUNGURU, G.T., THOMSON, M., WAIDA, T.D.R., RWIZA, E., JEREMIAH, S. and WESTBY, A. (1999b) Relationship between quality and economic value of dried cassava products in Mwanza, Tanzania. In Food Security and crop diversification in SADC countries the role of cassava and sweetpotato. Pp 408-414. Edited by M.O. Akoroda and J. Terri, SARRNET, Malawi. Paper as submitted

File 10: NDUNGURU, G.T., TOMLINS, K.I., RWIZA, E. and WESTBY, A. (2000b) Evaluation of methods for reducing postharvest handling losses in sweetpotato in Tanzania. *Tropical Science (submitted)* (Peer reviewed paper).

File 11: NDUNGURU, G.T., TOMLINS, K.I., RWIZA, E. and WESTBY, A. (2000a) Post harvest handling and its influence on the quality and shelf life of sweetpotatoes in Tanzania *Tropical Science (submitted)* (Peer reviewed paper).

File 12: NDUNGURU, G.T., WESTBY, A., GIDAMIS, A. AND TOMLINS, K.I. (2000) Losses in sweetpotato quality during post-harvest handling in Tanzania. Presented at the Fifth Triennial Congress of the African Potato Association. Kampala, Uganda May 29 – June 2 2000. Paper as submitted

File 13: REES, D., KAPINGA, R., MTUNDA, K., CHILOSA, D., RWIZA, E., KILIMA, M., KIOZYA, H. and MUNISI, R. (2001) Effect of damage on market value and shelf-life of sweet potato in urban markets of Tanzania (Joint output from R6507 and R6508)

File 14: SPARRINGA, R.A., KENDALL, M., WESTBY, A. and OWENS, J.D. (2001) Effect of temperature, pH, water activity and carbon dioxide concentration on growth and sporulation NRRL 2710. *To be submitted to Journal of Applied Microbiology. (Latest draft)*

File 15: THOMSON, M., NDUNGURU, G.T., WAIDA, T.D.R., RWIZA, E. and JEREMIAH, S. (1997) The relationship between quality and economic value of fresh sweetpotato and dried cassava products in Mwanza, Tanzania. NRI/TFNC/MoA, Tanzania, Technical Report.

File 16: TOMLINS, K.I., and NDUNGURU, G.T. (1999) Losses in sweetpotato quality at harvest and during the post-harvest handling and transport. Studies in the Dar es Salaam region (low season). Technical Report R2404. Chatham: Natural Resources Institute.

File 17: TOMLINS, K.I., NDUNGURU, G.T. and RWIZA, E. (1998) Losses in sweetpotato quality at harvest and during the post-harvest handling in the Mwanza Region of Tanzania. Technical Report (R2375). Chatham: Natural Resources Institute.

File 18: TOMLINS, K.I., NDUNGURU., G., RWIZA, E. and WESTBY, A. (2000). Post-harvest handling and transport of sweetpotatoes and their influence on quality in Tanzania. *Journal of Horticultural Science and Biotechnology* 75, 586-590 (Peer reviewed paper).

File 19: WESTBY, A. (1999) *Getting to the Roots (and Tubers) of Development.* Inaugural Professorial Lecture. Publisher: University of Greenwich Press (ISBN 1 86166 114 2), Greenwich, UK.

The following outputs are not available in electronic format, but copies can be obtained from the project leader or from The University of Reading in the case of reports authored by them.

KAPINGA, R.E., JEREMIAH, S.C., RWIZA, E.J. MAYONA, C., MTUNDA, K. and KILIMA, M. (1996). Sweetpotato and cassava post-harvest: In: 1996 Annual Report of the Tanzanian National Root and Tuber Crops Programme. TNRCP Report.

KENDALL, M. (1997) "Improving the quality of fungally fermented cassava" Literature review, University of Reading.

KENDALL, M. (1999) *Fungal fermentation of cassava.* MPhil/PhD Transfer Report, University of Reading. 76 pp. (Thesis)

KENDALL, M. (2000) Use of response surface methodology to identify environmental conditions favouring the growth of *Rhizopus stolonifera* over that of *Neurospora sitophila*. Technical Report No. 19, The University of Reading. 14 pp.

KENDALL, M., MSABAHA, R., NDUNGURU, G.T. and OWENS, J.D. (1998) Field studies on udaga fermentation in Tanzania. Technical Report, University of Reading.

KENDALL, M., OWENS, J.D. and WESTBY, A. (1998) Cassava solid substrate fermentation. Poster presented at the Society for General Microbiology Meeting, University of East Anglia, 8 September 1998. (Conference poster)

KENDALL, M.N. (1998) Changes in water activity and moisture content of cassava during simulated sun drying. Project Report. Reading: University of Reading

KENDALL, M.N. and OWENS, J.D. (1998) Effects of environmental conditions on the growth of udaga moulds assessed by response surface methodology. Report No. 17. Reading: University of Reading.

KENDALL, M.N., MSABAHA, R. NDUNGURU, G.T. and OWENS, J.D. (1998) Microbial flora of fermented cassava. Report No. 15. Reading: University of Reading.

SPARRINGA, R.A., KENDALL, M.N. and OWENS, J.D. (1999) Effects of temperature, pH, water activity and carbon dioxide on growth and sporulation of *Rhyzopus oligosporus*. Technical Report No. 18. The University of Reading, Reading. 17 pp. (Internal report).

THOMPSON, M., NDUNGURU, G.T. and RWIZA, E. (1996) Development of methodologies for testing the relationship between quality and economic value for fresh sweetpotato and dried cassava products based on fieldwork performed in Mwanza, Tanzania. NRI/TFNC/TNRCP Report.

THOMPSON, M., NDUNGURU, G.T. and RWIZA, E. (1997) Assessment of quality/value relations for fresh sweetpotato and dried cassava in Mwanza, Dar es Salaam and Mtwara. NRI/TFNC/TNRCP Report.

WESTBY, A., REILLY, P.J.A. and BAINBRIDGE, Z.A. (1997) Review of the effect of fermentation on naturally occurring toxins. *Food Control.* **8,** 329-339.

Annex 3. Methods for examining the relationship between quality characteristics and economic value of marketed fresh sweetpotato

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(3) Department of Research and Training, ARI Ukiriguru, PO Box 1433, Dar es Salaam, Tanzania.

In most urban markets in Tanzania sweetpotatoes are purchased in sacks or bamboo baskets and then sold to consumers in heaps. Heaps are sold at fixed prices which differ in total weight depending on factors such as the size (small, medium, large) and quality of the roots. The actual price of the roots is further complicated by a "top up" of additional roots which is given as part of the sale negotiation process. With respect to quality, sweetpotatoes within each heap may be undamaged or they may have cuts or breaks, be shrivelled or suffer from weevil damage.

Two complementary methodological approaches for assessing the relationship between quality and economic value of fresh sweetpotato are described The first approach used a range of participatory ranking and valuation exercises to gain an impression of the major quality issues, seasonality of marketing and the impact of specific types of quality deterioration on retail value. This was supported by a statistical analysis of heaps of produce being retailed in the market. This second approach allowed the impact of different quality characteristics to be quantified.

Application of these methods is demonstrated through analyses of the impact of different quality characteristics on retail value during low season marketing in Mwanza, Tanzania.

INTRODUCTION

Although sweetpotato (*Ipomoea batatas* (L) Lam.) is a traditional crop of subsistence farmers in Tanzania, the commodity is increasingly being marketed. The major production areas are Lake Zone (66% of national production), Southern Highlands (17%) and Western Zone (10%) (Anon. 1994). It is the third most important crop in terms of calorific value for rural and urban populations in Tanzania (Kavishe 1993). Sweetpotatoes are usually consumed as fresh boiled roots. In urban areas, particularly in Dar es Salaam, they are also roasted or deep fried for consumption as snack foods (Scott 1992). In Mwanza and Tabora Regions, the crop is sometimes processed into *mitchembe* (boiled, dried chips) or *matobolwa* (sun-dried chips).

Little information is available on the marketing systems for sweetpotatoes. The perishability of the fresh tubers is accepted as an important constraint. A survey of farmers undertaken by the National Root and Tuber Crops Programme (Kapinga *et al.* 1995) has drawn attention to the importance of minimising losses by improving post-harvest handling systems.

Marketing systems for sweetpotato are poorly developed with high levels of root damage. Grading and storage are not common. In most urban markets roots are purchased in sacks or bamboo baskets and retailed in heaps. Sacks usually contain ungraded roots and their price is negotiated on a daily basis depending on existing supply and demand conditions. Weighing scales are not normally available and therefore transactions are determined by volume rather than by weight.

Heaps, consisting of 5-7 roots, are sold at fixed prices but they differ in their weight depending on such factors as size, variety and quality. In this study, for simplicity, size is assessed by weight with no account taken of shape. Damage is a complex variable to assess, but can mostly be covered by four categories: breaks, cuts, shrivelling and weevil (*Cylas*) damage. Breaks commonly take place during transport of the produce, cuts occur during harvesting, shrivelling occurs over time as the produce loses water and weevil attack generally starts pre-harvest.

This paper sets out two different, but complementary, methodological approaches for assessing the relationship between the quality and economic value of sweetpotatoes. One is based on participatory data collection involving both traders and consumers and the other uses a statistical analysis of marketed heaps of roots. By

analysing the impact of the different types of damage on value of the produce, it should be possible to identify quality improvements that are most valued in the market.

METHODOLOGY

Participatory methods

Participatory methods rely on the active participation of market traders and consumers in the collection, analysis and interpretation of data. It is possible to generate more detailed information than can be obtained using formal survey methods alone. Kleih *et al.* (1997) gives an overview of participatory approaches to needs identification in root and tuber crops post-harvest systems.

Elaboration of quality criteria
Knowledge of the important quality characteristics of sweetpotato is essential before starting to assess the relationships between quality characteristics and retail value. Previous studies have been undertaken in Tanzania by Kapinga *et al.* (1997). This information was supplemented with opinions gained from informal open discussions with consumers and traders in Mwanza Market.

In this particular study, quality characteristics were divided into criteria associated with variety, damage and size (Table 1). This type of information was very easy to collect by a small team (1-2 people) in less than one day. This very simple approach to data collection provided a rapid means of obtaining an overview of the major quality criteria. Ranking exercises (Kleih *et al.* 1997) could have been used to further understand the importance of these characteristics, but were not considered necessary on this occasion because other exercises were used to relate these variables to retail value.

Sweetpotato marketing calendar
In order to gain an overview of the seasonality of the price quality relationships, a marketing calendar was prepared for each of the markets. The calendar was prepared through a participatory exercise with two market traders using a board and a set of counters such as beans. It was found that the use of two traders facilitated discussion and led to more self-correction of scorings. The involvement of more than two people led to situations that were difficult to manage. By trial and error, it was found that the best way to prepare the matrix was on a board with month on the horizontal axis and price, quantity and quality on the vertical axis. Beans were used to represent relative amounts. Traders were asked to place the appropriate number of beans for each month based on their knowledge of the market. They were encouraged to discuss their decisions and were allowed to change the scores until they were happy with the whole picture. The process was enjoyable for the traders and relatively quick (taking only 20 minutes). From the discussions with the traders, additional information to explain the trends and relationships in the matrix was obtained. An example of a seasonal calendar matrix is given in Table 2. Some of the additional information collected is given below.

The quantity of sweetpotato traded is highest between May and July (Table 2) which is the main harvesting season. Prices are relatively low at this time of year. There is a second lower peak in quantity traded in December that coincides with crop of sweetpotatoes from the paddy fields. Smaller quantities are traded in March and April (early harvest) and August and September (late harvest). Very little is traded in the remaining months since it is only available through in-ground storage and piece-meal harvesting. Produce quality is highest during the main harvest season when prices are low and quantities traded are high. Quality is lowest in September and October when roots have overstayed their optimum harvest time and become rather watery. Prices fall to compensate for the poor quality at this time of year.

The participatory development of seasonal calendars not only gives an overview of the price/quality relationship changes over the year, but also provides additional information (through the explanations given) on the traders' understanding of why these occur. Such additional information would have been very difficult to obtain through formal questionnaire based surveys. The example described above demonstrates that quality changes throughout the season, so this type of information is essential for a full understanding of the quality/value relationships in urban markets.

Participatory valuation of roots of different qualities
Although several approaches were evaluated for collecting participatory valuation data, only the most successful is reported here. The technique used involved creating heaps of sweetpotatoes of the same variety and weight (1.4 kg), but with different quality characteristics (good, with cuts, with breaks and with weevil damage). The

weight of roots selected (1.4 kg) was typical of a Tsh 200 heap. A sample of five traders and 15 customers were asked to rank the four heaps in terms of preference and then asked to value the heaps. For the second part of the exercise, Tsh 200 (the usual price) was assigned to the number one ranked heap and the individuals were asked to assign any one card labelled from Tsh 120 to Tsh 200 (in units of 10 Tsh) to each of the other heaps, bearing in mind their initial rankings.

An example of the data obtained is given in Table 3. Cut and broken roots were valued less than good roots (93% by traders and 85% by consumers of value of good roots for cut roots; 83% by traders and 87% by consumers of value of good roots for broken roots). Sweetpotatoes infested with *Cylas* weevil were valued at 64% of the value of undamaged roots by traders (63% by consumers).

This approach to data collection gives a relatively rapid means of assessing the importance placed by consumers and traders on different types of damage and allows a value to be assigned to the different preferences. The technique was rapid, taking less than one day per market and required only one researcher.

Statistical analysis of heaps of potatoes
The statistically based approach to assessing the relationship between produce quality and value was based on measurements of representative samples of sweetpotato sales. A sale comprises of roots in a heap on display plus additional ones that are given from behind the counter. These extra roots commonly comprise between 10 and 20% of the final weight of the heap and can not be considered insignificant in data analysis. As the additions tend to be of below average quality, this method is a way of selling poorer quality produce whilst displaying the better roots. Heaps sell at fixed prices. There are three major price categories for heaps: small roots, Tsh 100; medium sized roots, Tsh 200; and large roots, Tsh 300.

Five sweetpotato traders in each market was chosen at random. For each trader, three heaps of sweetpotato were chosen for each combination of variety and price. For example, if a trader was displaying three varieties in each of the Tsh 100 and 200 price categories, 18 heaps would be sampled in total. Traders were asked to supply the usual "top-up" from behind the counter for each of the heaps. In order to facilitate subsequent statistical analysis, only heaps of the same variety were sampled. If necessary, traders were asked to arrange heaps accordingly. Each root in each heap was weighed and assessed for damage using the following four criteria: breaks, cuts, shrivelling and weevil infestation. Scores of 0, 1 and 2 representing no, minor and major damage respectively were used. To ensure maximum consistency of data, one member of the team weighed the roots and recorded the data whilst the other assessed levels of damage. A weighted mean score for each damage criterion was calculated based on the weight and score for each root in a heap.

Data were analysed using SPSS (Statistical Package for Social Scientists), a powerful computer package which allows tabulation, regression and other statistical interpretation of results. Selling price per kilogram was calculated for each sampled heap and used to represent 'value'. This variable was compared with various indicators of quality including variety, average potato size and damage as represented by the scores for breaks, cuts, shrivelling, surface weevil and deep weevil attack. Multiple regression analysis using a step-wise approach was used to produce best fit formulae for each of the variables assessed.

The use of the statistically based method allows a quantitative analysis of the effects on value of variety, size, and damage to be made. Analysis of the data has to be done out of the market and interpretations are the responsibility of the scientist without reference to the traders or consumers.

As an example of the use of the method, a survey was undertaken of the four major markets in Mwanza in April 1997 and a total of 184 heaps of roots were sampled. The three most common varieties, locally known as Polista, Njano and Sinia made up 92% of all roots sampled. There were found to be marked differentials in average selling price per kilogram for each of these with Sinia selling at an average premium of 14% above the price of Polista, and Njano selling at a premium of 7% compared to Polista.

Root size had an effect on value. Sweetpotato in the medium size category, selling at Tsh 200 per heap and weighing an average of 223 g each, were found to sell at a 12% premium (on a per kilogram basis) when compared to the smallest size category (selling at Tsh 100 per heap and weighing an average of 109 g). Very large potatoes, selling for Tsh 300 per heap and weighing an average of 392 g, sold at a price per kilogram very similar to the smallest size category. These results suggest that customers prefer medium sized potatoes to very small or very large ones, possibly because very small ones are difficult to peel and give a higher proportion of waste and maybe because very large ones are difficult to handle.

Multiple regression analysis using a step-wise approach was used produced a 'best-fit' formula for Polista variety sweetpotato in Mwanza Central Market of:

$$y = 144.16 - 8.17 \, b - 9.99 \, c$$

where y = selling price per kilogram in Tanzania shilling

  b = weighted average heap score for breaks damage

  c = weighted average heap score for cuts damage

The constant term varies depending on the variety of sweetpotato and the market in which the sweetpotato are sold with a maximum of 168.74 and a minimum of 139.70. The equation does not contain terms for shrivelling or weevil damage. This is because relatively few sweetpotatoes with these types of damage were sampled.

Regression statistics for the data analysed are shown below in Table 4. Damage as measured by cuts and breaks, variety and market location each have a significant impact on the price at which roots are sold. As an illustration of the use of the model, the effect breaks in different markets on price is shown in Table 5.

The statistical analysis of the composition of heaps of roots provides quantitative data on the implication of various quality parameters on price. Both approaches produced similar levels of price reduction for broken roots (analysis of heaps, average 11.4% reduction; participatory approach, 13% for consumers and 17% for traders). Considerable resources are required for the statistically based approach. In the example detailed above, three researchers spent one week in the market collecting data and then a further one week was spent analysing it. Another limitation of the approach is that it dependant upon a reasonable level of all types of damaged roots being available in the market. In the example given above, there were very few weevil infested or shrivelled roots and so no analyses were possible with these variables.

DISCUSSION

The above data analyses illustrate how different methodologies, both participatory and statistically based, can be used to investigate the same relationship, in this case that between the quality and economic value of sweetpotato.

There are advantages and disadvantages to the two types of approach evaluated. Statistical based analysis of heaps allow data gathering in a consistent and concise way, but it can be monotonous and time consuming for both researchers and respondents. This can result in an element of carelessness when recording or giving data. Significant resources are required for field studies and access to a computer. It is also difficult to investigate opinions that are very sensitive or subjective in nature through such approaches. Data analysis is retrospective in nature and opportunities for the confirmation of observations or obtaining additional information are limited.

Participatory methods encourage a greater flexibility of data collection and can open up avenues of experimentation not previously thought of, but can be difficult to apply consistently or produce data that are difficult to summarise. As can be seen from the examples in this paper, participatory methods were significantly faster than the corresponding statistically based analytical approach. This has implications for human and financial resource allocation. It is sometimes necessary for policy decisions to have estimates of numerical relationships between variables and this is sometimes difficult to achieve through the use of participatory methods alone.

Compton *et al.* (1995) discuss the use of rapid survey methods for assessing storage losses of durable commodities and conclude a range of tools should be used to meet the specific objectives of the study. Extensive random surveys (equivalent to statistically based approach in this paper) were only recommended when strictly necessary because of the time and resources required and the amount of time required for data analysis.

Participatory exercises are the most appropriate when we are seeking to obtain in depth explanation of customer and trader opinions on an issue such as product quality. By involving participants in "games" such as the construction of marketing calendars and valuation using monetary cards, interest is generated and people are more likely to give in depth explanations of their preferences. More formal statistical methods are best where a large volume of numeric or simple verbal data is required that can be analysed back in the office. The approach does however lack flexibility. It is possible to adopt both approaches in order benefit from the advantages of each method and to compare the results of each as a cross check on accuracy. This was done during the development of the methodology in this study where the relationship between sweetpotato value and various

damage criteria was investigated. The approaches could be used to study similar relationships for other commodities marketed in a similar manner.

ACKNOWLEDGEMENT

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Table 1. The quality characteristics of sweetpotato.

Variety	Damage	Size
Taste	Breaks	Ease of handling
Starchiness / texture	Cuts	Ease of peeling
Speed of cooking	Shrivelling	Speed of cooking
Skin colour / appearance	Surface weevil	
	Deep weevil	
	Bruising	
	Rotting	

Note: Information was obtained by reviewing previous Tanzanian literature and interviewing market traders and consumers.

Table 4. Accumulated analysis of variance for different variables affecting the quality of sweetpotato.

Variable	Mean sum of squares	Variance ratio	F statistic	Confidence level
Variety	3414.5	10.71	<0.001	>99.9%
Market	1265.4	3.97	0.009	99.1%
Breaks score	1304.2	4.09	0.045	95.5%
Cuts score	1309.4	4.11	0.044	95.6%

Note: n = 184.

Table 5. Estimated selling prices (Tsh/kg) for broken and unbroken Polista sweetpotatoes in each market in Mwanza during April 1997.

Market	No breaks	Bad breaks	% of value of no breaks
Central	144.16	127.82	88.7
Mwaloni	144.38	128.04	88.7
Kirumba	156.31	139.97	89.5
Zimbabwe	139.70	123.36	88.3
Mean			88.6

Table 2. Sweetpotato calendar for Mwaloni Market, Mwanza, Tanzania.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Quantity	*	**	***	*****	******	********	***********	***	**	*	*	*****
Price	****	****	***	**	*	**	**	*	*	*	******	****
Quality	*	**	***	****	*****	*******	*******	*			******	*******

Notes: Number of stars indicate changes in variables from month to month as perceived by two key sweetpotato traders. Stars for quantity and quality give rough indications of changes, but cannot be used to measure absolute values. For prices however, each star represents approximately Tsh 1,000 on the average wholesale price of a sack.

Table 3. An example of market value assessment (Tsh/heap) of sweetpotatoes with different quality criteria

Quality	Trader number					Trader Mean	% Good	Consumer number															Consumer Mean	% of Good
	1	2	3	4	5			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Good	200	200	200	200	200	200	100	200	200	200	200	200	150	200	200	200	190	200	200	200	200	200	196	100
With cuts	180	190	180	190	190	186	93	160	170	190	190	150	130	120	140	150	200	180	190	180	180	170	167	85
With breaks	150	180	140	180	180	166	83	190	180	180	180	130	200	150	180	170	180	170	170	170	160	150	171	87
With weevil damage	130	120	120	150	120	128	64	140	120	120	120	120	120	130	120	120	120	130	130	120	120	120	123	63

1 **Annex 4. Effect of damage on market value and shelf-life of sweet potato in urban**

2 **markets of Tanzania.**

3

4 Running title: Sweet potato market damage.

5

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12 Morogoro, Tanzania.

13

14 **Abstract**

15 Sweet potato is an important staple crop in Tanzania, grown mainly for home

16 consumption, but marketing is becoming increasingly important. The short shelf-life is a

17 major constraint for marketing. This study assessed damage when the roots arrive at

18 market and established which forms of damage affect the shelf-life. Breakages, cuts,

19 infestation by weevils (*Cylas* spp.), rotting and superficial damage were assessed. 41 to

20 93% of roots arriving at urban markets were damaged corresponding to a loss in

21 economic value of 11 to 36%. Damaged roots had a shorter shelf-life due to increased

22 fresh weight loss and rotting. For six samplings during the low season the damage

23 reduced shelf-life by 13 to 46%.

24

25   Keywords: Sweet potato, handling, damage, shelf-life, weight loss

26

27 **Introduction**

28

29 Sweet potato is an important crop in East Africa, where its short growing season allows it

30 to be grown between long dry seasons. In Tanzania, it is produced in many areas of the

31 country. Production is generally on a small scale, and primarily for home consumption

32 (Kapinga *et al.* 1995). There is increased interest in marketing and several surveys of this

33 have been undertaken (Kapinga *et al.* 1997, Ndunguru *et al.* 1998, Tomlins *et al.* 2000,

34 Thomson *et al.* 1997). In several areas such as those surrounding Dar es Salaam and

35 Mwanza, production is focused primarily on marketing in the urban centres. Thus, in

36 addition to its role as a food crop, sweet potato has great potential as a source of income.

