CROP POST HARVEST PROGRAMME

Sweetpotato cultivars with improved keeping qualities for East Africa.

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ABBREVIATIONS

CIP	International Potato Center
DM	Dry matter
KARI	Kenyan Agricultural Research Institute
IITA	International Institute of Tropical Agriculture
ISTRC	International Society of Tropical Roots Crops
LI	Lignification index
LZARDI	Lake Zone Agriculture Research and Development Institute
NARO	National Agricultural Research Organisation (of Uganda)
NRI	Natural Resources Institute
PCA	principal component analysis
PPD	Post-harvest physiological deterioration
PRAPACE	Programme Regional de la Pomme de terre et de la Patata douce en Afrique Central et de l'Est
SARRNET	Central Africa and Southern Africa Root Crops Research Network
TNRTCP	Tanzanian National Root and Tuber Crops Programme
USDA	US Department of Agriculture

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EXECUTIVE SUMMARY

The objective of this project was to facilitate development of sweetpotato cultivars with improved post-harvest qualities, especially improved shelf-life and storability, thus improving food security and income generation through better marketing and storage. Breeding initiatives for sweetpotato are at an early stage compared to other staples, so there is particular potential for crop improvement, and a need to understand quality characteristics and how to select them.

A wide range in perishability was found among cultivars (R6507), underlining the potential for improvement by breeding. A major factor was the ability of a cultivar to heal wounds at moderate humidities, which was found to correlate with low dry matter (DM) content. Given that the preferred sensory characteristic of *mealiness* relates to high DM content, identification of cultivars with high DM content and efficient wound-healing would be beneficial.

Using methods developed earlier (R6507), we screened sets of germplasm covering 47 sweetpotato cultivars from many origins. Cultivars fall into groups depending on origin; East African cultivars have higher DM content and lower wound healing efficiency than cultivars from other locations. Wound healing efficiency is linked to DM content, but exceptional cultivars with high DM content and high wound healing efficiency were identified.

Research to determine the physiological basis for differences in wound healing efficiency, and the link with DM found that when roots are wounded at moderate/low humidity there is an initial accumulation of sugars close to the wound. The level of accumulated sugars is cultivar dependent and a major factor in controlling efficiency of healing. We hypothesize that the accumulation of sugars protects tissues from desiccation by increasing the osmotic potential. Although we cannot demonstrate a difference in initial weight loss, it is possible that specific cellular compartments are protected against water loss. A relationship between DM content and wound healing efficiency is a consequence of the fact that cultivars with rapid starch mobilisation tend to have lower DM content. We do not know if the good healing/high DM cultivars have some additional characteristic to improve wound healing.

We examined the potential for using semi-trained taste panels to assess sensory characteristics of new cultivars. For three sites in Tanzania over two seasons, consumer tests were used to rank local cultivars which were then profiled by a trained panel at LZARDI-Ukiriguru. The most popular varieties had very consistent profiles even though the sensory profiles of some cultivars changed with season. Important sensory attributes for consumer acceptability are starch and stickiness, which could be used for rapid tests of cultivar acceptability where large cultivar numbers are assessed.

A book entitled "Sweetpotato post-harvest assessment: Experiences from East Africa" has been produced as a collaboration between the Natural Resources Institute, the Tanzanian Ministry of Agriculture and the International Potato Center with input from the National Agricultural Research Laboratories of Kenya and the National Agricultural Research Organisation of Uganda. This book consolidates information and expertise gained in this and earlier projects and is to be disseminated to organisations involved in sweetpotato breeding, throughout the world.

CONTENTS

BACKGROUND

1. Introduction

1.1 The importance of sweetpotato as a food security crop and for income generation

Sweetpotato (*Ipomoea batatas*) is the world's seventh most important staple crop, grown in over 100 countries of the world, covering an estimated total area of 9.2 million Ha, with an annual global production around 125 million tonnes. Almost 95% of the total production is in developing countries (CIP 1996). Past and current production trends suggest that sweetpotato output in developing countries is increasing, for example in Africa it is estimated that it is presently growing at about five percent per year (CIP 1996).

For several reasons sweetpotato is particularly valuable for resource poor farmers; it can be grown with little inputs, is relatively resistant to pests and diseases, and is relatively water-use efficient. Thus it is grown particularly in areas marginal for agricultural production. This is illustrated by the fact that with an annual per capita production in Africa near 9 Kg, per capita consumption often exceeds 100 Kg within poorer communities (CIP 1996). Sweetpotato is becoming increasingly important in areas of increasing population and especially in those where cassava yields are being severely affected by African cassava mosaic virus.

Although of relevance to sweetpotato production areas throughout the world, this project is focused towards East Africa where, as in most parts of the developing world, sweetpotato is grown not only for home consumption, but increasingly to supplement household income by marketing. With the increasing urbanisation of the East African population, marketing of food to urban centres is of growing importance. The short shelf-life of sweetpotato is a major constraint to marketing, especially when the roots need to be transported to the urban centres.

1.2 Improvement of post-harvest characteristics through breeding.

Sweetpotato is considered to be the most under-exploited of the developing world's major crops (Walker and Crissman 1996). This has probably arisen as a result of its status as a poor man's crop, and the fact that it is produced almost entirely in developing countries. Research on this crop is therefore likely to produce particularly high returns for effort.

Breeding initiatives for sweetpotato are at a relatively early stage compared to other staple crops. The main international breeding effort for developing countries is led by the International Potato Center (CIP) based in Lima. CIP has breeding sites throughout the world, including in sub-Saharan Africa, and actively provides clones for testing in East Africa. In addition several of the national programmes in East Africa (including Tanzania, Kenya and Uganda) are now carrying out their own crossing and have reached the stage of releasing their own cultivars within the last decade.

While the main objectives of breeding programmes have traditionally been an increase in yield and improvement of other production characteristics, the importance of post-harvest characteristics is being increasingly recognised. The overall objective of this project, continuing from previous work, is the improvement of the post-harvest characteristics of the sweetpotato crop through breeding and cultivar selection. Given the enormous genetic diversity of sweetpotato world-wide, and the fact that breeding programmes of sweetpotato are relatively new, crop improvements are expected to be rapid.

Improvement to the sweetpotato crop through breeding requires first that a characteristic be identified as desirable. If this specific characteristic is already exhibited within the locally available germplasm, an appropriate method of selection must be devised for use by breeding programmes. In the case of sweetpotato there appears to be substantial genetic diversity between spatially distinct collections of germplasm. The process of improving cultivars will differ depending on whether the desirable characteristics are located within locally available germplasm, or are only found in germplasm collections in other parts of the world. In the former case, local breeding programmes will be able to carry out selection themselves, whereas in the latter case the involvement of an international organisation such as CIP may be necessary. The breeding strategy may also depend on the nature of the characteristic being sought, in particular whether it is appropriate to select directly for the characteristic, or whether some indirect method of selection is needed. In some cases the characteristic may not be readily available within the crop germplasm, in which case the only feasible strategy will be to resort to biotechnology. Whether or not this is justifiable will depend on many factors, including the balance between cost and economic benefit.

1.3 Information on cultivar qualities obtained from earlier projects

This project has built on work carried out in earlier projects, and in particular R6507 "The extension of storage life and improvement of quality in fresh sweetpotato through selection of appropriate cultivars and handling conditions". During project R6507 several issues relating to post-harvest quality characteristics of sweetpotato cultivars were considered:

- It was shown that sweetpotato cultivars vary considerably in shelf-life under the normal handling conditions encountered in East Africa, and considerable progress was made in developing our understanding of why this is the case (Rees *et al.,* 2003, van Oirschot *et al.,* 2003).

- The response of roots to infection by rotting pathogens was studied, in particular to *Rhizopus oryzae* one of the most important pathogens in Tanzania. It was demonstrated that cultivars differ in susceptibility to this pathogen, and that resistant cultivars produce antifungal toxins. As rotting is likely to be a particular problem at high humidity, it was proposed that resistant cultivars would be particularly suitable for long-term storage (Muhanna, 2001).

- Where storage of fresh roots is not feasible, sweetpotato can be stored as sun-dried chips, in which case storage life is limited by insect infestation. The most damaging infesting insect found in the area of study (Kumi District, Uganda) was *Araecerus fasciculatus*. Variation in susceptibility to *A. fasciculatus* was found among cultivars (Agona, 1998).

- Wherever new cultivars are being selected it is important that they have acceptable eating qualities. The results of earlier surveys were reviewed to identify the quality criteria by which farmers select sweetpotato cultivars. However, as very little information existed on the preferences of urban consumers and traders, survey work was conducted in Lake Zone of Tanzania to identify the most important criteria. These were defined as starchiness, good taste and good apearance (Kapinga *et al.*, 1996;1997).

- In another project R6769 "Investigating cultivar differences in susceptibility to sweetpotato weevils as a means of control" the variability among cultivars in susceptibility to *Cylas* spp. was considered. Although *Cylas* is a field pest, it has such important implications for root quality that it would be considered as a post-harvest problem (Stathers *et al.,* 2003a,b).

We believe that the information obtained during the studies listed above is of enormous value for institutes involved in sweetpotato improvement programmes, and hence an important part of this project is to produce a report describing our experiences with some additional input from other organisations.

In three particular areas further research work was considered necessary: firstly cultivar differences in root shelf-life, and the potential for breeding for extended shelf-life; secondly practical methods for assessing sensory characteristics of cultivars; and thirdly, root characteristics that would make a cultivar suitable for long-term storage. The background to the first two issues is given in more detail below. The third issue was considered in work that linked this and another project R7498 which ran consecutively. For clarity it will be considered in the report of project R7498.

2 . Practical methods for the assessment of cultivar sensory characteristics

Sensory characteristics (taste, texture and smell) of cooked roots are particularly important for consumer acceptability. The most important sensory criteria of sweetpotato cultivars identified by consumers and traders during R6507 included starchiness/mealiness, good taste and good appearance. Many are subjective and, therefore, difficult or impossible to measure by analytical means. This makes assessment of new cultivars for consumer acceptability very difficult. Direct consumer testing of new varieties is possible but, in order to get a reliable result, it is necessary to use a large number of consumers (usually at least 100), which is expensive and time consuming, and becomes possible only at a late stage of cultivar screening, where very few cultivars are being assessed. In R6507 we started to investigate an alternative strategy by using small trained taste panels of 10–20 people to produce sensory profiles of cultivars. To create a profile, the panel were asked to assess cooked sweetpotato samples for a range of pre-chosen characteristics as objectively as possible. This method differs from ‘Consumer Preference and Acceptability Tests’, which measure how consumers like, prefer or accept a product (O’Mahony, 1995). Instead profiles of sensory characteristics can be obtained, giving a broad analysis in terms of intensities of a set of sensory attributes. Attributes are normally generated in brainstorming sessions, followed by discussions among the panellists (Stone *et al.,* 1974). The objective was to identify a sensory profile that accurately represents the preferences of consumers, so that the profiles of new cultivars can be compared with this ‘ideal profile’. One key question when determining whether this is feasible is how consistent consumer preferences are across a country and, therefore, whether one consistently preferred profile exists for each country. Initial results in Tanzania suggested that there is a degree of consistency but the work was only conducted during one season (Rwiza *et al.,* 2000).

3. Shelf-life of sweetpotato storage roots

Within project R6507, it was also found that the variation in shelf-life observed among locally available germplasm was associated with dry matter content. High dry matter cultivars tend to have shorter shelf-life. Given that high dry matter has been identified as an important criterion for consumer acceptability in East Africa, this was an unwelcome finding. Thus, this project looked more widely among sweetpotato germplasm worldwide to seek out sources of variation in shelf-life not associated with dry matter content, and also sought to elucidate physiological factors controlling shelf-life. These issues are considered in more detail below

3.1 Constraints to marketing due to short shelf-life

Sweetpotato storage roots can be stored under controlled environments for several months. For example, in the USA, when roots are stored at temperatures of 13–15 ºC and high relative humidity, they can be kept for up to a year (Picha, 1986). The use of temperature-controlled storage of sweetpotatoes is usually not economically feasible in tropical developing countries. However, even in the absence of temperature control, storage for 3–4 months has been demonstrated, where roots are selected carefully and stored in traditional pits or clamps in which high humidity is naturally maintained (Hall and Devereau, 2000; van Oirschot *et al.*, 2000). During marketing under tropical conditions, sweetpotato roots have a much shorter shelf-life of only 2–3 weeks (Kapinga *et al.*, 1997; Rees *et al.*, 2001). The reason for this is that during marketing, for practical reasons, the conditions under which roots are kept are non-ideal. During transport, roots will be subjected to mechanical damage, temperatures may be very high, and generally humidity is low so that roots dry out

Several surveys conducted in East Africa prior to the start of project R6507 led to the recommendation that less perishable sweetpotato varieties should be developed and that handling techniques be devised to minimise post-harvest losses, especially in Tanzania. These included surveys conducted both by NRI, and by the Tanzanian National Programme (e.g. Fowler and Stabrawa, 1993; Kapinga *et al.*, 1995). Precise economic losses have not been quantified, although it has been estimated that losses of sweetpotato can range from 35% to 95% in developing countries. Such high figures require confirmation. Informal surveys, however, indicated that the marketing system is limited by the assumption that roots can remain in the market for a maximum of three days. Traders must reduce prices to clear stocks, and still report high levels of loss (Bancroft *pers. comm.*). More recent work conducted in Tanzania within projects R6507 and R6508 indicated that, during marketing, roots rarely keep for longer than two to three weeks (Kapinga *et al.*, 1997; Rees *et al.*, 2001). These findings are recognised by the Tanzanian Ministry of Agriculture who are giving increasingly high priority to post-harvest issues such that the National Agricultural and Livestock Research Masterplan gave priority 1 to post-harvest research in several zones of the country. Likewise the Ministry of Agriculture funded the establishment of a post-harvest unit within the National Root and Tuber Crops Research Programme based in Lake Zone.

