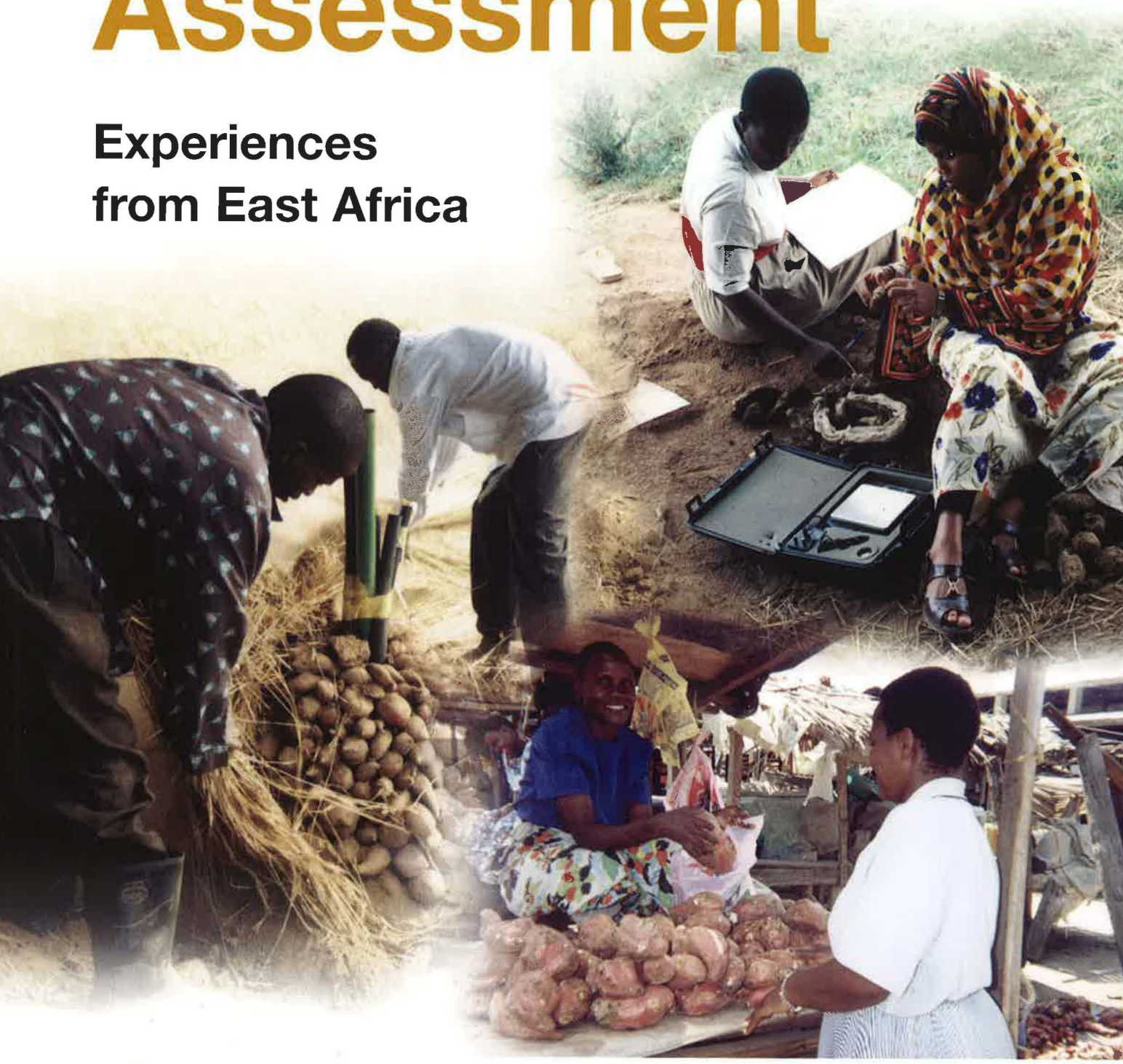
Sweetpotato Post-harvest Assessment

Experiences from East Africa



Natural Resources Institute

CPHP
Crop Post-Harvest Programme

DFID Department for International Development

Centro Internacional de la Papa CIP
International Potato Center (CIP)

Ministry of Agriculture Tanzania

For any crop cultivar to be successful it must not only have good production characteristics but also characteristics that ensure the harvested crop is acceptable and suitable for its intended use.

Sweetpotato Post-harvest Assessment summarizes work carried out on post-harvest aspects of sweetpotato between 1994 and 2002 within collaborative projects involving the Natural Resources Institute (UK), the International Potato Center and the Tanzanian Ministry of Agriculture, with input from the Kenyan Agricultural Research Institute and the National Agricultural Research Organization of Uganda. Methods are discussed for assessing different quality aspects of sweetpotato cultivars within breeding programmes.

The book is expected to be of particular interest to sweetpotato breeding organizations and those involved in research on sweetpotato, but will also be useful to those working on other crops.

Sweetpotato Post-harvest Assessment

Experiences from East Africa

Edited by
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The Natural Resources Institute (NRI) of the University of Greenwich is an internationally recognized centre of expertise in research and consultancy in the environment and natural resources sector. The Institute carries out research and development and training to promote efficient management and use of renewable natural resources in support of sustainable livelihoods.

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INTRODUCTION

The origin and objectives of this publication

This book was produced to summarize work carried out on post-harvest aspects of sweetpotato between 1994 and 2002 within collaborative projects involving the Tanzanian Ministry of Agriculture, the Natural Resources Institute (University of Greenwich at Medway, UK) and the International Potato Center, with input from the Kenyan Agricultural Research Institute and the National Agricultural Research Organization of Uganda.

The work arose out of a growing realization that for any crop cultivar to be successful it must not only have good production characteristics but also characteristics that ensure the harvested crop is acceptable/suitable for its intended use. Such characteristics are usually termed *post-harvest* characteristics. Although this term will be used throughout this book, it is in some ways misleading as the distinction between pre- and post-harvest characteristics is not always clear, and so-called post-harvest characteristics are very dependent on pre-harvest growing practices and conditions.

The selection of new cultivars is an important aspect of sweetpotato crop improvement. Sweetpotato is considered to be the most under-exploited of the developing world's major crops. This has probably arisen because of its status as a poor man's crop, and the fact that it is produced almost entirely in developing countries. Breeding initiatives for sweetpotato are at a relatively early stage compared to other staple crops. Given the enormous genetic diversity of sweetpotato worldwide, and the fact that breeding programmes of sweetpotato are relatively new, crop improvements are expected to be rapid. New cultivars can provide farmers with improved yields, earlier crops, reduced susceptibility to pests and diseases, and improved root quality characteristics, at little or no additional cost. Those interested in the selection of new cultivars include agricultural researchers, development and extension workers and, of course, farmers.

The book is focused primarily towards agricultural scientists and breeders anywhere in the world that work with sweetpotato, although it will also be useful for development and extension workers. The hope is that by learning of our experiences and findings through our work in East Africa, others will be helped to develop methods for assessing the quality aspects of sweetpotato cultivars within their own breeding programmes. We also hope that it will be of use to those working with other crops.

Within each chapter, the trials and experiments carried out to investigate a particular aspect of sweetpotato post-harvest quality are described. The relevance of the findings to other regions of the world is discussed. In most cases some details of the methods used are included (although separated from the main text in shaded boxes). Where a reader has a particular interest in a topic more detailed reports and publications listed in the References section at the end of each chapter should be consulted.

Funding for the work reported here was provided by the Department for International Development, UK through their Renewable Natural Resources Knowledge Strategy (RNRKS) programme, and by the International Potato Center. In addition, all other organizations involved donated staff time and use of field or laboratory facilities.

CHAPTER 1

Present status of sweetpotato breeding for eastern and southern Africa

R. E. Kapinga and E. E. Carey

1.1 The status of sweetpotato as a staple crop

The following overview is based on the synopses by Carey *et al.* (1997) and Minde *et al.* (1999).

Sweetpotato is an important food crop in many areas of sub-Saharan Africa where, according to FAO (FAOSTAT, 2002), it is grown on around 2.1 million ha, with an estimated production of 9.9 million tonnes. It is one of the main staples in the food systems of Uganda, Rwanda, Burundi and eastern Congo, with per capita production of around 100 kg/year. Sweetpotato is a secondary crop in the grain-based systems elsewhere in the region, becoming important only at certain times of the year or when other crops fail (Bashaasha *et al.,* 1995; Kapinga *et al.*, 1995; Scott *et al.*, 2000).

According to several studies in the region, sweetpotato is grown principally for its storage roots which are generally harvested either piecemeal, or progressively, and eaten fresh, steamed or boiled. In several southern African countries the leaves are also eaten as a vegetable. In some areas that are densely populated, vines are also fed to livestock within 'cut and carry' systems. In dry areas of Tanzania and Uganda, processing of sweetpotato storage roots by slicing and

drying takes place. The dried slices form part of the dietary staple mainly during seasons of low food supply. This has become more important in areas where cassava yields have been severely reduced by African

cassava mosaic virus. Recently, the marketing of fresh sweetpotato roots, mainly in urban areas, has been gaining importance.