37 Given its low need for inputs, and as it is usually regarded as a women's crop (Kapinga *et*

38 *al.* 1995), it is likely to be especially valuable in helping the less privileged sectors of the

39 community. The short shelf-life of fresh sweet potatoes (7-10 days) is a major limitation

40 to marketing (Kapinga *et al.* 1995), and is exacerbated by poor handling during transport

41 and storage in the markets.

42

43 This paper describes a study carried out in 1996 and 1997 to assess the extent and types

44 of damage for sweet potatoes when they arrive at market and its economic implications,

45 and to establish which are the most serious forms of damage affecting the shelf-life.

46

47 **Materials and Methods**

48

49   Observations were made in Dar es Salaam, Morogoro and Mwanza, and also on Ukerewe

50   Island, a sweet potato supply area, during months of peak and low supply.

51

52   For each urban centre, samples of wholesale sweet potatoes were collected twice in each

53   of the high and low seasons of sweet potato supply (Table 1). For each sampling, three

54   sacks of roots were bought as they arrived at the market, prior to any form of sorting by

55   traders (for Mwanza, high season 1, only two sacks were bought). Each sack was treated as

56   a separate replicate throughout the experiment. The roots of each sack were sorted into:

57   undamaged, roots with superficial damage (scuffing) only, and roots with more serious

58   damage. The last category was further classified as broken, cut, weevil (*Cylas* spp.) infested

59   or rotting. Many roots suffered from more than one form of damage, but each was

60   classified on the most obvious form. When this was doubtful classification was in the

61   order: rotting, *Cylas* infested, broken, cut (determined by the seriousness of the damage in

62   economic terms). The weight of roots in each class was recorded for each sack.

63

64   For each damage category, 15 roots were selected from each sack, and placed into separate

65   sacks (clean polypropylene fertiliser bags) for storage. For any categories with less that 15

66   roots, as many as possible were included. During storage, the sacks were kept open (rolled

67   down to half height), in a well ventilated room. The extent of root deterioration was

68   assessed weekly in terms of rotting and loss of fresh weight.

69

70   Rotting was scored on the extent observed on the external surface: 1: 0%, 2: 1-25%, 3: 26-

71   50%, 4: 51-75% and 5: 76-100%. After each assessment, those roots that scored 4 or 5

72   were discarded. In subsequent weeks the previously discarded roots were still included with

73   a score of 5 when the overall mean score was calculated.

74   Fresh weight loss was assessed by marking six random roots in each sack at the start of the

75   trial and recording their weights weekly.. Where roots were discarded due to rotting, only

76   the remaining roots were considered when calculating the mean percentage weight loss.

77

78   **Results and Discussion**

79   Table 1 summarises the background information for the markets studied. For all three

80   centres, the area from which sweet potatoes are supplied varies by season. The distance

81   of the supply area and the mode of transport are likely to affect the damage incurred by

82   roots during transport. The main cultivars marketed also vary with the supply area (Table

83   1), and the characteristics of the cultivars are in Table 2.

84

85   Figure 1 summarises the damage observed. In almost all cases insect infestation was due

86   to the larvae of sweet potato weevils (*Cylas* spp.), which burrow deep into the root, and

87   are a serious prblem worldwide (Chalfant *et al.,* 1990; Sutherland, 1986). Levels of

88   damage were variable, but were generally high with 44 – 67% seriously damaged roots

89   and total damage of 49 - 93%. There was a clear seasonal effect in Morogoro with more

90   damage, mainly rotting, in the low season, but such clear seasonality was not observed in

91   Dar es Salaam or Mwanza. The roots sampled from the rural market on Ukerewe Island

92   showed the least damage.

93

94   In studies in Mwanza, Ndunguru *et al.* (1998) found that the decrease in market value for

95   different forms of damage was: rotten 100%, *Cylas*-infested 55%, broken 25%, cut 28%,

96   with no effect of superficial damage. From these values, we estimated that the loss in

97   market value due to damage at each location was 11 – 36% (Table 3). In Dar es Salaam

98   and Mwanza the greatest loss in value was in breakages, while in Morogoro *Cylas*

99   infestation and breakages were both important in the high season, rotting and *Cylas*

100   infestation in the low season. The different forms of damage reflect the stage in the

101   handling chain at which they originate, so the data obtained could indicate possible

102   improvements in the system. *Cylas* infestation originates in the field,   cuts are caused by

103   hoes during harvesting, while breakages and superficial damage mostly result from post-

104   harvest handling. Rotting is a secondary effect, as any form of damage makes a root more

105   susceptible to pathogenic attack (Clark, 1992).

106

107   The economic analysis suggests that, in Dar es Salaam and Mwanza, considerable benefit

108   would be achieved by improving handling after harvest and during transport to prevent

109   breakage of roots. Breakages were 20 - 37% in Mwanza and 35 – 55% in Dar es Salaam,

110   where roots are often transported long distances by road, and this seems to be when most

111   breakages occur. The lowest level of breakages was on Ukerewe Island where roots were

112   transported only short distances. However, cuts during harvesting are likely to increase

113   the rate of breakage during transport. In Morogoro, rotting had serious economic effects

114   on market value, as did infestation by sweet potato weevil , the latter even at low levels as

115   roots develop an unacceptable bitter taste. Farmers usually discard any roots with signs

116   of *Cylas* infestation, but despite this, we observed more that 10% of infested roots in

117   seven of the eleven sample sets.

118

119   The main forms of deterioration of sweet potatoes under normal marketing conditions in

120   Tanzania are weight loss and rotting (Rees *et al.*, 1998), and the relative importance of

121   these depends on storage temperature, humidity, and growth conditions. In this study,

122   roots were stored in open sacks to simulate the conditions under which they would

123   normally be stored during marketing or in the home after sale. Figure 2 shows the

124   weight loss and rotting of roots classified as undamaged for all six samplings undertaken

125   during the low season. The rates of deterioration do vary, but the weight loss was higher

126   than anticipated, 10 - 17% over seven days, and 67% over three weeks in one case

127   (Morogoro, low season 2). The rates of weight loss and rotting in this case are in Figure

128   3. Weight loss differed significantly among damage classes at 7 and 14 days, but not 21

129   days. Least significant differences indicate that the undamaged roots lose weight more

130   slowly than the damaged roots of all classes, including superficial damage. For rotting

131   the undamaged roots had rotted less rapidly after 21 days but there was no significant

132   difference after 7 or 14 days. Kushman (1975) and Strikeleather and Harrell (1990)

133   showed that damage to sweet potato results in increased rates of weight loss and rotting.

134

135   Tables 4 and 5 summarise the low season data for weight loss and rotting after 7 days for

136   all six low season samplings. Undamaged roots lose weight more slowly than damaged,

137   but there were no clear differences between the types of damage. Superficial damage has

138   as significant an effect on shelf-life as the other forms of damage. The data for rotting are

139   generally consistent with those for weight loss, except that roots with only superficial

140   damage do not rot significantly more quickly.

141

142   Roots may be considered unmarketable after a substantial weight loss. In Kenya a weight

143   loss of 20 – 30 % results in loss in marketability (Q. van Oirschot *pers. Comm.*). Our data

144   for seven days show that damage causes a 1.6 - 1.9 fold increase in rate of weight loss

145   which indicates a decrease in shelf-life to 53-62% compared to the undamaged roots

146   (assuming a constant rate of weight loss). This information, together with the

147   observation that 35 - 93% of roots were damaged, indicates that bad handling practices

148   not only reduce the market value of roots, but also have a significant effect on root shelf-

149   life. It can be estimated that for the cases considered, damage caused a 13 – 46%

150   reduction in shelf-life.

151

152   **Acknowledgement**

153

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Table 1: Markets and sampling seasons.

Location	Season	Time of sampling	Markets sampled	Main supply area (distance and means of transport)	Main cultivar
Dar es Salaam	High 1	Late June 1996	Tandale	Gairo (350 Km by road)	Kasimama
	High 2	Late August 1996		Bagamoyo (75 Km by road) Kigambone (<50 Km by sea)	Kasimama Kanada
	Low 1	January 1997		Zanzibar (100 Km by sea)	Name unknown
	Low 2	April 1997		Zanzibar (100 Km by sea)	Name unknown
Morogoro	High 1	June 1996	Central (2 sacks) Saba saba (1 sack)	Gairo (150 Km by road)	Kasimama
	High 2	July 1996		Gairo (150 Km by road)	Kasimama
	Low 1	November 1996		Ifakara (250 Km by road)	Chanzuru
	Low 2	December 1996		Ifakara (250 Km by road)	Chanzuru
Mwanza	High 1	April 1996	Kirumba	L. Victoria Islands (100 Km by boat)	Sinia B
	High 2	May 1996		Various (by boat and road)	Mixed
	Low 1	February 1997		Various (by boat and road)	Mixed
	Low 2	March 1997		Various (by boat and road)	Mixed
Ukerewe Island		April 1996	Ukerewe Central, Ukerewe Soko Mshenzi	Local supplies Transported short distances by various means	Sinia B

Table 2: Characteristics of sweet potato cultivars included in this study.

Cultivar name	Cultivar characteristics
Kasimama	Cream skin, cream flesh, moderate dry matter content Grown widely throughout East Africa (also known as SPN/0)
Kanada	Cream skin, yellow flesh, moderate dry matter content
Cultivars from Zanzibar Name unknown	Cream skin, cream flesh, low dry matter content
Chanzuru	Cream skin, white flesh, moderate dry matter content
Sinia B	Purple skin, yellow flesh, high dry matter content

Table 3: Loss in market value (%) due to damage (from data given by Ndunguru *et al.* 1998).

Season	Dar es Salaam	Morogoro	Mwanza	Ukerewe
High 1	25	15	25	
High 2	16	15	11	
Low 1	15	35	17	
Low 2	18	36	21	
				5

Table 4: The effect of damage on weight loss.

Sampling location	Season	% weight loss during 7 days of storage				
		Undamaged	Superficial damage		Serious damage	
				Cut	Broken	*Cylas* damage
Dar es Salaam	Low 1	11.8	n.d.	16.5	17.6	18.8
	Low 2	12.2	14.3	15.0	13.4	13.1
Morogoro	Low 1	17.4	41.6	26.8	43.1	24.1
	Low 2	15.4	42.7	29.9	45.3	38.6
Mwanza	Low 1	12.2	14.6	12.3	14.5	10.6
	Low 2	10.0	15.1	19.8	19.3	15.6
Mean		13.2	25.6	20.0	25.6	20.1

Damage class effects***, Sampling location/time effect ***, interaction ***
LSD (0.05) among damage means 5.5
LSD (0.05) among damage within locations 10.9

weight loss relative to that of undamaged roots

		Undamaged	Superficial damage		Serious damage	
				Cut	Broken	*Cylas* damage
Dar es Salaam	Low 1	1.0	n.d.	1.4	1.5	1.6
	Low 2	1.0	1.2	1.2	1.1	1.1
Morogoro	Low 1	1.0	2.4	1.6	2.5	1.4
	Low 2	1.0	2.9	2.0	3.0	2.6
Mwanza	Low 1	1.0	1.2	1.0	1.2	0.9
	Low 2	1.0	1.6	2.0	2.0	1.8
Mean		1.0	1.8	1.6	1.9	1.6

Damage class effects***, Sampling location/time effect ***, interaction **
LSD (0.05) among damage means 0.4
LSD (0.05) among damage within locations 0.9

, * significant to 1%, 0.1%

Table 5: The effect of damage on rotting.

Sampling location	Season	Rotting score after 7 days of storage				
		Undamaged	Superficial damage		Serious damage	
				Cut	Broken	*Cylas* damage
Dar es	Low 1	1.95	n.d.	2.75	2.70	2.89
Salaam	Low 2	1.64	1.71	1.87	1.78	1.73
Morogoro	Low 1	1.18	1.49	1.51	1.56	1.24
	Low 2	1.44	1.67	1.60	1.71	1.74
Mwanza	Low 1	1.06	1.39	1.11	1.06	1.58
	Low 2	1.44	1.67	1.83	1.89	2.00
Mean		1.45	1.58	1.78	1.78	1.87

Damage class effects***, Sampling location/time effect ***, interaction **
LSD (0.05) among damage means 0.20
LSD (0.05) among damage within locations 0.40

, * significant to 1%, 0.1%
n.d. no data

Figure 1: Levels and types of damage to marketed sweet potato.

Dar es Salaam

Morogoro

Mwanza

Legend:
- □ Undamaged
- □ Superficial damage
- ▦ Cut
- ■ Broken
- ▦ Cylas infested
- ■ Rotten

Ukerewe (sweet potato growing area)
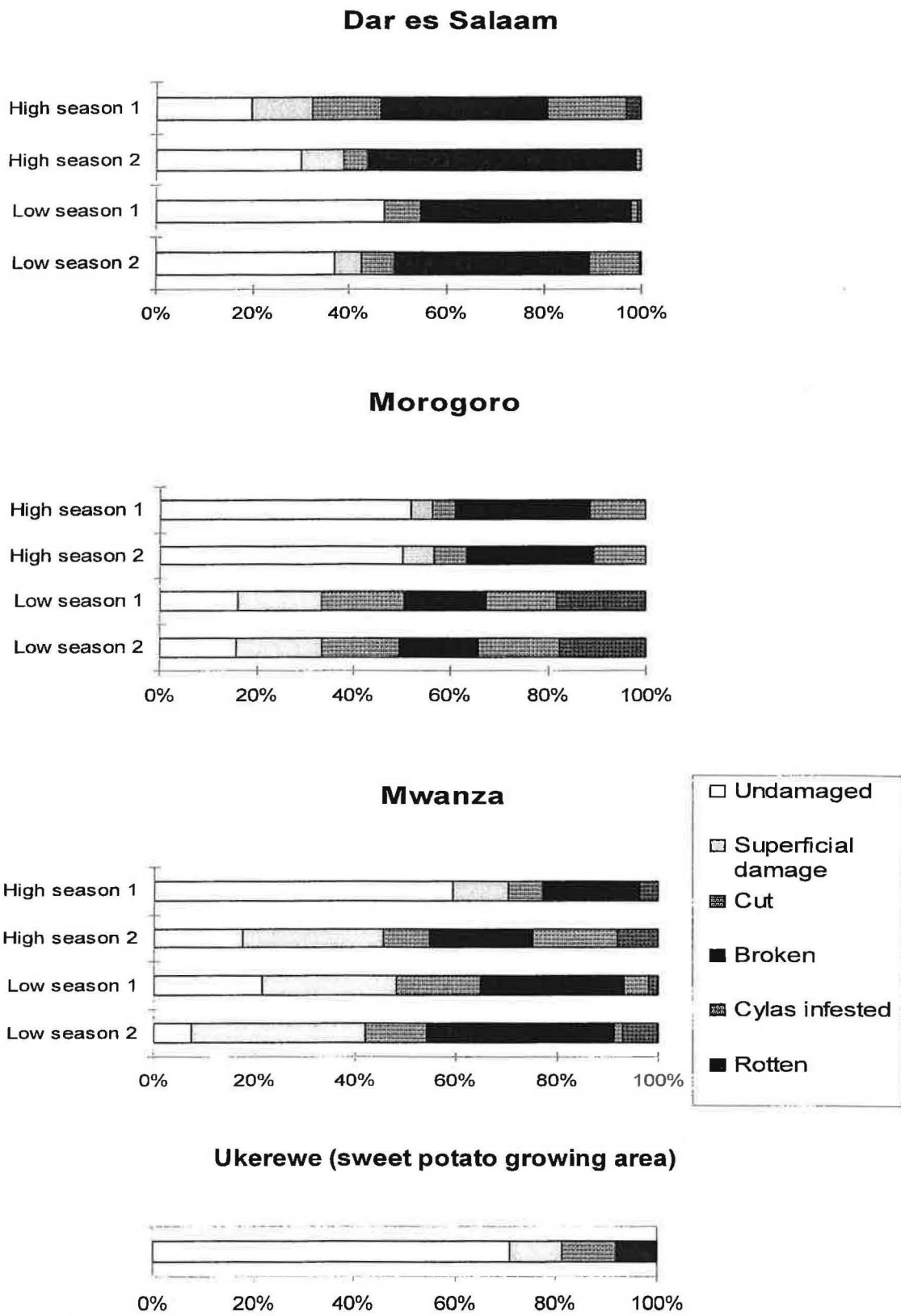
The average sack weights in kg were (high season 1,2, low season 1,2) - Dar es Salaam: 85, 79, 66, 80;

Morogoro: 62, 62, 27, 29; ,Mwanza: n.d., 107, 86, 94.

| | | Standard deviation of % damage levels for three sacks | | | | | |
| | | Serious damage | | | | Superficial damage | Un-damaged |
Location	Season	Rotten	Cylas infested	Broken	Cut		
Dar es Salaam	High 1	2.9	9.1	0.6	4.9	0.0	11.9
	High 2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	Low 1	0.4	0.7	2.2	0.6	n.d.	2.9
	Low 2	0.5	2.6	1.1	1.7	0.3	1.2
Morogoro	High 1	0.0	3.2	6.4	2.3	0.6	2.3
	High 2	0.0	2.9	5.1	1.5	0.6	3.2
	Low 1	0.6	1.1	1.2	2.8	0.9	1.4
	Low 2	0.9	1.3	0.4	1.8	0.8	1.4
Mwanza	High 1	0.9	0.0	7.9	2.5	0.3	6.6
	High 2	3.5	7.2	10.0	5.5	4.6	10.0
	Low 1	2.9	4.7	6.5	7.4	6.3	7.1
	Low 2	2.1	1.5	12.3	2.2	10.9	4.0
Ukerewe Island		0.0	0.0	2.2	2.8	1.3	6.2

Figure 2: Rates of weight loss and rotting for undamaged roots
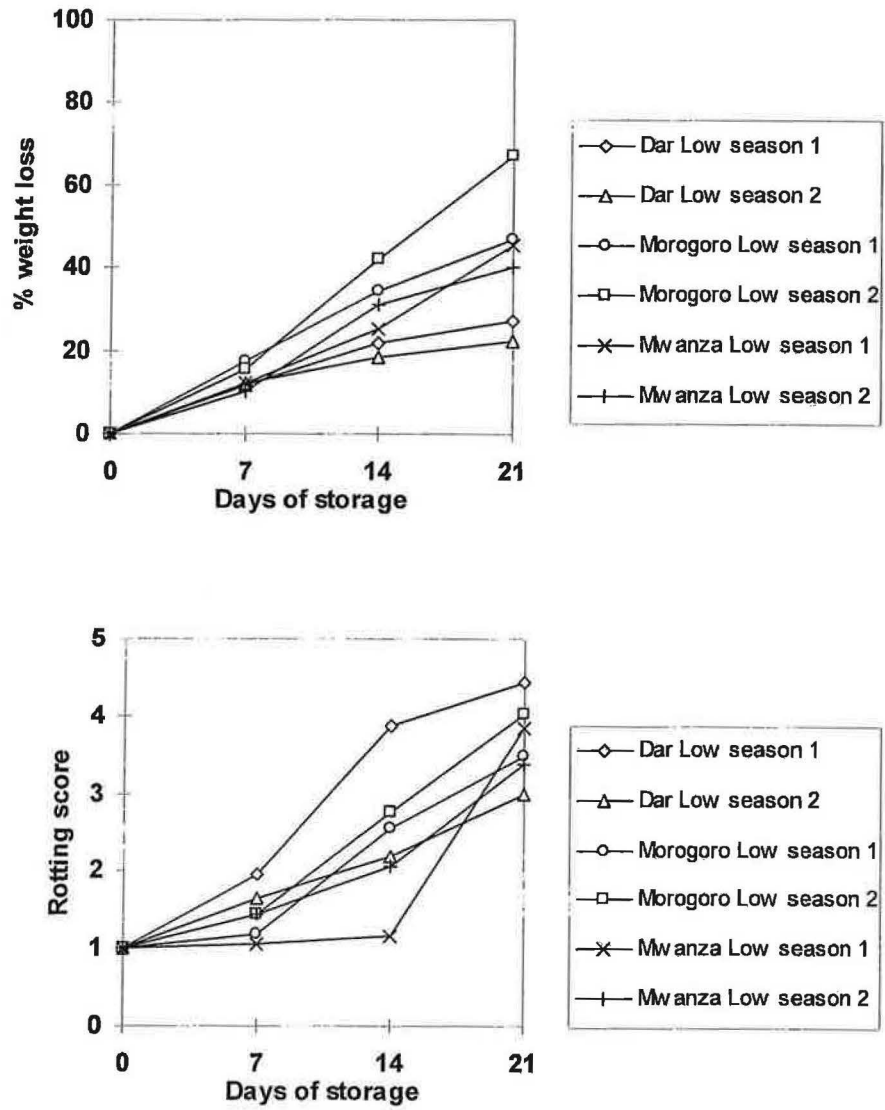
Figure 3: Rates of weight loss and rotting in Morogoro during low Season 2.

l.s.d.. error bars indicate least significant difference.
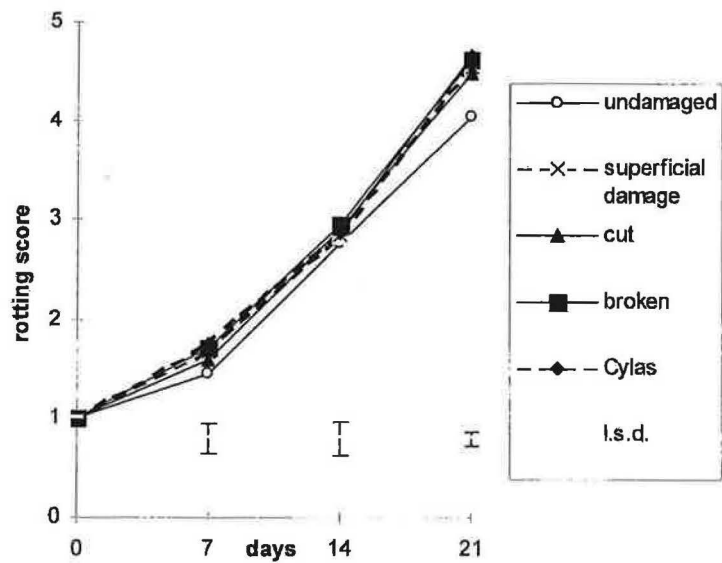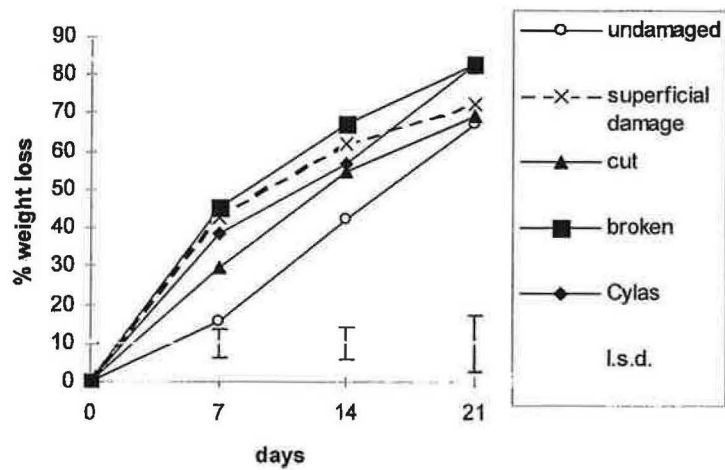
Annex 5. Relationship between quality and economic value of dried cassava products in Mwanza, Tanzania

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Abstract

Dried cassava products are important commodities in the urban markets of Mwanza in north west Tanzania. This study used participatory methodologies to gauge relationships between quality and value of the marketed produce. The two major dried cassava products marketed in Mwanza are *udaga* (a heap fermented product) and *makopa* (a non-fermented product). In both cases, traders and customers prefer a white product because this gives better tasting and more visually appealing *ugali* flour. Perceived valuations show a 30 - 50% discount for dark *udaga* compared with white *udaga*. *Makopa* is valued approximately 10% below *udaga* of similar colour and piece size. Moulds of various colours appear on *udaga* during the rainy months. No visible mould is liked, but some types are disliked more than others. Average valuation discounts are 10 - 15% for orange coloured mould, 20 - 25% for green coloured mould and 35 - 40% for black coloured mould. Consequently, product values might increase if mould was scraped off the roots after prior to sale. Produce is usually ungraded in the markets. The results suggest that if *udaga* was well graded when it entered the market, improved price differentiation could occur. Consumers who prefer better quality could fulfil their requirements by paying more, while those who are satisfied with (or could only afford) poorer quality could pay less.