3.2 Cultivar differences in shelf-life

An extension of shelf-life could be achieved by improving handling techniques, while another complementary approach is to introduce and promote cultivars with better keeping qualities. The introduction of such cultivars causes minimal extra expense to farmers and traders and it is likely that they would also improve the potential for long-term storage. Project R6507 considered the varietal factors that control shelf-life, and came up with the following observations. (Rees *et al.,* 1998; 1999; 2001; 2003; van Oirschot, 2000; van Oirschot *et al.*, 1999, 2003, submitted).

- The main forms of deterioration for roots stored under normal marketing conditions are water loss and rotting. Sprouting is generally insignificant. Where water loss and rotting are minimised, sensory properties are relatively stable.
- Under normal handling and marketing conditions observed in East Africa (moderately rough handling, sub-optimal humidity, tropical temperatures) a large range in the storability of sweetpotato exists among the available germplasm. Fresh weight loss and rotting are closely related, such that cultivars that lose weight rapidly also tend to rot rapidly. Assessment of cultivars on their rate of fresh weight loss therefore provides a simple method of selection.
- Under these conditions deterioration is dominated by water loss through unhealed or incompletely healed wounds. Variations between cultivars in the structure and thickness of the native periderm are insignificant, and differences are related primarily to wounding

and wound-healing characteristics.

- Susceptibility to damage (e.g. scuffing, breakages, bruising) varies between cultivars.

3.3 Background on wound healing and its control

Descriptions of the process of wound healing in sweetpotato date from the 1920s when Weimer and Harter (1921) described how moisture and temperature affect the wound periderm formation and the efficiency of the wound cork in preventing infection. Artschwager and Starret (1931) distinguished three stages of healing; 1) desiccation of several cell layers of parenchyma; 2) thickening of cell walls (suberization or lignification) in underlying cell layers; 3) formation of the wound periderm.

The desiccation of cell layers in which the cells on the surface dry out and die is the first response after wounding. Under sub-optimal healing conditions this layer of desiccated cells may be thicker, which is unfavourable for shelf life of the roots as it favours the growth of pathogens (Nielsen and Johnson, 1974). The effect of cultivar on the thickness of the desiccated layer in sweetpotatoes has not been reported.

Lignification is probably the most crucial step in the wound healing process. Cell walls below the desiccated cell layers become thickened, although there is some uncertainty about the exact chemical nature of this thickening (Walter and Schadel, 1982; 1983). Artschwager and Starett (1931) reported that the thickened cell layers absorb crystal violet which indicates suberisation. Later, McClure (1960) found that these cells have a much stronger affinity for a saturated solution of phloroglucinol in 18% HCl, which indicates a lignin like structure. With mass spectroscopy, Walter and Schadel (1983) confirmed that the polymeric compounds in these cells had the chemical properties of lignin. Once this lignified layer is formed a new wound periderm will form underneath, even if the roots are removed from curing conditions (Walter and Schadel, 1982; Morris and Mann, 1955), although it develops more quickly under curing conditions.

The wound periderm consists of cell layers, stacked in a similar way to the native periderm. The thickness of the wound periderm may vary according to the cultivar. Morris and Mann (1955) found thicknesses varying from 4 to 10 layers while Walter and Schadel (1983) and St Amand and Randle (1991) reported thicknesses between 5 and 6.7 layers. Walter and Schadel (1982) considered a wound periderm needed to be approximately 4.2 cell layers thick to be effective against water loss and pathogen invasion.

Wounds in sweetpotatoes heal most efficiently when the roots are exposed to temperatures of 28-30°C and a relative humidity (RH) greater than 85% (Kushman and Wright, 1969). Although curing is practised commercially in temperate areas, in the tropics it is often assumed that it takes place naturally (Collins and Walter 1985; Woolfe 1992) and is not actively practised. Jenkins (1982) reported that artificial curing under tropical conditions in Bangladesh did not reduce weight losses. However, the high levels of weight loss and very short shelf-life often seen in the tropics put into doubt whether wound healing takes place.

Most of the work on the control of wound healing in sweetpotato has been carried out in the United States or in Japan. Wounding induces ethylene production which has been strongly implicated in the control of the wound response. Imaseki *et al.* (1968) demonstrated that ethylene stimulates the activity of the enzyme phenylalanine ammonia-lyase (PAL), which catalyses the first reaction in the biosynthesis of phenylpropanoids, and is therefore a key enzyme in the synthesis of lignin and suberin. By using inhibitors of ethylene synthesis and ethylene antagonists, St-Amand and Randle (1989) demonstrated a relationship between ethylene and the development of wound periderm.

Cultivar differences in ethylene production have been observed (Saltveit and Locy 1982, St.-Amand and Randle 1991) and the possibility of using ethylene production as an indication of wound response, and therefore in cultivar selection, has been investigated. This is complicated by the fact that different cultivars can exhibit different patterns of ethylene production with time, and also that ethylene production is affected by factors such as prior curing and storage time (Randle and Woodson 1986, St-Amand and Randle 1991). For example, wound-induced ethylene production is significantly higher in pre-cured roots. An attempt has been made to relate the levels of ethylene production on specific days after wounding to the final number of wound periderm cell layers (St.-Amand and Randle 1991). The results were not completely convincing, and further investigation would be necessary before such a method could be accepted as a reliable selection technique.

The literature is much more extensive for potato, and it is possible, although the physiological origin of the potato tuber and the sweetpotato root are quite distinct, that much of the information could be extrapolated. As in sweetpotato, the activity of PAL increases after wounding. This is due both to activation of existing enzyme and synthesis of new enzyme. There appears to be an inactivation system for the enzyme which operates once wound healing is completed (Ishizuka et al 1991). Studies on the control of PAL activation and synthesis have been undertaken by Ishizuka *et al* (1991), and Shaw *et al* (1990). Ishizuka *et al.* used sweetpotato cDNA and antibodies in their studies, which indicates a high degree of interspecies homology for the enzyme, and supports the idea that control mechanisms are likely to be similar in potato and sweetpotato. The induction of other enzymes, presumably also involved in the wound response, such as 3-deoxy-D-arabino-heptulosonate-7-phosphate (DAHP) synthase (Dyer 1989) and lipoxygenase (Lulai 1988) has also been observed in potato.

Interestingly, the induction of PAL by the addition of elicitor molecules derived from pathogens has also been studied in bean cell cultures (Edwards *et al.* 1985). This might indicate a useful system for future studies on sweetpotato.

3.4 Findings from project R6507 on wound-healing in sweetpotato

(Rees *et al.,* 1998; 1999; 2001; 2003; van Oirschot, 2000; van Oirschot *et al.*, 1999, 2003, submitted). Most of the scientific literature on wound-healing considers the process as it occurs under optimal conditions i.e. at high humidity. In practice we have found that sweetpotato shelf-life is determined by the ability of roots to heal at sub-optimal humidities, as this is more representative of the environment to which they are exposed during handling and marketing. During project R6507, a considerable amount of information was obtained on the wound-healing behaviour of a range of cultivars.

Under sub-optimal humidities (65% ± 10) the depth of the lignified layer i.e. the thickness of the desiccated cell layers is affected by both cultivar and humidity. While some cultivars can form a continuous lignified layer, some consistently fail to produce a lignified layer and for others the layer is often not continuous. The continuity of the lignified layer is essential for effectiveness of wound healing than the actual thickness.

A method for assessing efficiency of wound healing based on assessing the continuity of lignified layers was developed, and called the lignification index, and thus it was confirmed that wound healing efficiency as measured by the lignification index was a major factor for the shelf-life of sweetpotato cultivars. Studies confirmed that lignification of wounds correlates with reduced rate of weight loss and reduced susceptibility to microbial infection. Throughout the studies we found that a high dry matter content in cultivars correlated with a low lignification index. This relationship was consistent for 5 trials, including 34 cultivars. We thus developed a hypothesis that there is a critical moisture content, below which healing cannot occur, and that as wounds dessicate, high dry matter cultivars reach this level more rapidly than low dry matter cultivars. One implication of this hypothesis is that at high humidities this effect should be minimized. This prediction was verified.

3.5 Potential problems due to the relationship between wound healing efficiency and dry matter content

Our findings provided simple selection methods for sweetpotato cultivars with long shelf-life, either by following rates of weight loss, or by assessment of wound-healing directly through staining of lignin by phloroglucinol. However, the finding that cultivars with higher dry matter content have less efficient wound healing was unwelcome. Mealiness, associated with high dry matter content was one of the main consumer criteria for sweetpotato cultivars identified in Lake Zone of Tanzania (Kapinga *et al.* 1997). High dry matter content is also very important where roots are used for processing, and world-wide the characteristic is considered so important that CIP has a specific initiative to breed for higher dry matter cultivars.

It thus becomes very important to determine the basis of the relationship between high dry matter content and wound-healing efficiency, and to determine to what extent high dry matter cultivars with good wound-healing characteristics can be developed.

3.6 The feasibility of and strategies for the development of high dry matter cultivars with good wound healing characteristics

For the reasons given above it was proposed that screening be carried out to search out cultivars that have unusually high wound healing efficiency with respect to their dry matter content. Prior to this project we already had some evidence that this might be successful. During R6507, three cultivars tested in Tanzania (two Tanzanian cultivars (Kagole, Bilagala) and one clone introduced by CIP (440088)) were found to have better keeping qualities than predicted from their dry matter content. However their wound healing efficiency was not specifically determined. There are also indications that North American germplasm has better keeping qualities than East African germplasm (J. Bohac, USDA, pers. comm.). Although some introduced germplasm was available for experimentation during project R6507, we believed that studies of a wider range of germplasm will not only increase our understanding of key factors in storability, but also increase the likelihood of finding beneficial traits for breeding. During the course of project R6507 the research team at NRI developed a useful dialogue with the sweetpotato breeding programme in the USA, so that there was potential for a very valuable collaboration to be established.

Additional encouraging evidence came from past work on North American cultivars by Clark and co-workers, in Louisiana. They carried out a number of studies, developing methodologies to look at variation in susceptibility of North American sweetpotato cultivars to bacterial and fungal rots (Clark 1986, 1992, Clark et al. 1989). They used the rate of water loss, and resistance to rots as indicators of wound healing, and have demonstrated that cultivar differences are significant (Clark 1992). The relationship between the work carried out by Clark and that carried out within project R6507 was discussed with Clark. The differences observed by Clark were of a smaller magnitude than those we observed. However, Clark conducted his studies at high humidities (> 95%), under which conditions we would not expect to see differences related to high dry matter content, suggesting that some alternative factor exists.

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PROJECT PURPOSE

Programme output: Strategies developed and promoted which improve food security of poor households through increased availability and improved quality of root crop and horticultural foods and better access to markets.

Sweetpotato is an important staple crop in many parts of the developing world, and has many agronomic properties which make it particularly suitable for production in marginal agricultural areas. It is one of the most under-researched of the staple crops. Many breeding programmes are at an early stage, and great genetic diversity is available, so that there is enormous potential for crop improvement. The successful introduction of improved cultivars depends on them having appropriate pre and post-harvest qualities. The overall objective of this project is to facilitate the development of sweetpotato cultivars with improved post-harvest qualities, with particular focus on improved shelf-life and storability.

The effective introduction of improved sweetpotato cultivars, which depends on selecting for acceptable post-harvest characteristics will increase food availability thereby improving food security. The research conducted within this project will help in particular the selection of cultivars with improved storability, which will allow more efficient marketing over longer distances and facilitate storage during seasons of shortage. For the rural poor this will result in improved food security and income generation as a result of marketing. For the urban poor more efficient food supply from the rural areas will improve food security.

The dissemination of the project findings is an integral part of this project.

RESEARCH ACTIVITIES

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

Project staff

During the course of the project several staff changes occurred. The project manager was absent on maternity leave from January to May 2001, during which time project management was taken over by Dr Quirien van Oirschot. Dr Regina Kapinga was originally based at Lake Zone Agricultural Research and Development Institute (LZARDI)-Ukiriguru, but transferred to COSTECH, in Dar es Salaam in 2000, and then to the International Potato Center, Kampala in 2001. Dr Julia Aked was originally at Cranfield University at Silsoe, but left in 2001, although retaining her links with Cranfield as an associate lecturer. Partly as a consequence of Dr Aked's change in status, Dr Patricia Harvey of the University of Greenwich joined the project team in 2002.
These changes had implications for certain project activities as indicated for specific outputs.

1. Protocols for the post-harvest assessment of sweetpotato cultivars within national breeding programmes disseminated.

The Crop Post-harvest Programme has funded a considerable amount of work within several projects in East Africa on post-harvest aspects of sweetpotato. This output is concerned with the dissemination of key findings of this research in the form of a book (activity 1.2). Activity 1.1 describes work conducted to complete a study initiated in a previous project.

1.1 Assessment of locally available cultivars at three sites in terms of consumer preferences and sensory profile, to determine the potential for using trained panels for cultivar selection.

This activity was carried out by staff of LZARDI-Ukiriguru with technical supervision and analysis by NRI

Within a breeding programme it is essential to assess new cultivars in terms of acceptability of sensory characteristics, but these can be very complex and technically difficult to measure. A trained taste panel may provide the most practical and effective method to assess sensory acceptability.

Methodology of trials
Further details are provided in Appendix I.

Trials were conducted in 2000 at Mwanza, Meatu and Misungwi, using methods similar to those used in 1998. For each site 4-5 locally available cultivars were selected and subjected to consumer testing using 100 consumers. Each consumer was presented with randomly labelled cooked samples and asked to select their most and least preferred. 20 consumers at each site were asked additional questions on their sensory perceptions of the samples in order to build up a consumer sensory profile. A questionnaire was used to obtain further information on the socioeconomic background of all the consumers and their patterns of sweetpotato consumption using a questionnaire. As for the previous trial, samples of the same sweetpotato cultivars were then subjected to sensory profiling using a trained taste panel of ten people based at LZARDI-Ukiriguru.

Interpretation of data

For this and the earlier project, technical input on trial methods and also data analysis was provided by Keith Tomlins of NRI. During the course of this project, NRI provided funding for Mr Tomlins to obtain further training at the University of Bath on statistical analysis of sensory data. We were therefore able to apply more powerful analytical techniques than originally considered to the data obtained during the trials of both 1998 and 2000.