1.2 The main constraints to the crop in eastern and southern Africa

Farmers in the region grow a wide range of cultivars, which have principally been distributed by informal means. However, information on available cultivars is incomplete, and in most places it is difficult to determine the extent to which relatively recent cultivar introductions or escapes from breeding programmes contribute to the mix of varieties grown by farmers. It appears, however, that most cultivars are indigenous and with relatively few recent improved varieties in the regions, there are many constraints that still have to be addressed. The main constraints identified in sub-Saharan Africa are summarized in Table 1.1. Their relative importance varies with agro-ecologies, and a summary of the situation in eastern, central and southern Africa is given in Table 1.2.

Of the major constraints considered above those that might more easily be addressed by breeding are: late maturity, low yields, and perishability of the fresh roots. Breeding can also be used to produce varieties with high dry matter content and increased beta carotene content. The latter has potential for counteracting vitamin A deficiency found in many regions of sub-Saharan Africa. Much effort has been expended over the past decades to breed for insect and virus resistance, but this is a more difficult task. Another important limiting factor for the crop is the slow rate at which utilization of the crop is diversifying, which is considered to limit demand for sweetpotato in the region. (**Note**: Surveys conducted in Tanzania to identify the main constraints and focus breeding priorities are described in Chapters 2 and 3.)

Table 1.1 Major constraints to the sweetpotato crop identified in sub-Saharan Africa

Type of constraint	Constraint
Biotic	Viruses Weevils (mainly *Cylas* spp.)
Abiotic	Declining soil fertility and natural resource base
Available varieties and planting material	Lack of varieties that are high yielding, early maturing, drought resistant, have high dry matter content and have high beta carotene content Lack of good quality planting material of improved varieties
Post-harvest	Lack of storage and processing technology Lack of varieties that are less perishable Opportunity for utilization and marketing not well developed
Socio-economic and policy	Lack of policy for the production and supply of seed or planting material Lack of market studies and weak distribution systems Poor linkage between research, extension and private sector Lack of credit systems and inability of farmers to purchase inputs

Source: Hagenimana (1999).

Table 1.2 Major sweetpotato agro-ecological zones in eastern, central and southern Africa and associated production constraints

Agro-ecological zone	Major areas	Principal mode of utilization	Main identified constraints
Moist, warm environments (bimodal rainfall)	Major production zones of Kenya, Uganda, western Tanzania, Rwanda, Burundi, Zambia, Angola, Zimbabwe, Malawi	Fresh consumption and forage	Sweetpotato viral diseases (SPVD) Moles
Dry, warm environments (unimodal rainfall)	Northern Uganda, parts of Kenya, Tanzania, northern Namibia, Botswana, southern Zambia, parts of Zimbabwe and Malawi	Fresh consumption and limited processing (mainly in Uganda and Tanzania)	Weevils (*Cylas* spp.) Drought Scarcity of planting materials
Moist cool environments high elevations (bimodal rainfall)	South-west Uganda, Rwanda, Burundi, parts of Angola, Zimbabwe and Malawi	Fresh consumption and forage	*Alternaria* disease Low soil fertility

1.3 Previous breeding efforts in eastern and southern Africa

A sweetpotato breeding initiative conducted at the International Institute for Tropical Agriculture (IITA) at Ibadan, Nigeria from the early 1970s through to 1986, led to the development of a considerable number of clones with high yielding potential under low input conditions and broad adaptation to environments in Africa. The programme was based largely on elite breeding stocks from outside Africa, but selected and bred in Nigeria for resistance to regionally important constraints, including sweetpotato viral diseases (SPVD) and sweetpotato weevils (Hahn, 1982). These clones from IITA have been distributed to different places in Africa, both by IITA and, more recently, by the International Potato Center (CIP), which took over the mandate for sweetpotato in the late 1980s. CIP presently maintains 40 of the original IITA clones on its list of pathogen-tested sweetpotato cultivars for distribution (CIP, 1998). The utilization of IITA clones in east, central and southern African countries has, however, been limited. The major reasons for this are: poor consumer acceptability because of low dry matter content and poor taste, and susceptibility to local viruses; for example, in Uganda, all IITA clones introduced succumbed to SPVD. This underlines the need for localized breeding programmes that exploit the potential of local germplasm, and the importance of assessing for consumer acceptability.

In Tanzania, a sweetpotato breeding programme was established at the Lake Zone Agricultural Research and Development Institute (LZARDI), Ukiriguru, Mwanza, Lake Zone in 1968. A variety, named by the programme as SPN/O, was identified and to date the variety is widespread in eastern and southern Africa under several synonyms, including Tanzania, Kemb 10, Kasimama (Ewell, 1997). The Tanzanian programme has utilized sweetpotato germplasm from local collections, from collections outside Africa through CIP, and has also obtained germplasm from several African regions through network organizations (see section 1.4). Crossing blocks used open-pollination of seeds.

In Rwanda, at the breeding station located at the Institut Des Sciences Agronomique du Rwanda (ISAR), the varieties Rusenya and Mugande were identified between 1990 and 1994. These are indigenous varieties selected from among local farmers' varieties, but have been successful following distribution over a wide area covering Rwanda, Burundi, Kenya, Democratic Republic of Congo and other countries in the Southern Africa Development Community (SADC) region. Other clones from IITA and CIP had reached the stage of on-farm testing at the time the war began.

Selection criteria in both eastern and central African countries were based mainly on: high yield, early maturity, broad adaptation, resistance to SPVD and resistance/tolerance to sweetpotato weevils. Other considerations were good taste, high dry matter content, and attractive root shape and flesh colour. The approach differed for South Africa, as until recently, the targeted market has always been for livestock feed (Carey *et al.*, 1997). Most varieties used were from USA and have lower dry matter content (18%) than is acceptable in the rest of the region.

The main lessons learned from previous breeding efforts were listed by Carey *et al.* (1997).

- Local farmers' varieties can make a significant contribution either as varieties *per se* or progenitors in breeding programmes.
- It is important to select a target environment that allows the assessment of clones for both reaction to production constraints such SPVD, and quality traits related to consumer acceptance.
- Varieties should be selected that are adapted to SPVD and *Alternaria*.
- It is important to share tasks and results among a number of countries. This is possible through networks such as the Programme Regional de la Pomme de terre et de la Patata douce en Afrique Centrale et de l'Est (PRAPACE) and the Central Africa and Southern Africa Root Crops Research Network (SARRNET) (see section 1.4). The approach minimizes the risk of having one programme in one country given the present political uncertainties and limited financial resources.

1.4 Current breeding approaches and results

In recent years, breeding efforts have been intensified in eastern, central and southern Africa, largely under the auspices of CIP and co-ordinating networks such as PRAPACE, a regional potato and sweetpotato improvement programme in eastern Africa, and SARRNET. One of the key objectives of these networks is to increase the efficiency of breeding and research into the target crops by dividing responsibilities among the participating countries.

Countries in eastern and central regions (i.e. Uganda, Rwanda, Eritrea, Kenya, Ethiopia, Burundi, Madagascar, southern Sudan, and Democratic Republic of Congo) are covered by PRAPACE. Here the responsibility for varietal screening for virus resistance and early maturity has been taken by Uganda, Kenya, Ethiopia and Democratic Republic of Congo (Carey *et al.*, 1997). SARRNET is the network for countries in the southern region (i.e. Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe). Among SARRNET participants, Malawi, Mozambique, South Africa, Tanzania and Zambia take a more active role in the breeding of new varieties. In all regions technical support is provided by CIP.

International distribution of seed populations for selection by breeding programmes has been carried out by CIP (Table 1.3). Principal sources have included the CIP breeding programmes in Peru and Indonesia, the Chinese programmes, Mississippi State University (USA), and the USDA Vegetable Research Laboratory (South Carolina, USA). In the past, the ISAR programme in Rwanda served as a source of seed for distribution both within and outside of Africa. More recently, Namulonge, Uganda and Roodeplat, South Africa have become principal sources of seed in the eastern and southern African countries. The seeds are generated from crossing blocks as well as open-pollinated fields. The parents used are both from the region as well as introductions from other countries through CIP. Kenya, having the advantage of hosting CIP, serves as the principal location for the regional redistribution of clonal germplasm by CIP from the Kenya Plant Quarantine Station at Muguga.

The introductions by country have been supported by rigorous multiplication schemes. This has enabled new germplasm to be evaluated in the national breeding trials. Results from different countries have shown that many of the clones initially selected from IITA have poor performance with respect to dry matter content, indicating the need to use regionally adapted parental clones with acceptable qualities, for example, SPN/O, Mugande, etc. In fact Mwanga (2001) has shown that most varieties selected, which have reached the advanced breeding stage, have the regionally important sweetpotato variety, SPN/O as their female progenitor.

Key elements of the regional breeding strategy as highlighted by Carey *et al.* (1997) are:

- the introduction and testing of elite varieties and seed populations from outside Africa
- the clean up (i.e. removal of viruses)[1] and distribution within Africa of varieties identified as promising or important by individual national programmes
- breeding in key agro-ecological zones to generate new varieties for the region
- the use of a farmer participatory approach and extension and NGO partners for final stages in the selection and dissemination of new varieties
- the importance of choosing parental clones from local varieties.

1.5 Current areas of focus for regional breeding efforts

For sweetpotato breeding programmes throughout the world the following objectives are given high priority.

- Breeding for high yield in terms of dry matter per unit of land and time.
- Breeding for resistance to, and cultural control of, economically important diseases and pests.