Introduction

Cassava is an important staple food in several areas of Tanzania. In particular, Lake, Eastern and Southern Zones contain areas of high cassava production (Kapinga *et al.* 1997). A large proportion of the crop is dried to prolong its storage life (COSCA Tanzania 1996).

Little information has been published about the local marketing of root and tuber crops in Tanzania. This study was undertaken to (a) determine the quality criteria which traders and customers use to assess the value of dried cassava products; (b) obtain market value estimates for products of varying quality; and (c) use the "most valued quality" characteristics as the basis for recommending improvements in the post-harvest systems for the products. The study focussed on Mwanza, the second largest urban centre in Tanzania. Analysis of data gathered in 1995 as part of the Collaborative Study of Cassava in Africa (COSCA) identified Mwanza as an important dried cassava trading centre, particularly for fermented dried cassava (Ndunguru *et al.* 1997).

Background information

The main cassava products in Mwanza are known locally as *udaga* and *makopa*. *Udaga* is normally used to describe fermented dried cassava, but is occasionally used for all dried cassava products in small pieces. *Makopa* is generally used to describe non-fermented dried cassava, but sometimes refers to any dried cassava product in large pieces. In this paper, *udaga* is used to describe any fermented cassava product whilst *makopa* refers to the unfermented product.

During the production process for *makopa*, cassava roots are typically peeled and sun dried for 3 to 5 days or even longer. The roots are then broken, packed into sacks and marketed. For *udaga*, roots are peeled and partially sun dried for only 1 to 2 days. The sun-dried roots are heaped, covered with grass and left to ferment for 5 to 7 days, normally inside a covered structure. There is then generally a further sun drying stage of 3 to 5 days before the *udaga* is broken, packed into sacks and transported.

Most consumers use *udaga* to make the staple stiff porridge called *ugali* although some is used to make beer. *Makopa* is also used for *ugali*, but as it is not fermented and is not used for alcoholic products. Both *udaga* and *makopa* need to be machine-milled or hand-ground into flour before use in the final product. For *ugali*, most people claim to prefer flour that is as white as possible because darker material is said to produce a bad smelling end product. Some consumers claim that hand-ground *ugali* flour is better than machine-milled flour in terms of taste or texture.

Udaga flour is used either on its own or mixed with maize or sorghum flour. *Makopa* flour is often regarded as inferior and is almost always mixed with other types of flour.

Large volumes of dried cassava are sold in Mwanza town, especially at Zimbabwe market, but also at Mwaloni and Kirumba. Produce arrives in sacks by boat or lorry on a sporadic basis, leading to marked daily supply and price fluctuations. As produce is not graded when it arrives at the market, there is a standard price for a sack of dried cassava for any delivery, negotiated by the seller and the buyers depending on overall market conditions. However, buyers inspect each sack before it is unloaded, using a hollow metal rod that allows a sample of the product to be extracted from anywhere in the sack. Buyers look at the colour of the produce in particular, preferring white and disliking darker colouring. They also check for the presence of sand and soil pieces. If the buyer is dissatisfied he will try to negotiate a discount off the standard price.

Traders sell the product by the sack or, more commonly, by the bucket. A standard bucket of dried cassava known as a 'plastic', weighs between 11 and 14 kg depending on the size of pieces and the resulting compactness, although produce is sometimes sold in smaller buckets. Traders claim that each sack is equivalent to an average of seven 'plastics', giving an estimated sack weight of around 75 to 100 kg. Traders sometimes attempt to grade the produce, but often sell buckets of mixed colouring and piece size.

Methodology

This study was conducted in five stages between December 1996 and June 1997. First, the study team tapped into traders' knowledge to produce a calendar of the seasonal relationships between the quality, quantity and price of dried cassava products. Second, the team developed and tested a participatory methodology for assessing traders' and consumers' quality preferences for *ugali* and *makopa*. Third, this methodology was adapted to measure the quality price relationship during the dried cassava low availability season. Fourth, the same exercise was repeated during the peak avialability season. Finally, methodology was specifically to measure the price discounts which traders and consumers attach to dried cassava which has been affected by various types of mould.

Calendar of quality, quantity and price. To gain a quick annual overview of cassava markets, two key traders at Zimbabwe market were asked to complete a calendar matrix for produce quantity, price and quality. The traders were asked to rank each of the three factors on a monthly basis using a board and a bag of beans for counters. It helped to deal with each factor separately, to begin with the month in which the variable was lowest and to work month by month from this point. The process was further facilitated when each bean was assigned a more concrete value such as one lorry load or TShs 1,000. The traders were encouraged to explain the trends and relationships between variables and to make adjustments to the rankings as they proceeded. In this way, the exercise generated very valuable incites to the seasonality of market conditions.

Initial preference exercise. As a first step in the analysis of quality, 10 buckets of dried cassava products were taken from Zimbabwe market, three each from sacks of white, medium and dark coloured *udaga*, and one from a sack of *makopa*. Care was taken to ensure that the bags contained a uniform colouring throughout and that there was no evidence of product mixing. For each grade of *udaga*, the three buckets were emptied, re-sorted and refilled, one with fine pieces, one with large pieces and one with a mixture of piece size. As the *makopa* on display was fairly uniform in terms of both colour and piece size, only one bucket was sampled. The 10 buckets were labelled and various sub-group ranking exercises performed among a sample of three traders and three customers.

Low season, high season and rainy season valuations. Three separate experiments were performed at different times of the year to assign valuations to selected quality characteristics and preferences. Note

that general inflation was quite high (more than 20%) over the period covered so it is impractical to compare absolute prices from one season to the next.

Low season valuations. The first of the experiments took place in December 1996 after the short rains when quantities of dried cassava were low. Three dried cassava traders and 15 customers in Zimbabwe market were asked to estimate the values of ten sample buckets, arranged into three groups of same piece size but different colour.

Wet season valuations. The second experiment was performed in April 1997 and focussed specifically on moulds. These are commonly found during the rainy season. Three colours of mould were seen on dried cassava - orange, green and black. A black mould commonly grows during heap fermentation of the roots. This is sometimes scraped off the roots before packing and transportation. Although none was seen, a white mould can sometimes grow during fermentation, possibly being the initial stage of black mould growth. An orange mould grows if the product is not well dried before the fermentation process starts. This can also be scraped off before packing. A green mould develops on dried cassava that is not deliberately fermented, but which gets wet during storage or transport. A sack of dried cassava arriving at the market can contain products bearing all types of mould. As previously noted, there is generally little grading of dried cassava and traders often mix products purchased from different farmers and produced under different conditions.

To obtain value perceptions of different moulds, four similar sized pieces of cassava were selected, one having orange mould, one with green, one with black and one without any mould. A sample of 5 traders and 10 customers were requested to rank each of the four pieces on the basis of personal preference and to explain their reasons. Participants were then asked how much they would be prepared to sell or buy a bucket of dried cassava for if all the product were of the same quality as each individual piece.

Peak season valuations. A final valuation exercise was performed in June 1997, a month in which there is much more dried cassava in the market place. This time, the methodology was simplified to include only five samples of produce - fine white *udaga*, large-pieced white *udaga*, fine dark *udaga*, large-pieced dark *udaga* and *makopa*, arranged in small buckets. Produce of intermediate colour and mixed piece size was excluded so as to focus more specifically on the extremes of quality. It was possible to find more traders at this time of the year, so a sample of 7 traders and 13 customers were asked to rank the five samples in terms of preference and then to give a valuation of the produce for a large plastic bucket.

Results and Discussion

Calendar of quality, quantity and price. The results of the participatory quality, quantity and price assessments are represented in Chart 1. Quantities traded are lowest between November and April, rise to a peak between June and September (when most cassava is harvested) and then fall. Estimates suggest that peak volumes are three or four times the low season figures. Prices bear a very close relationship to quantity with lowest prices at harvest time and highest prices between November and February, approximately double the peak season levels. Trends in product quality follows trends in quantity very closely. This is because most cassava is harvested in the dry season when dried cassava products are less spoiled by rain. Little is harvested when it is raining and the quality of the dried product declines.

Taking an annual perspective, there is a negative correlation between product price and product quality. Prices are highest when the quality is the worst and lowest when quality is best. At any given time however, a better quality product can be expected to be valued more higher than a lower quality one.

Initial preference exercise. Discussions with a sample of traders and customers together with visual inspections of produce suggest that the two most important quality attributes for dried cassava are colour and piece size.

The ranking exercises suggested that for both traders and customers there is a consistent difference in perceptions of dried cassava quality in relation to colour, with whiter products / grades being preferred to darker ones. Preferences based on piece size are less consistent.

Both colour and piece size can have an impact on product preferences. All six people ranked the three buckets of fine *udaga* in exactly the same order, i.e. white, then medium and then dark. The major determinant of *udaga* preference therefore appears to be colouring of the product with whiter grades preferred. There was also agreement on the ranking of large piece products. Everyone ranked large white *udaga* and *makopa* ahead of large medium coloured *udaga*, followed by large dark *udaga*.

Rankings among individual colours of *udaga* were much more variable. Some people prefer large pieces and some people fine ones within a given colour category. There appears to be a trade-off for customers between the greater weight contained in a bucket of denser packed finer material and the higher chance of sand/dirt contamination which can to some extent be disguised in these finer grades. However,

for very white *udaga* impurities can be more easily seen and if the product appears to be totally white then fine material is preferred to larger pieces for weight reasons. It should be remembered that all grades are pounded/milled into flour before use.

Low season valuations. The results are summarised in Table 1. The traders readily gave different value judgements for the sample buckets and, as expected from the earlier ranking exercises, whiter products were given the highest values. Customers found it more difficult to assign values and so to assist them they were given a set of 9 cards covering all prices from 800/= to 1600/= in steps of 100/=. This gave a manageable number of cards, one at the current general price for dried cassava products of 1200/=, and four either side. The range also covered the approximate range of prices noted by the traders from 750/= to 1,600/=. Each customer was asked to assess the three sub-groups of buckets in turn and to place one of the value cards on each bucket. All the price cards were carefully displayed before hand so that the customer was fully aware of the range and any three of the 9 cards could be used for each of the three valuation exercises.

The customer valuations are fully consistent with earlier rankings and are also broadly in line with the average trader perceptions of value. The results suggest that customers perceive top grade, white *udaga* to be worth around 200/= more per bucket than the medium colour, which in turn is valued at around 200/= more than the lowest, darkest grade. Dark *udaga* is therefore valued at an average discount of around 30% when compared to the white *udaga*. *Makopa* is consistently valued in-between the top two grades of *udaga*, equivalent to an estimated 10% discount on the value of white *udaga*.

Peak season valuations. The results from this experiment (summarised in Table 2) again show that the whiter the product, the higher the valuation. Trader valuations show an approximate 35% discount for fine dark *udaga* when compared with the fine white product, while customers give around a 50% discount. These results are slightly above the low season discounts, perhaps reflecting the fact that people can be more choosy when more produce is available. Darkness discounts for the finer product are larger than those for larger pieced variety because fine *udaga* can hide a lot of sand and other dirt. Finally, as with the low season experiments, *makopa* is valued above dark *udaga*, but at an estimated 10% discount below large pieced white *udaga*.

Wet season valuations. The results shown in Table 3 are remarkably consistent between traders and customers. No mould is liked, but there is a definite order of dislike. Average valuation discounts are 10-15% for orange mould, 20-25% for green and 35-40% for black. A few people claim to like the taste of orange mould, saying that it makes nice tasting *ugali*, but no one claimed to like the taste of green or black mould. The discount for black mould is very similar to the discounts recorded during the low and peak season experiments for dark coloured *udaga*.

Conclusions

In Mwanza town, there appears to be a marked preference for dried cassava that is as white as possible. Darker products give *ugali* that is less appealing to the eye and that some say has an inferior taste. These products are generally only bought by brewers, poorer individuals who negotiate discounts or other customers if better quality produce is not available.

The analysis indicates that if *udaga* was well graded when it entered the market, rather than selling at a standard price, significant price differentiation could be made. However such differentiation would only occur if traders have an incentive to grade their produce. Traders would therefore have to ensure that the average price they receive across all grades of processed cassava would be higher than prevails with the ungraded status quo. However, while consumers would pay a higher average price, they would probably accrue two benefits. First, they would have greater choice: Those who would like a better quality product could pay more, and those who would be satisfied with (or could only afford) poorer quality could pay less. Second, the grading system would send price incentives through the marketing chain and hopefully back to the producer. If the incentives are strong enough, the quality of produce available to consumers would improve.

Customers in Mwanza town clearly do not like any of the visible moulds that appear on dried cassava.

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Kapinga R., Mafuru J., Jeremiah S. & Rwiza E. 1997. Status of Cassava in Tanzania: Implications for Future Research and Development. Department of Research and Training, Ministry of Agriculture and Co-operatives, Tanzania. p. 2.

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Table 1: Low season valuations of dried cassava

Product Quality	Average Valuation (TShs per Bucket)	
	Traders	Customers
Udaga, fine, white	1367	1440
Udaga, fine, medium colour	1200	1220
Udaga, fine, dark	1000	993
Udaga, large, white	1267	1360
Udaga, large, medium colour	1167	1140
Udaga, large, dark	900	940
Makopa, large	1167	1293
Udaga, mixed, white	1267	1387
Udaga, mixed, medium colour	1100	1147
Udaga, mixed, dark	917	967

Notes: Data obtained from Zimbabwe market, Mwanza town during December 1996. A bucket is the standard measure for dried cassava, containing 11 to 14 kg depending on the size of pieces. Full sample details are shown in Appendix 1.

Table 2 High season valuations of dried cassava

Product Quality	Average Valuation (TShs per Bucket)	
	Traders	Customers
Udaga, fine, white	2271	2038
Udaga, fine, dark	1500	1146
Udaga, large, white	2129	2062
Udaga, large, dark	1643	1308
Makopa, large	1914	1869

Notes: Data obtained from Zimbabwe market, Mwanza town during June 1997. A bucket is the standard measure for dried cassava, containing 11 to 14 kg depending on the size of pieces.

Table 3: Wet season valuations of dried cassava with different colours of moulds

Product Quality	Average Valuation (TShs per Bucket)	
	Traders	Customers
No mould	2360	2290
Orange mould	2050	2030
Green mould	1810	1790
Black mould	1500	1440

Notes: Data obtained from Zimbabwe market, Mwanza town during April 1997. A bucket is the standard measure for dried cassava, containing 11 to 14 kg depending on the size of pieces. Full sample details are shown in Appendix 3.

Chart 1: Relative relationship between quantity, price and quality for dried cassava entering Zimbabwe market, Mwanza
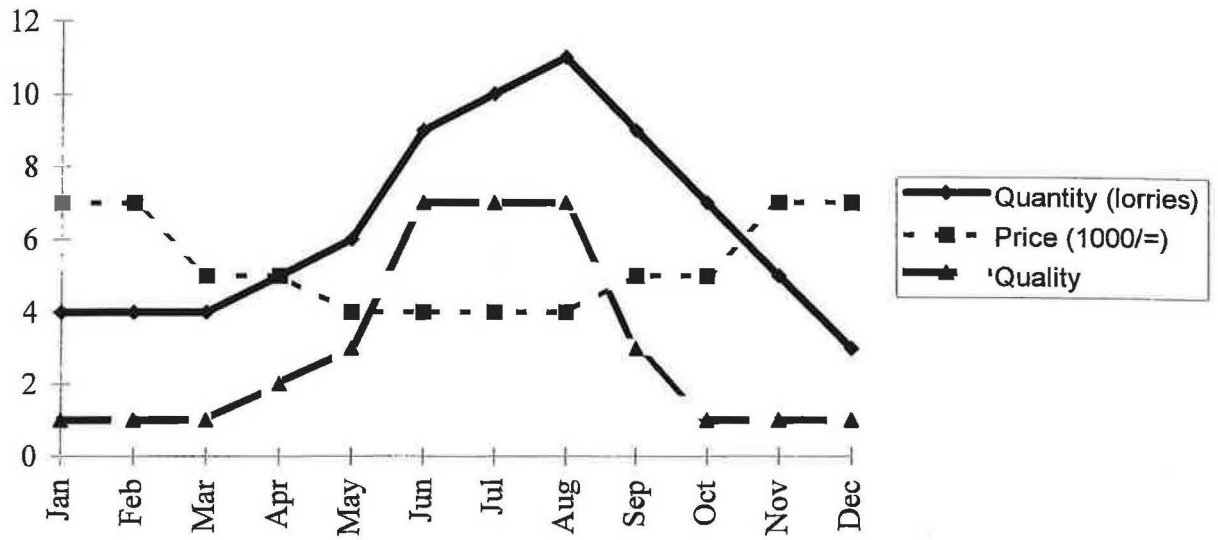
Notes: The chart indicates changes in variables from month to month as perceived by two key dried cassava traders in December 1996. The quality line gives rough indications of changes but cannot be used to measure absolute values. For prices, each scale unit represents approximately 1,000 Tanzanian Shillings on the average wholesale price of a sack. For quantity, each scale unit represents approximately one lorry of average seven tonnes capacity.

Annex 6. Post-harvest handling and transport of sweetpotatoes and their influence on quality in Tanzania.

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SUMMARY

Commercial consignments of sacks of sweetpotatoes (100 kg) were surveyed from harvest to markets at Mwanza and Dar es Salaam in Tanzania. The handling and transport system used resulted in up to 20 per cent of roots in a sack with severe breaks and between 35 per cent and 86 per cent with severe skinning injury. Reductions in market value (due to breakages) could be as high as 13 per cent per sack. Impact loggers located at the centre of sacks were used to continuously monitor shipments. The most severe impacts occurred during unloading and loading from road vehicles and ships. However, multiple regression analysis indicated that a large number of minor impacts between 0.2 and 2 g correlated with skinning injury and broken roots. The impact logger results also indicated that when transported in sacks containing 100 kg of roots, both of the cultivars assessed (Polista and SPN/0) were equally susceptible to skinning injury and root breakage and this was not affected by season. The implications of these findings for improvements to the handling and transport of sweetpotato in Tanzania are discussed.

INTRODUCTION

Sweetpotato (*Ipomoea batatas* (L) Lam) is a traditional crop for subsistence farmers in Tanzania but is now increasing being marketed. The major production areas are the Lake Zone, Southern Highlands and Western Zone. The marketing systems for sweetpotato, however, are poorly developed with high levels of root damage. A survey in Mwanza in the Lake Zone, Tanzania noted a significant reduction in the quality of sweetpotatoes sold in the markets which had implications for market value (Ndunguru *et al.*, 1998; Thomson *et al.*, 1997). Traders and customers gave lower valuations (10 to 30%) when roots were shrivelled, cut or broken.

Monitoring the damage sustained by produce during handling is key to understanding the causes of the losses and developing means of overcoming them. Objective methods for monitoring the handling of fruits and vegetables have been previously reported. Various electronic devices known as 'instrumented or electronic spheres' (Morrow and Ruscitti, 1990; Orr *et al.*, 1994; Thomson and Lopresti 1996; Baheri and Baerdemaeker 1997), 'electronic tubers' (Peters and Leppack 1991; Leppack 1996), 'pressure balls' (Herold *et al.*, 1996) and 'artificial fruits and vegetables' (Anderson 1990) have been used. While these instruments have not been reported in research on sweetpotatoes, they have been used for investigating the mechanised handling of Irish potatoes (*Solanum tuberosum*). They have been used to identify the critical points that affect quality, in the mechanical handling of Irish potatoes and to allow remedial action to be taken (Anderson 1990).

Fresh sweetpotatoes are transported in sacks in Tanzania. This is in contrast to the use of partitioned fibreboard cartons filled with between 13.6 and 18.2 kg roots as recommended by Medlicott (1990) for export. Little is known about the handling and transport of sweetpotatoes and their effect on quality and market value in Tanzania. The purpose of this study was to identify the critical stages in the handling and transport system that affect quality so that low cost interventions can be developed to improve quality for the consumer and improve returns for farmers.
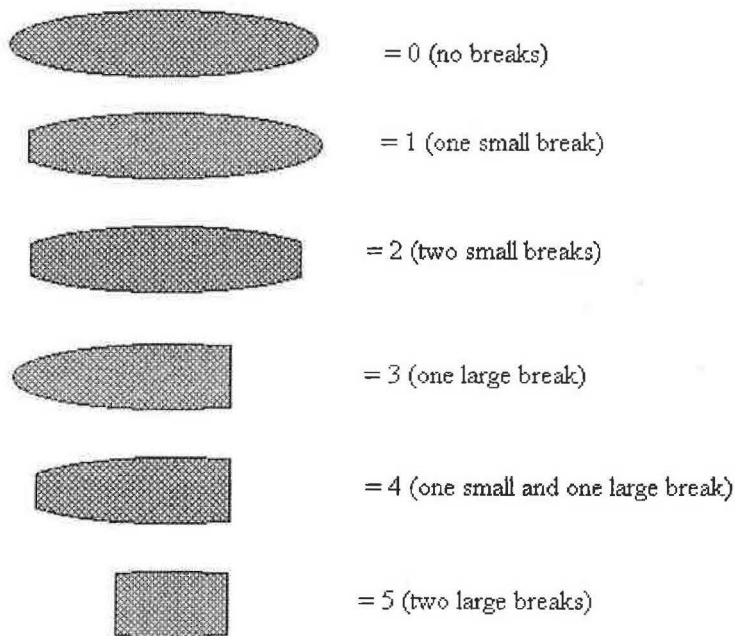
MATERIALS AND METHODS

Sweetpotato samples

Sweetpotato roots of the Polista and SPN/0 cultivars were purchased from commercial farmers in the Lake Zone and from near Morogoro, respectively.

Quality assessment

Post-harvest quality characteristics, at harvest and at stages in the transport chain, were assessed using the methods developed by Ndunguru *et al.* (1998). From each sack or freshly harvested roots, forty sweetpotatoes roots were selected at random and each assessed for shrivelling and skinning injury using a 0 to 5 scale (0, none; 5,severe). Cuts were scored as 0 – none, 1 - minor and 2 - major. Details of the scoring system for broken roots are given in Figure 1. The total score for each type of damage was the sum of the individual scores for each of the 40 roots evaluated.

Figure 1: Scoring system for broken roots.

Surfaces:
= 0 (no breaks)
= 1 (one small break)
= 2 (two small breaks)
= 3 (one large break)
= 4 (one small and one large break)
= 5 (two large breaks)

Surveys of sweetpotatoes transported from the farm to markets at Mwanza (Lake Zone) or Dar es Salaam

Farmers packed 100 kg of sweetpotatoes into polypropylene sacks. A total of six consignments of sweetpotatoes, varying between 2 and 12 sacks, of either the Polista or SPN/0 cultivars were followed during transport from the farm to the market. If the sacks were unloaded during transport, they were sampled to evaluate the quality of the roots.