1.2 Production of publication

This publication has been produced as a collaboration between NRI, the Tanzanian National Root and Tuber Crops Programme (TNRTCP) and CIP, with additional input from the Kenyan Agricultural Research Institute (KARI) and the National Agricultural Research Organisation (NARO) of Uganda.

The initial plan had been that the production would be co-ordinated by Dr Regina Kapinga while she was on study leave from her position within the TNRTCP. However after initiating the publication, Dr Kapinga left LZARDI-Ukiriguru to take up new responsibilities within COSTECH, and subsequently within CIP. Hence most of the coordination responsibilities were taken on by the project manager and other NRI staff.

Dr Kapinga visited NRI for two weeks in October 2000 to work with NRI staff in order to produce a publication plan. Subsequently a draft publication was produced which was circulated within all collaborating institutions for comment in early 2001. Having reviewed this draft, however, it was decided that the style and focus should be altered to make the publication more appropriate to the target audience. Initially we took the approach that we were writing a manual with a set of instructions for national programmes to use when setting up their own methodologies for assessing sweetpotato cultivars. On reflection we decided that this was too proscriptive, and that the emphasis should be on presenting our experiences, in the form of a report, with a subsequent discussion as to how this might relate to work being conducted in other countries. In addition, in the light of our experiences during the course of the present project, we decided to expand some of the material, particularly on sensory profiling and root wound-healing. As a consequent the publication underwent considerable rewriting was delayed until certain project activities were complete (These changes were discussed and agreed with the Programme Manager during the course of the project). For this reason, due to the staff changes described above, and due to overoptimistic timescales, the publication has been delayed by almost two years. However, we believe that the result is a much more valuable publication for dissemination.

Professional editing and typesetting was undertaken by the University of Greenwich. Proofs of the publication were completed in January 2003. Printing will be carried out as soon as final approval is obtained from CIP and the Tanzanian MoA.

1.3 Dissemination of publication

Due to late completion of the publication, distribution will take place after the official end of the project. NRI already has databases of appropriate organisations that were used for distribution of earlier publications on root crops. Additional addresses will be obtained through CIP, SARRNET, PRAPACE, APA and ISTRC. As stated in the project memorandum we will aim to distribute to 100 institutions.

2. The feasibility of and strategies for the development of high dry matter cultivars with good wound healing characteristics determined.

Within a previous project (R6507) it was found that perishability of sweetpotato and efficiency of wound healing at moderate humidity (corresponding to normal marketing conditions in East Africa) is related to dry matter content, with higher dry matter corresponding to reduced efficiency of wound healing and hence greater perishability. Given that high dry matter content is an important consumer criterion and is preferred for processing, it is not generally acceptable to select low dry matter cultivars. The main question being addressed for Output 2 was whether it is possible to select for cultivars with both high dry matter content and efficient wound healing characteristics.

2.1 Screening of diverse germplasm for wound healing efficiency

The cultivars considered in earlier work were grown in East Africa, and included local cultivars with some introduced cultivars from other regions of the world. Screening of a wide range of germplasm was carried out to determine whether the relationship between dry matter content and wound-healing efficiency was universal, and specifically whether cultivars with high dry matter and high wound-healing efficiency already existed within germplasm collections.

The work was conducted in laboratories at the NRI using roots grown by CIP in Nairobi, Kenya and USDA, South Carolina, USA.

2.1.1. Development of humidity control chambers for screening programme

In order to assess wound-healing efficiency, roots needed to be maintained at a moderate humidity (65-70% RH) during the healing process. Figure 2.1 shows the design of a humidity controlled chamber developed specifically for this project with technical input from Stan Burrage (S.W. & W.S. Burrage), and Figure 2.2 shows one of the three chambers built, in use for screening.

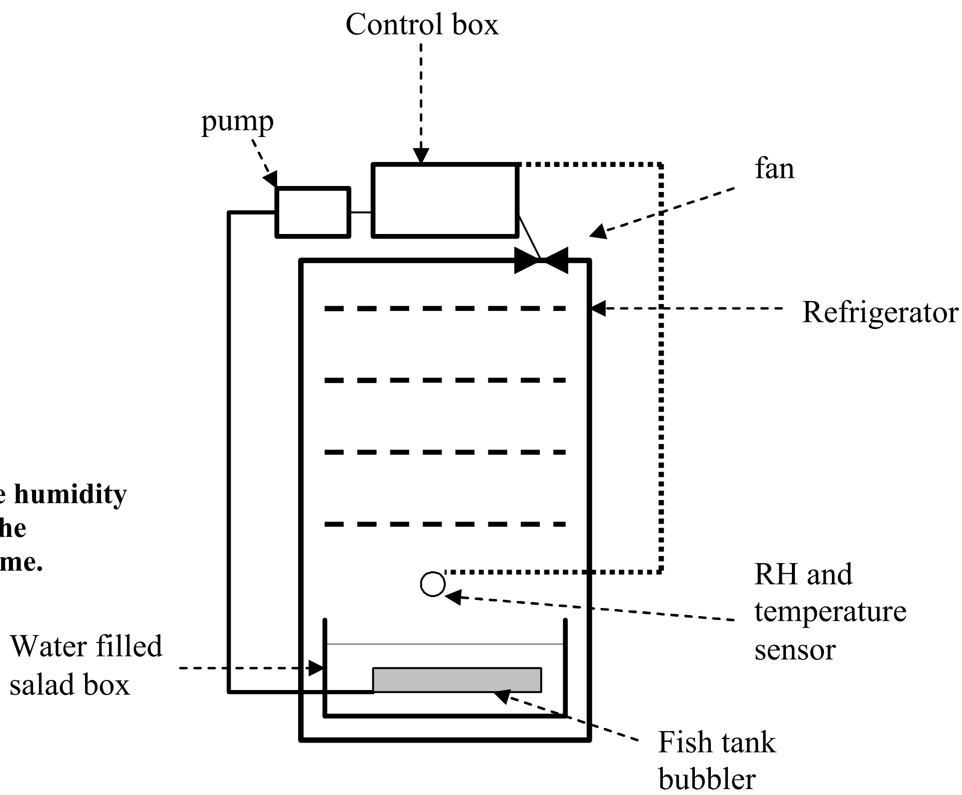

Figure 2.1: Diagram of relative humidity chambers used in the screening programme.

The chamber itself was a standard refrigerator with four shelves. A humidity and temperature sensor was positioned near the bottom of the refrigerator, and attached to a control box, on which both relative humidity (RH) and temperature ranges could be specified. When RH fell below the minimum level, a pump was switch on to bubble air through the water filled salad box using a fish tank bubbler. When RH rose above the maximum level, air was pulled through the chamber using one or two fans placed at the top. When temperature fell below the minimum level a small heater placed above the sensor was turned on. When temperature rose above the maximum level, the refrigeration system was turned on.

Figure 2.2 A humidity control chamber containing sweetpotatoes for screening.

2.1.2 Screening programme

For further details see Appendix III

Three sets of cultivars were included in the screening programme, each of which was assessed twice. Cultivars were grown in field trials by CIP in Nairobi, and by Dr Janice Bohac in South Carolina, USA. CIP provided extensive assistance in arranging for several cultivars of set C to be transferred from Tanzania to Kenya, and taken through the quarantine system.

Set A (GxE cultivars) consisted of 15 cultivars, sourced from many regions of the world grown by CIP at Kabete, Nairobi, Kenya. These cultivars were chosen to cover a wide range of characteristics, and have also been included in a set of trials conducted by CIP at several locations around the world to test germplasm by environment interactions. Five additional cultivars, grown in a separate field trial were included in the assessments of the roots from the first harvest.

Set B (US cultivars) consisted of 18 cultivars sourced mainly from North, South and Central America grown at the US Vegetable Laboratory, USDA-ARS, in South Carolina, USA.

Set C (East African cultivars) consisted of 18 cultivars primarily of East African origin grown by CIP at Kabete, Nairobi Kenya. 6 of the cultivars were only screened in the second season as supplies were delayed due to quarantine restrictions as cultivars were transferred from Tanzania to Kenya.

The cultivars within each set are listed in Table 2.1, and the timetable for screening is illustrated below. The initial plan had been to complete screening by the end of August 2000. With delays to the start of the project, and the time taken to take several cultivars through quarantine procedures, screening was completed in April 2001.

Timetable for activity 2.1

	1999	2000				2001				2002			
Development of humidity controlled chambers													
Screening of cultivar set A			1	2									
Screening of cultivar set B		1			2								
Screening of cultivar set C				1		2							

2.1.3 Method used for screening for wound-healing efficiency

For assessment of wound-healing efficiency at moderate humidity roots were maintained in three humidity controlled chambers at 65-70% R.H., 25-26ºC. After one day a shallow wound (approximately 2 x 5 cm and 1.5 mm deep) was cut using a potato peeler. Staining for lignin was carried out using phloroglucinol after a further 5 days. For staining, three or four thin cross sections with a depth of 10 mm and approx 0.5 mm thick were cut from each wound using a razorblade. These sections were stained with phloroglucinol (1% in 95% ethanol) for 1 min, followed by concentrated HCl for 1min and washed in water. Each wound was scored subjectively between 0 and 1 on the basis of the extent and continuity of lignification seen in the 3-4 sections.

In each screening experiment 12 roots were assessed per cultivar. Roots were arranged in a complete randomised block design, with each shelf considered as a block. Thus one root per cultivar was placed on each of 4 shelves per chamber.

For assessment of wound-healing efficiency at high humidity the same protocol was used, but roots were placed in an enclosed chamber with four shelves and water in the base. Measured relative humidity was greater than 95% throughout. In each screening experiment 4 roots were assessed per cultivar, with one root per cultivar on each of the four shelves.

Table 2.1. Cultivars included in screening programme

Set A			Set B			Set C		
No.	Name	Origin	No.	Name	Origin	No.	Name	Origin
6	Blesbok	SA	15	Beau Regard	USA	4	Beau Regard	USA
7	Brondal	SA	4	PI 538354	S/C Am	22	Budagala	EA
10	Cemsa 74-228	S/C Am	10	PI 595856	S/C Am	12	Hernadez	S/C Am
21	Kemb 10	EA	5	PI 595873	S/C Am	15	Iboja	EA
11	Kemb 37	EA	3	Picadito	S/C Am	1	Jewel	USA
9	Mafutha	SA	13	Regal	USA	9	Kemb 10	EA
20	Mogamba	EA	11	SC 1149-19	USA	20	KSP 20	EA
8	Mugande	EA	7	Sumor	USA	19	L86-33	USA
13	Naveto	PNG	8	Tanzania	EA	18	Mwanamonde	EA
17	NC 1560	USA	12	Tinian	J	5	Sinia	EA
15	Santo Amaro	S/C Am	1	W287 Ruddy	USA	11	SPN/0	EA
19	Tainung No 64	T	14	W-308	USA	10	Zapallo	S/C Am
18	Xu Shu 18	CH	6	W-317	USA	17	Bilagala**	EA
16	Yan Shu 1	CH	16	W-325	USA	14	Kagole**	EA
14	Zapallo	S/C Am	17	W-341	USA	13	Polista**	EA
2	Kemb 10*	EA	18	W-345	USA	7	Sinia B**	EA
3	KSP 20*	EA	2	W364 97k-11	USA	21	SPK 004**	EA
5	SPK 004*	EA	9	White Regal	USA	3	Yanshu 1**	CH
1	Yan Shu 1*	CH						
4	Zapallo*	S/C Am						

CH, China; EA, East Africa; J, Japan; PNG, Papua New Guinea; SA, South Africa; S/C Am, South/Central America; T, Taiwan; USA, United States of America.

*Screened for first harvest only

** Screened for second season only

2.2. Determining the basis of the relationship between dry matter content and wound healing efficiency.

2.3. The feasibility of breeding for high dry matter cultivars with efficient wound-healing reviewed.

2.4. Identify markers for characteristics of efficient wound-healing.

The overall objective of output 2 was to determine how, if possible, to develop sweetpotato cultivars with high DM content and high wound-healing efficiency. The most appropriate strategy was dependent on the findings on the screening programme carried out as activity 2.1. For this reason, it was originally proposed that the results of the screening programme be presented at the CIP annual review in Lima in August 2000, and that the further objectives of the project be reviewed at that point. However, this was not practical as the screening programme was not completed until April 2001. In order to review the findings and determine the future focus of the project, Dr Dapeng Zhang, sweetpotato breeder from CIP, Lima, was invited to NRI in May 2001. This also enabled the Project manager, who was on maternity leave, to attend.

The main conclusions of the review are summarised in Outputs (2.2.1). On the basis of the review a recommendation was made that a programme of work to elucidate the physiological basis of differences in wound-healing efficiency be continued. The results of the screening were also presented at a CIP organised workshop in Lima in July 2001 (van Oirschot *et al.* 2001)

The programme of research was discussed and developed by a collaboration between NRI staff (project manager, Quirien van Oirschot) and Julia Aked of Silsoe College. Dr Aked left her position as lecturer at Cranfield University during the course of the project, but continued to input as an independent consultant. A review of existing literature was carried out by Dr Aked (appendix IV) and formed the basis for hypotheses used to plan the experimental programme. A set of 12 cultivars, covering a wide range of DM and wound-healing efficiency was selected, and grown by CIP in Nairobi. All experiments were carried out at NRI. Technical assistance was provided by Christopher Lucas, Marie Lebas, Stephen Craycraft and James Neilson.

Towards the end of the programme Dr Patricia Harvey of the Chemical and Life Sciences Department, University of Greenwich was included in the project as a consultant. Her expertise is in peroxidases, which form an important part of the plant tissue stress responses.

As is often the case in an investigation of this nature, each experiment was designed on the basis of the results of preceding experiments, so that the experimental work differed from the original plans described in the project memorandum. The work is summarised in Outputs, with more detail given in the appendices where appropriate.

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3. The extent of cultivar variability in root metabolism and implications for long-term storage determined.

3.1 Assessment of cultivars for metabolic characteristics

3.2 Assessment of the physical constraints to long-term storage and the relative behaviour of selected key Tanzanian cultivars

3.3 Factors controlling susceptibility to anaerobiosis determined

This output is concerned with the feasibility of selecting cultivars for good long-term storage. The activities were closely co-ordinated with those of project R7498 "Maximising incomes from sweet potato production as a contribution to rural livelihoods." They will therefore be presented with the Final Technical Report for R7498.