Table 1.3 Sweetpotato germplasm distributed by CIP to eastern, central and southern Africa countries 1993–2002

Country of destination	Source of germplasm			Number of seed families received
	South America	North America	Other countries	
Angola	16	4	21	-
Burundi	2	-	4	
Botswana	17	4	13	-
DR Congo	20	17	36	-
Eritrea	-	-	18	-
Ethiopia	-	-	26	-
Madagascar	-	-	4	-
Malawi	-	-	20	29
Mozambique	-	-	28	-
Kenya	73	41	171	265
Rwanda	34	21	41	92
Sudan	6	4	29	-
Tanzania	28	7	60	149
Uganda	83	34	116	117
Zambia	11	3	48	234

Source: CIP and SARRNET reports for 1999, 2000 and 2001/02.

[1]The removal of virsues from a cultivar is a complex process which involves producing callus material, heating to kill the viruses, and the production of plantlets from the callus. This process can be carried out at CIP in Peru and is recommended before material is moved between regions, to prevent the spread of viruses.

Table 1.4 Main breeding goals by region after assessment of constraints and opportunities

Factor	CIP region			
	Latin America	South-west Asia	East and southern East Asia and the Pacific	Sub-Saharan Africa
Weevil resistance/tolerance		X	X	X
Virus resistance				X
Drought tolerance	X	X	X	X
High dry matter (starch) content	X		X	X
High foliage yield	X*	X*		X*
Non-sweet storage roots				West Africa
Good storability	X	X		X

*Potential demand for forage-type sweetpotato (forage only).

Source: CIP (1995).

- Breeding for high keeping qualities.
- Breeding for improved quality in terms of consumer acceptance, processing and nutritional values.
- Breeding for wide adaptation.

Table 1.4 summarizes global breeding priorities as set by sweetpotato breeders in a workshop held by CIP in Lima, Peru in June 1994 (CIP, 1995).

For eastern and southern Africa primary and secondary focus areas have been highlighted by Carey *et al.* (1997).

Primary

In addition to assuring widespread dissemination of released varieties, the major objectives are to select varieties with acceptable utilization characteristics. These characteristics include:

- acceptable taste, high dry matter content, etc.
- suitability for improved farm-level processing
- extended shelf-life of roots and tolerance to market conditions
- attractive appearance and properties of products, particularly flour
- ability to produce vines for animal feed.

Secondary

These are selected mainly on the basis of testing in the major production environments. Important areas are:

- earliness vs. inground storability
- drought tolerance
- high root yield
- good establishment
- good resistance to SPVD and sweetpotato weevils.

Breeding procedures both on-farm and on-station are summarized in *CIP Research Guide* Nos 5 and 6 (Fonseca *et al.*, 1994; Carey and Reynoso, 1997). An overview is also given in Appendix I.

References

BASHAASHA, B., MWANGA, R., OCITTI P'OBWOYA, C. and EWELL, P.T. (1995) *Sweetpotato in the Farming and Food Systems of Uganda: A Farm Survey Report*. Kampala: International Potato Center and National Agricultural Research Organization.

CAREY, E.E., GICHUKI, S., NDOLO, P.J., TURYAMUREEBA, G., KAPINGA, R. and LUTALADIO, N.B. (1997) Sweetpotato breeding for Eastern and Southern Africa: an overview. pp. 89–93. In: *Proceedings of the Fourth Triennial Congress of the African Potato Association, Pretoria, South Africa, 23–28 February 1997*. Mienie, N.J.J. (ed.). Pretoria: Agricultural Research Council.

CAREY, E.E. and REYNOSO, D.M. (1997) Procedures for the evaluation of pathogen-tested sweetpotato clones. *CIP Research Guide*, No. 6. Lima: International Potato Center.

CIP (1995) *Vines to Roots: Sweetpotato Breeding for Impact. Recommendations and Abstracts from an International Workshop, Lima, Peru, 1–3 June 1994*. Lima: International Potato Center.

CIP (1998) *Pathogen-tested Sweetpotato Germplasm for Distribution*. Fourth edition. Lima: International Potato Center.

EWELL, P. (1997) International cooperation for the improvement of potato and sweetpotato in sub-Saharan Africa. pp. 157–164. In: *Proceedings of the Fourth Triennial Congress of the African Potato Association, Pretoria, South Africa, 23–28 February 1997*. Mienie, N.J.J. (ed.). Pretoria: Agricultural Research Council.

FAOSTAT (2002) http://agrifor.ac.uk/subject-listing/310.html

FONSECA, C., MOLINA, J.P. and CAREY, E. (1994) Farmer participation in the selection of new sweetpotato varieties. *CIP Research Guide*, No. 5. Lima: International Potato Center.

HAGENIMANA, V. (1999). Micro-scale enterprise approach to sweetpotato and potato improvement systems. pp. 20–26. In: *Enhancing Post-harvest Technology Generation and Dissemination in Africa*. Kwarteng, J. (ed.). Mexico City: Sasakawa Africa Association.

HAHN, S.K. (1982) Research priorities, techniques and accomplishments in sweetpotato breeding at IITA. pp. 23–26. In: *Root Crops in Eastern Africa. Proceedings of a Workshop, Kigali, Rwanda, 23–27 November 1980*. Ottawa: International Development Research Centre.

KAPINGA, R.E., EWELL, P.T., JEREMIAH, S.C. and KILEO, R. (1995) *Sweetpotato in Tanzanian Farming and Food Systems: Implications for Research*. Nairobi: International Potato Center and Ministry of Agriculture and Livestock Development, Tanzania.

MINDE, I.J., EWELL, P.T. and TERI, J.M. (1999) Contribution of cassava and sweetpotato to food security and poverty alleviation in the SADC countries: current status and future prospects. pp. 27–39. In: *Proceedings of the Scientific Workshop of the Southern Africa Root Crops Research Network (SARRNET), Pamodzi Hotel, Lusaka, Zambia, 17–19 August 1998*. Akoroda, M.O. and Teri, J.M. (eds).

MWANGA, R.O.M. (2001) *Nature of Resistance and Response of Sweetpotato to Virus Diseases*. A dissertation submitted to the Graduate Faculty of North Carolina State University in partial fulfilment of the requirements for the Degree of Doctor of Philosophy. Department of Horticultural Sciences, Raleigh, USA.

SCOTT, G.J., ROSEGARNT, M.W. and RINGLER, C. (2000) Roots and tubers for the 21st century. Trends, projections, and policy options. *Food, Agriculture and the Environment Discussion Paper*, No. 31. Washington: International Food Policy Research Institute and International Potato Center.

CHAPTER 2

Farmer criteria for selection of sweetpotato varieties

R.E. Kapinga, S.C. Jeremiah, E.J. Rwiza and D. Rees

2.1 Background

In Tanzania, despite its importance in food systems there has been little expansion in the aggregate acreage of sweetpotato over several years. Although research has lead to many recommendations for practices to increase production of sweetpotato at the farm level, the rate of adoption of improved practices is low. In cases where 'improved' varieties have been introduced, a low rate of uptake may indicate that the variety is in some way unacceptable. This observation has led research scientists to revisit the approaches previously used, and to take more account of growers' and consumers' preferences when developing and selecting sweetpotato varieties for release.

This chapter describes two activities undertaken by the Tanzanian sweetpotato breeding programme. Firstly, surveys were undertaken between 1990 and 1995 to obtain information on practices and constraints relating to sweetpotato production and utilization, and to determine the main criteria by which farmers judge varieties. Secondly, the methods by which the breeding programme in Tanzania incorporated the opinions of farmers in the selection of new cultivars through the use of farmer groups and on-farm trials are described.

2.2 Surveys for the identification of farmers' selection criteria for sweetpotato varieties

Between 1990 and 1995 surveys were conducted in several important sweetpotato production areas of Tanzania (see Figure 2.1 for major sweetpotato production areas) to obtain information on the suitability of sweetpotato in farming and food systems. Details of the surveys are given in Hart (1991), Kapinga (1992) and Kapinga *et al.* (1995).

2.2.1 Methods

The methodology used in all the surveys was similar. The information was obtained by group interviews where a group consisted of 15–20 people. This information was supplemented by interviews with individual households, generally 4–6 per village per district.

Although checklists were used to aid the interviews, the survey depended very much on open discussion with the groups.