Dataloggers (RS Components, UK) were used to monitor: impact (Tinytag; acceleration of 0 to 50 g +/- 10%); temperature (Tinytalk II; +/- 0.2°C); and humidity (Tinytalk II; +/- 4%). They were fitted inside a plastic pipe (16 cm long and 6.5 cm diameter) that was approximately the same size as a sweetpotato root and were positioned at the centre of sacks. The pipe prevented unrepresentative movement of the datalogger when inside a sack. The impact dataloggers were set to record the maximum acceleration (g) at either 30 or 60 s intervals and the temperature and humidity dataloggers recorded data at 10 min intervals.

Control sacks, which remained on the farm, were also monitored if sufficient roots were harvested. Otherwise, small samples (20 kg) of roots were carefully wrapped in newspaper and transported in the cab of the vehicle.

Statistical methods

Analysis of variance (ANOVA) and multiple linear regression (stepwise, backward mode, accept criteria F = 0.05, reject criteria F = 0.1) were carried out using SPSS (version 8.0) statistical software.

RESULTS AND DISCUSSION

Sweetpotato roots in both the Lake Zone and Dar es Salaam regions of Tanzania are traditionally transported in polypropylene sacks weighing between 100 kg and 200 kg. Farmers stuff as many roots into a sack as possible because they are sold by volume. Traders or wholesalers will demand a discount if they do not do this. The sacks are usually not large enough to accept the required volume of roots and hence a 'head of roots' is built to the sack by wrapping roots in sweetpotato vines and string. In the Lake Zone skinning damage is acceptable to consumers, but broken, cut and shrivelled roots are known to be a significant factor in reducing the market value by up to 30 per cent (Thomson *et al.* 1997; Ndunguru *et al.*, 1998).

Studies in the Lake Zone

Polista roots, to be sold at markets in Mwanza, were transported from the farm to the shores of Lake Victoria by handcart or bicycle. At the lakeshore, the sacks were loaded onto a ship and transported overnight (9 to 12 hours) to Mwanza. The roots were then transported by light commercial vehicle to markets in the town for sale. The total journey varied between 16 and 30 hours with a mean of 24 hours.

Table 1 shows the mean quality of the sweetpotato roots at each stage in the transport chain during the low (January 1998) and main (July 1998) harvest seasons.

Table 1: Sweetpotato (Polista variety) quality when handled and transported during the low and main seasons in the Lake Zone.

Root damage (total score)	Season	Stage in marketing chain			
		Farm	Lakeshore	Port (Mwanza)	Market (Mwanza)
		Total score (and per cent of roots with severe damage)*			
Broken roots	Main	4 (0)	7 (1)	43 (19)	40 (17)
	Low	16 (4)	20 (9)	33 (16)	44 (21)
Skinning injury	Main	22 (1)	30 (2)	85 (28)	89 (37)
	Low	21 (3)	70 (18)	118 (72)	133 (86)
Cuts	Main	6 (2)	9 (3)	17 (6)	13 (4)
	Low	9 (0)	8 (1)	15 (3)	16 (4)

*The total score is the sum of individual scores of 40 randomly selected roots. In brackets, the percentage of all 40 roots with severe damage (a score of three or greater), is indicated. Low season values are the means of 3 sacks and main season values are the means of 6 sacks.

ANOVA indicated that the occurrence of broken roots and cuts were similar with respect to the season, the only significant effect being increased losses in quality with handling and transportation (P = 0.000). The largest loss in quality occurred between the lakeshore and the port at Mwanza when sacks were loaded and unloaded from the ship and handled at the port. This is therefore a critical point in the transport system. Roots with severe breaks account for about 20 per cent of the roots in a sack (Table 1). Using estimates suggested by Thomson *et al.* (1997) for relating quality to market value, this corresponded to a loss of between 3 and 13 per cent (mean of 9 per cent) in market value per sack.

Skinning injury increased significantly (P = 0.011) during loading and unloading from the ship and was greatest in the low season than in the main season. Those roots with severe skinning injury represented 37 per cent and 86 per cent of roots in a sack in the main and low seasons respectively. Skinning injury, however, has no effect on market value in Tanzania (Thomson *et al.*, 1997).

Thomson *et al.,* (1997) noted a higher incidence of shrivelling in sweetpotatoes sold at markets in Mwanza in the low season. In this study, few incidences of shrivelling were noted in either the low and main season. Shrivelling was probably not a direct result of transport and handling, occurring if roots remained at the farm for too long prior to transport. Delays may occur when the yield is low and farmers wait until sufficient roots have been harvested to fill a sack.

Since the sweetpotatoes were stuffed tightly into the sacks, it was hypothesised that the internal pressure inside a tightly packed sack might contribute to the loss in quality when they were held over a period of time. However, roots that were not transported suffered no loss in quality, which disproved the hypothesis.

Studies during marketing to Dar es Salaam

SPN/0 roots, to be sold at the Tandale market in Dar es Salaam, were transported from commercial farms in the Morogoro Region by light commercial vehicle or truck for a distance of about 300km. The total journey took between 21 and 31 hours (mean of 25.5 hours). Table 2 shows the losses in quality that occurred during the journey.

Table 2: Quality of sweetpotatoes (SPN/0 variety) when transported from the farm (near Morogoro) to markets in Dar es Salaam.

Type of injury	Location in transport system		
	Farm	Market	
		Control (20 kg)	Sack (100 kg)
	Total score (and per cent of roots with severe damage)[*]		
Broken roots	16 (2)	15 (1)	42 (15)
Skinning injury	8 (0)	6 (0)	75 (34)
Cuts	4 (3)	5 (2)	6 (3)

The total score is the sum of individual scores of 40 randomly selected roots. In brackets the per cent of all 40 roots with severe damage (a score of three or greater) is indicated. Values are the means of 2 lots of 40 roots (controls) and 4 sacks. Control samples were individually wrapped in newspaper prior to transport.

ANOVA (P = 0.000) indicated that broken roots and skinning injury (SPN/0 variety) increased with handling during transportation. The mean total score for broken roots increased from 16 at the farm to 42 at the market and this is estimated to represent a loss between 6 and 13 per cent (mean 9 per cent) in market value when calculated using the method of Thomson *et al.* (1997). Handling and transportation had no significant effect on injury to the roots from cuts. If roots with severe (score of 3 or greater) breaks and skinning injury are considered, breaks increased from 2 per cent at harvest to 15 per cent in sacks arriving at the market and severe skinning injury increased from 0 to 34 per cent (Table 2). Control samples, wrapped in newspaper and carried in the cab of the vehicle, showed no increase in broken roots or skinning injury after transport (Table 2).

Use of the impact datalogger to evaluate handling systems

The impact logger provided a low-cost method for comparing the handling of sacks during transport either by road or by ship. While the quality scores indicated a loss in quality, dataloggers measuring impact indicated when the poor handling and transport occurred.

Comparison of sensors and relationship between acceleration (g) and the height that a sack was dropped

The relationship was determined between readings taken from two impact dataloggers inserted in a sack weighing 120 kg when dropped on a firm dirt floor. The curve indicates that the impact recorded increased with the height of the drop (R squared = 0.875 and 0.792). The results were similar for the two dataloggers although the readings are scattered. The scatter in the data is thought to be because of the movement of sweetpotatoes within the sack.

Figure 2: Correlation between impact (g) and height (m) from which a polypropylene sack filled with 120 kg sweetpotatoes was dropped.
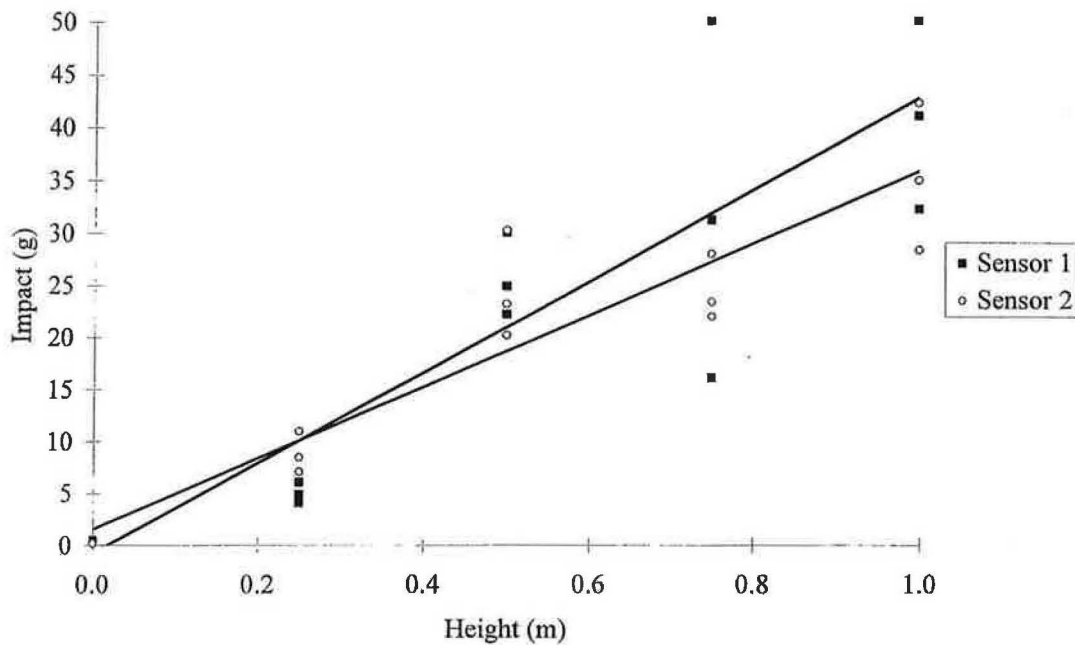
Use of the impact datalogger to compare transport and handling systems

Impact histories for roots transported to Mwanza in the Lake Zone and to Dar es Salaam were different as shown in Figures 3 and 4. In the Lake Zone (Figure 3), where boats are used, the sacks were transported by hand-cart to the Lake Shore, then loaded on the boat (at 8.5 hours), unloaded at the port in Mwanza (at 17.5 hours) and handled at the market (at 19 hours).

For the sack transported by road to Dar es Salaam, the impacts during the first 12 hours are thought to occur when the truck was moving with possible stops at 3, 6 and 10 hours. The period of inactivity between 12 and 18 hours occurred when the vehicle stopped overnight. The impacts after this were associated with unloading and handling of sacks at the market.

For both methods of transport, the largest impacts were recorded at times of loading and unloading.

Figure 3: Example impact history chart for a sack of transported by cart and boat to Mwanza market.
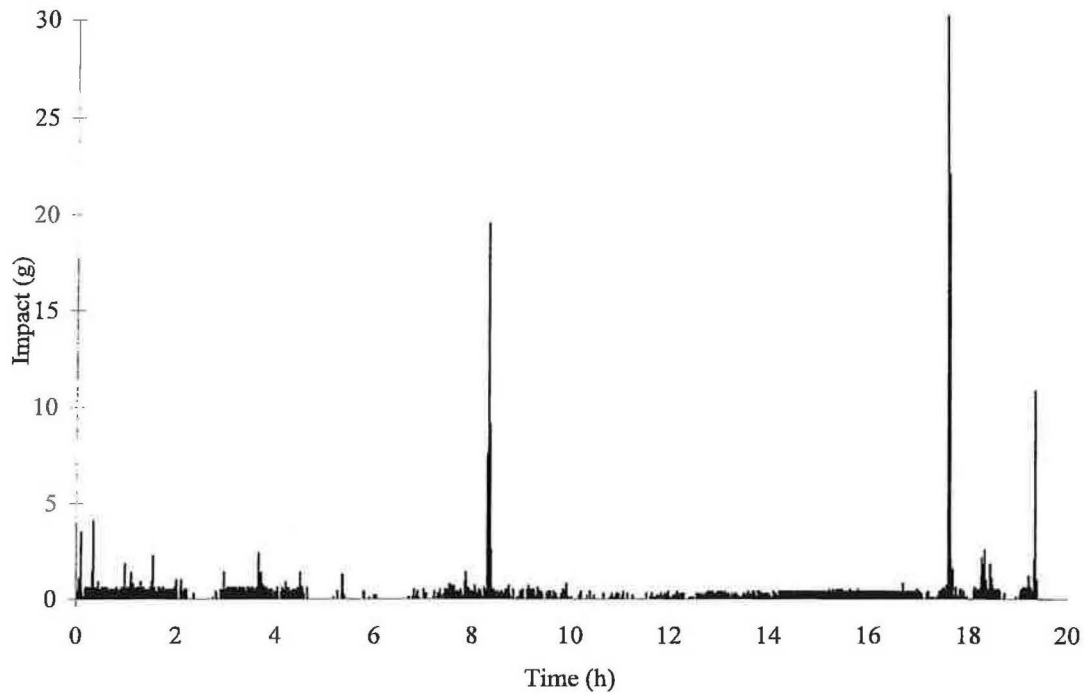
Figure 4: Example impact history chart for a sack transported by truck to Dar es Salaam market.
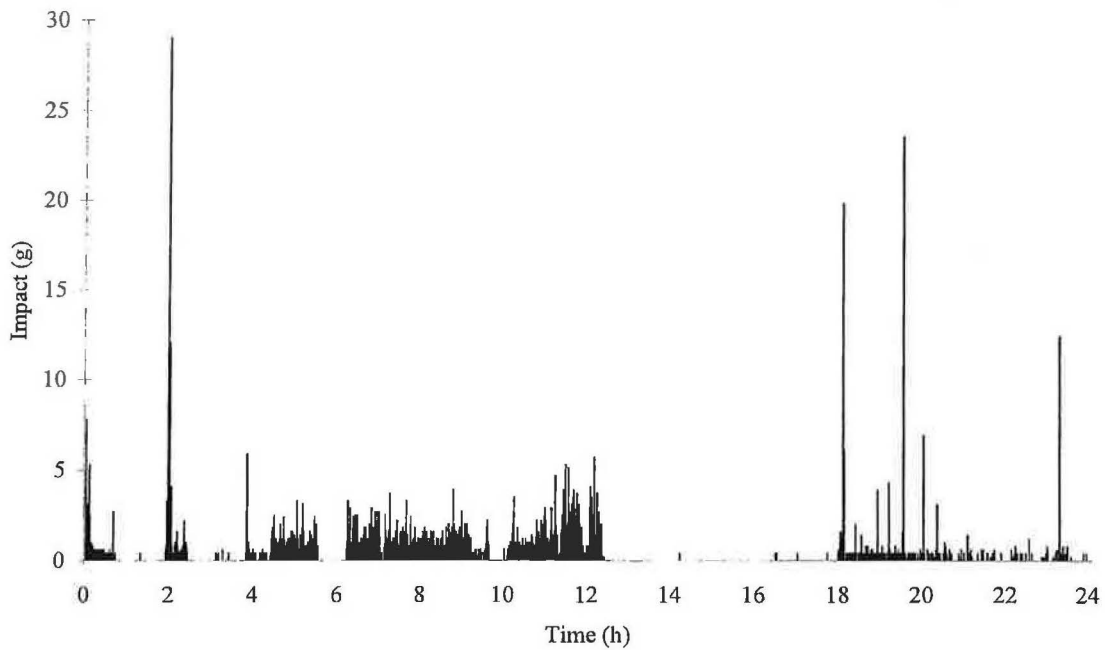
Table 3 illustrates the mean occurrences of impacts for 12 sacks transported to Dar es Salaam and 11 sacks transported to Mwanza in the Lake Zone. The smaller the impact, the greater the occurrence. For sacks transported by road to Dar es Salaam and Mwanza in the Lake Zone, the occurrence of impacts was similar. Considering impacts greater than 20 g (equivalent to a drop height of about 0.5 m), they tended to occur during loading and off-loading from the truck or from the ship and port.

Table 3: Mean occurrence of impacts (by category) for sacks of sweetpotato transported to Dar es Salaam and to Mwanza.

| Impact category (g) | Destination | |
| | Dar es Salaam | Mwanza |
	Number of occurrences*	
0.2 to 2	1205	1121
2 to 5	24	17
5 to 10	5	6
10 to 20	2	2
20 to 30	1	1
30+	0	1

* Values for Dar es Salaam and Mwanza are means of 12 and 11 sacks respectively.

Relationships between impact and injury to sweetpotatoes

The impacts (g) were classified into categories being 0.2 to 2g, 2 to 5g, 5 to 10g, 10 to 20g, 20 to 30g and greater than 30g. Multiple linear regression analysis (backward mode, accept $F = 0.05$, reject $F = 0.01$) indicated that the number of impacts in the category between 0.2 and 2 g significantly correlated with skinning injury (R^2 adjusted = 0.651) and broken roots (R^2 adjusted = 0.407). The scatter plots for skinning injury and broken roots (Figures 5 and 6) suggest that susceptibility to injury was not influenced by cultivar (SPN/0 and Polista) and season (main and low).

The impact sensor appeared to be better for predicting susceptibility to skinning injury that was caused by surface abrasion. The sensor was less effective at predicting broken roots. It is thought that an instrument capable of measuring compression forces might be more suited to predicting this type of injury.

Figure 5: Effect of number of impacts between 0.2 and 2 g on skinning injury for sweetpotatoes transported in 100kg sacks.
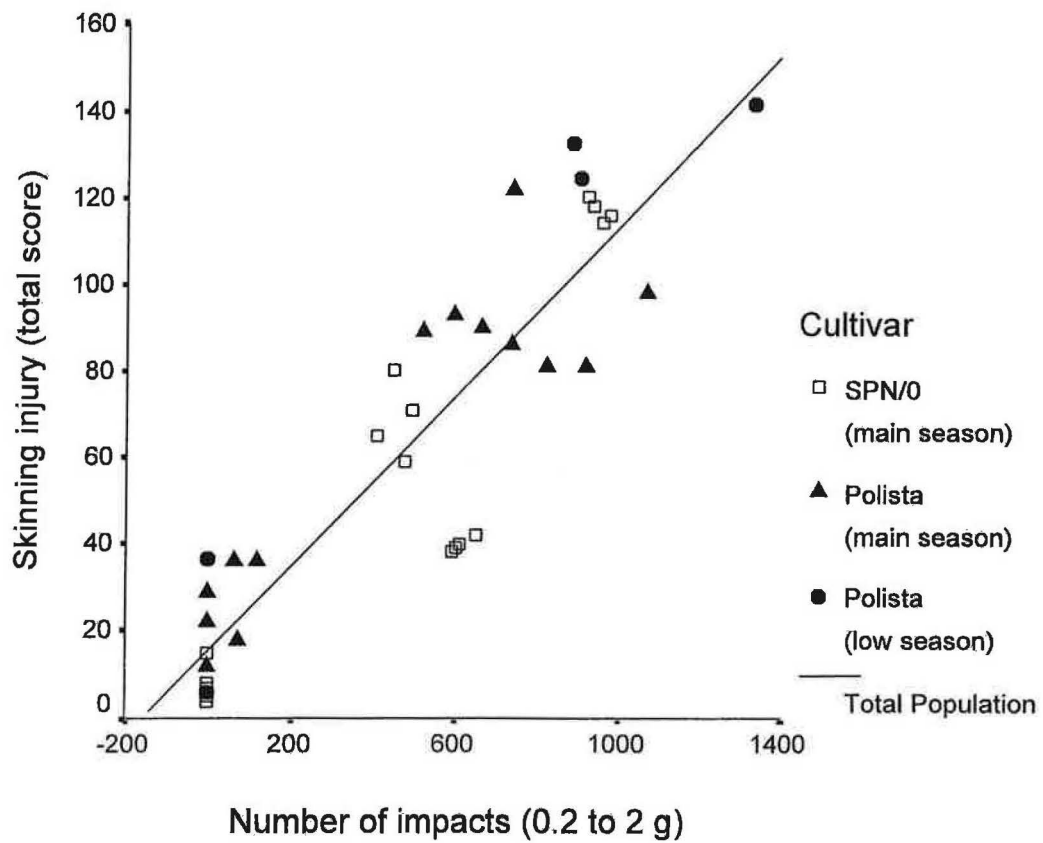
Figure 6: Effect of number of impacts between 0.2 and 2 g on broken roots for sweetpotatoes transported in 100kg sacks.
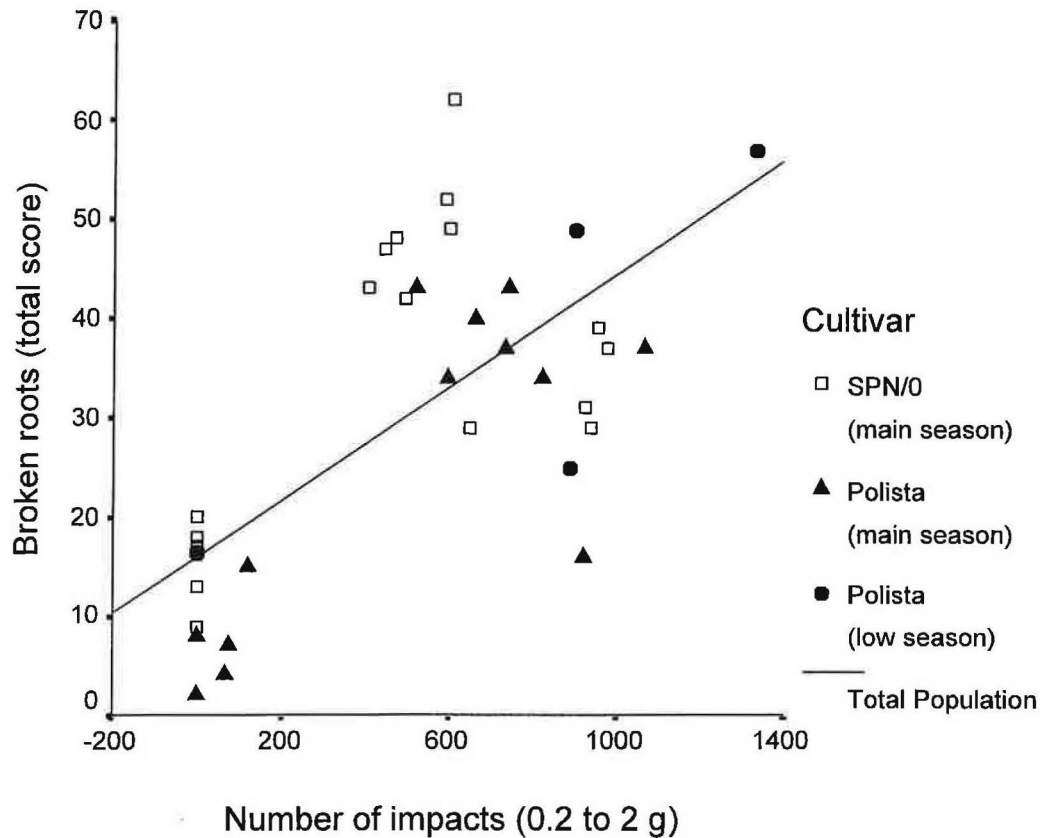
Temperature and humidity inside sacks during handling and transport

Sweetpotatoes generate more heat from respiration than the Irish potato (150W/ton and 50W/ton at 20°C respectively; Anon 1989). Since large quantities of sweetpotatoes were transported in a confined space, the temperature and humidity in the centre of sacks was monitored to determine if detrimental changes occurred. The mean temperature (Figure 7) tended to be more influenced by the ambient temperature than by sweetpotato cultivar; it was cooler in the main harvest season. The mean temperatures at the centre of the sack in the main and low harvest seasons were 23°C and 26°C respectively. The relative humidities in the sacks were similar at 90% or greater. These temperatures and humidities did not appear to be injurious to the quality of the roots during handling and transportation.