OUTPUTS

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

1.1 Assessment of locally available cultivars at three sites in terms of consumer preferences and sensory profile, to determine the potential for using trained panels for cultivar selection.

Further details are given in appendix II.

Within a breeding programme it is essential to assess new cultivars in terms of acceptability of sensory characteristics, but these can be very complex and technically difficult to measure. A trained taste panel may provide the most practical and effective method to assess sensory acceptability. This output was carried out to determine the practicality and reliability of this method.

Table 1.1 summarises the consumer preferences for the local cultivars at the three sites surveyed over both years (1998 and 2000). Polista and SPN/0 were consistently preferred, while Mzondwa, Bilagala and Serena were consistently disliked. The cultivar Sinia B was unusual in that it was not liked in 1998 but was liked at all three locations in 2000.

Table 1.1: Consumer acceptability – ranking of sweetpotato cultivars by 100 consumers at Mwanza, Meatu and Misungwi

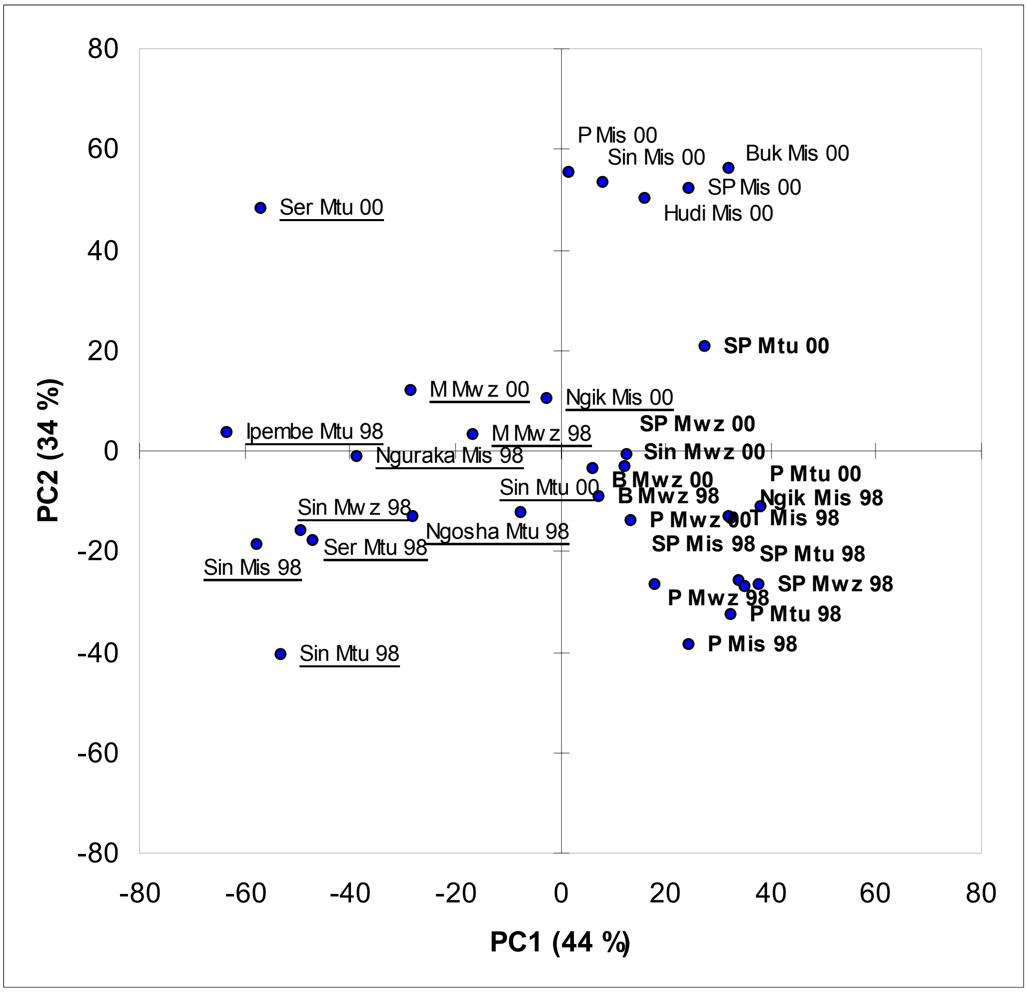
	Mwanza		Meatu		Misungwi	
Liking	**1998**	**2000**	**1998**	**2000**	**1998**	**2000**
1 (most)	Polista (54))	SPN/0 (56)	SPN/0 (77)	Polista (79)	Ngikuru (57)	SPN/0 (57)
2	Sinia B (52)	Sinia B (47)	Ngosha (51)	Sinia B (67)	SPN/0 (45)	Sinia B (52)
3	SPN/0 (42)	Polista (39)	Polista (42)	SPN/0 (47)	Polista (36)	Polista (50)
4	Mzondwa (18)	Mzondwa (8)	Serena (19)	Serena (5)	Toniki (30)	Bukolu (14)
5	Bilagala (28)	Bilagala (6)	Sinia B (6)		Sinia B (26)	Hudi Shinyanga (6)
6 (least)			Ipembe (3)		Nguruka (14)	Ngikuru (3)

The percentage of consumers expressing a preference for each cultivar is given in brackets.

The panel at LZARDI-Ukiriguru used to provide a sensory profile of each cultivar was the same in both years, so that a comparison between cultivars and between years was possible. Statistical analysis indicated that the panel was able to distinguish between samples in both years for ten of the eleven attributes considered (except for fibre content). This gives an indication of the sensitivity of a trained panel.

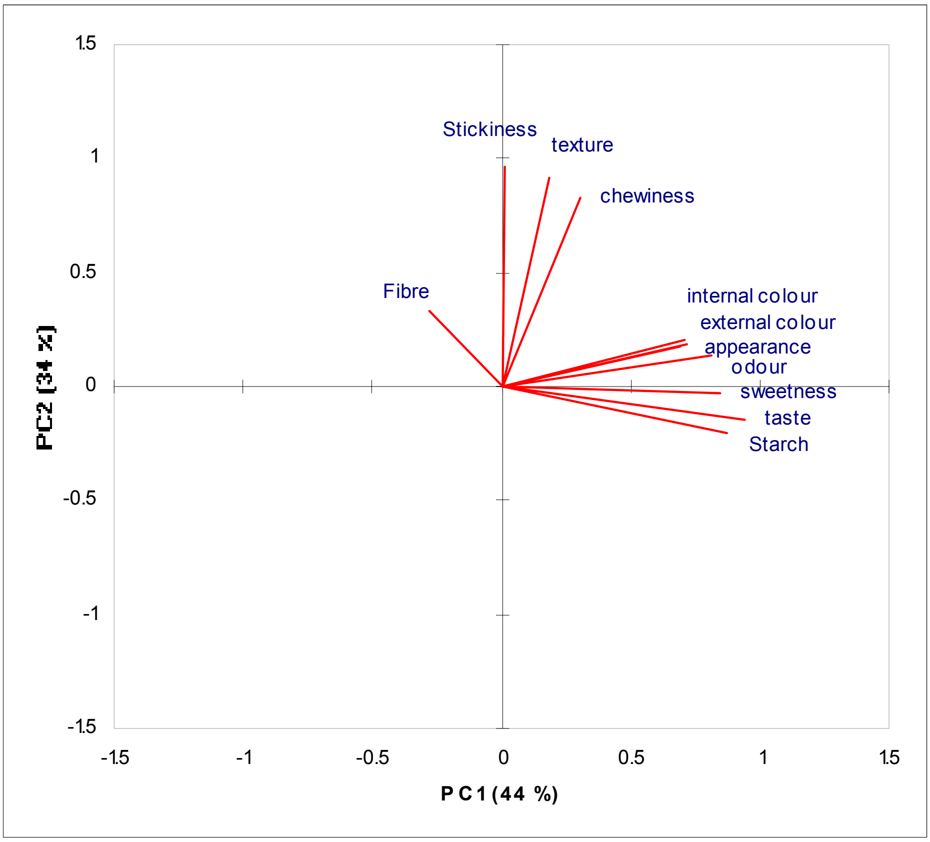
With a large number of attributes being assessed for each cultivar, the data can become very complex to interpret. For that reason, a mathematical technique called Principal Component Analysis (PCA) was used to simplify the data (see Figures 1.1 a and b). By this method the data is mathematically *transformed* so that the eleven attributes can be expressed by *vectors* (lines) pointing in different directions on a two dimensional graph (Figure 1.1b). In this case this representation accounts for 78% of the data variability (the greater the variability accounted for, the more reliable the fit). Attributes which are closely related have vectors which are almost parallel (e.g. Starch, taste and sweetness), while those which are not related tend to be perpendicular (e.g. Sweetness and stickiness). Cultivars can be described by a point on the same graph, depending on their sensory characteristics (Figure 1.1a). Thus Serena (Meatu 2000) is very fibrous, whereas Sinia (Mwanza 2000) is not fibrous, but is sweet. Similar cultivars will be clustered together. Thus, samples of the same cultivar tended to be clustered together. SPN/0 and Polista were in the right hand quadrants in both years while Mzondwa and Serena were consistently in the left-hand quadrants. This implies that for these cultivars, the sensory characteristics are broadly similar from year to year and not influenced by location where they were grown. Sinia B, however, was in the lower left-hand quadrant in 1998 but in the right hand quadrant in 2000. The cultivars from Misungwi in 2000 were generally more sticky, chewy and scored higher for texture. It is not clear why these cultivars differed, although climatic differences and differences in storage by the traders are likely to have contributed.

Figure 1.1a
Principal component plot showing spacing of sweetpotato cultivars with respect to the sensory attributes (figure 1.1b).



Where: M = Mzondwa, SP = SPN/0, Sin = Sinia B, Ser = Serena, B = Bilagala, P = Polista, Ngik = Ngikuru, Mwz = Mwanza, Mis = Misungwi, Mtu = Meatu

Figure 1.1b
Principal component plot showing relationship with respect to the sensory attributes

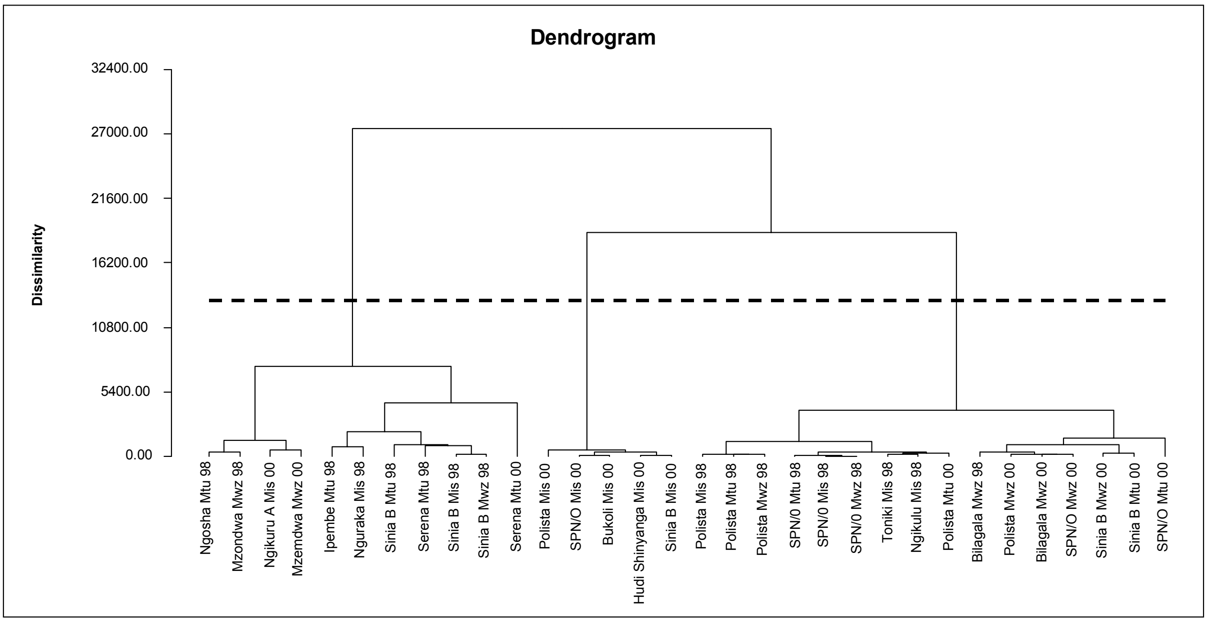


Considering figure 1.1a, cultivars appear to be clustered into a number of groups. This was investigated using cluster analysis (Hierarchical Cluster Analysis, Wards Method, Euclidean distance) of the full data set for both years. The dendrogram, illustrating the make-up of the clusters is shown in Figure 1.2, and indicates that the data fell into three groups (Table 1.2). Cluster 1 was comprised of cultivars that were generally not liked by consumers (on average only 19% preferred these the most). The cultivars within this cluster were predominantly Mzondwa (98 and 00), Serena (98 and 00) and Sinia (98). Cluster 2 was comprised entirely of the cultivars from Misungwi (00). Cluster 3, the group most liked by the consumers (on average 47% consumers preferred these the most), was mostly comprised of Polista and SPN/0 from both years and Sinia B for year 2000.

Consistent with the consumer preferences, Polista and SPN/0, were consistently in the most liked group (cluster 3) in both years, Mzondwa and Serena, were consistently in the least liked group (cluster 1), whereas Sinia B was in cluster 3 in 1998 but generally in cluster 1 in 2000. This suggests that the reason that the consumer impression of Sinia differed between the two years surveyed was that the sensory characteristics changed.

The mean sensory scores for each cluster are given in Figure 1.3. Cluster 3 had the highest scores for taste, sweetness and starch and the lowest scores for stickiness and texture. This represents the sensory profile of the most preferred cultivars, and would therefore be the profile for which a breeding programme should aim.