The general issues normally addressed included:

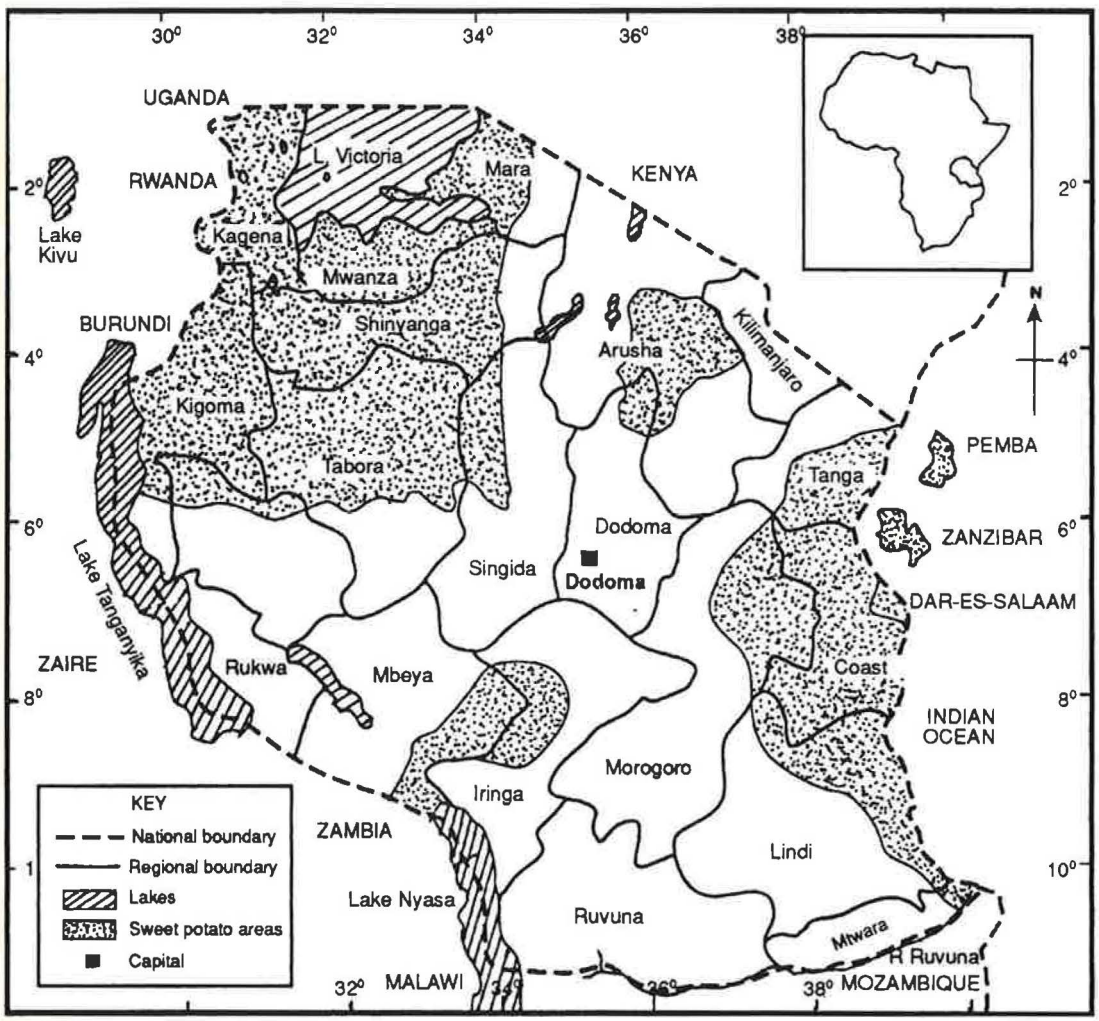
- identification of criteria used by farmers to abandon or select sweetpotato varieties
- identification of farmers' preference for sweetpotato varieties currently grown
- identification of utilization practices
- ranking of varieties in order of utilization practices
- desirable characteristics in sweetpotato varieties
- identification of research gaps for increased utilization of sweetpotato varieties.

2.2.2 Results

Criteria used by farmers to abandon or select sweetpotato varieties

Information was compiled from Kapinga *et al.* (1995) and the Farming Systems Research-National Co-ordination Unit (FSR-NCU) survey (1996).

Farmers in all the surveyed zones (Eastern, Southern, Western, Southern Highlands, Lake) confirmed that



Adapted from: Msabaha (1990).

Figure 2.1 Major sweetpotato producing areas in Tanzania

there are several important criteria which act as a basis for selection of sweetpotato varieties. The frequencies at which the various criteria were mentioned in the different zones are summarized in Table 2.1. The attributes considered most important by farmers are high root yield, early maturity, tolerance to pests and diseases and good root characteristics (low fibre, sweetness, high root firmness, etc.). The most important characteristics referring to qualities of the roots are described in more detail below.

These characteristics have been ranked in Table 2.1 on the basis of the percentage of farmers mentioning them as important selection criteria, averaged across zones. As this percentage is not weighted for the importance of each zone in total sweetpotato production, it can only be taken as a qualitative indication of the importance of that criterion. (**Note**: The five zones are considered to rank in the following way with respect to sweetpotato production: 1 Lake; 2 Western; 3 Eastern; 4 Southern Highlands; 5 Southern.)

(i) High root yield

This was the selection criterion most frequently mentioned. Farmers in all of the surveyed zones indicated that high yield is an important attribute in sweetpotato variety selection. The root yield in this case depends mainly on the number of storage roots per plant.

(ii) Early maturity (early bulking)

Early maturity was an important criterion in all zones, although the frequency with which it was mentioned varied. The overall percentage for all surveyed areas which mentioned this criterion was 88%, and it ranked second among all other criteria across zones. Farmers in the Southern, Western and Lake Zones were more

Table 2.1 Selection criteria by zone for sweetpotato varieties as mentioned by surveyed farmers (%)

Criterion	Zones						
	EST	SOUT	WEST	SHL	LAK	Mean	Rank
Ranking of zones by importance of sweetpotato production	3	5	2	4	1		
Pre-harvest							
High yielding	100	100	100	100	67	94	1
Early maturing	67	100	100	75	100	88	2
Disease tolerance	67	100	0	75	67	62	4
Insect tolerance	67	100	0	25	67	52	6
Good in-ground storability	0	100	0	75	0	35	8
Tender leaves	33	0	0	0	0	7	11
Tolerant to waterlogging	33	0	0	0	0	7	11
Potential to be grown all seasons	33	0	0	0	0	7	11
Post-harvest							
Sweetness	67	100	100	100	67	87	3
Low fibre content	0	100	100	100	0	60	5
High root firmness	67	0	0	25	100	38	7
Less starch for storage	0	0	100	0	0	20	9
Marketability	0	0	0	67	0	13	10
Large root size	33	0	0	0	33	13	10
Good root shape	0	0	0	0	33	7	11
Good chips	0	0	0	0	33	7	11

EST = Eastern Zone; SOUT = Southern Zone; WEST = Western Zone; SHL = Southern Highlands Zone; LAK = Lake Zone.

Source: Compiled from FSR-NCU data file (1996).

concerned with this criterion (100%) compared with those in the Southern Highlands and Eastern Zones (75% and 67%, respectively).

Farmers clarified their response by mentioning the ability of a variety to give a reasonable number of harvestable storage roots from 3 months after planting. The early maturing varieties were mostly preferred in areas where sweetpotato is a commercial crop. In addition, early maturing varieties can be particularly important when there is an extended dry spell and sweetpotato is a food security crop when other crops fail. In some zones, such as the Lake and Western Zones, early maturing varieties bridge the gap before the harvest of main crops.

(iii) Sweetness

The term 'sweet' applied to sweetpotato in Tanzania appears to be very subjective and refers to a desired taste rather than sugar levels. Thus root sweetness as explained by farmers indicated a taste for a root that is not very sweet, nor very 'flat' like that of yam. Any sweetpotato with that desired taste is considered very sweet. This post-harvest criterion ranked third in importance and was mentioned in all zones. The average percentage of surveyed farmers who mentioned sweetness as important was 87% (Table 2.1). The highest percentage was observed in the Southern, Western and Southern Highlands Zones, respectively.

(iv) Disease and pest tolerance

Farmers interviewed were able to identify some common pests and diseases of sweetpotato. They preferred sweetpotato varieties that tolerate diseases and also that are tolerant/resistance to sweetpotato pests. This criterion was mentioned by farmers in all surveyed zones with the exception of Western Zone (Table 2.1). Tolerance to insects (primarily the sweetpotato weevil, *Cylas* spp.) was mentioned on average in 52% of cases and ranked sixth in importance.

(v) Low fibre content

Low fibre content was another important selection criterion, which ranked fifth in importance (Table 2.1). On average 60% of the surveyed farmers indicated that low fibre content was of great value in selection of sweetpotato varieties. This may be an underestimate of its importance, since the survey results indicated that it was not mentioned in the Eastern and Lake Zones, although it was mentioned by all farmers in the other three zones. It appears that this quality may have been included with root 'sweetness' in these two cases.

Selection criteria for specific zones

Information was compiled from the FSR-NCU survey (1996).

Some selection criteria were very specific to zones, probably because they answer the specific needs of the particular environment.

One example is high root firmness which was only mentioned by farmers in the Lake, Eastern and Southern Highlands Zones. This is probably because storage roots with high dry matter content and, therefore, high starch content, are more suitable for secondary processed products such as starch and flour.

Other specific criteria were for varieties which make good chips, have good root shape and large root size. These criteria were mentioned specifically in the Lake Zone, and reflect the type of root utilization commonly practised in this zone.

Good in-ground storability was specifically mentioned in Southern and Southern Highlands Zones. There are two requirements related to this attribute. One is extended in-ground storability before harvesting; the other is the ability for the fresh roots to keep for prolonged periods in specific storage structures. Insufficient information was obtained to determine whether the same varieties are good in both cases.

Characteristics of sweetpotato varieties commonly grown by farmers

Information was obtained from the FSR-NCU survey (1996).

An indication of the characteristics of sweetpotato varieties presently grown in different zones of Tanzania is presented below. These data were obtained during FSR-NCU surveys on a wide range of crops. As a consequence, in some zones, especially those where sweetpotato is less important, only a small number of varieties were recorded which may not be a true indication of the real situation. Nevertheless, the overall results can be taken as an indication of the varieties grown nationally. In some cases the characteristics of varieties grown correspond quite closely with farmers' preferences, while in other cases there is clearly room for improvement.