Figure 7: Internal temperatures of sacks containing 100 kg sweetpotatoes during transport in two regions of Tanzania
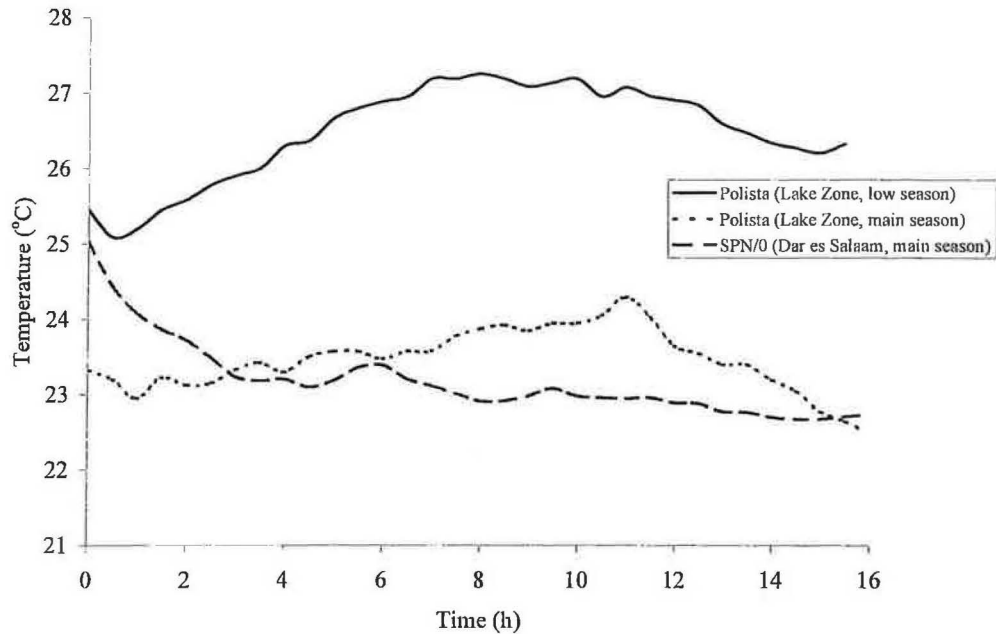
Where: temperatures for SPN/0 (main season) and Polista (main season) and Polista (low season) are means of 12, 4 and 3 sacks respectively

CONCLUSIONS

Commercial consignments of sacks of sweetpotatoes were monitored from harvest to markets in Mwanza or Dar es Salaam. Overall the handling and transport system could result in up to 20 per cent of roots in a sack with severe breaks and between 35 per cent and 86 per cent with severe skinning injury. Using the method for relating quality to value developed by Ndunguru *et al.* (1998), the loss in market value could be as high as 13 per cent per sack.

Impact loggers located at the centre of sacks provided an objective method for continuously monitoring the handling of the produce. The most severe handling occurred during unloading and loading. Sacks transported in the Lake Zone received an average to two impacts of 20g or greater, which is equivalent to a drop from 0.5 m. Sacks transported to Dar es Salaam received an average of one impact of 20 g or greater. Multiple regression analysis indicated that skinning injury and broken roots correlated with minor impacts between 0.2g and 2g.

These studies using impact loggers also provide a useful means of comparing varieties. Regression analysis indicated that for roots handled and transported in 100 kg sacks, both cultivars tested (Polista and SPN/0) were equally susceptible to skinning injury and broken roots and that this was not affected by season. This technique could be used for evaluating other cultivars or alternative packaging systems.

In this paper the major causes of loss in quality of sweetpotato during handling and transport have been identified. Overcoming problems associated with severe handling requires a combination of education of the handlers and in some cases, redesigning of the unloading areas. The effect of minor impacts may be reduced by improved vehicle suspension, improved road conditions, reduction in weight of roots in a sack or changes in packaging material (for example, from polypropylene sacks to cardboard boxes). Changes in practice that are within the financial means of those involved need to be evaluated technically and economically. The data obtained in this study should assist this process.

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Annex 7: Influence of post-harvest handling on the quality and shelf life of sweetpotato (*Ipomoea batatas* (L) Lam)

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Abstract

Sweetpotato is an important food crop in Africa. In Tanzania, sweetpotatoes are traditionally handled and transported in polypropylene sacks that weigh 100 kg or greater, but losses in market value of 13% can occur. The effect of different factors during loading and unloading of sacks (weight, height and number of impacts) on the quality and shelf life of sweetpotato (SPN/0 cultivar) was investigated. Considerable damage, resulting in broken roots, occurred when a sack was dropped from a height of 0.25 m or greater whereas skinning injury steadily increased with greater impact heights. Damage from broken roots and skinning injury increased the more times a sack was dropped. Quality was not influenced by the weight of the sack (50 or 100 kg). Skinning injury and to a lesser extent, broken roots, led to the greatest losses in shelf life (indicated by weight loss) during storage. The use of alternative methods of packaging to reduce handling and pre-harvest treatments (such as pruning prior to harvest) may lead to improved quality but need to be investigated.

Keywords: Sweetpotato, *Ipomoea batatas*, storage, shelf life, postharvest handling, breaks, skinning injury, cuts, weight loss, Africa.

1.   Introduction

In East Africa, sweetpotato (*Ipomoea batatas* (L) Lam) remains an important crop. Production figures for 1998 indicate that it ranks third in importance in relation to 20 other major crops in Uganda and Kenya and seventh in Tanzania (Anon 2000). Handling and transport of sweetpotato can lead to reduced market value, for example, in Tanzania losses were (13%) where up to 20% and 86% of roots were severely broken and skinned respectively (Tomlins *et al.* 2000). The most severe handling occurred during unloading and loading from road vehicles and ships, where porters dropped the sacks from shoulder height.

Injury can reduce the shelf life of sweetpotato. Mechanical injuries sustained by retailing in bulk in New York supermarkets resulted in shelf life losses of approximately 5% through *Rhizopus* soft rot decay and moisture loss (Woolfe 1992). Skinning injury has been shown to be a major factor that contributes to weight loss during storage, make them more susceptible to rots and less appealing to consumers (Kushman 1975; Stikeleather and Harrell 1990). In East Africa, farmers, traders, wholesalers and retailers have no access to storage facilities. Retailers in the Lake Zone of Tanzania sold most of their roots within 7 days of receipt while consumers stored roots for up to 14 days in the home before consumption (Kapinga *et al.* 1997).

This study shows the effect of handling of sacks of sweetpotato on quality by varying sack weight, height of drop and the number of impacts received. After damage, the roots were subsequently stored at ambient conditions to determine how handling influenced shelf life.

Materials and Methods

2.1.   Plant material

Sweetpotato (cultivar SPN/0) was purchased from commercial smallholder farmers near Morogoro, Tanzania during the main harvesting season (July to August 1998). Roots were harvested by

hand and covered with vines, when feasible, to protect them from direct sunlight. Farmers filled polypropylene sacks with either 50 or 100 kg sweetpotato; roots were stuffed tightly into sacks and the top was covered with sweetpotato vines before sealing with twine.

Experiments were in duplicate unless stated otherwise.

2.2.   Sweetpotato cultivar and quality assessment
The quality of 40 randomly selected roots, from either a heap of harvested roots (control) or from sacks of roots, was measured by scoring for breaks, skinning, shrivelling, rotting and cuts (Tomlins *et al.* 2000).

2.3   Effect of filling sacks on root quality.

Four polypropylene sacks were filled with 100 kg sweetpotato. The quality of the roots was measured before and after filling.

2.4.   Effect of the number of times a sack in dropped on quality and shelf life

Sacks of sweetpotatoes weighing 50 or 100 kg were dropped one, three or six times from a height of 0.5 m.

2.5.   Effect of the height that a sack is dropped on quality and shelf life

Sacks of sweetpotato weighing 50 or 100 kg were dropped three times from heights of 0.25, 0.5 or 0.75 m.

2.6.   Storage of sweetpotatoes

Sweetpotato roots were stored in open sacks under ambient conditions. The sack weight and quality (shrivelling and rotting) was assessed after 1, 3, 7 and 14 days. Ambient temperature and humidity were recorded using temperature (+/- 0.2°C) and humidity (+/- 4%) dataloggers (Tinytalk II; RS Components, UK) set to record every 10 min. The ambient temperature and relative humidity (RH) varied between 23 and 34°C (mean 26°C) and 35 and 73% RH (mean 57%) respectively.

2.7.   Determination of type of injury that contributes to shelf life losses of sweetpotato (SPN/0 cultivar).

The results from all the storage experiments were combined and regression analysis was used to determine influence that root damage from broken roots, skinning injury, cuts, shrivelling and rough (Blosyrus spp.) and sweetpotato (Cylas spp.) weevil damage make to on losses (weight loss, shrivelling, rots) during storage.

2.8.   Statistical analysis

Regressions were carried out using SPSS (version 8.0) statistical software. For regression analysis, linear models were assumed as there was insufficient data to conclude that non-linear ones were significant. All experiments were carried out in duplicate unless stated otherwise.

3.   Results and Discussion

3.1.   Effect of filling sacks on root quality

Filling polypropylene sacks with 100 kg roots did not significantly affect the quality of the roots.

3.2.   Effect of the number of impacts on the quality and shelf life roots sold in the markets

Dropping sacks increased the occurrence of broken roots while the weight of the sack has no effect (R^2 adjusted = 0.602, P >0.001) (Fig. 1). Skinning injury and cuts were not affected by dropping the sack or its weight.

The number of impacts increased weight loss when the roots were stored (R^2 adjusted = 0.898; P >0.001); each impact increased weight loss by 0.25% for each day of storage (Fig. 2). The number of impacts did not influence rots and shrivelled roots when stored (data not shown).

3.3.   Influence of the height from which a sack of sweetpotatoes in dropped on quality and shelf life

The proportion of broken and skinned roots in a sack increased the higher they were dropped (Fig. 3 and 4); the weight of the sack (50 or 100 kg) had no effect. While skinning injury increased with the height of drop (R^2 adjusted 0.509, P >0.05), breaks increased to a threshold height of 0.5 m. Above 0.5 m, there was no further increase in broken roots. It is thought that the forces occurring in a sack dropped from a height of 0.5 equalled the maximum breaking strain for the roots. The wide scatter in the scores, however, suggests that dropping a sack above 0.25 m would result in significant damage from broken roots.

The height that a sack was dropped significantly increased weight loss by up to 2.6% when the roots were stored (R^2 adjusted 0.908; P >0.001) (Fig. 5). The height from which a sack was dropped did not affect the occurrence of rots or shrivelled roots.

3.4.   Determination of type of root injury that contributes to shelf life losses of sweetpotato (SPN/0 cultivar).

Skinning injury (R^2 adjusted 0.857; P = >0.001) and to a lesser degree broken roots (R^2 adjusted = 0.838; P >0.001) correlated with increased the weight loss during storage (Fig. 6 and 7). Roots with no skinning injury would lose weight by 1% each day. Severe skinning injury (score of 70) would account for an additional loss in weight of 3.7%.

Skinning injury (Kushman 1975; Stikeleather and Harrell 1990) has been reported elsewhere to be a major factor contributing to weight loss during storage. In Tanzania, avoiding injury to roots may improve incomes as retailers keep roots for up to 7 days before sale and consumers keep them for an additional 14 days (Kapinga *et al.* 1997). Broken and cut roots have been reported as factors that contribute to shelf life losses in sweetpotato (Onwueme 1978; Medlicott 1990; Woolfe 1992; Kapinga *et al.* 1997).

Skinning injury also made the roots significantly more susceptible to rots during storage (R2 adjusted = 0.178; P = >0.001) (fig. 8). Skinning injury has been reported to make sweetpotatoes more susceptible to rots (Stikeleather and Harrell 1990). The wide scatter of the data, however, suggests that rots are influenced by additional factors. Broken and cut roots did not influence rots.

4.   Conclusions

The height and number of drops reduced the quality of sweetpotato (SPN/0 cultivar). The occurrence of broken roots increased with both height and number of times a sack was dropped while skinning injury increased with height. The weight of the sack (50 or 100 kg) had no influence of quality. The shelf life, indicated by weight loss, was most influenced by the height that a sack was dropped and to a lesser extent the number of drops. Of the classes of injury (weevil, cuts, skinning, breaks, shrivelling) sustained by sweetpotatoes during handling, skinning injury, and to a lesser degree broken roots, correlated most with weight loss.

Reduced handling of sacks of sweetpotato will improve the their marketability and returns to farmers and extend the shelf life by reducing skinning injury and broken roots. A simple intervention by reducing the weight from the current 100 kg to 50 kg did not reduce damage. The use of alternative methods of packaging (cardboard and wooden boxes) may lead to improved quality; this needs to be investigated under actual conditions. Furthermore, pre-harvest curing of the roots (Bonte and Wright 1993) by pruning the plant canopy up to 14 days before harvest has been reported to reduce the injury to

roots during handling and transport by facilitating wound healing. Pruning is not widely practised in Tanzania and East Africa and may offer a simple and low-cost technique for reducing susceptibility to injury. This deserves further investigation.

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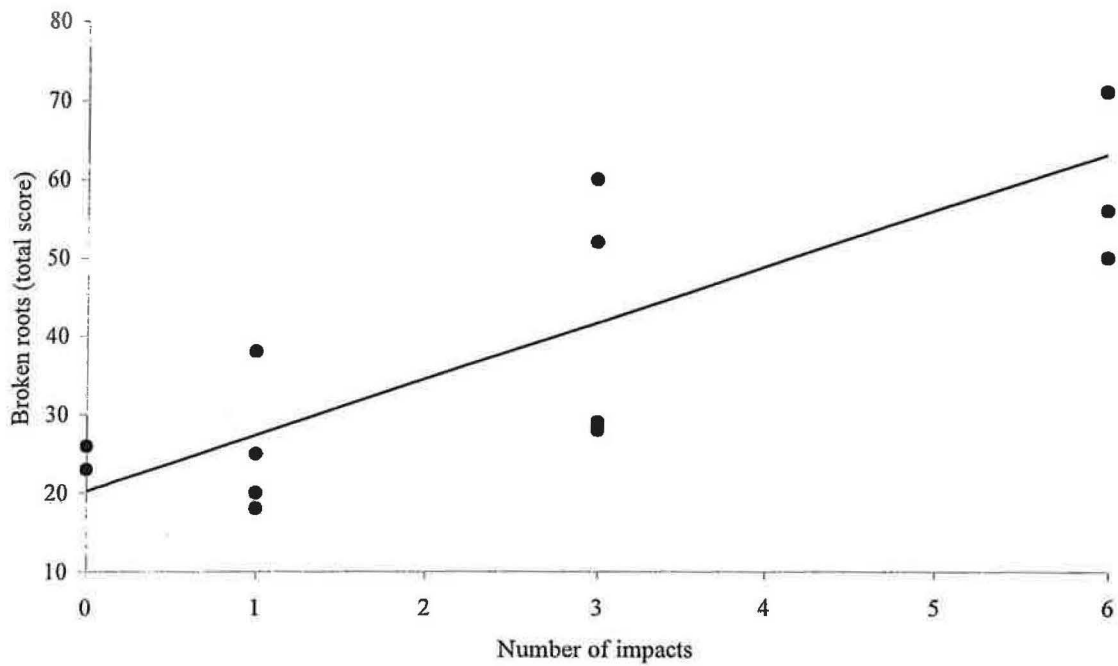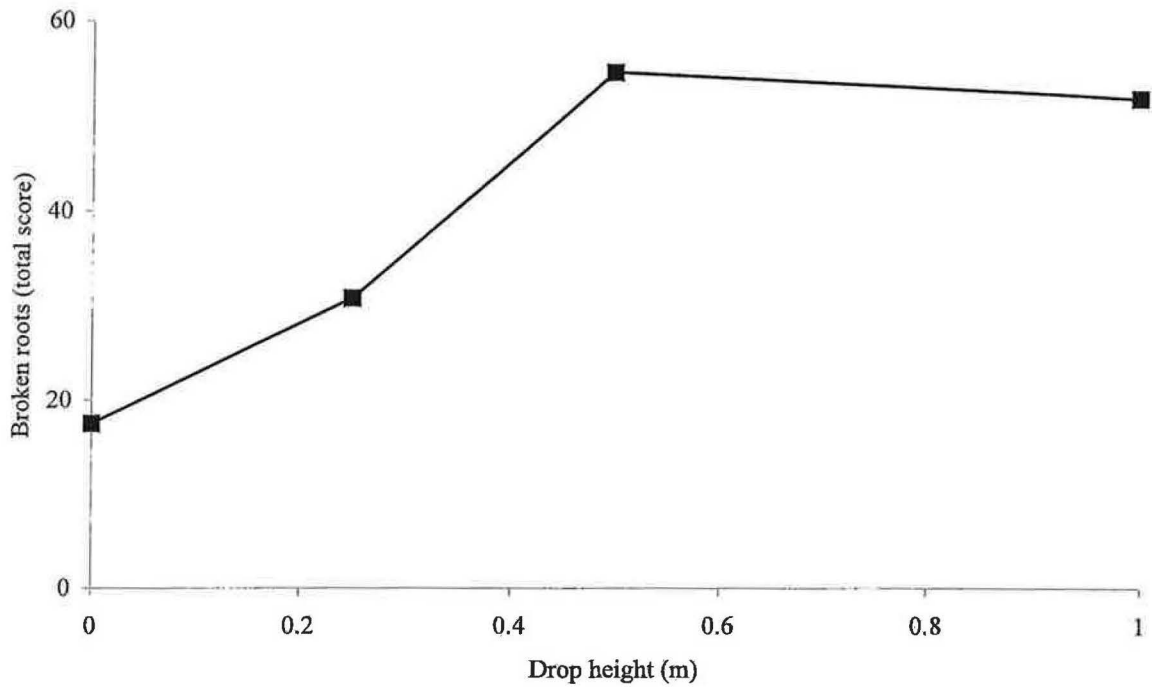
Where: broken roots (total score) = (number of impacts x 5.881) + 22.197

Figure 1. Relationship between number of impacts from a height of 0.5m of sacks of sweetpotato and broken roots (total score)
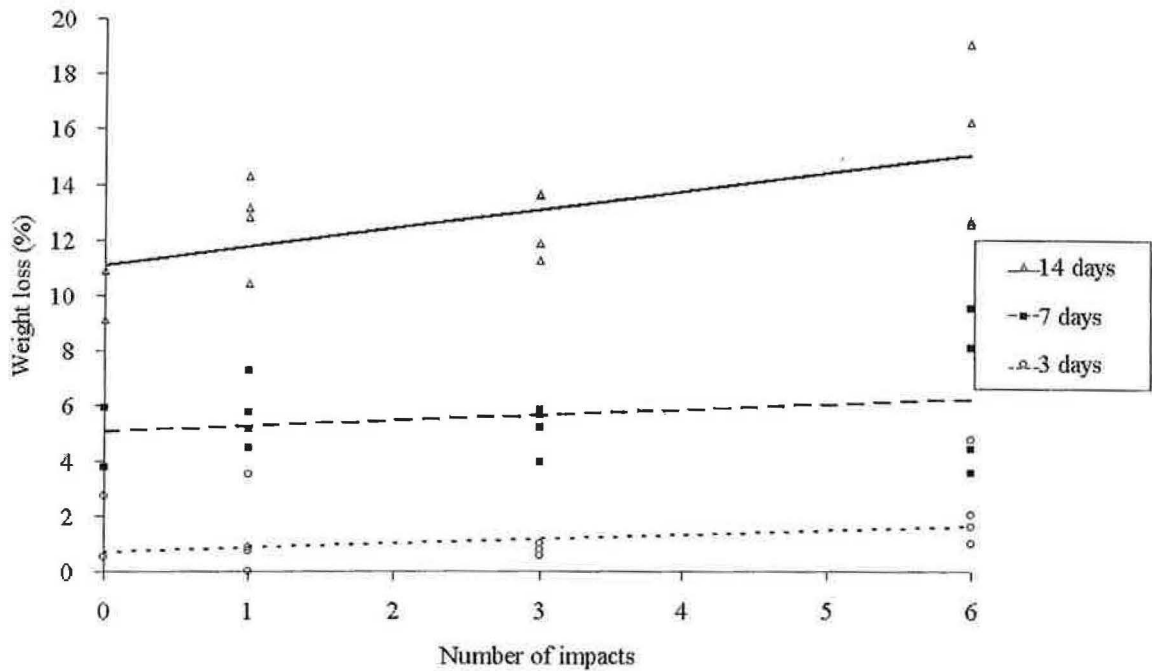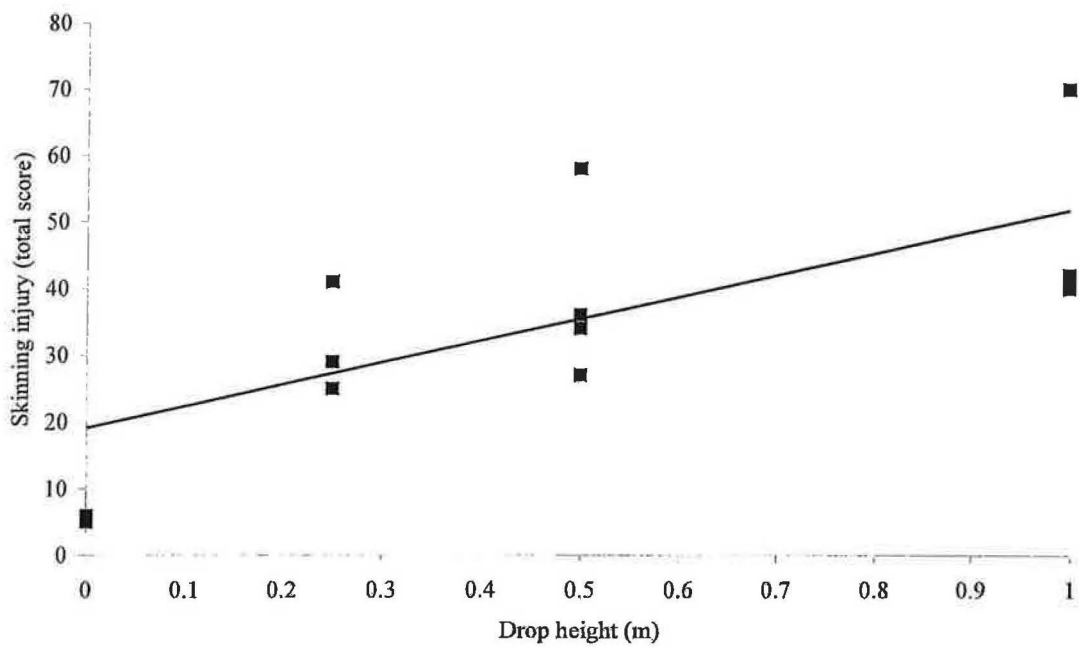

Where: weight loss (%) = (number of drops x 0.251) + (storage time in days x 1.023) –2.184