Fig 1.2
Dendrogram illustrating the make-up of the three selected clusters



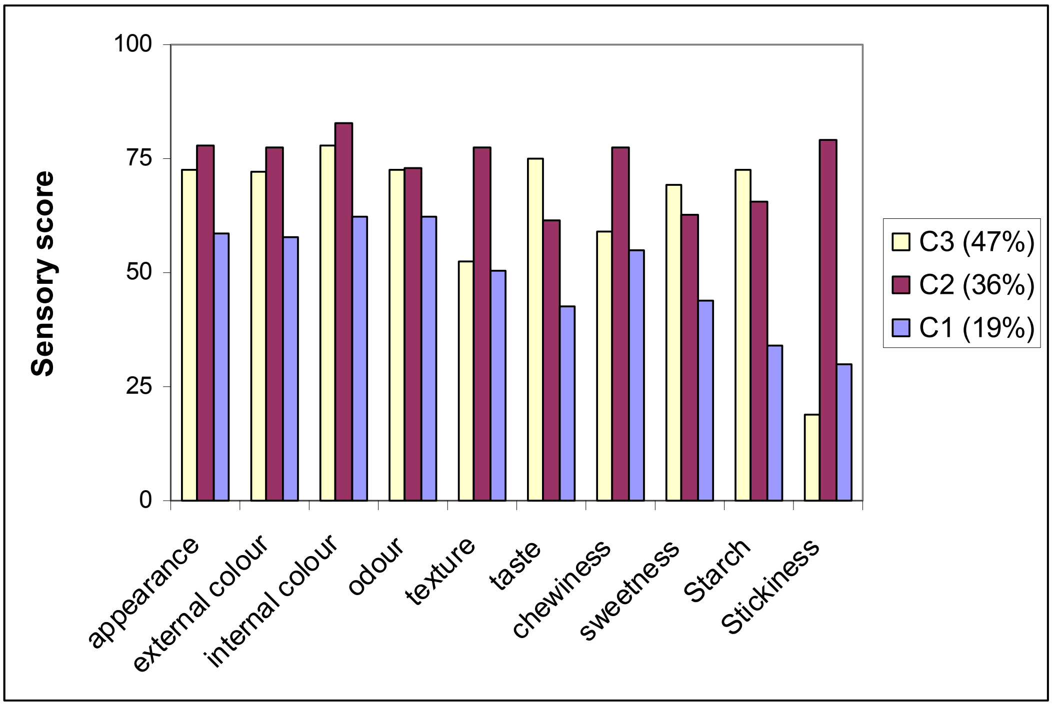
Where: dotted horizontal line shows the dissimilarity where clusters were selected

Table 1.2: Hierarchical cluster analysis - Classification of cultivars with respect to sensory attributes

	Cluster 1	Cluster 2	Cluster 3
	Ipembe Mtu 98 (3) Mzondwa Mwz 00(8) Mzondwa Mwz 98 (18) Ngikuru A Mis 00 (3) Ngosha Mtu 98(51) Nguraka Mis 98 (14) Serena Mtu 00 (5) Serena Mtu 98 (19) Sinia B Mis 98 (26) Sinia B Mtu 98 (6) Sinia B Mwz 98 (52)	Bukoli Mis 00 (14) Hudi Shinyanga Mis 00 (6) Polista Mis 00 (50) Sinia B Mis 00 (52) SPN/O Mis 00 (57)	Bilagala Mwz 00 (6) Bilagala Mwz 98 (28) Ngikulu A Mis 98 (57) Polista Mis 98 (36) Polista Mtu 00 (79) Polista Mtu 98 (42) Polista Mwz 00 (39) Polista Mwz 98 (54) Sinia B Mtu 00 (67) Sinia B Mwz 00 (47) SPN/0 Mis 98 (45) SPN/0 Mtu 98 (77) SPN/0 Mwz 98 (42) SPN/O Mtu 00 (47) SPN/O Mwz 00 (56) Toniki Mis 98 (30)
Mean per cent of consumer saying most liked	19	36	47

Where: Mwz = Mwanza, Mis = Misungwi and Mtu = Meatu

Figure 1.3: Mean sensory scores for each cluster of cultivars



The PCA illustrates that many of the sensory attributes were correlated. For example, stickiness, texture and chewiness were correlated, while internal colour, external colour, appearance, odour, sweetness, taste, starch and fibre were correlated. This suggests that the number of sensory attributes for discriminating the cultivars might be reduced, while still retaining most of the important information. Screening programmes often consider a large number of cultivars, so that any method for simplifying assessments would be advantageous. We therefore wished to determine what was the minimum number of characteristics that we could consider while still being able to distinguish between the clusters of cultivars. Considering the F statistic (ANOVA for discriminating between the clusters, table 4), highest values (indicating greatest differences among cultivars) were for stickiness (56.0), starch (48.5), taste (35.6) and sweetness (14.9). Of these, correlation analysis indicated that starch, taste and sweetness were significantly correlated; hence only starch was retained. Starch did not significantly correlate with stickiness and therefore both were retained as suitable sensory attributes for predicting the cultivar sensory characteristics. Discriminant analysis models (not shown) on all the sensory attributes and on starch and stickiness only were very similar in distinguishing between the clusters. The discriminant model developed on all the attributes correctly classified 17 out of 18 cultivars; Ngikuru A (Misungwi, 2000) was incorrectly classified as cluster 1 instead of cluster 2. In comparison, the discriminant model based on starch and stickiness was almost as good correctly classifying 16 out of 20; Ngikuru A (Misungwi, 2000, cluster 2) was incorrectly classified as cluster 3 and Sinia B (Meatu, 1998, cluster 1) was incorrectly classified as cluster 3.

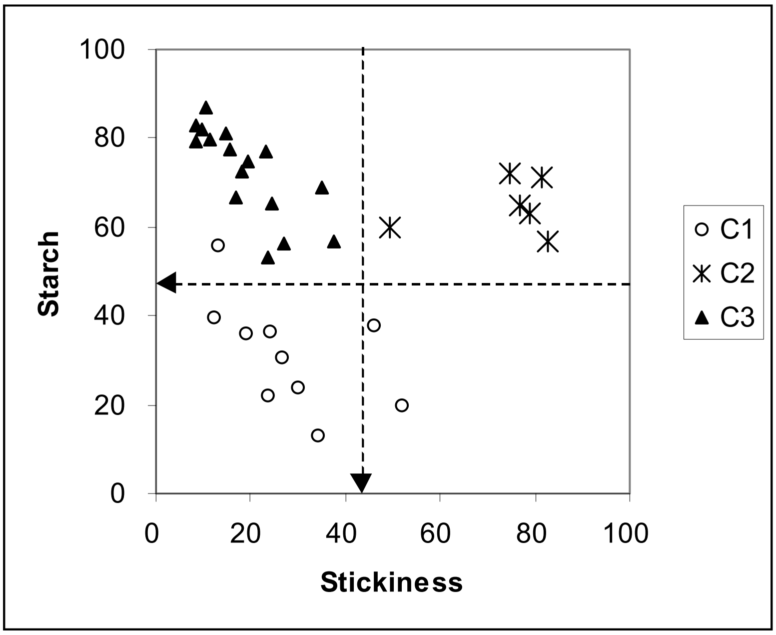
The scatter plot (figure 4) shows the clusters relative to starch and stickiness. Cluster 3 (most liked cultivars) is in the top left-hand quadrant, cluster 1 is in the bottom left-hand quadrant and cluster 2 is in the top-right quadrant. In a selection process for cultivars for cluster 3, a cultivar would need to score more than 50 for starch and less than 42 for stickiness.

Table 1.3
F statistic for discriminating between sweetpotato clusters

Sensory attribute	F statistic	Probability
Stickiness	56.0	0.000
Starch	48.5	0.000
Taste	35.6	0.000
Sweetness	14.9	0.000
Odour	13.6	0.000
Internal colour	12.4	0.000
Texture	9.0	0.001
Appearance	9.0	0.001
External colour	8.5	0.001
Chewiness	5.9	0.007
Fibre	2.0	0.159

Where degrees of freedom = 2

Figure 1.4
Differences between clusters with respect to stickiness and starch.



Conclusions

This study has shown that a trained panel can be used to assess sensory attributes of sweetpotato varieties and can be a useful selection tool in cultivar selection. The finding that the most popular varieties in three locations and from year to year have similar sensory profiles is very encouraging. Consumer preferences are relatively stable, but there are some cultivars (notably Sinia) for which sensory attributes can change markedly between years while others (Polista, SPN/O, Mzondwa and Serena) are very consistent.

While for detailed cultivar assessment it is important to screen using the entire spectrum of sensory attributes, our data shows that the most important sensory attributes in selecting for consumer acceptability are starch and stickiness. This information could be used to develop rapid tests for cultivar acceptability to be used at an early stage in the breeding programme..

The study was based in three locations which are all in one zone of Tanzania. It will now be important to determine whether the preferences of consumers remain consistent over the whole country.

1.2 Production of publication

A black and white copy of the publication "Sweetpotato post-harvest assessment: Experiences from East Africa" is included as appendix I. At the time of submitting this report, the publication is ready for printing as soon as final permission is obtained from the collaborating organisations. The chapters included are as follows:

Chapter 1. Present status of sweetpotato breeding for eastern and southern Africa.
Chapter 2. Farmer criteria for selection of sweetpotato varieties.
Chapter 3. Trader and consumer criteria for selection of sweetpotato varieties.
Chapter 4. The use of consumer tests and trained taste panels to assess sensory characteristics.
Chapter 5. Extending root shelf-life during marketing by cultivar selection.
Chapter 6. Curing and the physiology of wound healing.
Chapter 7. Improving long-term storage under tropical conditions: role of cultivar selection.
Chapter 8. Damage to storage roots by insect pests.
Chapter 9. Assessment of sweetpotato cultivars for suitability for different forms of processing.
Appendix I. Sweetpotato breeding methodologies and targets in sub-Saharan Africa
Appendix II. Measurement of dry matter content.

1.3 Dissemination of publication

To be completed (see Research activities)

2.1. Screening of diverse germplasm for wound healing efficiency

For further details see Appendix III

2.1.1 Lignification efficiency, range and stability of cultivars

As outlined in activities, three sets of cultivars were included and screened separately in the screening programme. For all three sets of cultivars a wide range in lignification index (LI) at moderate RH was found. For example Figure 2.1 shows the data for set A for both harvests. The consistency of LI at moderate relative humidity (RH) over harvests/seasons was tested by simple correlation analysis. In all cases the correlation was significant (set A, r = 0.795 significant to 0.01%, set B, r = 0.473 significant to 5% and set C, r = 0.903 significant to 0.01%). The weaker correlation for set B, was probably because in this case the first assessment was carried out on roots which had been stored for 2 months.

Figure 2.1: Cultivar set A, LI at moderate RH for two harvest times of a single trial planted in 2000 Cultivar names are given on p. 17. Error bars are s.e.m. using individual LI measurements

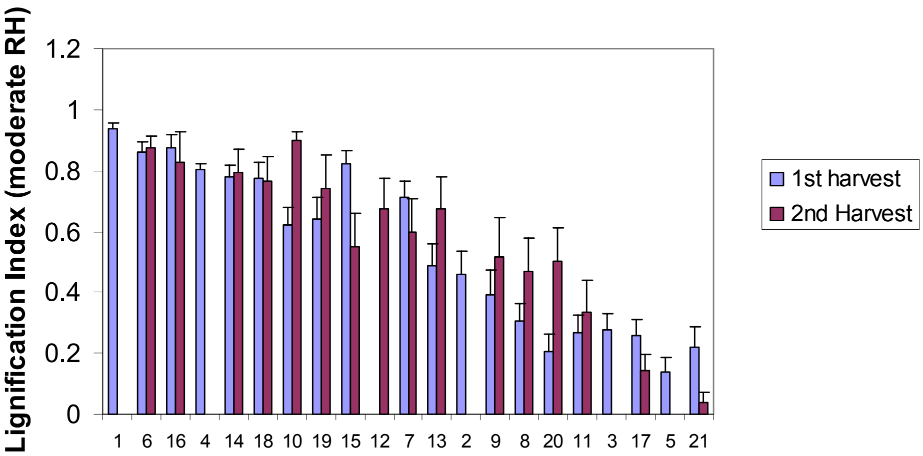


Table 2.1 shows the DM content and LI for two cultivars which were assessed after being grown at both locations (Nairobi and South Carolina). Kemb 10, SPN/0 and Tanzania are considered to be the same cultivar. In both cases good consistency was seen. This supports the previous evidence that there is reasonable cultivar stability for both attributes.

Table 2.1: Consistency of cultivars between sites.

Set	Origin	Location of field trial	Cultivar name	DM content [%]	L.I.
AC	EA	Nairobi, Kenya	Kemb 10	30.4	0.28
C	EA	Nairobi, Kenya	SPN/0	32.9	0.34
B	EA	South Carolina, USA	Tanzania	29.9	0.15
B	USA	South Carolina, USA	Beau Regard	19.4	0.71
C	USA	Nairobi, Kenya	Beau Regard	19.3	0.83

EA East Africa

The results obtained for all cultivars are given in Table 2.2. Where cultivars were grown in both locations (Nairobi and South Carolina) both sets of data are included. As well as LI measured at moderate RH, LI at high RH is also included. As observed previously, (van Oirschot 2000), in contrast to root behaviour at moderate RH, most cultivars showed high wound healing efficiency (high LI) when assessed at high RH. There are however exceptions, notably Beau Regard (in both set B and set C) and L86-33 and Hernandez in set C. There is however, no relationship between low LI measured at high RH and low LI at moderate humidity.