(i) Maturity

Although farmers prefer early maturing varieties, most sweetpotato varieties grown by farmers are considered by farmers' definition to be late maturing (Table 2.2). Farmers considered the critical time to distinguish late and early maturing varieties is 4–5 months. Varieties that do not give mature roots within this period are considered to be late maturing. Early maturing often means that in the case of piecemeal harvesting, big

Table 2.2 Rate of maturing of commonly grown sweetpotato varieties

Zone	Number of varieties considered	Early maturing	Late maturing
Eastern	10	3	7
Western	11	3	8
Southern Highlands	35	19	16
Central	3	2	1
Lake	18	8	10
Total	77	35	42
Percentage		45%	55%

Source: Compiled from FSR-NCU data file (1996).

Varieties were categorized by the interviewed farmers as early maturing and late maturing. An early maturing variety produces mature storage roots within 4–5 months, whereas a late maturing variety takes longer.

The overall percentage has not been weighted to take into account the relative importance of varieties or zones.

roots can be obtained within 3–5 months, while others are left to bulk. Farmers also mentioned the advantage of early maturity for drought avoidance, particularly in areas with long dry spells. Analysis from all zones surveyed (Southern and Northern Zones were not included) showed that 55% of the total varieties grown by farmers were referred to as late maturing and 45% early/medium maturing varieties (Table 2.2). This overall percentage does not take into account the relative importance of varieties or zones, but gives an indication that research efforts for the development of early maturing varieties should be strengthened.

(ii) Root sweetness

As discussed above, root 'sweetness' is a very subjective quality, being an indication of good taste, rather than sweetness (sugar content) *per se*. In addition, a watery or fibrous root is never considered 'sweet', so that it is difficult to distinguish completely between taste and texture. It was observed that most sweetpotato varieties grown by farmers have medium 'sweet' to 'very sweet' taste (Table 2.3).

(iii) Root fibre content

Although ranked lower than 'sweetness', the texture of root flesh in terms of fibre content is an important criterion used by farmers in selecting sweetpotato varieties. Sweetpotato roots with no or low fibre content are preferred. The majority of sweetpotato varieties currently grown by farmers have no fibre or low fibre. It was noted from the study that for the four zones assessed, 55% of the total varieties grown were considered to have no fibre and only 15% of the total

Table 2.3 Root sweetness of commonly grown sweetpotato varieties

Zone	Number of varieties	Very sweet	Sweet	Not/slightly sweet
Eastern	4	1	2	1
Southern	3	1	2	0
Western	4	2	0	2
Southern Highlands	36	12	21	3
Central	3	0	2	1
Lake	-	-	-	-
Total	50	16	27	7
Percentage		32	54	14

Source: Compiled from FSR-NCU data file (1996).

The overall percentage has been calculated without weighting the varieties with respect to their importance in each zone, nor weighting the zones with respect to their importance for sweetpotato production.

Table 2.4 Root texture of commonly grown sweetpotato varieties

Zone	Number of varieties	Texture		
		No fibre	Low fibre	Very fibrous
Eastern	-	-	-	-
Southern	3	0	3	0
Western	12	6	4	2
Southern Highlands	35	21	8	6
Central	3	2	1	0
Lake	-	-	-	-
Total	53	29	16	8
Percentage		55	30	15

Source: Compiled from FSR-NCU data file (1996).

The overall percentage has been calculated without weighting the varieties with respect to their importance in each zone, nor weighting the zones with respect to their importance for sweetpotato production.

varieties mentioned were considered to be very fibrous (Table 2.4).

(iv) Root firmness/hardness

Firmness is an indicator of high dry matter content, which is a preferred attribute in sweetpotato roots. However, farmers indicated that most sweetpotato varieties that they grew had 'medium' to 'slightly' firm roots. Of the total varieties assessed, only 26% were considered to have very firm roots (Table 2.5).

Table 2.5 Root firmness of commonly grown sweetpotato varieties

Zone	Number of varieties	Very firm	Medium firm	Slightly firm
Eastern	-	-	-	-
Southern	2	2	0	0
Western	-	-	-	-
Southern Highlands	36	8	22	6
Central	-	-	-	-
Lake	-	-	-	-
Total	38	10	22	6
Percentage		26	58	16

Source: Compiled from FSR-NCU data file (1996).

The overall percentage has been calculated without weighting the varieties with respect to their importance in each zone, nor weighting the zones with respect to their importance for sweetpotato production.

These findings suggest that more attention should be given in the breeding scheme to selecting varieties with firm roots. The chances are high that these varieties once selected by farmers will be adopted.

(v) Outer skin colour of roots

Although not mentioned as major selection criteria, skin and flesh colour are likely to be important for uptake of new varieties. Many of the varieties (45%) grown by farmers have a purple/red outer skin colour (Table 2.6). Next was a white/yellow outer skin colour (33%) and a brown/cream colour (22%).

The predominant skin colour appeared to differ between zones, although the results may be distorted by the fact that the number of varieties recorded varied greatly between zones. In the Lake Zone, the predominant colour was purple/red (51% recorded varieties). On the other hand in the Eastern Zone most of the varieties assessed (88%) had white/yellow skins, and the same was reported by farmers in the Central and Western Zones. If, as these data indicate, preference for skin colour varies from one zone to another, this must be taken into account by breeders.

(vi) Flesh colour of roots

Two main flesh colours were mentioned by farmers: white and yellow/orange (Table 2.7). Discussions with farmers indicated that white fleshed roots are preferred because they produce good chips – *michembe* – when processed and give good quality flour. In addition, farmers perceive that white flesh in a storage root is a good indicator of high starch/dry matter content. The overall percentage of varieties mentioned with each flesh colour is given in Table 2.7. It is consistent with the hypothesis that white fleshed roots are preferred to yellow/orange ones, as 63% of the total varieties assessed have white root flesh.

In some zones, such as the Western Zone, farmers mentioned varieties with purple or blue coloured roots, which had low dry matter.

Table 2.6 Outer skin colours of roots of commonly grown sweetpotato varieties

Zone	Number of varieties	Skin colour (roots)		
		White/ yellow	Purple/ red	Brown/ cream
Eastern	8	7	1	0
Southern	3	2	1	0
Western	2	2	0	0
Southern Highlands	21	8	9	4
Central	3	2	1	0
Lake	68	14	35	19
Total	105	35	47	23
Percentage		33	45	22

Source: Compiled from FSR-NCU data file (1996).

The overall percentage has been calculated without weighting the varieties with respect to their importance in each zone, nor weighting the zones with respect to their importance for sweetpotato production. The relative numbers of varieties with each skin colour may, therefore, not be a quantitative indication of the popularity of that colour.

Table 2.7 Colour of root flesh of commonly grown sweetpotato varieties

Zone	Number of varieties	Root flesh colour	
		White	Yellow/orange
Eastern	13	7	6
Southern	3	2	1
Western	3	0	3
Southern Highlands	-	-	-
Central	-	-	-
Lake	69	47	23
Total	88	56	33
Percentage		63	38

Source: Compiled from FSR-NCU data file (1996).

The overall percentage has been calculated without weighting the varieties with respect to their importance in each zone, nor weighting the zones with respect to their importance for sweetpotato production. The relative numbers of varieties with each flesh colour may, therefore, not be a quantitative indication of the popularity of that colour.

Table 2.8 A selection of the most popular sweetpotato varieties grown by farmers in Tanzania and their desirable characteristics

Local name	Characteristics
Suguti (L)* Songea (SHL) Simama (L, E) Tulwawima (L, SHL)	White skin/yellow flesh, high yielding, semi-erect, floury, early maturing, large root size, medium sweetness, very firm/floury, no fibre
Mayai (W, E)	White skin/orange flesh, high yielding, good underground storability
Mwezigumo (W, L)	Very early maturing to bridge a famine gap between major harvests
Karoti (E, S)	Early maturing, broad leaves, spreading, red skin/yellow flesh, medium fibre content, medium sweetness, medium root size, firm, moderately drought tolerant
Sinia (SHL, L)† Kasinia (L)	Early maturing, large root size, red skin/white flesh, very sweet, very firm, no fibre
Kinahanaha (W, SHL)	Very early maturing, fibrous, good as vegetable, white flesh, sweet, firm, no fibre
Kandoro (W, SHL)	Medium maturity, large root size, white skin/white flesh, sweet, firm, not fibrous

L = Lake Zone; SHL = Southern Highlands Zone; E = Eastern Zone; W = Western Zone; S = Southern Zone.

* Officially released as Simama.
† Officially released as Sinia.

Table 2.8 lists some of the most popular varieties grown in Tanzania together with a summary of their characteristics.

2.3 The use of farmer groups and on-farm cultivar testing

2.3.1 Background

From the previous sections, it is clear that farmers select suitable sweetpotato varieties by criteria that relate both to production and post-harvest issues. The breeding programme within Tanzania has found that the best way to incorporate the opinions of farmers in the selection of new cultivars is firstly, to use farmer groups to assess early trials on-station, and secondly, to carry out on-farm trials of the more advanced cultivars. On-farm trials are found to be essential in order to take into account the effects of actual farmer practices and conditions, which may differ substantially from on-station practices.