Figure 2. Influence of impacts on the weight loss during storage

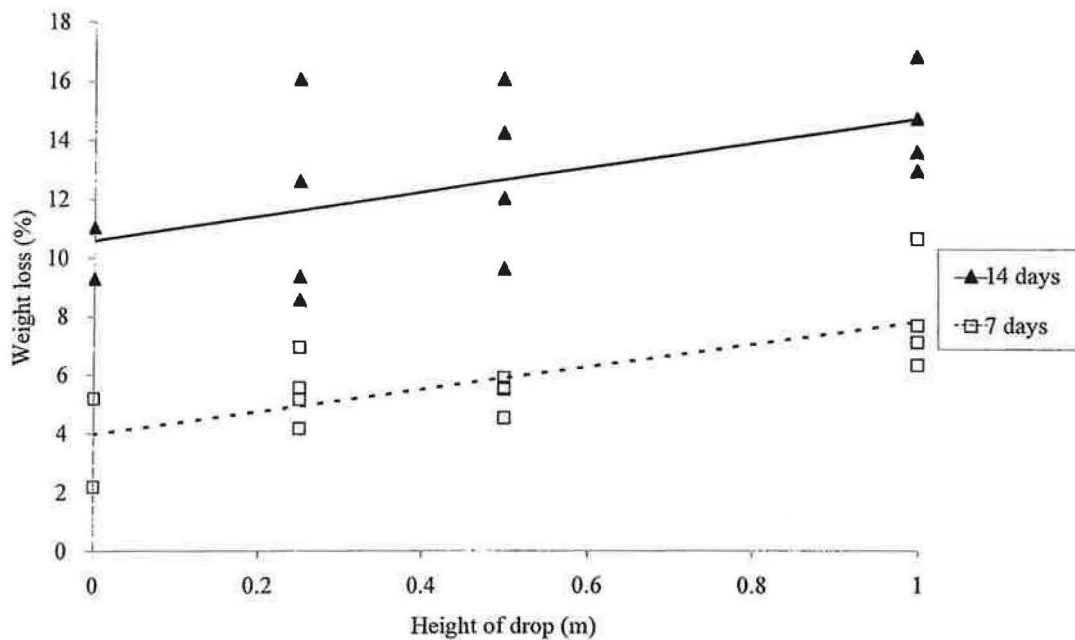*Where each reading is the mean of sacks*

Figure 3. Relationship between breaks sustained by sweetpotato roots and the heights from which they were dropped

where: skinning injury (total score) = (height of drop in metres x 32.571) + 19.071

Figure 4. Influence of height of drop of sacks of sweetpotato on skinning injury

Where: weight loss (%) = (Height of drops x 2.633) + (storage time in days x 0.970) – 2.264

Figure 5. Influence of height of drops and storage time on weight loss (%) of sweetpotatoes
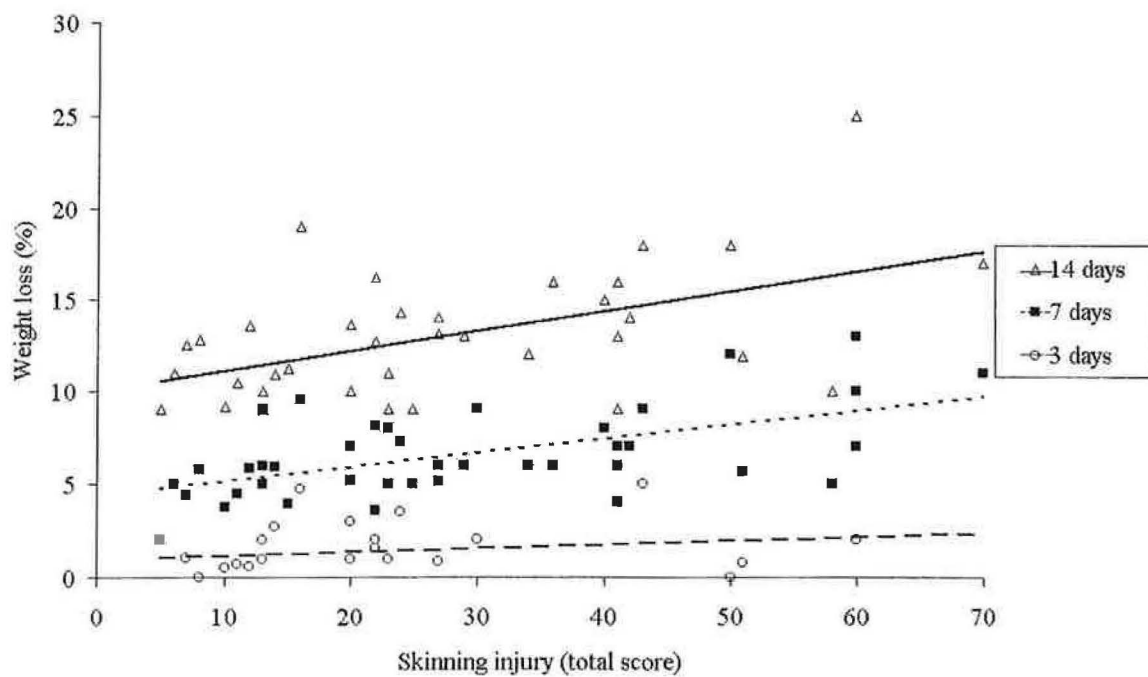
Where: weight loss (%) = (skinning injury x 0.0531) + (storage time in days x 1.014) – 2.536

Figure 6. Effect of skinning injury incurred during experimental trials on weight loss (%) during storage at ambient temperature and humidity
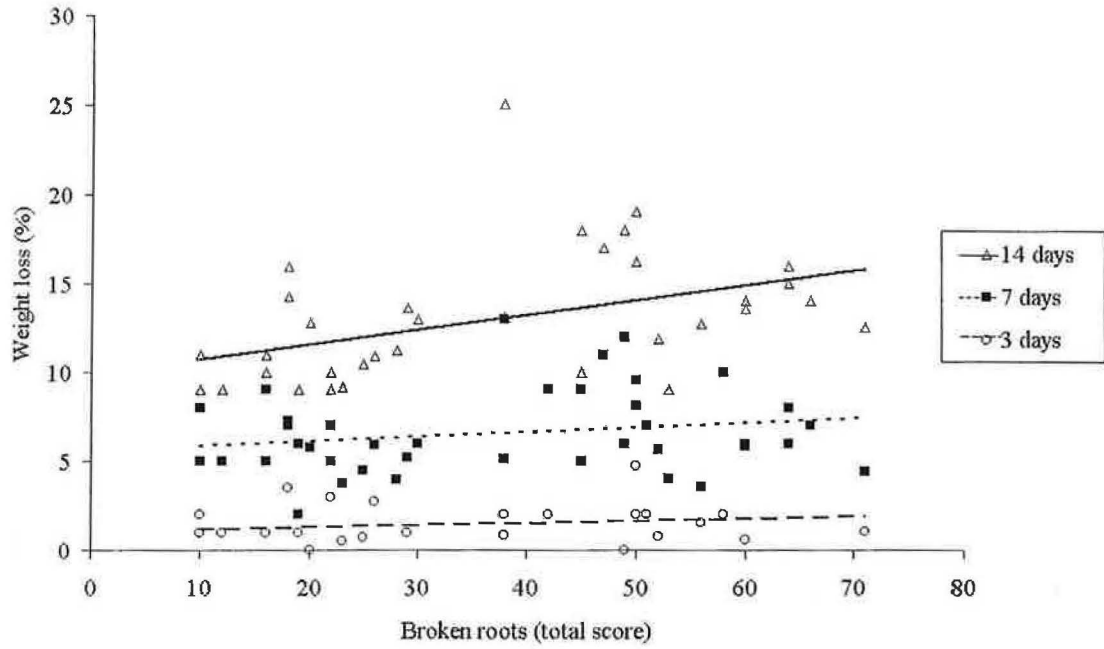
Where: weight loss (%) = (broken roots x 0.011) + (storage time in days x 1.013) – 2.221

Figure 7. Effect of broken roots incurred during experimental trials on weight loss (%) during storage at ambient temperature and humidity
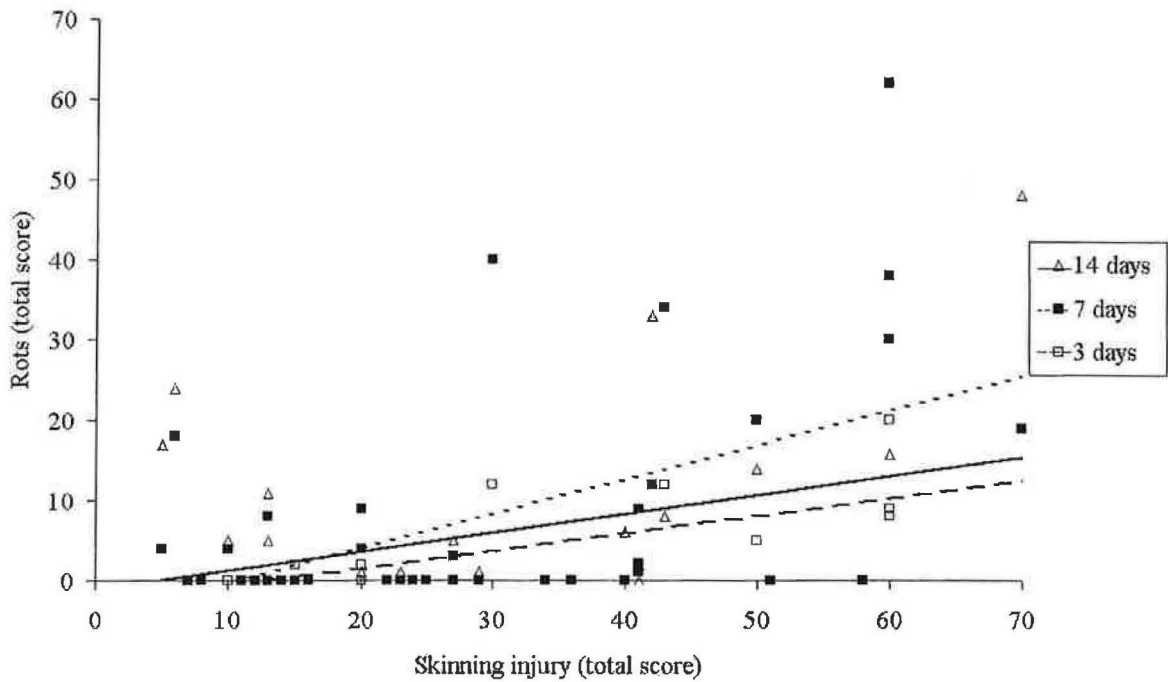
Where: rots (total score) = (skinning injury x 0.223) + (storage time in days x 0.410) – 4.780

Figure 8. Effect of skinning injury incurred during experimental trials on rots (total score) during storage at ambient temperature and humidity

Annex 8: Methods for reducing post-harvest handling losses of sweetpotato (*Ipomoea batatas* (L) Lam)

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Abstract

To improve the quality of sweetpotato (*Ipomoea batatas* (L) Lam) sold in East Africa, the effectiveness of packaging methods for handling and transportation and pre-harvest curing was investigated. Transporting in cardboard cartons instead of polypropylene sacks and pre-harvest curing by pruning 14 days or more before harvest improved quality by reducing skinning injury. This, however, did not improve returns to farmers because skinning injury does not influence market value. Education of traders, wholesalers and auction agents of the advantages of extended shelf life may lead to improved market value for roots with reduced skinning injury and a demand for roots transported in cardboard cartons and pre-harvest pruning. Further investigations may be required to identify packaging methods that reduce breaks and cuts.

Keywords: Sweetpotato, *Ipomoea batatas*, postharvest handling, packaging, curing, Africa

1. Introduction

Sweetpotato (*Ipomoea batatas* (L) Lam) is a traditional crop for subsistence farmers in much of East Africa and it is now increasingly being marketed. Production in Africa (1998) was estimated to be nearly 7 million tonnes and is ranked, in order of importance compared to 20 other major foods, third in Uganda and Kenya and seventh in Tanzania (Anon 2000). Transportation of roots in polypropylene sacks, often weighing in excess of 100 kg, however, can account for losses market value of 13% (Tomlins *et al.* 2000) and reduce shelf life (Ndunguru *et al.* 2000).

The quality of roots transported in polypropylene sacks in Tanzania, were most affected by the height of the drop and number of drops (Ndunguru *et al.* 2000) during loading and unloading and a large number of minor impacts (Tomlins *et al.* 2000). Partitioned cardboard boxes, containing between 14 and 23 kg roots, are used for handling and transport in the USA (Estes *et al.* 1989) and for export from the Caribbean (Medlicott, 1990).

Underground storage organs such as sweetpotato roots tend to have poorly developed cuticles. Curing is recommended so that a surface layer of protective suberised wound periderm tissue is formed, especially at wound sites (Wills *et al.* 1998). Pre-harvest curing of the roots (Bonte and Wright, 1993), by removal of the plant stem and canopy up to 14 days before harvest, has been reported to reduce the injury to roots during handling and transport by 62%.

This purpose of this study was to determine if simple low-cost methods (alternative packaging technologies and using pre-harvest curing) could be developed that might be used to improve quality and market value of sweetpotato. The effect on quality of four methods of packaging was compared by transporting them varying distances and pre-harvest curing by comparing roots from pruned (left in the ground for different times) and unpruned plants.

2. Materials and Methods

Experiments were in duplicate unless stated otherwise. Sweetpotato roots (SPN/O cultivar) were purchased from farmers near Dar es Salaam, Tanzania.

2.1. Quality evaluation of sweetpotatoes

Samples of 40 sweetpotato roots were randomly collected during harvest or selected following packaging, transport or pre-harvest curing trials. They were scored for breaks, cuts, skinning injury, shrivelling, rots and weevil (*Blosyrus* and *Cylas* spp.) damage using a simple visual scoring system (Tomlins *et al.* 2000).

2.2. Effect of packaging method on root quality

Woven polypropylene sacks filled with either 20 or 100 kg sweetpotatoes, wooden boxes (height 36 cm, length 60 cm, width 36 cm) lined with cardboard containing 30 kg sweetpotatoes and cardboard boxes (height 33 cm, length 44 cm, width 30 cm) containing 20 kg sweetpotatoes were compared. An impact logger (Tomlins *et al.* 2000) was positioned at the centre of each package to monitor the handling during transport.

The packages were transported together for distances of 24 km, 98 km or 167 km by light commercial vehicle from the farm to a market (Tandale) in Dar es Salaam where the roots were assessed for quality and sold at the local auction.

2.3. Effect of pre-harvest pruning on root quality at harvest and after handling.

Rows of sweetpotatoes plants were either left untouched or had the stem and leaf canopy pruned 9, 14 or 18 days prior to harvest. At harvest, both pruned and un-pruned roots were lifted at the same time.

The effect of pruning treatment on susceptibility to damage during handling was assessed by dropping duplicate woven polypropylene sacks, containing 50 kg sweetpotatoes, three times from a height of 0.5 m. The root quality was assessed for breaks, skinning injury and cuts.

2.4. Statistical analysis

Analysis of variance (ANOVA) was carried out using SPSS (version 8.0) statistical software.

3. Results and Discussion

3.1. Effect of packaging method on root quality

The distance that the packages were transported had no significant effect on quality and so the results were pooled (Table 1). The method of packaging influenced skinning injury ($P > 0.001$) but did not reduce the occurrence of breaks, cuts or rots. Skinning injury was reduced when roots were transported in cardboard boxes and the greatest when transported in polypropylene sacks (20 or 100 kg).

The impact histories for each method of packaging (Figures 1 to 4) show that they were on the road for the first 9 hours, stored overnight storage and at 18 to 21 hours off-loaded at the market. The impacts were greater for roots transported in sacks compared to the cardboard box and wooden crate. The number of minor impacts (less than 2 g) was greatest for roots transported in the cardboard box (Table 2). For impacts greater than 2 g, their occurrence was greater for the cardboard box and wooden crate and least in the polypropylene sacks. While the number of impacts greater than 2 g was lowest for the sacks, the occurrence of skinning injury was the highest. It is thought that tightly packing roots in polypropylene sacks caused the surface of the roots to absorb the impact energy whereas in loosely filled cartons, the roots were able to move and dissipate the energy.

At auction, the roots transported in the sacks and cardboard box fetched the same price (80 Tanzanian Shillings per kg) regardless of the distance travelled. Those transported in the wooden crate fetched a lower price (67 Tanzanian Shillings per kg). The auction agent and traders commented that the roots in the cardboard cartons were of good quality while those in the woven polypropylene sacks containing either 20 or 100 kg were of acceptable quality. Roots transported in the wooden crates were mainly of good quality but some roots were cut when they were pressed against the side of the box. The failure of roots transported in cardboard cartons to fetch a higher price might be because skinning injury does not affect market value (Ndunguru *et al.* 1998).

Further investigations are required to identify methods of packaging that reduce breaks and cuts. While transporting in cardboard boxes did not improve the market value, a reduction in the skinning injury would increase shelf life (Ndunguru et al. 2000).

3.2. *Effect of pre-harvest pruning on root quality at harvest and after handling*

Pruning the canopy up to 18 days before harvest ($P < 0.05$) reduced the skinning injury of freshly harvest roots and in roots that had been packed into sacks and dropped (Tables 3 and 4). Pre-harvest pruning did not reduce the occurrence of broken, shrivelled or cut roots and weevil infestation.

Bonte and Wright (1993) reported that the optimal pre-harvest pruning treatment was 10 days before harvest (Beauregard and Jewel cultivars grown in Louisiana, USA). Roots began to sprout if the pruning treatment occurred at 15 days. In this study, the optimal pre-harvest pruning was greater than 10 days and roots did not. These different findings may be because of the different cultivar (SPN/0) and climatic conditions.

Little has been reported on the influence of pre-harvest curing on the changes in morphological characteristics, such as skin thickness, cell size and suberin content, that occur in sweetpotatoes. For other root crops, such as the Irish potato (*Solanum tuberosum*), pre-harvest pruning (haulm destruction) increased skin adhesion but the magnitude differed with variety (Bowen et al. 1996). Changes in morphological characteristics do not appear to influence skin adhesion strength. It is speculated that changes in water content and in the biochemistry (pectins) are more important for Irish potatoes (Muir and Bowen 1994).

While reduced skinning injury is unlikely to increase the market value (Ndunguru et al. 1998), it may, however, extend the shelf life (Ndunguru et al. 2000).

4. Conclusion

Cardboard boxes filled with 20 kg of sweetpotato and pre-harvest pruning of 14 days or more improved quality by reducing skinning injury. This did not lead to improved market value at auction because traders do not consider roots with skinning injury to be unacceptable (Ndunguru et al. 1998) and the presentation in cardboard boxes was new to them. An advantage of roots with reduced skinning injury is an extended shelf life (Ndunguru et al. 2000) but traders are unaware of this. Education of traders, wholesalers and auction agents of the advantages of extended shelf life may lead to improve market value for roots with reduced skinning injury and a demand for roots transported in cardboard cartons and pre-harvest pruning. Further investigations may be required to identify packaging methods that reduce breaks and cuts.

Acknowledgement

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Table 1. Effect of packaging materials on root quality after handling and transport.

	Root quality (total score)				
	Fresh roots	Cardboard box (20 kg)	Wooden box (30 kg)	Polypropylene sack (20 kg)	Polypropylene sack (100 kg)
Skinning injury[*]	6 ± 1.2	12 ± 2.0	19 ± 4.4	38 ± 5.0	43 ± 5.4
Broken roots	3 ± 1.0	2 ± 0.4	2 ± 0.2	4 ± 1.2	5 ± 1.1
Cut roots	7 ± 1.4	7 ± 1.5	5 ± 0.9	6 ± 1.1	7 ± 0.6
Rots	2 ± 0.5	2 ± 0.6	1 ± 0.6	2 ± 0.3	2 ± 0.6

[*]*Significantly different (P < 0.05). Values represent the mean ± S.E.*

Table 2. Mean number of impacts for the different types of packaging.

	Mean number of impacts			
Intensity	Cardboard box (20kg)	Wooden crate (30kg)	Polypropylene sack (100kg)	Polypropylene sack (20kg)
0.2 to 2 g	546	454	493	414
2 to 5 g	29	35	4	6
5 to 10 g	6	6	1	2
10 to 20 g	1	0	0	0

Where: mean values are pooled for packages transported 24, 98 or 167 km.

Table 3. Effect of pre-harvest pruning on skinning injury when harvesting sweetpotato roots.

	Skinning injury (total score)		
	9 days	14 days	18 days
Pruned	**9 ± 3.55**	**5 ± 3.55**	**7 ± 3.55**
Not pruned	**7 ± 3.55**	**28 ± 3.55**	**21 ± 3.55**

Significantly different (P < 0.05). Values represent the mean ± S.E.

Table 4. Effect of pre-harvest pruning o skinning injury when polypropylene sacks, containing 50 kg sweetpotatoes, were dropped from a height of 0.5 m.

	Skinning injury (total score)		
	9 days	14 days	18 days
Pruned	**69 ± 4.35**	**30 ± 4.35**	**40 ± 4.35**
Not pruned	**48 ± 4.35**	**78 ± 4.35**	**79 ± 4.35**

[*]*Significantly different (P < 0.05). Values represent the mean ± S.E.*

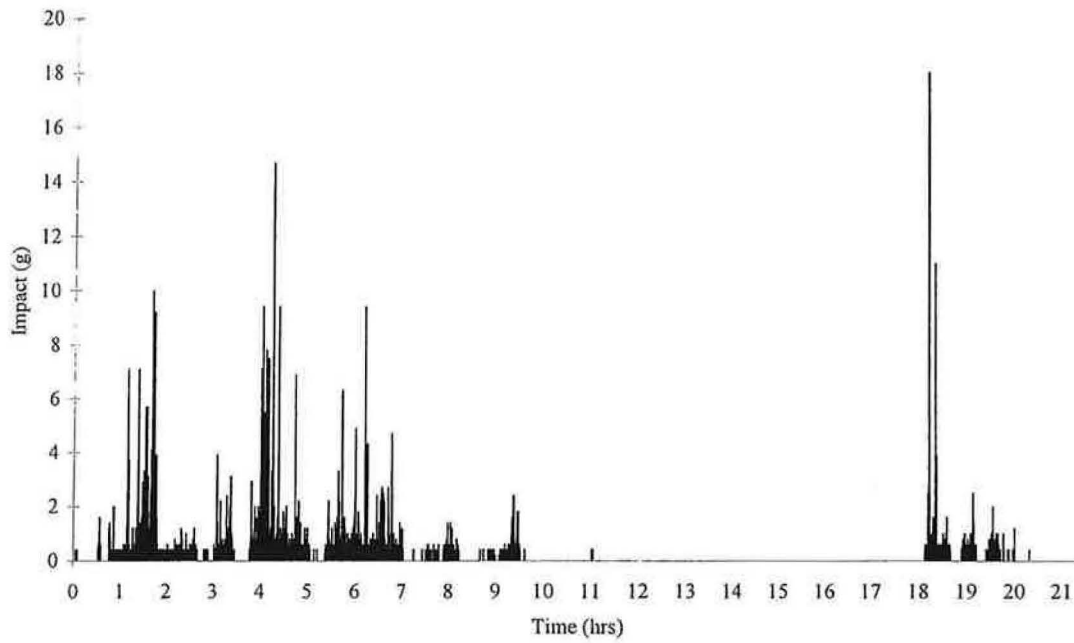**Figure 1. Impact chart for 20 kg sweetpotatoes transported 169 km in a cardboard box**