Table 2.2. LI, DM content and origin for all cultivars screened

Set	Origin	Cultivar name	DMC	L.I.
A	CH	Xu Shu 18	24.93	0.77
AC	CH	Yan Shu 1	26.42	0.88
C2	EA	Bilagala	35.89	0.29
C	EA	Budagala	30.13	0.15
C	EA	Iboja	34.98	0.07
C2	EA	Kagole	31.63	0.08
AC	EA	Kemb 10	30.37	0.28
A	EA	Kemb 37	24.22	0.30
AC	EA	KSP 20	27.41	0.38
A	EA	Mogamba	28.99	0.35
A	EA	Mugande	31.07	0.39
C	EA	Mwanamonde	32.16	0.06
C2	EA	Polista	37.01	0.10
C	EA	Sinia	34.28	0.67

Continued…

Set	Origin	Cultivar name	DMC	L.I.
C2	EA	Sinia B	35.24	0.53
AC	EA	SPK 004	35.65	0.38
C	EA	SPN/0	32.94	0.34
B	EA	Tanzania	29.85	0.15
B	J	Tinian	27.06	0.58
A	PNG	Naveto	27.78	0.58
A	S/C Am	Cemsa 74-228	26.34	0.76
C	S/C Am	Hernandez	22.33	0.17
B	S/C Am	PI 538354	25.71	0.18
B	S/C Am	PI 595856	28.05	0.80
B	S/C Am	PI 595873	26.72	0.43
B	S/C Am	Picadito	30.65	0.45
A	S/C Am	Santo Amaro	26.51	0.69
AC	S/C Am	Zapallo	20.14	0.80
A	SA	Blesbok	18.69	0.87
A	SA	Brondal	21.49	0.66
A	SA	Mafutha	26.14	0.45
A	T	Tainung No 64	21.96	0.69
B	USA	Beau Regard	19.39	0.71
C	USA	Beau Regard	19.25	0.83
C	USA	Jewel	21.31	0.76
C	USA	L86-33	17.60	0.61
A	USA	NC 1560	20.35	0.20
B	USA	Regal	22.37	0.68
B	USA	SC 1149-19	24.48	0.39
B	USA	Sumor	27.44	0.86
B	USA	W287 Ruddy	19.57	0.83
B	USA	W-308	23.23	0.91
B	USA	W-317	20.47	0.50
B	USA	W-325	19.88	0.38
B	USA	W-341	25.57	0.57
B	USA	W-345	28.70	0.38
B	USA	W364 97k-11	30.69	0.73
B	USA	White Regal	24.09	0.58

2.1.2 Accuracy and reliability of the screening method

The accuracy and reliability of the screening method was assessed by considering the individual screening experiments. For the individual experiments where 12 roots are assessed per cultivar, a very significant cultivar effect ($P<0.001$) was seen in all but one case, and the 95% confidence limit for differences in LI between cultivars was below 0.3 in all cases. There were three cases where exactly the same cultivar set was assessed in consecutive screening experiments. Although there were significant differences between the experiments in two of the three cases, the differences were generally small (differences in mean LI <0.2), and there were no significant cultivar x experiment interactions. (see appendix III for full data) From this data we deduce that the practice of using 12 roots per cultivar is sufficient when screening cultivars for wound-healing efficiency.

2.1.3 Cultivars considered by location

Figure 2.2 shows the mean LI for each cultivar plotted against mean DM content. (cultivars grown in different locations are included more than once). There is a fairly clear grouping of cultivars, with those from East Africa having higher DM content and lower LI than those from other regions. We suspect that the difference in DM content may have been accentuated by breeding. Pressure for high root fresh weight yield would tend to favour lower root DM, except in regions where high DM content is an essential characteristic for consumer acceptability, as it is in East Africa.

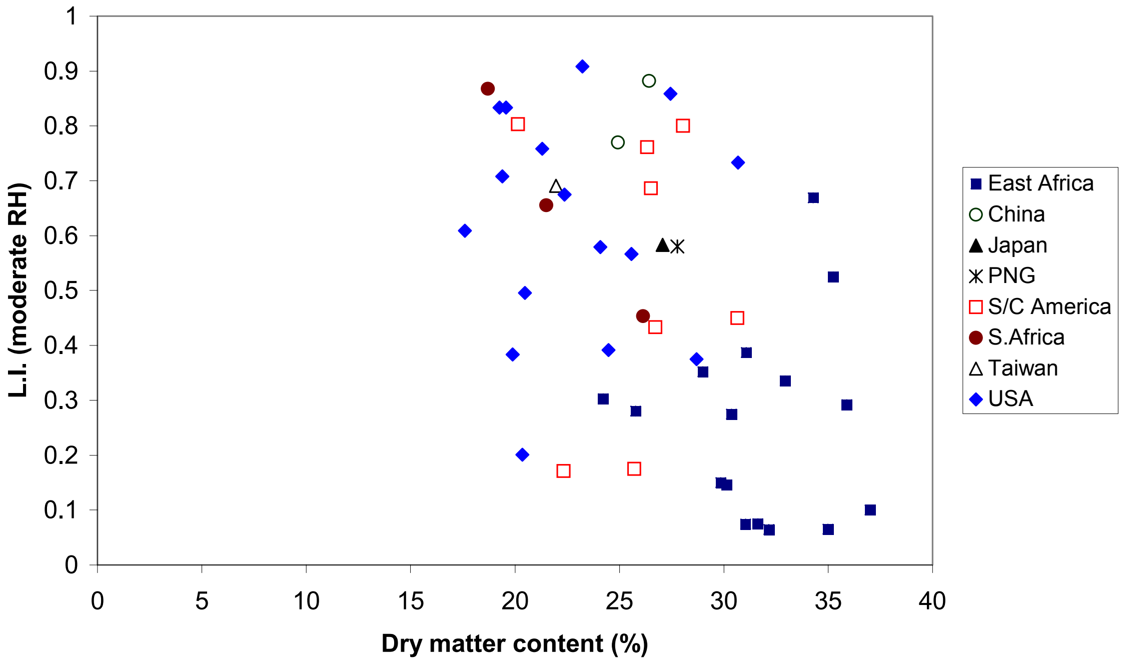


Figure 2.2: The LI and DM content by cultivar for the complete set of screened germplasm, with indication of cultivar origin.

2.1.4 Selection of cultivars for high DM content and high LI

An important objective of this screening programme was to identify cultivars with high DM and yet good wound-healing efficiency that would be good parents for subsequent breeding. From our data, imposing arbitrary lower limits of 25% DM content and LI of 0.5, the following cultivars emerge: From the USA; W364, W341 and Sumor, both cultivars included from China; Yan Shu 1 and Xu Shu 18 (DM 24.9%), from South/Central America; Santo Amaro, Cemsa 74-228 and PI 595856, from Japan; Tinian, from Papua New Guinea; Naveto and two related cultivars from East Africa; Sinia and Sinia B.

2.2 Determining the basis of the relationship between dry matter content and wound healing efficiency.

(2.3) The feasibility of breeding for high dry matter cultivars with efficient wound-healing reviewed.

(2.4) Identify markers for characteristics of efficient wound-healing.

2.2.1 Overview of outputs 2.2, 2.3 and 2.4

The overall objective of these outputs was to facilitate the breeding of sweetpotato cultivars with high DM content, and with high wound-healing efficiency, so that they are both acceptable to consumers and have sufficient shelf-life for marketing. Our perception of several issues changed during the course of this project, so that in retrospect it is more logical to consider these three outputs together.

Once the cultivar screening programme was complete the project findings and objectives were reviewed with input from Dapeng Zhang from CIP. Our original objective had been to investigate the basis of wound-healing efficiency with a view to identifying a marker (possibly one or more isoenzymes) to enable screening of new germplasm for efficiency of wound-healing. During the review it was concluded that as only very rapid methods of screening are practical where large numbers of progeny are to be considered, it would be more useful to obtain information that firstly would allow identification of good parents, and secondly might identify strategies for genetic engineering (The latter would obviously depend on the outcome of the present worldwide debate on the acceptability of genetically engineering food crops). The review supported the value of continuing research to elucidate the physiological factors controlling wound-healing efficiency.

As will be described below (Section 2.2.2), we obtained results which confirmed our previous observations that wound-healing efficiency is linked to DM content, although the link was perhaps not as strong as we had originally suggested.

We then put forward three hypotheses as follows to explain the differences in wound-healing efficiency (at lower humidity), which, although not describing specific mechanisms, would provide a framework for our subsequent investigations. Note that these hypotheses are not mutually exclusive.

Hypothesis 1. Sweetpotato cultivars differ in rate of lignification at all humidities. Slow healing cultivars are unable to complete the lignification as desiccation reaches a critical level before they complete healing.

Hypothesis 2. Sweetpotato cultivars differ in drying characteristics at moderate humidity. Those that desiccate more rapidly reach a state earlier where lignification is inhibited.

Hypothesis 3. Sweetpotato cultivars differ in the effect of desiccation on lignification efficiency.

We obtained evidence against the first hypothesis fairly rapidly (Section 2.2.3). After review of the literature (see appendix IV) we then established a new theory linking the accumulation of sugars to high wound-healing efficiency (Section 2.2.4), a theory that fits with both hypotheses 1 and 2 above. Having established the use of tissue blocks as a valid system for studying wound-healing (section 2.2.5), we were able to provide strong evidence in support of this theory. As will be discussed below, these findings are completely consistent with our earlier indications of a link with DM content.

2.2.2 DM content is physiologically linked to wound-healing efficiency

For further details see appendix III

One objective of the screening programme (Output 2.1) was to obtain more information about the role of DM content in controlling wound-healing efficiency. Considering all the cultivars (see Figure 2.2), a very significant negative correlation is found between LI and DM content (r = -0.5 significant to 0.1%). However, when the cultivars within each region of origin are considered separately, no significant relationship is seen. This could be partly because the range in both LI and DM within each collection of cultivars is smaller. However, the theory has been put forward that the relationship seen between DM content and LI can be explained if there are two classes of sweetpotato depending on their origin, those with high DM and low LI (from East Africa), and those with lower DM and high LI (from other locations). In this case there would not need to be any physiological link between the two characteristics. However, we have additional data that does not support this theory.

In order to look at DM content effects more directly, five experiments were carried out in which both the LI at moderate RH and the dry matter content of each individual root was measured. Regression analysis was then used to model root LI in terms of cultivar and dry matter content.

For four of the five experiments (experiments 1-4) DM content was measured at the end of the experiment at the time of assessment of lignification. This introduces a bias to the data, as bad wound-healers would tend to lose more water during the assessment, and would therefore have increased final DM content. To correct for this, an initial DM content was estimated assuming that all weight loss during the experiment was water loss. For experiment 5 a different method was used. In this case the root was cut into two longitudinally. One half was assessed for DM content and the other half was assessed for ability to lignify under moderate RH. Thus initial DM content was measured directly.

The regression models obtained are shown in Table 2.3. The percentage variance accounted for by the models differ between experiments, but a common pattern emerges. In all cases, cultivar is the more important factor controlling LI. However, in all cases a model including both DM and cultivar accounts for more of the data variance than cultivar alone, but less than the sum of the variances when cultivar and DM are considered individually. This indicates two things; firstly that DM content differences between cultivars is a factor controlling LI, and secondly that within each cultivar root differences in DM content are related to differences in LI (i.e. roots with lower DM tend to have higher LI). These two factors strongly suggest that there is a physiological link between DM content and LI, even though the low variance values suggest that other factors are more important.

Table 2.3: Regression models for root LI in terms of cultivar and root DM content

Expt	Variance accounted for	Regression models for LI
1	34.3%	0.303 + cultivar
	2.5%	1.020 – 0.016 DMC
	36.0%	1.182 – 0.030 DMC + cultivar
2	23.1%	0.625 + cultivar
	2.5%	0.874 – 0.015 DMC
	28.2%	1.276 – 0.036 DMC + cultivar
3	40.0%	0.272 + cultivar
	14.8%	1.27 – 0.031 DMC
	41.7%	0.902 – 0.021 DMC + cultivar
4	43.1%	0.224 + cultivar
	17.6%	1.287 –0.034 DMC
	45.4%	1.075 – 0.027 DMC + cultivar
5	7.2%	0.37 + constant *cultivar
		No model found in terms of DMC alone
	18.3%	1.59 – 0.058 DMC + cultivar

2.2.3 Selection of cultivars for further experiments

Using the data from the screening programme we chose a set of cultivars covering a range of DM content and wound-healing efficiency for further experiments. To avoid delays due to quarantine procedures, we chose only cultivars which were already available in Kenya. The cultivars listed below, and indicated in Figure 2.3 were grown in field trials by CIP, Nairobi.

Class 1 (Low Dry matter, good healers)
Zapallo, Yanshu, Beau Regard
Class 2 (High Dry matter, good healers)
Sinia, Naveto, Cemsa 74-228
Class 3 (Low Dry matter, bad healers)
Hernandez, KSP20, Kemb37
Class 4 (High Dry matter, bad healers)
Bilagala, Kemb10, Polista

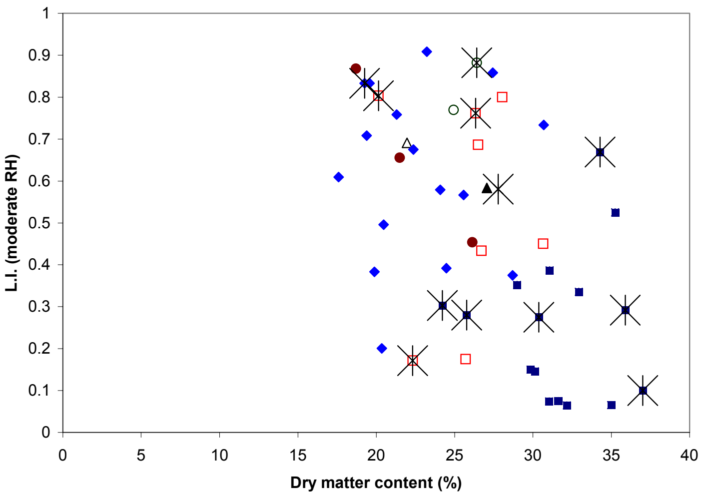


Figure 2. 3 LI and DM content by cultivar for the complete set of screened germplasm. Cultivars chosen for further experiments are indicated by a star.

2.2.4 The development of tissue blocks as a model system for investigating wound-healing

The use of whole roots to study wound-healing has several problems. Sweetpotato roots are very non-uniform in size and shape, and it is very difficult to cut a uniform wound. Thus any assessment of tissue weight loss is complicated by inter-root variability. Any studies of the effects of water loss on metabolism are complicated by the non-homogeneous desiccation of the root.