The rationale for on-farm cultivar testing

In Tanzania, sweetpotato is grown primarily by women in a range of land use systems. Within each system, sweetpotato fields differ greatly in biophysical properties (i.e. soil type, soil fertility, etc.) and management practices (i.e. ridges, hills, intercropping, etc.). This necessitates an approach to testing which includes the environment-genotype interaction. Therefore, testing sweetpotato varieties in a wide range of conditions, with many female farmers, is needed.
The methodology of testing is based on concepts of environment-technology interactions (Hildebrand and Russell, 1994), agroecosystem diversity (de Steenhuijsen Piters, 1995), and on the 'niche theory' in biology. The main idea is that a certain technology performs according to the environment into which it is introduced. Specific production environments ('niches') favour specific technologies. A production environment is composed of several variables, such as soil type, rainfall pattern, but also crop husbandry, such as timing of weeding. Understanding the performance of a new technology needs: (i) a description of the production environments; and (ii) an understanding of their relation to the newly introduced technology.

The approach consists of the following elements.

- Testing of several varieties over a wide range of production environments, which include different rainfall patterns, soil types and farmers' practices.
- Standardization of a few cropping practices, for example, planting date, plant spacing and cropping pattern; all other conditions and husbandry practices are not controlled.
- Recording and measurement of all important non-controlled variables at each field.
- Active participation of farmers as observers capable of monitoring the trial.
- Assessment by farmer groups of the varieties' performance at harvest time. Criteria of comparison are discussed, varieties are compared pair-wise and final priority ranking is performed. Accordingly, three types of trial fields are assessed, i.e. successful, moderately successful and failure. Sweetpotato is also subjected to tasting.
- Quantification of yields.

Statistical analysis includes simple, descriptive statistics, ANOVA (analysis of variance), multiple regression and environmental index analysis.

Advantages of farmer participation in variety testing

For those criteria, such as yield, which are routinely tested on-station, farmers' assessments are in strong agreement. However, farmers consider many other criteria which are not considered on-station. This explains why some varieties may be ranked low despite their good field performance. Multiple criteria selection of varieties leads to flexible recommendations which appreciate the diverse use of varieties depending on the producers production objectives.

Involvement of farmers in the planning and implementation stages appears to hasten the process of technology testing and dissemination. The feedback flow process obtained helps researchers to target research towards demand-driven priorities.

2.3.2 Procedure for conducting on-farm assessment of sweetpotato varieties

Selection of farmers

- Organize planning meetings in different villages to select farmers to participate in the trials.
- Participation of farmers should be voluntary although a good balance of farmers in different social strata should be attained.
- The number of farmers per village should be determined by the availability of planting materials. However, for a good assessment, 8–10 farmers per village should participate in a trial.

Selection of fields

- Land for a trial is provided by the selected farmers.
- Sweetpotato fields should differ in biophysical properties (i.e. soil types, soil fertility, slope, etc.).

Note

- Farmers in different social strata should be selected.
- Do not make the common mistake of conducting the trials under optimum conditions otherwise you may end up selecting breeding clones that perform poorly under less than optimum conditions.
- Assess the overall farmers' management practices, and use this as a base for field selection. For instance, if farmers grow most of their sweetpotato on low-fertility soil, then trials should be established in such fields,

Trial establishment and management

Plot size
Minimum plot size should be 6 m x 2 m.

Number of replications
One (i.e. each farmer's field trial should be considered as one replicate).

Spacing
Plant at a spacing of 30 cm between plants and 1 m between rows. This is mainly for low fertility sandy soils. However, spacing between plants can be increased to 40 cm in fertile soils, to avoid overcrowding of plants.

Size of cuttings
20–25 cm long vines should be used.

Source of cuttings
Vines aged 1.5 to 2 months should be sourced from a nursery. Very old fields produce materials that do not establish well and harbour pests (e.g. weevils) and diseases (e.g. viruses).

Plant parts
Vine tips are recommended for good establishment and reduced pest attack. If insufficient planting material is available, the middle parts can also be used; avoid the basal parts because they harbour sweetpotato weevils.

Number of new varieties
3–5 plus a popular local variety as a check.

Planting of a trial
This is a joint activity with the farmer to ensure uniformity.

Length of trial cycle
Normally trials are harvested 5 months after planting, but this can be adjusted to suit the normal harvesting time of sweetpotato in the area concerned.

Data collection

Before planting
Record rainfall status, soil type (sandy or loamy), soil colour, soil stoniness (fine or gravel), slope (gentle or step), age of the field and previous crops.

After planting
Record the number of weedings at each farm and weeding intervals. Assess the establishment, pest and disease incidences, etc.

Assessment by farmers
Advise the farmers to observe the following during trial execution:

- establishment rate of each variety
- vigour

- ability to control weeds
- maturity time
- leaf retention
- resistance to important diseases, drought and pests.

Harvesting

Record yields.

Farmers' assessment

At harvest, two contrasting fields should be selected for assessment by all farmers (i.e. those participating in the trial and invited villagers). Selection of contrasting fields for assessment could be based on the management practices of farmers (i.e one field that received the best management and the other that received worst or less management by farmers).

Ranking of varieties is carried out in terms of foliage vigour, resistance to diseases and pests, maturity time, number, shape and size of roots, and colour of skin and root flesh. General crop appreciation is rated on a scale of increasing appreciation from 1 to 5.

Figures 2.2 and 2.3 show example data sheets to be used by farmers for this assessment.

After assessment of samples by individuals (Figure 2.2), ranking of varieties through group discussion is carried out by pair-wise comparison of each variety. Assessors should agree on which is a preferred sample over the other until all samples are compared. A sample of the ranking score sheet used by the investigator is presented in Figure 2.3. Each space corresponds to the comparison of two varieties. For example, the space marked with * is used to record the comparison between variety B and variety D. The preferred variety of these two should be recorded in that space. An example of a completed form is given in Figure 2.4.

Name of the evaluator: **Sex:**

Date: **Village:**

Attribute	Variety				
	A	B	C	D	E
Foliage coverage					
Resistance to diseases					
Resistance to pests					
Drought tolerance					
Maturity/earliness					
Yield of roots					
Shape of roots					
Size of roots					
Appearance of root skin					
Appearance of root flesh					
General crop appreciation					

Subjective score:

1 = very bad; 2 = bad; 3 = moderate; 4 = good; 5 = very good.

Note

- Scoring should be done by everyone participating in the assessment.
- The number of evaluators should be between 15 and 20 for unbiased results.
- Do not disclose the names of varieties to the evaluators until the exercise is completed. This will reduce bias in the ranking of well known popular varieties.

Figure 2.2 Sample score sheet for field assessment of sweetpotato varieties tested on-farm

Variety	Variety				
	A	**B**	**C**	**D**	**E**
A	X				
B		X			
C			X		
D		*		X	
E					X
Total scores per variety					
Rank					

Reasons for high ranked varieties

Reasons for less ranked varieties

Figure 2.3 **Sample ranking sheet of varieties for field performance compared pair-wise**

Variety	Variety				
	A	**B**	**C**	**D**	**E**
A	X				
B	B	X			
C	A	B	X		
D	D	D	D	X	
E	A	B	C	D	X
Total scores per variety	2	3	1	4	0
Rank	3	2	4	1	5

Reasons for high ranked varieties
D has high yield and low susceptibility to weevils

Reasons for less ranked varieties
E has low yield and is late maturing

A typical set of results has been included for illustration.

Figure 2.4 **Completed sample ranking sheet of varieties for field performance compared pair-wise**

Example of results

Table 2.9 Farmers' field assessment of sweetpotato varieties in Mwagala village, Missungwi District, Lake Zone of Tanzania

	Attribute (N = 25)									
Variety	Earliness	CV (%)	Root storability	CV (%)	Root size	CV (%)	Root shape	CV (%)	General impression	CV (%)
440144	3.3	24.9	3.7	13.0	3.6	14.3	4.4	11.7	4.3	15.7
SP93/5	3.9	22.5	3.9	25.5	4.3	19.1	3.8	29.9	4.3	15.6
S993/13	2.3	41.2	3.1	35.5	2.8	32.8	3.5	30.9	2.9	30.2
Mwananjemu	2.9	41.3	3.6	29.8	3.3	20.5	3.7	25.6	4.0	20.4
Polista	3.9	14.6	3.6	19.4	3.8	11.1	3.6	14.3	4.2	15.1
Kagole	3.8	27.2	4.4	15.9	4.2	18.8	4.2	18.8	4.6	15.2
Bagalanentukuru	3.2	24.6	3.4	28.4	3.5	24.3	3.6	19.4	3.7	18.2

Subjective ranking: 1 = very poor; 2 = poor; 3 = moderate; 4 = good; 5 = very good.

Note: Higher values of CVs indicate wide variability in farmers perception. N = number of farmers who participated in the assessment.

Table 2.10 Assessment of sweetpotato varieties by farmers for suitability in diverse production systems and objectives at farm-level in Bukoba District, Lake Zone of Tanzania (1995/96 – 1996/97)

Do you...?	Then grow...!	But do not grow...!
Have a sandy field with low soil fertility	Sinia-B*, SPN/0*	Iboja, Mwanamonde, Biganana
Want a high yield	SPN/0*, Sinia-B *, Iboja	Biganana
Want to harvest piecemeal	Mwanamonde, Sinia-B*, Iboja, Biganana	SPN/0*
Have problems with weevils in your field	Biganana, Iboja, Sinia-B*	SPN/0 *, Mwanamonde
Want vines for livestock	Biganana, Sinia-B*	Iboja
Want to process	Biganana, Iboja, Sinia-B*	SPN/O*
Want leaves for a vegetable	Biganana, SPN/O*	Iboja
Want roots for selling	Sinia-B*, SPN/0*	Iboja

* Varieties released in 1999.