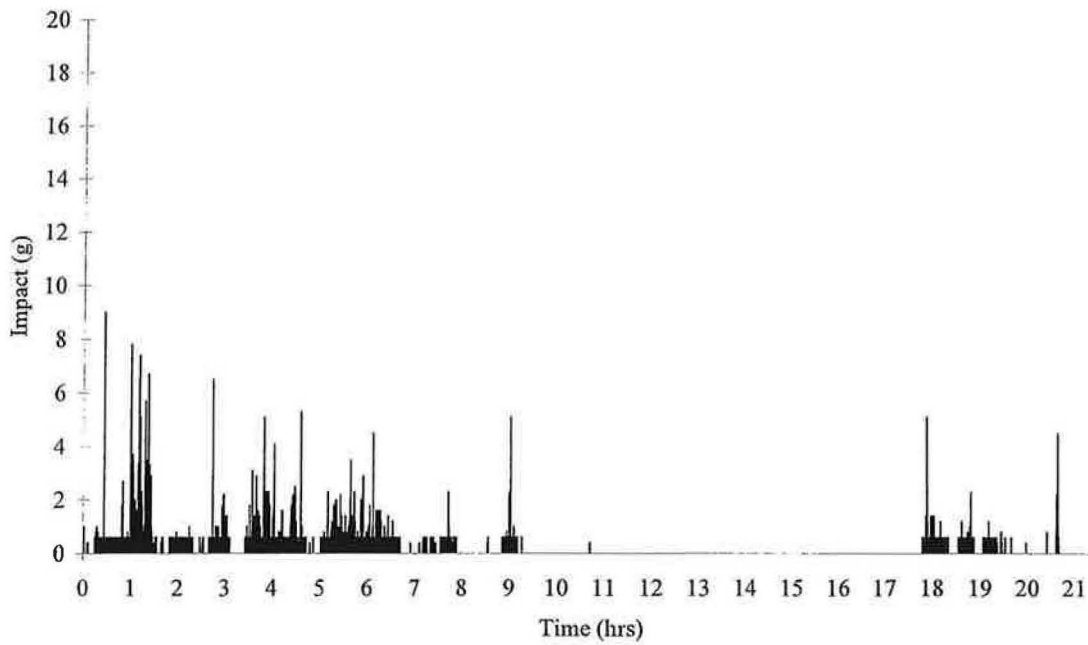**Figure 2. Impact chart for 30 kg sweetpotatoes transported 169 km in a wooden crate**

Figure 3. Impact chart for 20 kg sweetpotatoes transported 169 km in a polypropylene sack (tightly packed)
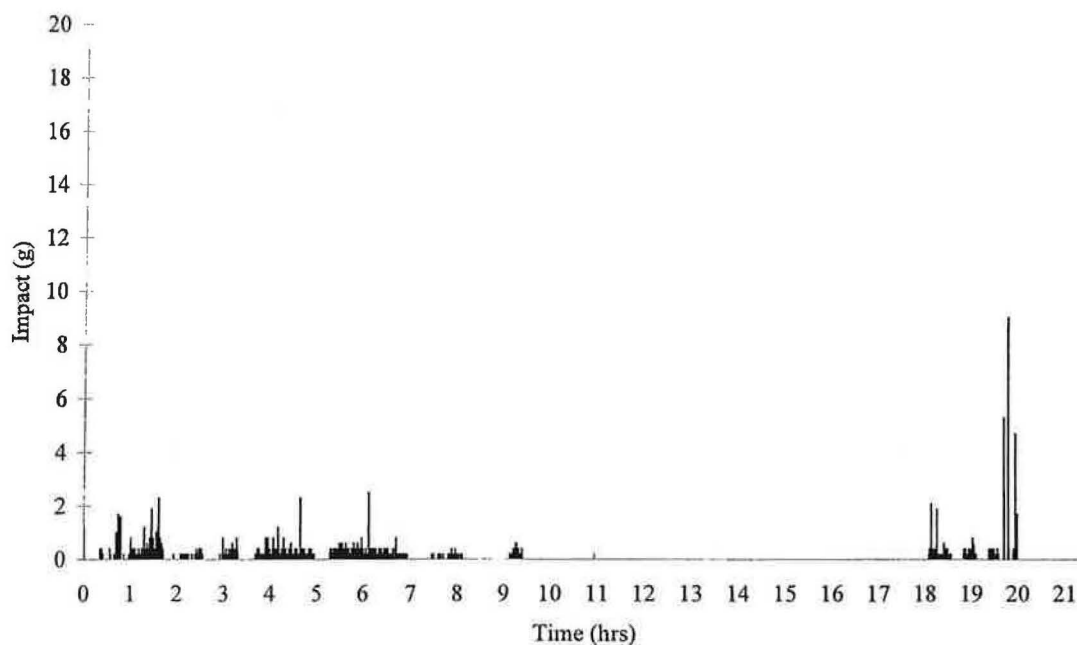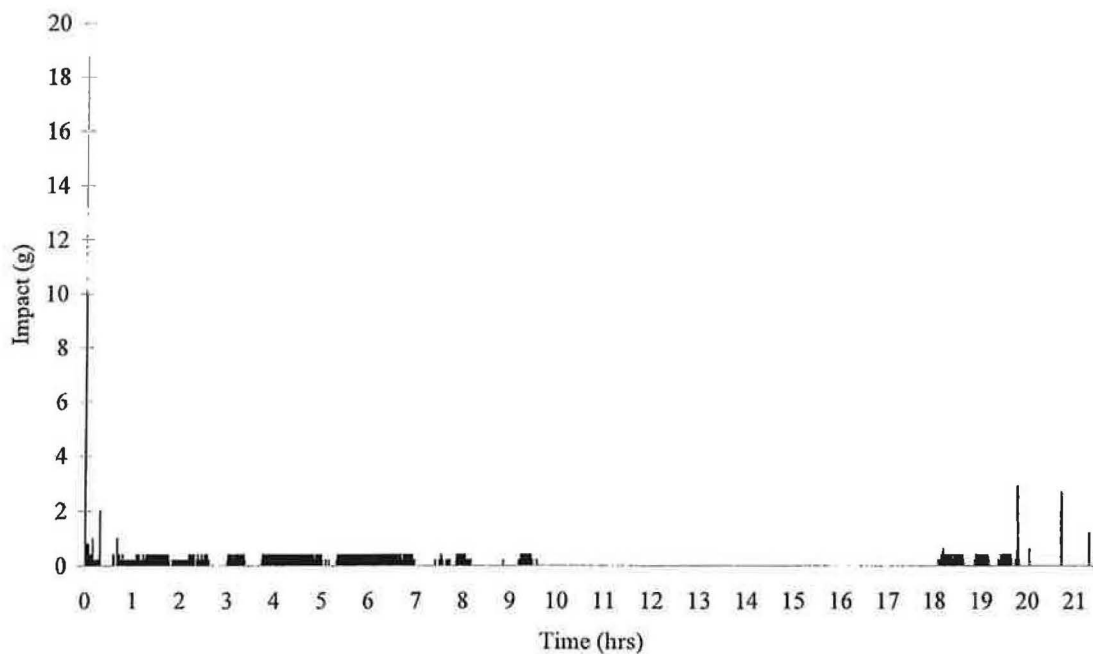

Figure 4. Impact chart for 100 kg sweetpotatoes transported 169 km in a polypropylene sack (tightly packed)

Annex 9: Effect of temperature, pH, water activity and carbon dioxide concentration on growth and sporulation. *Rhyzopus oligosporus* **NRRL 2710.**

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Effects of temperature, pH, water activity and carbon dioxide concentration on growth of *Rhizopus oligosporus* NRRL 2710

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Running title header: Growth of *Rhizopus oligosporus*

INTRODUCTION

Rhizopus spp. are important moulds as the major organisms in tempe fermentation (moulded soybean cake; Nout and Rombouts 1990; Steinkraus 1996) and in cassava heap fermentations (Essers and Nout 1989). In both of these solid-substrate fermentations, *Rhizopus* spp. are readily supplanted by *Neurospora sitophila*, another fast growing mold. Fermentation of soybeans by *N. sitophila* can lead to alternative products, such as ontjom (Steinkraus 1996) but in the case of cassava heap fermentations in Tanzania it leads to colouration and a reduced value for the final product (udaga; Ndunguru *et al.* 1999). Hence, there is interest in identifying environmental conditions that favour the growth of *Rhizopus* spp. over that of *N. sitophila*.

Solid substrate fermentations are characterised by the initial conditions offered by the substrate (nutrients, pH a_W *etc.*) and changes in conditions consequent on microbial growth. In particular, in the absence of forced aeration, large changes in can occur in the gaseous composition. (Nout 1987) reported oxygen concentrations reduced to 2% v/v and carbon dioxide concentrations up to 22% in solid substrate soybean fermentations. Growth of most aerobic moulds is relatively unaffected by oxygen concentrations down to1 % but increased carbon dioxide concentrations affect the growth of a wide variety of microorganisms (Jones 1989). Hence, any attempt to predict growth of moulds in solid substrates needs to take into account at least the effects of temperature, pH, water activity, carbon dioxide concentrations and their interactions.

Lee and Magan (1999) investigated the use of nutrient utilisation patterns (niche overlap indixes) to predict colonisation patterns of maize by *Aspergillus ochraceus* and other spoilage fungi but concluded that growth/dominance/coexistence were much influenced by other environmental factors.

Studies on tempe moulds suggest that most rapid growth occurs at pH values less than 6.0 (Graham *et al.* 1976; Sparringa and Owens 1999), at temperatures around 40 °C (Rathbun and Shuler 1983), at oxygen concentrations above about 1% v/v and carbon dioxide concentrations of 1-20% % v/v (de Reu *et al.* 1995).

There appear to be no reports on the effects of water activity on growth of tempe moulds but three *Rhizopus* spp. examined by Hocking and Miscamble (1995) grew most rapidly at water activities above 0.94 or 0.90. Many studies have been made on the effects of single or two environmental factors on the growth of moulds but relatively few studies have investigated three or four factors and their interactions. Marin *et al.* (1995) evaluated the effects of temperature, pH and water activity on growth of *Fusarium* spp. and demonstrated interactions between all three factors.

Previous studies on tempe moulds have generally investigated the effects of single environmental factors and there are no reports on the interactions between environmental factors and their effects on growth. This study investigated the effect of temperature, pH, water activity and carbon dioxide concentration on the growth of *Rhizopus oligosporus* NRRL 2710, using surface response methodology.

METHODS

Mould culture
Rhizopus oligosporus NRRL 2710 was grown on Potato dextrose agar (PDA; Oxoid CM139) at 30 °C until it sporulated (5 d) and then stored at 5 °C.

Preparation of spore suspension
Spore suspensions were prepared in purified water as previously described (Sparringa and Owens 1999). *Rhizopus oligosporus* spores do not swell or germinate in distilled water (Medwid and Grant 1984).

Preparation of mycelial inoculum

Cellophane disks (9 cm diameter; Courtaulds 325P) were boiled in purified water (10 min, two times) to leach out any soluble materials and then sterilised by autoclaving at 121 °C for 15 min. Plates of PDA were overlaid with sterile Cellophane disks. Spores suspension (0.5 ml containing 10^7 spores ml^{-1}) was spread over the Cellophane and the cultures were incubated at 30 °C for 24 h. The Cellophane, bearing the mycelia, was lifted off, transferred to a sterile Petri dish, and cut with a cork borer into disks (0.7 cm diameter) which were then transferred to the centres of plates of experimental media.

Preparation of PDA-based media at different water activities and pH values

Modified PDA media at different pH values were made by adding buffer compounds (pH 3.5, 0.02 mol l^{-1} potassium hydrogen phthalate; pH 5.5, 0.03 mol l^{-1} MES buffer, 2-[N-morpholino] ethane-sulfonic acid]; pH 7.5, 0.01 mol l^{-1} potassium dihydrogen phosphate) and adjusting the pH with KOH or HCl solutions to the desired value.

The water activity (a_w) of modified PDA media was adjusted with sucrose (a_w ~1, no addition; a_w 0.98, 0.46 mol l^{-1} added sucrose; a_w 0.96, 0.90 mol l^{-1} added sucrose) according to Chen (1989). *R. oligosporus* NRRL 2710 does not utilise sucrose as a carbon and energy source (Graffham *et al.* 1995). The water activity of prepared media was checked with a dewpoint meter (Protimeter DP 383R).

To maintain the pH values of media in the presence of carbon dioxide, sodium bicarbonate was added to media at pH 7.5 incubated in the presence of 12.5 and 25% v/v CO_2. The concentrations of $NaHCO_3$ added (mmol l^{-1}) were: at 30 °C and 12.5% v/v CO_2, 54.5; 30 °C and 25% v/v CO_2, 109; 37 °C and 12.5% v/v CO_2, 47; 37 °C and 25% v/v CO_2, 93; 42 °C and 12.5% v/v CO_2, 41; 42 °C and 25% v/v CO_2, 82.

Media components were combined, boiled to dissolve the agar, the pH was adjusted to the desired value, and media were sterilised by autoclaving at 121 °C for 15 min.

Incubation of cultures in modified atmospheres

Duplicate Petri dishes were placed in a separate polypropylene plastic bag (Cryovac BB4L, 250 x 330 mm, capacity about 1600 m; Grace Ltd., St. Neots, Cambridge, UK). The air in the bag was evacuated and then it was filled with gas mixture as required (12.5 or 25 % v/v CO_2 and air) using a Multivac Gastrovac Machine (Model A300, Multivac UK, Swindon, UK). Cultures with 0.03% v/v CO_2 were incubated in air.
Concentrations of oxygen and carbon dioxide inside the plastic bags were measured before and after incubation with a portable gas analyser (Portamatic 2, Oxygen/Carbon dioxide analyser; Systech Instruments, Thame OX9 3XA).

Selection of combinations of environmental conditions

The environmental conditions used were selected as relevant to those occurring in tempe and udaga fermentations and to ensure that only conditions allowing growth were included (necessary to obtain meaningful response surfaces). The combinations of environmental conditions used was selected using Design Expert 5 version 5.0.8 (Stat-Ease Inc., 2021 East Hennepin Avenue, Suite 191, Minneapolis, MN 55413). The design was a central composite one with four factors, each at three values: temperature, 30, 37 and 42 °C; pH, 3.5, 5.5 and 7.5; water activity, ~1.0, 0.98 and 0.96; and carbon dioxide. 0.03, 12.5 and 25% v/v (Table 1).

Duplicate plates were used for each experimental condition, except for those at the centre point (37 °C, pH 5.5, a_w 0.98, and 12.5% CO_2) where 6 plates were used. .

Determination of hyphal extension rate using spores inocula

R. oligosporus spores suspension (10^9 spores ml^{-1}) was stab inoculated into the centre of the plates using a sterile needle. Cultures were incubated at 30, 37 or 42 °C in the presence of 0.03, 12.5 or 25% v/v CO_2.

Mycelium size was measured (without opening the plastic bags) across two diameters, at right angles to each other, every 3 h and the presence or absence of sporulation was noted. For each culture, mean mycelial radius was plotted against time and the mean hyphal extension rate was estimated by linear regression. Depending on the rate of growth, 9-14 data points were used in the linear regressions and correlation coefficients of 0.995 to 0.999 were obtained.

Determination of hyphal extension rate and sporulation using mycelial inocula

Cellophane disks bearing mycelium was placed in the centre of plates of experimental media and the mean hyphal extension rate was determined as for spore inocula. The occurrence of sporulation was determined by noting the development of a grey/black colouration on the mycelia.

Analysis of data

The effects of temperature, pH, water activity and carbon dioxide concentration on the time to initiation of hyphal extension and hyphal extension rate were modelled using response surface methodology (Design Expert 5 version 5.0.8).

RESULTS

Characteristic of cultures

Growth of cultures inevitably led to some changes in the composition of the atmosphere in the plastic bags, with increases in carbon dioxide concentration of up to 5.5 % v/v and decreases in oxygen concentration of up to 6.5 % v/v. Nevertheless, hyphal extension rates were linear over the entire incubation period, or until the mycelium reached the edge of the Petri dish, indicating that extension rates were little affected by the changes in oxygen and carbon dioxide concentrations.

It is recognised that hyphal extension rates may not accurately reflect actual growth rate (increase in biomass) because of possible effects of environmental conditions on mycelial density and/or hyphal diameter. Nevertheless, hyphal extension rates do give an accurate indication of potential habitat colonisation rates.

Effects of environmental conditions on hyphal extension rate

Hyphal extension rates determined for mycelia from spore inocula were very similar to those determined from mycelial inocula. Hence, the two sets of data were combined for analysis, giving four determinations for each combination of environmental conditions and 12 replicate determinations for the centre point (Table 1). A third order (cubic) polynomial equation gave superior fit to the data to a second order (quadratic) equation, with R^2 of 0.9937 and a predicted R^2 of 0.9911:

Hyphal extension rate (mm h^{-1}) =

36.71
-5.02Temperature (T °C) -2.76pH +21.46Water activity (a_w) -0.99CO_2 (% v/v)
+0.64T^2 +.096pH^2 -65.42a_w^2 +0.00055CO_2^2
+0.15TpH +5.37Ta_w +0.018TCO_2 +3.01pHa_w +0.1pHCO_2 +0.97$a_w CO_2$
+0.00106T^2pH - 0.072$T^2 a_w$ -0.0078TpH^2
-0.0002TpHCO_2 -0.018T$a_w CO_2$ -0.1pH$a_w CO_2$

All the terms in the equation were highly significant (P = <0.001) except for pH (P = 0.62), T^2 (P = 0.08), a_w^2 (P = 0.03), Ta_w (P = 0.355) and T^2a_w (P = 0.0007). The less significant terms were included in the equation in order to maintain hierarchy in the model.

The relative influences of individual factors on the hyphal extension rate (with other factors at their midpoints: 36 °C, pH 5.5, a_w 0.98, 12.5% CO_2) are shown in the perturbation plot (Fig. 1). A steep slope or curvature shows that hyphal extension rate is sensitive to that factor. It is evident hyphal extension rate was very sensitive to pH value and exhibited a pronounced optimum at pH 5.5. Hyphal extension rate was less sensitive to temperature, a_w and carbon dioxide concentration, with temperature and a_w supporting the highest extension rates at the highest values tested (42 °C and ~1.0) and carbon dioxide allowing the fastest extension rates at the lowest concentration tested (0.03%).

Interactions between temperature, pH and a_w

Hyphal extension rate was very sensitive to pH value, with the rate declining either side of the optimum at all temperatures (Fig. 2). In air (0.03% CO_2), with decrease in a_w, the optimum pH value dropped from ~6.0 at a_w ~1.0 to ~5.5 at a_w 0.96 (Fig. 3). In the presence of 25% CO_2 the optimum pH was unaffected by a_w and remained at ~5.5 at all water activities (data not shown).

At a_w ~1.00, the optimum temperature was reduced to 37 – 40 °C at low pH values but otherwise the maximum extension rates occurred at ≥42 °C (Fig. 3).

Interactions between temperature and water activity

At pH values of 5.5 and 7.5 the hyphal extension rate declined with decrease in temperature and a_w, with the maximum rates at ≥42 °C and ~1.0 a_w, but at pH 3.5 the response was quite different (Fig. 4). Although extension rates were very low at pH 3.5, the fastest rate occurred at 36-37 °C at all water activities.

Interactions between temperature, CO_2 concentration and pH at a_w ~1.0

At pH 5.5 and 7.5 the responses were similar with maximum extension rates occurring at ≥42 °C and 0.03 % CO_2 (Fig. 5). At pH 3.5 extension rates were very slow and, again, the optimum temperature was lower at ~36-37°C.

Interactions between temperature, CO_2 concentration and pH at a_w 0.96

At pH 5.5 extension rate increased with increase in temperature and decrease in CO_2 concentration (Fig. 6) and occurred at reasonable rates over the entire range of conditions tested. At pH 7.5 the pattern of the response was similar but growth was very slow and ceased at combinations of low temperature (≤~38 °C) and high CO_2. (≥~15%). At pH 3.5 the hyphal extension rate was very slow under all conditions, again with a reduced optimum temperature.

Interactions between temperature and CO_2 concentration and a_w at pH 5.5

At near optimum pH (5.5), the pattern of response to temperature and CO_2 was similar at all water activities (Fig. 7) with maximum extension rates at ≥42 °C and 0.03 % CO_2

Effects of environmental conditions sporulation

Sporulation was not greatly affected by the environmental conditions, though it tended to be later in slower growing cultures. No specific effects of any environmental factor was noted. However, two combinations of environmental conditions (42 °C, pH 7.5, a_w 0.96, 25 % CO_2 and 42 °C, pH 7.5, a_w 1.0, 25 % CO_2) that supported slow hyphal extension did not support sporulation, either from spore or mycelial inocula.

DISCUSSION

The model

The fact that a cubic model, providing interactions between up to three factors, was superior to a quadratic one providing interactions between only pairs of factors, is not surprising since one would expect microbial growth rate to be influenced by multiple interactions between environmental factors. The hyphal extension rates predicted by the model were very close to the mean observed values, with all but two of the predicted values being within 10% of the observed values (Table 1). Nevertheless, it should be recognised that, while the model gives accurate predictions of extension rates at the experimentally determined points, it does not follow that rates predicted at intermediate conditions are necessarily accurate. The model assumes a smooth transition in the rate from one set of conditions to another and it is possible that this is not the case. For example, the model predicts that the extension rate is progressively slowed as CO_2 concentration increases from 0.03 to 12.5% (Fig. 7) but De Reu *at al.* (1995) found no effect of carbon dioxide concentration on the growth of *R. oligosporus* NRRL 5905 at carbon dioxide concentrations between 1 and 10%.

There are a few three factor models but no four factor models in literature describing the effects of environmental factors on mould growth, though for food borne bacterial pathogens predictive microbiology models exist that model their responses to combinations of four or five factors.

Effects of environmental conditions on the rate of hyphal extension

Within the range of conditions examined, *R. oligosporus* NRRL 2710 grew most rapidly at 42 °C, pH 5.5, a_w ~1.0 and 0.03 % CO_2. Rathbun and Shuler (1983) suggested that the optimum temperature for an unspecified *R. oligosporus* strain was near 40 °C.

R. oligosporus NRRL2710 is able to grow at pH values up to 9.0 in the absence of ammonia (Sparringa and Owens 1999) but appears to be particularly sensitive to carbon dioxide at pH 7.5, when growth was inhibited by CO_2 concentrations >17% v/v and a_W 0.96 (Fig 6).

Hocking and Miscamble (1995) examined the effect of water activity on the growth of a number of *Rhizopus* spp. *R. oryzae* and *R. microsporus* grew equally rapidly at a_W 0.94 - ~1.00 while *R. stolonifera* did so from 0.90 to ~1.00. *R. oligosporus* NRRL2710 appears to be rather more sensitive to low a_W and its growth was slower at 0.98 than at ~1.00. Again, the prediction that hyphal extension rate progressively slows with decrease in a_W from ~1.00 to 0.98 could be a model artifact.

The hyphal extension rate of *R. oligosporus* NRRL 2710 was reduced in the presence of 12.5 and 25% v/v CO_2. This is in general agreement with observations of De Reu *et al.* (1995a) that the growth rate of *Rhizopus oligosporus* NRRL 5905 was little affected by 1, 5 or 10% v/v CO_2, and was reduced in the presence of 35%, and possibly 20% CO_2. The prediction of the model that hyphal extension rate progressive slows as CO_2 concentration increases from 0.03 to 12.5% needs to be confirmed.

Interactions between environmental factors

Growth of living organisms is influenced simultaneously by all the components of the environment and growth rate is reduced when environmental conditions are not optimal. This observation was first codified by Shelton in 1913, who stated that an organisms tolerance to unfavourable conditions is reduced when other environmental factors are also at non-optimal levels (Pianka 1973). Many food preservation processes do, of course, depend on the use of combinations of environmental parameters at unfavourable levels. The effects on hyphal extension rate of interactions between environmental factors and the additive effects of factors at unfavourable values are well illustrated by the present model. For example, as water activity is decreased the extension rate declines at all values of temperature and pH (Fig. 3).

Modification of optimum values by other environmental conditions

Optimum temperature describes the temperature at which microbes grow most rapidly, even though it is recognised that at the optimum temperature the organism is to some extent stressed and balancing the accelerating effects of high temperatures on metabolism and on degradative reactions. It is commonly observed that the optimum temperature for microbial growth is lower at unfavourable pH values that at the optimum pH for an organism (e.g. Chung and Goepfert 1970). This phenomenon is clearly evident with R. oligosporus, where the optimum temperature was lowered from $\geq$42 °C at pH 5.5 and 7.5 to 36-37 °C at pH 3.5 (Figs. 4, 5 and 6).