We have found that small tissue blocks (e.g. 8mm x 3mm x 25 mm) can lignify on all surfaces when placed at high humidity. We subsequently demonstrated that when placed at lower humidity the behaviour of tissue blocks of roots from different cultivars is consistent with that of whole roots. We have exploited this, and have used tissue blocks in some of the experiments described below. In all cases we have attempted to validate the findings by comparison with data from whole roots. The use of tissue blocks allows us to make several measurements from the same root, thus reducing the effects of variability between roots on our experimental data, and also allowing us to follow metabolic changes during the course of healing.

We have conflicting data as to whether all tissues within a sweetpotato lignify with equal efficiency. One experiment indicated that when roots were cut transversly, healing was initiated near the periderm and was slower in the parenchyma. On the other hand, a second experiment found no difference in rates of lignification for blocks cut from different parts of the root (data not shown). To avoid artefacts, tissue blocks have always been cut from the central parenchyma tissue only.

2.2.5 An intrinsic difference in rates of lignification among cultivars cannot explain the range in wound-healing efficiency.

For further details see appendix V.

To determine whether the differences in wound-healing efficiency at moderate humidity were due to differences in rate of the wound-healing process (hypothesis 1, section 2.2.1) two methods were used to measure rate of lignification at high humidity.

For the first method, roots were wounded by the standard method and placed at high humidity to heal for two days. They were then assessed for lignification using the standard scoring system. At this stage lignification was not complete, so that only weak staining occurred. For this reason objective scoring was more difficult. To increase the reliability of the method, more than one assessor was used, and the mean score calculated.

The second method relied on the use of tissue blocks. Three cuboids were cut from each of four roots per cultivar and placed at high humidity to heal for 2 days. They were then moved to moderate humidity and their weight loss measured after 4 and 8 hours. The rate of weight loss was taken to indicate the extent of healing.

For the first method, although significant differences in rates of healing were indicated, there was no relationship with the LI measured at moderate RH. However, we were not completely confident of these results as with the faint staining we believed that there might be an effect of tissue colour on the LI score. For orange fleshed cultivars there was a tendency to give a lower score, as the red staining did not standout so clearly from the background flesh colour. (Note: this is not a problem for LI at moderate RH when the stained layer is thicker.)

Table 2.4 shows results obtained using the second method. In this case no significant differences among cultivars was found.

Table 2.4: extent of healing over two days as indicated by subsequent rate of weight loss.

Cultivar	No.	% wt loss over 4 hours	% wt loss over 8 hours
Beauregard	1	4.04	7.80
Bilagala	2	4.60	8.84
Cemsa-74-228	3	4.72	8.56
Hernandez	4	4.57	8.78
Kemb 10	5	5.19	9.68
Kemb 37	6	5.33	9.83
KSP 20	7	5.25	9.91
Naveto	8	5.21	9.85
Polista	9	4.45	8.33
Sinia	10	3.99	7.59
Yanshu 1	11	4.93	8.75
Zapallo	12	4.45	8.71
Cultivar effect		n.s.	n.s.

Our conclusion is that efficiency of wound-healing at moderate humidity is not due to intrinsic differences among cultivars in **rate** of lignification.

2.2.6 Development of a hypothesis for a link between carbohydrate metabolism and wound-healing efficiency.

In order to enable us to focus our experiments most effectively, a detailed review of the scientific literature was carried out. As a result of this, and discussion within the project team, we established a hypothesis for a mechanism by which we believed there could be a link between carbohydrate metabolism and wound-healing efficiency (the review is included as appendix IV).

The effect of desiccation on lignification

When plant tissue loses water, we hypothesise that the first serious effects occur as the cell shrinks and the plasmamembrane is pulled away from the cell wall. Thus, among the first cellular processes to be inhibited are those which involve biochemical processes located at the cell wall such as cell expansion and wall synthesis (Taiz, L. and Zeiger, E. (1991) Plant Physiology. The Benjamin/Cummings Publishing Company, Inc. California, USA). In the case of lignification, synthesis of monolignols occurs in the cytosol, and these are then polymerised at the cell wall, (using H_2O_2 produced by peroxidases and reducing power from the pentose phosphate pathway.). It therefore seems reasonable to assume that when the tissue desiccates, the conversion of monolignols to lignin is inhibited before there is an effect on monolignol synthesis. This is consistent with previous observations that in micrographs of wounds that have healed incompletely due to desiccation there is pink staining of the desiccated layer, indicating presence of monolignols.

Protection against desiccation by sugar accumulation

A hypothesis to explain how some cultivars can wound-heal more effectively at moderate humidities would be that some sweetpotato cultivars are able to slow water loss and cell shrinkage by using sugars to maintain a high osmotic potential. These cultivars would either have intrinsically high sugar levels or the ability to rapidly increase sugar levels (by converting starch to sugars or disaccharides to monosaccharides.) The increase in osmotic potential *per se* is unlikely to be detrimental to intracellular enzymatic reactions (Salisbury, F.B. and Ross, C.W. (1991) Plant Physiology. Wadsworth Publishing Company, Belmont, California, USA).

Conversion of starch into soluble sugars as a mechanism by which plant tissues can increase their osmotic potential and thereby slow down water loss, has been observed before. In leaves it has been observed that water deficit leads to the accumulation of soluble sugars. This appears to be brought about by several processes: stimulation of sucrose synthesis, inhibition of starch synthesis and stimulation of starch breakdown. Specifically, there is evidence that activation of Sucrose Phosphate Synthase (SPS) by reversible protein phosphorylation is involved. It appears that the same mechanism occurs to protect potato tubers from the effects of water deficit. The water content of potato tubers can fluctuate between 10 and 20% during the day (Geigenberger *et al.* 1997 and references therein: see appendix IV).

2.2.7 Attempts to compare rates of tissue water loss among sweetpotato cultivars

See Appendix VI for further details

One prediction from the hypothesis set out in section 2.2.6 is that rates of water loss would be slowed down from the tissues of some cultivars. We attempted to investigate this using two approaches, both involving tissue blocks.

Firstly tissue discs cut from roots of contrasting cultivars were placed in a highly desiccating environment, and the rate of weight loss assessed. For this experiment we were attempting to get a sufficiently high rate of desiccation so that any effects of wound-healing would be insignificant. We achieved rates of weight loss in the order of 5% over 5 hours, but were unable to detect any difference between cultivars.

The second approach was to impose a desiccating regime by putting tissue discs in liquids of increasing osmotic potential. In this case we were able to demonstrate increasing moisture loss with increasing osmotic potential, and did observe cultivar differences. However, contrary to our predictions, the extent of weight loss related closely to moisture content, so that low DM cultivars lost more moisture than high DM cultivars. Thus we saw no relationship between high wound-healing efficiency and ability to slow water loss.

2.2.8 A comparison of sugar levels and wound-healing efficiency

See appendix VII for further details

We conducted four separate experiments to investigate the relationship between sugar content and wound-healing in sweetpotato roots. In order to follow changes in sugar levels during wound-healing we exploited our previous findings that small sections of tissue cut from roots are able to lignify.

Table 2.5 summarises the findings of an experiment in which the initial DM content and sugar levels of roots of a range of cultivars was measured, and compared with LI at moderate humidity. The correlation between LI and total sugar content was stronger than with DM content. There was also a very strong negative correlation between DM content and sugar content. This data supports, but does not prove our hypothesis that sugar levels are more directly linked to wound-healing efficiency than is DM content.

Table 2.5: Relationship between lignification index measured at moderate humidity, dry matter content and sugar levels by cultivar for experiment 1

	Correlation coefficient (r)	
	Lignification index	%Dry matter content
% Dry matter content	-0.535*	
Fructose [mg/g dry wt]	0.447*	-0.670**
Glucose [mg/g dry wt]	0.516*	-0.685***
Fructose+glucose [mg/g dry wt]	0.480*	-0.681**
Total sugars [mg/g dry wt]	0.592**	-0.882***
Fructose +glucose [mg/g fresh wt]	0.438+	-0.542*
Total sugars [mg/g fresh wt]	0.427+	n.s.

n.s. not significant
+, *, **, *** indicates significance to 10, 5, 1 and 0.1% respectively.

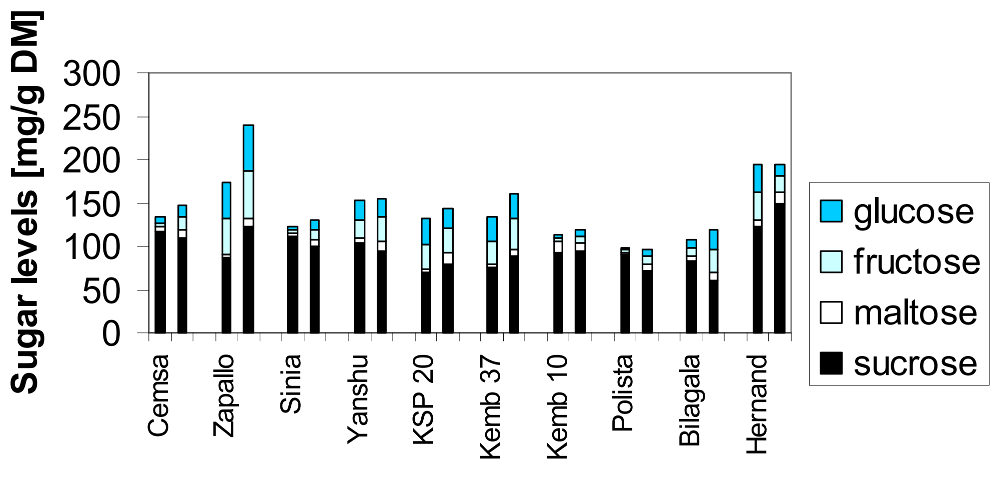
In a subsequent experiment, in order to compare wound-healing efficiency with DM content and sugar levels of individual roots, we cut roots into two parts longitudinally, using one half for sugar and DM measurement and the other half for assessment of lignification. We did not have complete confidence in the results of this experiment, as the root behaviour in terms of LI was inconsistent with that of whole roots.

Two further experiments, one using whole roots, and one using cuboids were designed to enable us to determine the sugar levels near to healing wounds, and their changes during the healing process. In the case of the whole root experiment, we assessed tissue composition at a wound made on an intact root at wounding, and after healing was complete, by cutting thin layers from the root. In the cuboid experiment, by considering the healing of tissue cuboids, and using several cuboids cut from adjacent tissue from one root we were able to assess sugar levels at wounding and after one and five days of healing

As previously observed there is a significant difference among cultivars in ability to wound heal (LI) for both experiments. For the cuboid experiment the extent of lignification was generally lower than for the root experiment but the relative performance of cultivars was reasonably consistent.

The cultivar sugar levels and the changes during the experiments are illustrated in Figures 2.4 and 2.5. Initial sugar levels differed significantly among cultivars for both experiments. As predicted from our hypothesis there was a general trend for the tissues close to wounds to accumulate sugars, so that in both cases the sugars after five days tended to be higher than the initial levels. In the case of the cuboids (Figure 2.5), it can also be seen that there was a greater accumulation of sugars over the first day from the time the cuboids were cut, and in most cases a subsequent decline from day 1 to day 5. The day 0 and day 5 data is very consistent between the experiments (Correlation of total sugar levels r = 0.846 (significant to 1%), 0.933 (significant to 0.1%)). We assume, although we could not do the measurements, that there was an initial accumulation beneath the wounds of the intact roots as well, so that the maximum sugar levels would have been higher than those measured on day 5.

Figure 2.4 sugar levels at the wound for roots of 10 sweetpotato cultivars at the start and after 5 days of healing at moderate humidity.



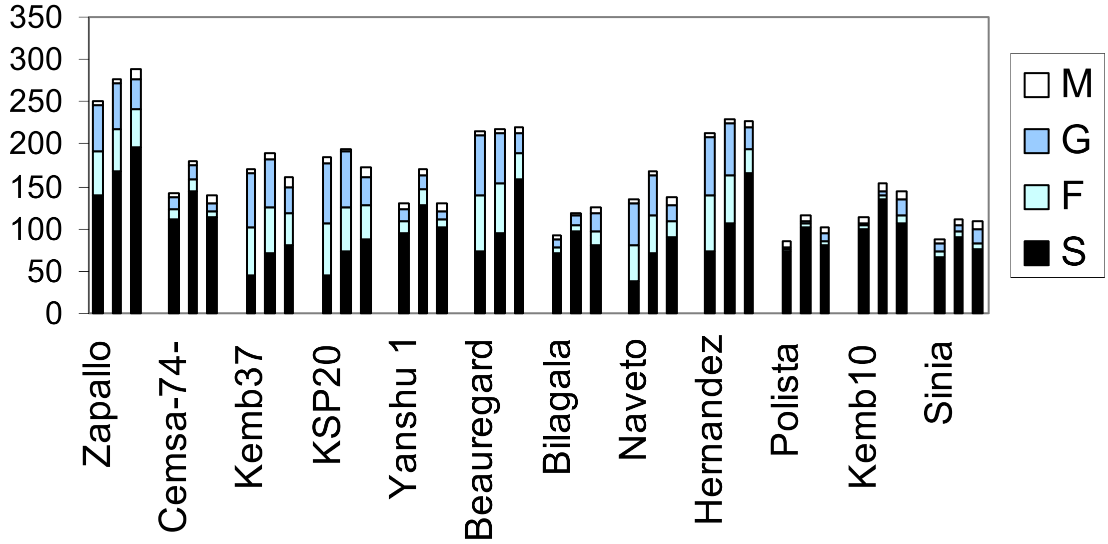


Figure 2.5 Sugar levels in cuboids cut from roots of 12 sweetpotato cultivars at the start and after 1 and 5 days of healing at moderate humidity.

Linear regression models of root and cuboid LI in terms of DM content and sugar levels are given in Table 2.6 .

The strong relationship between DM content and sugar levels, means that the two cannot be included in the same models. As observed previously LI can be modelled in terms of DM content. However, better models can be obtained by considering sugar increase for the root experiment, and sugar levels after day 1 for the cuboid experiment.