Data analysis

Use social statistical programs, such as SPSS, ABSTAT and GENSTAT, to analyse the information collected on the farmers' assessment.

Table 2.9 shows a summary of data obtained from a set of on-farm assessments conducted in the Lake Zone, while Table 2.10 shows how results can be used to provide a set of recommendations on suitable varieties for farmers.

2.3.3 Procedure for conducting taste tests

Simple taste tests are conducted at harvest for both on-farm and on-station trials. The samples for taste testing are taken from selected roots of each variety. A panel of tasters, consisting of at least 10 farmers and invited neighbours, is selected. It is important that the name of each taster be recorded on the data sheets. Roots should be cooked and cut into slices. They should be presented to the tasters labelled only with letters, for example, A–E. Characteristics normally assessed through this method include: appearance, taste, starchiness and fibre content of cooked roots. (Quantitative measurements of a larger set of characteristics by the use of trained panellists is explained in Chapter 4.) Two example assessment forms are presented in Figures 2.5 and 2.6. The first allows scoring of five samples, while the second format requires one form per sample.

Name of the evaluator: **Sex:**

Date: **Village:**

Attribute	Variety				
	A	B	C	D	E
Appearance					
Taste					
Flavour					
Starchiness					
Fibre content					
General acceptability					

Subjective ranking:

1 = very good; 2 = good; 3 = moderate; 4 = good; 5 = very good.

Figure 2.5 Sample score sheet for post-harvest assessment of sweetpotato cooked roots

Sweetpotato Taste Testing

Name of evaluator:_____ **Age:**_____ **years**

Date:_____ **Cultivar:**_____ **Sex: Male / Female**

Attribute	 1=Very bad	 2=Bad	 3=Fair	 4=Good	 5=Very good
Appearance					
Colour					
Colour intensity					
Colour uniformity					
Discoloration					
Flavour					
Sweetness					
Texture					
Moistness					
Fibre (free)					
Overall taste acceptability					

Figure 2.6 Detailed taste test evaluation sheet for consumers

2.4 Conclusions and implications

Poor uptake of some new varieties in the past has underlined the importance of incorporating the preferences of growers and consumers into the breeding process. This chapter describes surveys conducted in Tanzania to determine the farmer criteria for preferred sweetpotato varieties. The opinions of farmers on available varieties indicate that there is considerable room for improvement.

Thus, on-station assessment of varieties by farmers and on-farm testing are both central to the Tanzanian sweetpotato breeding programme.

References

FSR-NCU data file (1996) Farmers Preference of Crop Varieties and their Selection Criteria. (Draft). Farming Systems Research. Dar es Salaam: National Co-ordination Unit, Ministry of Agriculture. (unpublished)

HART, D.T. (1991) *Sweetpotato Production in Maswa and Meatu Districts: An On-farm Study*. Mwanza-Bukoba: Tanzania/Netherlands Farming Systems Research Project, Lake Zone.

HILDEBRAND, P.E. and RUSSELL, J.T. (1994) Adaptability Analysis for Diverse Environments. Paper presented at the *American Society of Agronomy Meeting, Seattle, Washington.*

KAPINGA, R.E. (1992) *Root and Tuber Crops and Their Constraints in Bukoba District. Field Note*, No. 24. Mwanza-Bukoba: Tanzania/Netherlands Farming Systems Research Project, Lake Zone.

KAPINGA, R.E., EWELL, P.T., JEREMIAH, S.C. and KILEO, R. (1995) *Sweetpotato in Tanzanian Farming and Food Systems: Implications for Research*. Dar es Salaam: International Potato Center and Ministry of Agriculture.

STEENHUIJSEN PITERS, B. DE (1995) *Diversity of Fields and Farmers; Explaining Yield Variations in Northern Cameroon*. PhD thesis, Wageningen Agricultural University, Netherlands.

CHAPTER 3

Trader and consumer criteria for selection of sweetpotato varieties

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3.1 Background

Up until the late 1990s, although information existed on the criteria by which farmers select sweetpotato varieties (see Chapter 2), very little information existed in Tanzania on the preferences of consumers (especially urban consumers) and traders. With the increasing marketing of this crop, an appreciation of the views of urban users becomes more important for breeders. In Tanzania, sweetpotato roots are primarily used for human food, and mainly consumed freshly cooked. However, processing and the use of sweetpotato for animal food are also common. Information on how roots are to be consumed is clearly vital when determining important quality criteria.

In this chapter, we describe the methods by which the Tanzanian breeding programme obtained the information necessary to determine the main selection criteria for new cultivars, and summarize the main results obtained.

Further details of the surveys and their results can be found in Kapinga *et al.* (1997).

3.2 Methods

3.2.1 Areas surveyed and selection of interviewees

Surveys were conducted between September and October 1996 in three districts of the Lake Zone of Tanzania (Meatu, Mwanza and Ukerewe). A list of the urban areas surveyed and the number of respondents per district is presented in Table 3.1. Only areas where sweetpotato was considered an important commodity were selected. The selection criteria for the areas surveyed were as follows:

- the importance of sweetpotato relative to other food staples
- the contribution of sweetpotato to household food security and household income
- the growing demand of sweetpotato for sustaining household earnings through the sale of roots
- the availability of fresh roots and processed sweetpotato products in the markets
- the level of diversification of sweetpotato utilization.

Within the chosen areas, a total of 35 market agents and 58 urban households were interviewed.

Households were selected on the advice of local leaders and extension workers. Only households known to consume sweetpotato were interviewed. Information about the size and income group of households is given in Table 3.1. Income group was assessed on the basis of the appearance and contents of the house. For example, a household with a 'good-

Table 3.1 Urban households interviewed in Mwanza, Meatu and Ukerewe Districts of Lake Zone of Tanzania, categorized by size of household and income group*

	Number of households interviewed in each income group		
Size of household	**Low**	**Medium**	**High**
Mwanza			
Areas	Igogo, Nyegezi, Mkuyuni		
2–3	1	1	
4–5	1	3	
6–8	4	1	
9–14	2	5	
>14			
TOTAL	**8**	**10**	
Meatu			
Areas	Mwanhuzi town		
2–3	3		
4–5	7	1	
6–8	3	2	
9–14	2	1	
>14	1		
TOTAL	**16**	**4**	
Ukerewe			
Areas	Nakatunguru		
1	1		
2–3	4		1
4–5	2	2	
6–8	3	3	
9–14	3	1	
>14			
TOTAL	**13**	**6**	**1**
	Total number of households interviewed in each income group		
	37	20	1

* Income groups were assessed subjectively by observation of the house and contents.

looking' house and electronic assets was considered to be high income.

Traders were classified as retailers or wholesalers, with some undertaking both functions. The numbers of traders interviewed and the markets at which they worked in each area is given in Table 3.2. The markets were categorized subjectively as small, medium and large (Table 3.2).

3.2.2 Data collection

The interviews were conducted using a set of questions which were adapted from a related study on cassava carried out in urban areas by the Collaborative Study of Cassava in Africa (COSCA) (Nweke *et al.*, 1998).

During the surveys, the information collected was considered under two categories: urban households (consumers) and market agents (traders). The main issues covered during interviews were as follows.

Urban households

- Sweetpotato consumption patterns.
- The quantity and frequency of purchase of sweetpotato.
- Acceptance and rejection of specific sweetpotato varieties.
- Utilization practices for sweetpotato roots.
- Post-harvest handling of sweetpotato.
- Sweetpotato cultivation and the varieties commonly grown.
- Sweetpotato marketing.

Market agents

- The nature of markets and categories of traders.
- Marketing of sweetpotato.
- Storage after purchase.
- Varietal preferences.

Checklists used for sweetpotato consumers in urban areas and for market agents are shown below (see Figures 3.1 and 3.2).

Table 3.2 Urban markets visited and sweetpotato traders interviewed in Lake Zone of Tanzania

Market / District	Market size	Number of traders interviewed by category		
		Retailers	Wholesalers	Retailer/wholesalers
Mwanza				
Mwaloni	Big			1
Kirumba	Big		1	2
Mwaloni/Kirumba*		1	1	
Songoro	Small	4		
Central	Big	4		
Kirumba Sokoni	Medium	2		
TOTAL		**11**	**2**	**3**
Meatu				
Bukundi Permanent	Medium	4		
Market day only	Non-permanent	2	2	3
TOTAL		**6**	**2**	**3**
Ukerewe				
Nakatunguri	Small	4		
Nansio	Medium	4		
TOTAL		**8**		

Market size was a subjective assessment by the interviewers.

* Retailer and wholesaler working in both markets.

Checklist For Semi-Structured Interview (consumers)

Background information

The following information should be noted by the interviewer, but not necessarily asked directly.

1. Location of house
2. Income group
3. Ethnic origin

Interview

4. How often does your family eat sweetpotato, e.g. number of times per week?
5. How many people are there in your household?
6. How much do you spend on buying sweetpotatoes per week? Fresh? Processed?

7a. (i) Which sweetpotato varieties do you prefer to buy, and what are the reasons? If the variety name is not known, go to 7b.

Varieties	Good characteristics

7a.(ii) Are there any sweetpotato varieties that you avoid buying, and what are the reasons?

Varieties	Reasons for avoiding

7b.What characteristics do you like in a sweetpotato? Can you rank these in order of importance.

Preferred characteristics	Ranking

8. (i) Do you grow sweetpotatoes?
(ii)If yes, which varieties and for what reason?