The optimum pH for R. oligosporus was also affected by water activity of the medium, being ~5.9 at a_W ~1.0, ~5.6 at 0.96 and ~5.3 at 0.98 (Fig. 3).

The optimum water activity and carbon dioxide concentration did not appear to be affected by the values of other environmental factors and remained at ~1.0 and 0.03%, respectively, throughout.

Effects of environmental conditions on sporulation

The observation that sporulation was inhibited at 42 °C, pH 7.5 and 25 % v/v CO_2 at a_w of 0.96 and ~1.0 (0.98 was not tested) is noteworthy and suggests that investigations on the possible use of high carbon dioxide concentrations as a means of inhibiting sporulation in mature tempe or cassava heap fermentations is warranted.

Practical implications

The present work is the first to investigate the interactions between the major environmental factors likely to influence growth of moulds in the tempe fermentation. The traditional tempe fermentation is conducted at ambient temperature (~30 °C) and an initial pH of 4.5 – 5.5. During the fermentation the temperature rises to 40 °C or more and the pH increases to 6.5 – 7.0 in mature tempe or higher in over-incubated tempe (Ruiz-Teran and Owens 1996). The initial acidic conditions favour rapid spore germination (Medwid and Grant 1984) but is not optimal for rapid hyphal extension. However, before one could suggest any changes to the traditional procedure one would need to know their effect on contaminant microorganisms.

In Tanzanian cassava heap fermentations, the roots are peeled and partially sun dried prior to heaping for the fermentation. Rhizopus spp. appear to be relatively tolerant of low water activity so long as other conditions are near optimal (Fig. 3). Preliminary data suggests that Neurospora sitophila is much less tolerant of low water activity and it is possible that drying the surface of the cassava roots is important in favouring dominance by Rhizopus spp. in the fermentation. When comparable data are available for N. sitophila it may be possible to formulate specific recommendations to ensure the dominance of Rhizopus in the traditional fermentation.

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Table 1. Experimental design, observed and predicted values of hyphal extension rates and occurrence of sporulation by *Rhizopus oilgosporus* NRRL 2710 under different environmental conditions.

| Treat-ment no. | Environmental conditions | | | | Hyphal extension rate (mm h^{-1}) | | Occurrence of spores‡ |
	Factor A Temp-erature (°C)	Factor B pH	Factor C a_w	Factor D CO_2 (%v/v)	Observed*	Predicted†	
1	30	3.5	0.96	0.03	0.29 ±0.01	0.31	+
9	30	3.5	0.96	25	0.11 ±0.02	0.10	+
5	30	3.5	~1.0	0.03	0.34 ±0.01	0.31	+
12	30	3.5	~1.0	25	0.18 ±0.00	0.18	+
17	30	5.5	0.98	12.5	0.75 ±0.03	0.77	+
3	30	7.5	0.96	0.03	0.31 ±0.01	0.29	+
11	30	7.5	0.96	25	0.00 ±0.00	0.004	no growth
7	30	7.5	~1.0	0.03	0.75 ±0.04	0.77	+
14	30	7.5	~1.0	25	0.18 ±0.02	0.17	+
19	37	3.5	0.98	12.5	0.28 ±0.01	0.30	+
21	37	5.5	0.96	12.5	0.89 ±0.01	0.91	+
23	37	5.5	0.98	0.03	1.34 ±0.02	1.34	+
25	37	5.5	0.98	12.5	1.12 ±0.06	1.08	+
24	37	5.5	0.98	25	0.94 ±0.01	0.98	+
22	37	5.5	~1.0	12.5	1.17 ±0.02	1.19	+
20	37	7.5	0.98	12.5	0.28 ±0.01	0.30	+
2	42	3.5	0.96	0.03	0.34 ±0.02	0.31	+
10	42	3.5	0.96	25	0.23 ±0.01	0.23	+
6	42	3.5	~1.0	0.03	0.39 ±0.02	0.41	+
13	42	3.5	~1.0	25	0.21 ±0.03	0.19	+
18	42	5.5	0.98	12.5	1.24 ±0.04	1.26	+
4	42	7.5	0.96	0.03	0.48 ±0.00	0.53	+
15	42	7.5	0.96	25	0.15 ±0.01	0.13	-
8	42	7.5	~1.0	0.03	1.13 ±0.03	1.10	+
16	42	7.5	~1.0	25	0.17 ±0.01	0.17	-

*, means of quadruplicate determinations except for treatments 4, 16 (duplicates) and 25 (12 replicates) ±range. Data includes spore inoculum and mycelial inoculum cultures.

†, predicted by equation given in the text

‡, + spores formed within 87 h; - no visible spores formed

Fig. 1 Perturbation plot showing the predicted effect of temperature, pH, water activity and CO_2 concentration on the hyphal extension rate of *Rhizopus oligosporus* when other factors are at their midpoints (36 °C, pH 5.5, a_W 0.98 and CO_2 12.5% [v/v]). A, temperature (-1.0 = 30 °C; +1.0 = 42 °C); B, pH (-1.0 = 3.5, +1.0 = 7.5); C, a_W (-1.0 = 0.96, +1.0 = ~1.00) and D, carbon dioxide concentration (-1.0 = 0.03, +1.0 = 25 %[v/v]).
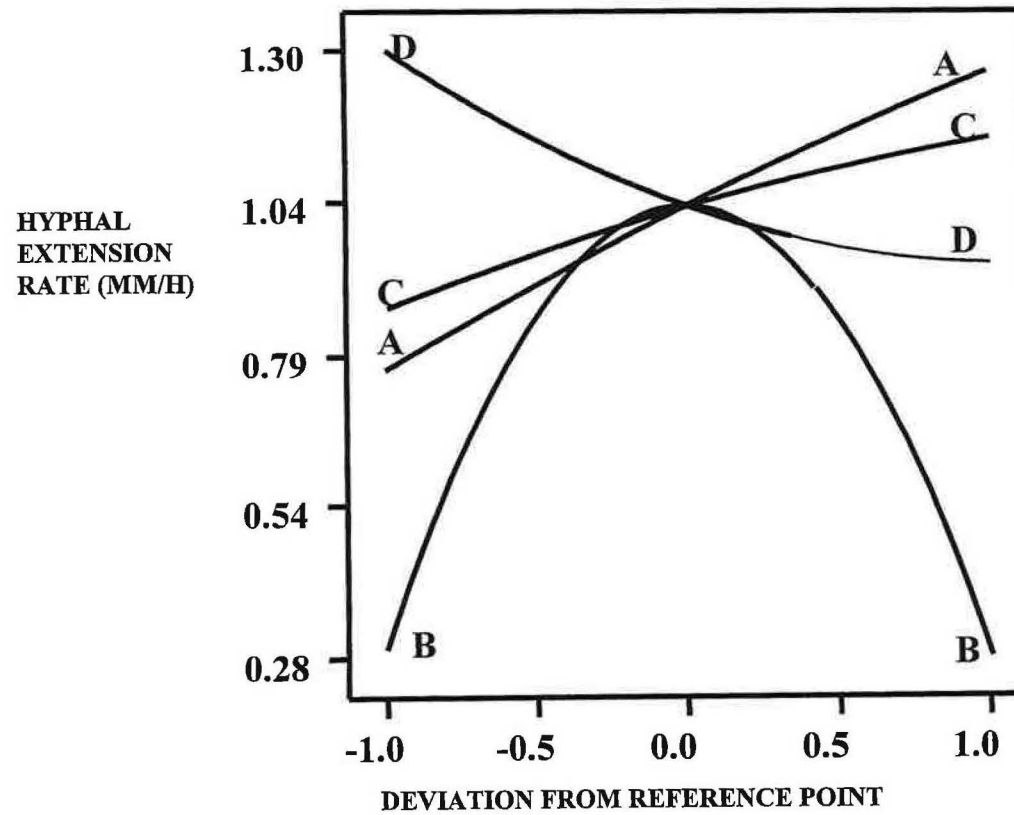
Fig. 2 Response surface showing predicted effect of temperature and pH on hyphal extension rate of *Rhizopus oligosporus* at pH 5.5 and 0.03 %(v/v) CO_2.
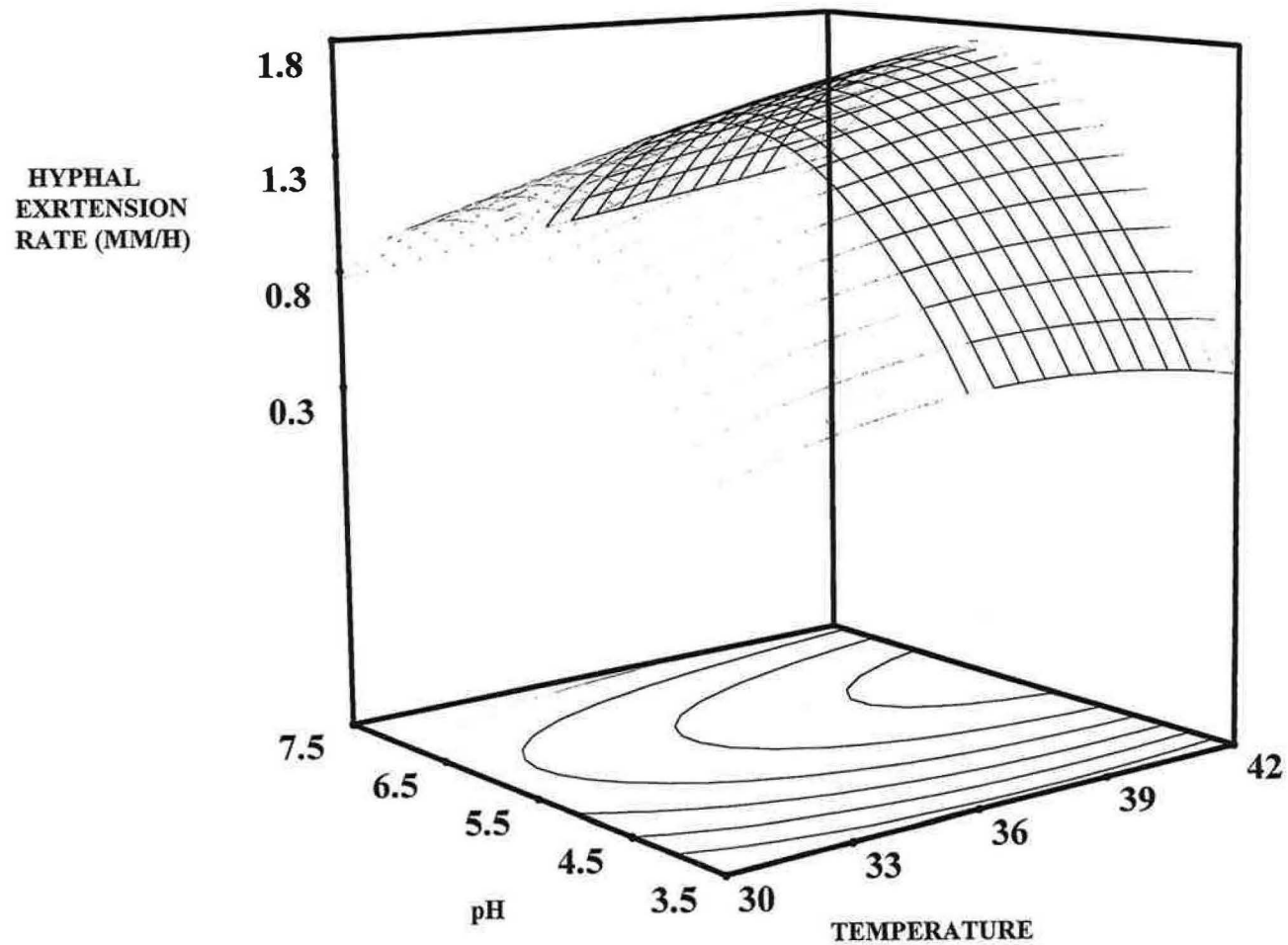
Fig. 3 Predicted effect of temperature and pH value on hyphal extension rate (mm h^{-1}) of *Rhizopus oligosporus* at different water activities in the presence of 0.03 % (v/v) CO_2.
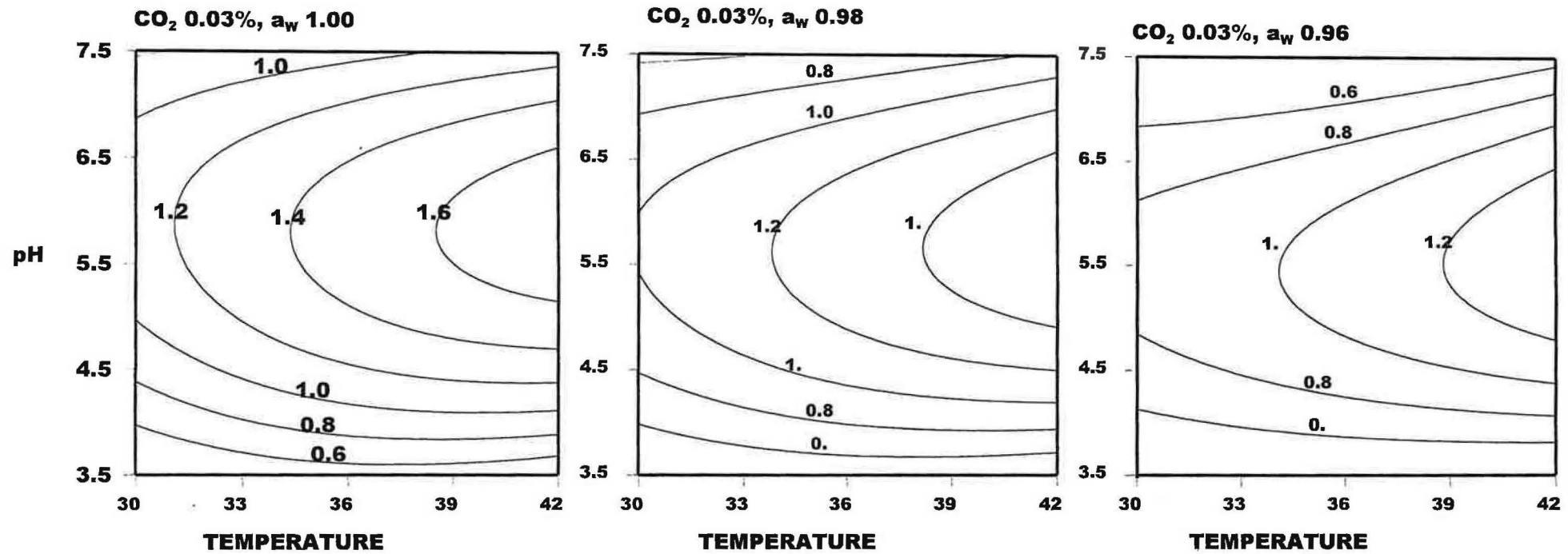
Fig. 4 Predicted effect of temperate water activity on hyphal extension rate (mm h^{-1}) of *Rhizopus oligosporus* at different pH values in the presence of 0.03 % (v/v) CO_2.
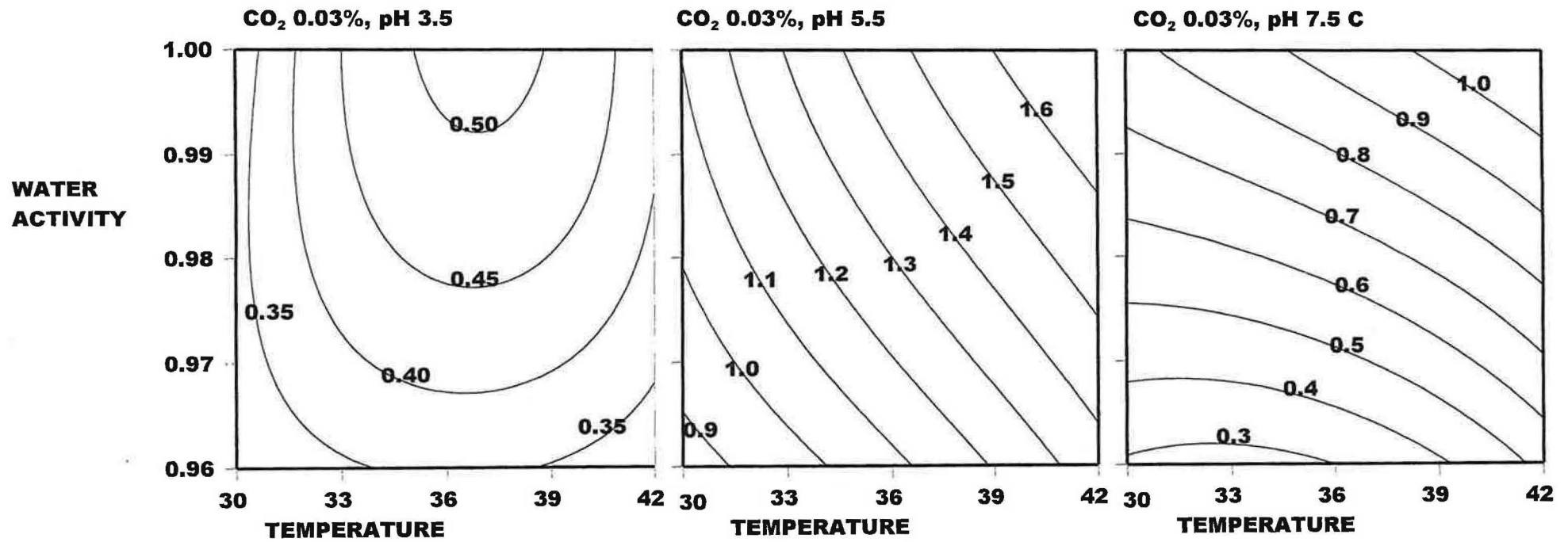
Fig. 5 Predicted effect of temperature and carbon dioxide concentration on hyphal extension rate (mm h^{-1}) of *Rhizopus oligosporus* at different pH values in the presence of water activity ~1.0.
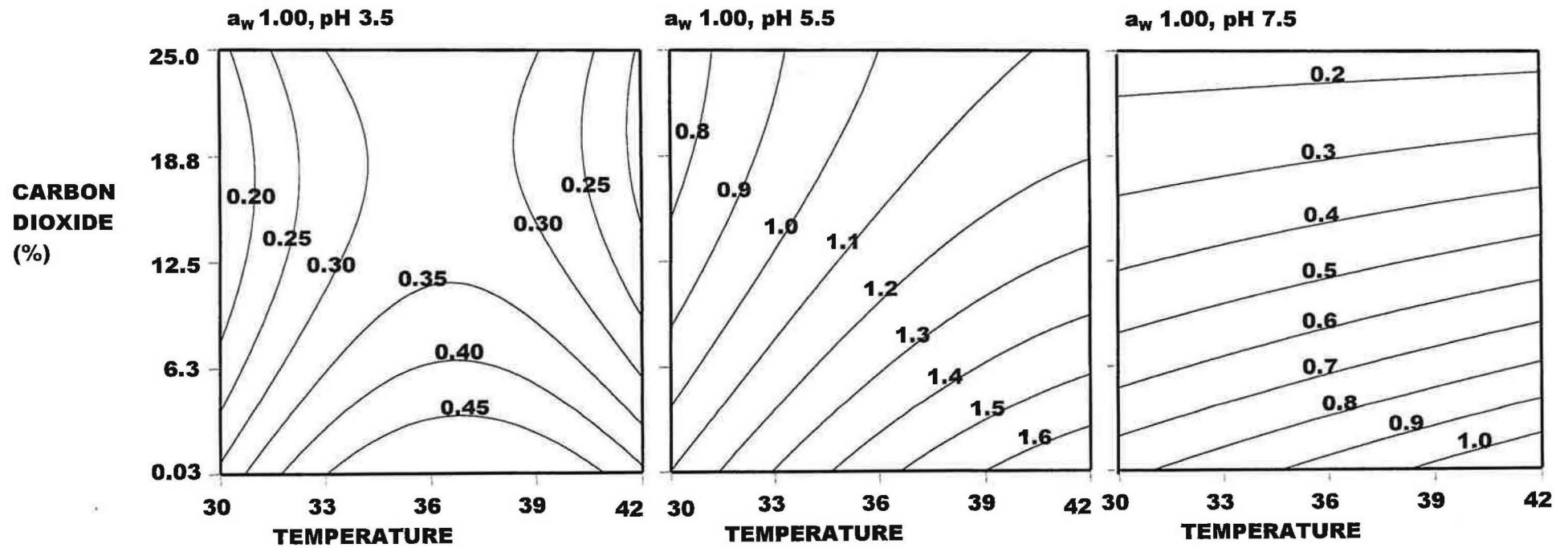
Fig. 6 Predicted effect of temperate and carbon dioxide concentration on hyphal extension rate (mm h^{-1}) of *Rhizopus oligosporus* at different pH values in the presence of water activity 0.96.
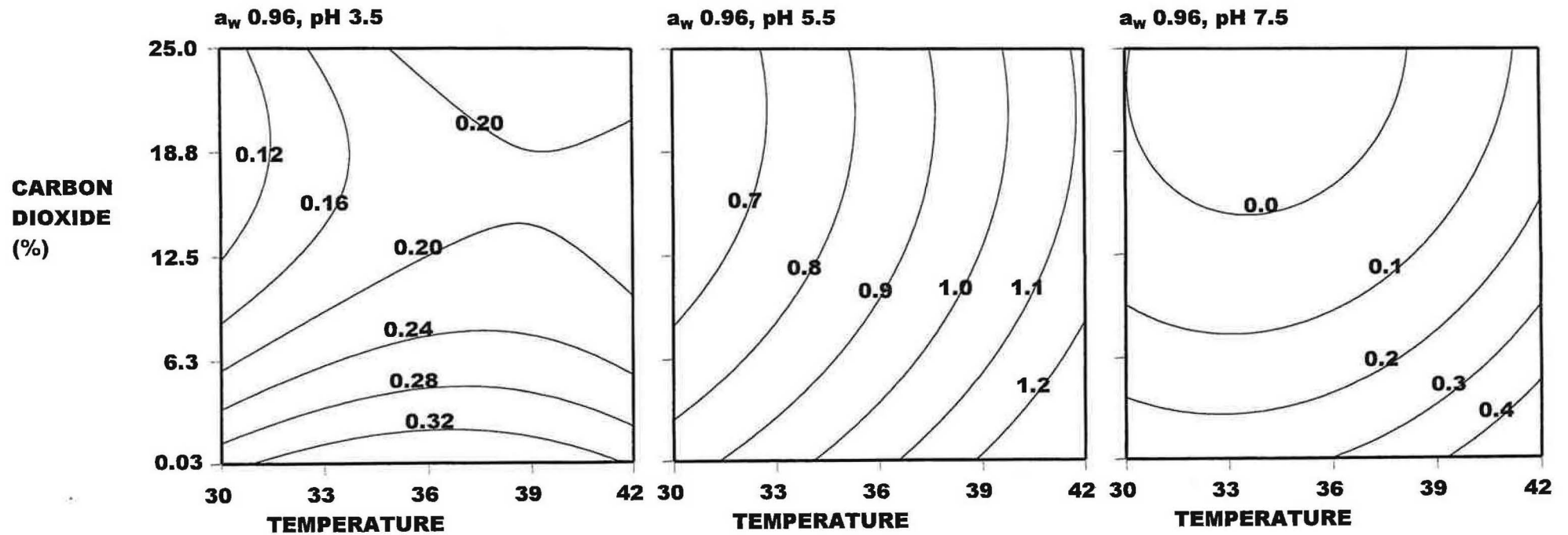
Fig. 7 Predicted effect of temperate and carbon dioxide concentration on hyphal extension rate (mm h^{-1}) of *Rhizopus oligosporus* at different water activities in the presence of pH 5.5.