Table 2.6

a) Linear regression models of LI for whole root experiment

Parameter included in the model	% variance accounted for	model
Cultivar	29.8%	0.175 + cultivar
DM	6%	0.999 – 0.023 DM
DM, cultivar	34%	1.138 – 0.035 DM + cultivar
Sugar increase	9.4%	0.368 + 0.00316 sugar incrase
Sugar increase, cultivar	35.8%	0.149 + 0.00256 sugar increase + cultivar
Sugar_day 5	5.3%	0.137 +0.00184 sugar_day 5
Sugar_day 5, cultivar	34.7%	= -0.107 + 0.00239 sugar_day 5 + cultivar

b) Linear regression models of LI for cuboid experiment

Parameters included in model	% variance accounted for	Model
Cultivar	38%	0.200 + cultivar
Sugars_day 0	20%	-0.0008+0.0014 sugars_day 0
Cultivar, sugar_day 0	40.9%	0.014 +0.0086 sugars_day 0 + cultivar
Sugars_day 1	32.9%	-0.106 +0.0018 (Sugars _day 1)
Cultivar, Sugars_day 1	50.1%	-0.136 + 0.0015 (TSday1) + cultivar
DM	16.1%	0.597 - 0.0136 DM
Cultivar, DM	45.9%	0.719 – 0.024 DM + cultivar

In the light of our hypothesis the most important model is in terms of sugar levels after one day for the cuboid experiment. We would assume that it is during the first day that the tissue would need to work hardest to slow down water loss. The model of LI in terms of sugar_day 1 accounts for 33% variance between roots. Cultivar alone accounts for 38%, and the two together for 50%. This can be interpreted as indicating that most of the cultivar difference can be explained by the sugar levels. The validity of the hypothesis is further strengthened by the fact that differences in sugar levels among roots of each cultivar also have an effect (indicated by the observation that the two factors together provide a stronger model than cultivar alone).

The similarity of the models for experiments 3 and 4, give us confidence in the validity of using the cuboids to investigate wound healing of whole roots.

In summary we believe that the data from the cuboid experiment supports the view that sweetpotatoes which are better able to heal wounds at low humidities are those which have efficient conversion of starch to sugar. This effect can be best observed with a system that allows us to follow sugar levels during the healing process, as in the cuboid experiment.

Water loss

We have hypothesised that the increased sugar levels protect the tissue against desiccation by increasing the osmotic potential. If our hypothesis is correct, we would expect to see some relationship between sugar levels and water loss at the start of the healing process.

Although in most of our experiment it has been very difficult to compare initial rates of water loss between cultivars due to differences in root size and shape, and non-uniformity of wound size, the use of cuboids should remove these problems. However, in the cuboid experiment we observed no significant difference among cultivars in rate of weight loss for day 1.

2.2.9 Summary of findings

By using a model system consisting of tissue cuboids cut from adjacent positions within the sweetpotato we have been able to follow changes in sugar levels during the process of wound-healing at moderate humidity.

We have demonstrated that there is an initial accumulation of sugars close to the wound.

We have shown that the efficiency of wound-healing at moderate humidity is cultivar dependent, and that the level of accumulated sugars is a major cultivar factor in controlling efficiency. We chose for convenience to measure sugar levels after one day of healing. It is probable that maximum levels would have occurred either earlier or later, and that peak sugar levels would provide an even better model of wound-healing efficiency. We might therefore have underestimated the contribution of this mechanism to wound-healing efficiency.

We have hypothesised that this is due to protection against desiccation by high osmotic potential, but cannot demonstrate a difference in rates of initial weight loss as might be predicted. It is possible that accumulation of sugars is protecting specific cellular compartments against water loss, and that this would not be reflected in the water loss of the bulk tissue.

Our previous observations of a relationship between DM content and wound-healing efficiency is likely to be a result of the link with ability to mobilise starch. Cultivars with rapid starch mobilisation would tend to have lower DM content.

2.2.10 Possible implications of findings for other commodities

The ability to heal wounds and thereby protect against water loss and pathogen invasion is important for all plant tissues. It is likely that the accumulation of sugars near wounds to facilitate wound-healing by reducing desiccation (or some other as yet unidentified mechanism) is a common response. We propose that this will be particularly important when tissues are exposed to lower humidities, as will generally be the case for above ground tissues, and for root and tuber crops after harvest. Our findings may therefore have implications for keeping qualities of crops other than sweetpotato.

The Crop Post-harvest Programme is currently funding research to study the process of post-harvest physiological deterioration (PPD) in cassava (*Knowledge and tools for the modulation of post-harvest physiological deterioration in cassava, managed by J. Beeching*). PPD is an enzymatically driven response that occurs throughout the root as a result of wounding and oxidative stress incurred at harvest, and severely limits the root shelf-life. Biochemical events during deterioration in a range of cassava varieties showing differential deterioration responses are being studied with the objective of developing cultivars with reduced PPD. It is known that PPD is less when roots are placed at high humidities immediately after harvest. Further it has been observed that PPD is less where the sugar:starch ratio is high, for example in certain cultivars and after pre-harvest pruning (van Oirschot, Q.E.A., O'Brien, G.M., Dufour, D., El-Sharaway, M.A. and Mesa, E. 2000, *The effect of pre-harvest pruning of cassava upon root deterioration and quality characteristics.* J.Sci. Food Agric. 80, 1866-1873). This is consistent with the behaviour of sweetpotatoes and suggests that PPD is reduced where the root is able to facilitate wound-healing by accumulation of sugars. If we could confirm that this mechanism occurs in cassava, then it might provide a means of reducing PPD through manipulation of carbohydrate metabolism. As for sweetpotato, consumer preferences require a high starch content, but this could still be maintained if a localised wound response were targeted. (Note the project manager is presently discussing this with Dr John Beeching of Bath University).

2.2.11 Related work on-going at the University of Greenwich on stress responses of sweetpotato

Research work has been conducted at the University of Greenwich in parallel with the project reported here, but funded from other sources, on the biochemical response of sweetpotato tissue to oxidative stress, which is one of the effects of wounding. The main aspects of the research pertinent to R7520 are mentioned here for two reasons: Firstly, the work has helped project R7520 by increasing our understanding of the biochemical events associated with wounding. Secondly, the information obtained and the techniques developed could input into future research on the issue.

The research work has been carried out by Mingyan Xiang as a PhD programme with main supervisor Dr Patricia Harvey, and second supervisor, Dr Debbie Rees. The research has concentrated on two aspects of cellular biochemistry related to stress. Firstly, within mitochondria the alternative oxidase is a system which appears to have developed to prevent over reduction of the electron transfer chain under conditions where other metabolic processes are inhibited. Over reduction of the electron transfer chain can be damaging as it results in production of oxygen radicals. Secondly, peroxidases are enzymes produced both intracellularly and extracellularly in response to a range of stresses including oxidative stress. They appear to have a wide range of roles, including the removal of damaging active oxygen species. They are also involved in the polymerisation of mono-lignols to lignin. During this project the induction and profile of extracellular peroxidases was studied when sweetpotato culture cells were subjected to oxidative stress. The project also involved the development of a sweetpotato culture cell line. At one stage of project R7520 we proposed to use this to study the biochemical response to desiccation. In the event we used tissue cuboids, however, for any future work culture cells might be a more appropriate system.

CONTRIBUTION OF OUTPUTS

The overall objective of this project was to facilitate the development of sweetpotato cultivars with improved post-harvest qualities (especially keeping qualities), thereby improving food security and income generation of poor populations.

Output 1 concentrated on the production of a publication through which our experience of cultivar qualities, their relationship to consumer preferences and their assessment could be disseminated. The publication covers information obtained from several earlier and current projects funded by the CPHP. The distribution of this publication will take place shortly after this report has been submitted and we believe that it will be a very valuable mechanism for sharing our expertise. The publication will be sent to sweetpotato breeding institutions in the developed as well as the developing world. We will encourage all institutions to send us comments, in particular outlining their own experiences, and we will ensure that these are included in any subsequent distributions. Thus, as well as dissemination of CPHP programme outputs we expect that the publication will contribute to improved interaction among institutions in the developing and developed world.

Output 2 concentrated on assessment of sweetpotato germplasm for high efficiency of wound-healing, (a characteristic that we have identified as being essential for long shelf-life), and elucidation of the factors that control wound-healing efficiency. We identified a number of cultivars within existing germplasm collections that had efficient wound-healing and acceptable quality (high dry matter content) that would be useful within breeding programmes. We have also progressed significantly in our understanding of the factors controlling wound-healing. Following a mid-term review of this project, it was proposed that the most constructive way forward was to use our findings to identify good parents for breeding programmes and possibly to provide a future focus for genetic engineering. The institutions that are likely to be able to use our findings in this context most constructively are those such as CIP and breeding programmes in the US, Japan and China with relatively sophisticated facilities, and a broad breeding remit. Dissemination is therefore straightforward. CIP, as a collaborator within this project will automatically and immediately receive information on all of our findings. Papers for publication in international scientific journals are in preparation (see list of outputs), so that the work will be subjected to rigorous peer review and will be available to the international community.

As is always the case with scientific research, further research would increase the value of our findings. Below we highlight two areas of research that we think would be particularly valuable.

We have demonstrated that accumulation of sugars close to wounds is associated with increased wound-healing efficiency of sweetpotato roots at sub-optimal humidity, probably by reducing water loss from certain cellular compartments. From work on potatoes specific enzymes have been implicated in the control of this accumulation. If future genetic manipulation were to be possible, further work would be needed to determine the key enzymes, mechanisms of control and to find out whether it were possible to manipulate them to improve sugar accumulation without detrimental effects on starch levels. As discussed previously (Outputs 2.2.10), we believe that our findings may be relevant for other issues, specifically to reduce post-harvest physiological deterioration of cassava. This could be investigated very simply using techniques already developed in this project.

Output 3 is discussed in the Final Technical Report for project R7498.

PUBLICATIONS

Note: Additional publications relating to output 3 will be included in the FTR for R7498

AKED, J. (2001) Literature review on wound healing in root and tuber crops (with a special focus on sweet potato). Natural Resources Institute (NRI), Chatham, UK. 20 pp. (C)

REES, D. (2003) Studies on osmotic adjustment of tissue discs suspended in mannitol. Natural Resources Institute (NRI), Chatham, UK. 4 pp. (C)

REES, D., VAN OIRSCHOT, Q.E.A., AKED, J., LEBAS, M., CRAYCRAFT, S., and NEILSON, J. (2003) Investigating the relationship between carbohydrate metabolism and wound-healing at sub-optimal humidities. Natural Resources Institute (RNI), Chatham, UK 21 pp [draft manuscript] (C)

REES, D., VAN OIRSCHOT, Q., and KAPINGA R. eds (2003) Sweetpotato Post-harvest Assessment: Experiences from Tanzania. Natural Resources Institute (RNI), Chatham, UK 125 pp

REES, D. and VAN OIRSCHOT, Q.E.A. (2003) To determine whether there is an intrinsic difference in rates of lignificiation among cultivars, and whether this relates to differences in wound-healing efficiency at sub-optimal humidities. Natural Resources Institute (RNI), Chatham, UK 6 pp [draft manuscript] (C)

REES, D., VAN OIRSCHOT, Q.E.A., MCHARO, T., MAINA, D., BOHAC, J., and LUCAS, C. (2003) Screening sweetpotato cultivars for wound-healing efficiency. Natural Resources Institute (NRI), Chatham, UK. 27 pp. [draft manuscript] (C)

REES, D., VAN OIRSCHOT, Q. and LUCAS, C. (2000) Screening sweet potato cultivars for wound-healing efficiency. Report 2. Natural Resources Institute (NRI), Chatham, UK. 23 pp. (C)

REES, D. and VAN OIRSCHOT, Q. (2000) Screening sweet potato cultivars for wound-healing efficiency. Report 1. Natural Resources Institute (NRI), Chatham, UK. 8 pp. (C)

TOMLINS, K., RWIZA, E., NYANGO, M., AMOUR, R., NGENDELLO, T., KAPINGA, R.,and REES, D. (2003) The use of sensory panels for the selection of sweetpotato cultivars in East Africa. Natural Resources Institute (NRI), Chatham, UK. 12 pp. [draft manuscript] (C)

VAN OIRSCHOT, Q.E.A., TOMLINS, K.I., NGENDELLO, T., AMOUR, R., RWIZA, E., REES, D., JEFFRIES, D. and WESTBY, A. (2002) The potential for long-term storage of fresh sweetpotatoes under tropical conditions - On station trials 2000. Natural Resources Institute (NRI), Chatham, UK. (C)

VAN OIRSCHOT, Q.E.A., REES, D., AKED, J. and KIHURANI, A.W. (2003) Sweetpotato cultivars differ in efficiency of wound healing. *Submitted to Plant Physiology*.

VAN OIRSCHOT, Q., REES, D., LUCAS, C., MAINA, D., MCHARO, T and BOHAC, J. (2002) Sweetpotato: Germplasm Evaluation for Wound Healing Efficiency. Proceedings of the 1st International Symposium on Sweetpotato. *Sweetpotato: food for health and future, Lima, Peru. 26-29 November 2001* Ed. T. Ames. Acta Horticulturae, 583: 31-40 (B)

VAN OIRSCHOT Q. (2002). Reaching the full potential of sweet potatoes in East Africa. New Agriculturalist 6.. http://www.new-agi.co.uk/02-6/focuson/focuson5.html

VAN OIRSCHOT, Q., REES, D., KAPINGA, R. and AKED, J. (2001) Spuds that last! Solving the problem of Africa's poor. *Presented at the National Week of Science, Engineering and Technology, House of Commons for the UK.* [poster] (B)

VAN OIRSCHOT, Q.E.A., NGENDELLO, T., AMOUR, R., RWIZA, E., REES, D., TOMLINS, K.I., JEFFRIES, D., BURNETT, D. and WESTBY, A. (2000) Preliminary observations on the potential for long-term storage of fresh sweet potato under tropical conditions. p 341-344. In: Potential of root crops for food and industrial resources. *Proceedings of the 12th symposium of the the International Society for Tropical Roots Crops. Ed. M Nakatani and K Komaki. Sept 10-16, 2000, Tsukuba, Japan* [poster and paper] (B)