Name or description of varieties	Reasons for preference

Figure 3.1 A sample of a checklist for data collection on the preference for sweetpotato varieties by urban consumers

9. (i) Do you store sweetpotato roots after purchase?
   (ii) If no:
   Are there reasons why you do not store?
   iii) If yes: where?
   (iv) For how long?
   (v) Do you find that some varieties store better than others, and which?
   (vi) What type of damage (quality losses) do you experience, if any?
   (vii) What control measures do you use?

10. By what methods do you cook your sweetpotatoes for eating?

    Do you find that some varieties are better for certain preparation methods than others?

Method of preparation	Best varieties (Describe if name unknown)

11. (i) Do you use processed sweetpotato roots?
    (ii) If yes, which products?
    (iii) Do you buy the processed products, or process them yourself?
    (iv) If you process yourself, which varieties do you prefer to process, and why?

12. (i) Do you sell processed products?
    (ii) If yes, who do you sell them to?
    (iii) How much do you sell?
    (iv) What are the prices?/throughout the year?

13. (i) Do you store processed products?
    (ii) If yes, where?
    (iii) For how long?
    (iv) Do you find that some varieties store better than others, which?
    (v) What type of damage (quality losses) do you experience, if any?
    (vi) What control measures do you use?

Figure 3.1 ***cont.***

Checklist For Semi-Structured Interview (traders)

Background information

The following information should be noted by the interviewer, but not necessarily asked directly.

1. Location of market
2. Size of market
3. What type of trader (i.e. itinerant, wholesaler, or retailer)?

Interview

4. Do you trade in any crops other than sweetpotato? If so, what proportion of your trade is in sweetpotato?
5. How much do you sell per week/ month/ year?
6. Where do you obtain most of your sweetpotatoes? Name the towns and villages in order of importance.

Village or town	District/region	Distance from here

7. What type of customers buy sweetpotatoes?

Preferred characteristics and varieties

8a.(i) Which varieties do you like to sell and why?

If the variety names are not known, go to 8b.

Note: These characteristics may include both the characteristics preferred by consumers (texture, colour, price), and also any characteristics that make that variety good for trade (storability)

Varieties	Good characteristics

8a.(ii) Which varieties do you not like to sell, and why?

Varieties	Reasons for avoiding

8b. What characteristics do you like in a sweetpotato? Can you rank these in order of importance.

Preferred characteristics	Ranking

Figure 3.2 A sample of a checklist for data collection on the preferences for sweetpotato varieties by traders

9. What are the prices?/throughout the year?
   Does this differ by variety?

10. (i) Do you store sweetpotato roots at the place of sale?
    (ii) If no, are there reasons why you do not store?
    (iii) If yes, where?
    (iv) For how long?
    (v) What type of damage (quality losses) do you experience, if any?
    (vi) What effect does this have on the sale price?
    (vii) Do you find that some varieties store better than others, and which?
    (viii) What control measures do you use?
    (ix) What do you do with the roots that have deteriorated?

11. (i) Do you sell processed sweetpotato products?
    (ii) If yes, which products?
    (iii) How much do you sell?

12. (i) What type of customer buys processed products?
    (ii) What qualities are sought for good processed products?

Product	Desired qualities

    (iii) Do you buy the processed products, or process them yourself?
    (iv) If you process yourself, are there some varieties which you prefer to process, and if so, which ones?
    (v) What are the prices?/throughout the year?
    Do these vary by variety?

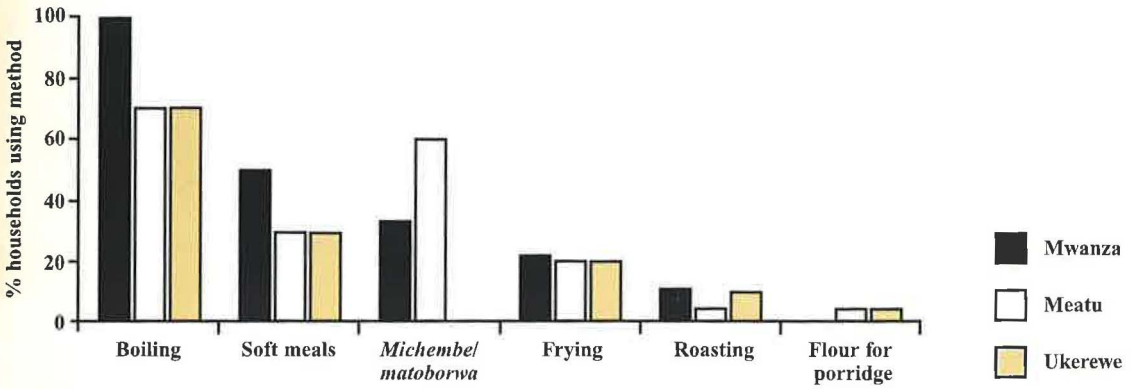
13. (i) Do you store processed products?
    (ii) If yes, where?
    (iii) For how long?
    (iv) What type of damage (quality losses) do you experience, if any?
    (v) Do you find that some varieties store better than others, which?
    (vi) What control measures do you use?

Figure 3.2 ***cont.***

3.3 Results and discussion

3.3.1 Selection for suitability for local processing methods

Figure 3.3 and Table 3.3 respectively, show different methods of using fresh sweetpotato roots and the varieties identified as suitable for different purposes by consumers in the urban areas of the Lake Zone of Tanzania.



Eighteen households were interviewed in Mwanza and 20 in each of Meatu and Ukerewe. Boiling refers to cooking of whole roots. For soft meals, sweetpotato is mixed with beans and nuts (to make a 'stew'). *Michembe* and *matoborwa* are dried products which are either prepared within the household or purchased ready processed.

Figure 3.3 The methods by which sweetpotato is prepared for eating by urban consumers in Lake Zone of Tanzania, and the percentage of households using each method

Table 3.3 Sweetpotato varieties considered most suitable for each preparation method in Lake Zone of Tanzania

Mwanza ($N = 11$)	Number of households preferring variety	Meatu ($N = 20$)	Number of households preferring variety	Ukerewe ($N = 20$)	Number of households preferring variety
Boiling		**Boiling**		**Boiling**	
Sinia	7	Kaputula	1	All	19
Simama/Suguti (SPN/O)	6	Nyerere	1	Mzondwa	1
Mzondwa	2	Serena	1		
Kasamwa	2	No difference	10		
Polista	1				
Mixing with other dishes		**Mixing with other dishes**		**Mixing with other dishes**	
Mzondwa	1	Serena	1	Mzondwa	1
Kasamwa	2	Kibluu	1		
Sinia	3	Ngoshaatena nimo	2		
Simama/Suguti (SPN/O)	3	Ntulawima	1		
Roasting		**Roasting**		**Roasting**	
Mzondwa	1	Serena	1	Mzondwa	1
Lutambi	1	Nzegamatolo	1		
Simama/Suguti (SPN/O)	1				
Sinia	1				
Frying		**Frying**		**Frying**	
Simama/Suguti (SPN/0)?	2	Matungangoso	1	Mzondwa	1
Sinia	2	Koroboi	1		

Note: Varieties suitable for processing into *michembe* and *mataborwa* are discussed in a later section (see Chapter 9). This is because when buying these products it is not easy to distinguish between varieties and generally only households that carry out processing are aware of which varieties are used.

Selection of improved varieties suitable for indigenous processing methods, particularly slicing and sun-drying to produce reconstitutable foods, should be an essential component of variety development programmes in areas where processing is important, but at present little is known about selection criteria (Kapinga *et al.*, 1995; Agona, 1998). We assume that an important selection criterion for varieties used to make dried products is high root dry matter content, as this results in a product that dries more rapidly.

Additionally selection for low oxidation would lead to a product with an attractive appearance. However, clear definition of selection criteria for indigenous processing requires a strong component of farmer participation. Attention should be given to quality factors likely to be important in the production of flour as a commercial product made from sun-dried chips. (See Chapter 9 for more discussion on processing of sweetpotato.)

3.3.2 Selection criteria of sweetpotato varieties as identified by urban consumers

Results obtained on urban consumer varietal criteria are presented in Tables 3.4 and 3.5. Table 3.4 indicates the preferred varieties and their characteristics, while Table 3.5 indicates preferred root characteristics and their ranking. The order of these tables indicates the order in which the questions were asked during the interviews. Thus interviewees were given the opportunity to think about what they liked about varieties before having to rank characteristics most important to them. The data indicate that two criteria, 'starch/floury' and 'tasty/sweet', are particularly important to consumers in all three regions. Good cooking quality and good flesh colour are also considered. Good storability was mentioned in Mwanza and Ukerewe, but not Meatu. This may be because Meatu is the only one of the three areas where processing is important. Thus (although not indicated here), this is the only area where interviewees considered good processing quality an important attribute for varietal selection.

Table 3.4 Sweetpotato varieties most preferred for buying by urban consumers and the main criteria considered

District	Variety	Frequency (number of households mentioning variety)	Preferred characteristics (number of households)				
			Starchy/ floury	Tasty/ sweet*	Good cooking qualities†	Good root flesh colour‡	Good storability
Mwanza ($N = 18$)	Sinia	10	9	8	2	3	5
	Suguti	6	4	4	-	6	-
	Simama	4	4	3	-	2	2
	Chilile	2	1	-	1	1	-
	Mzondwa	2	1	2	-	-	-
	Polista	1	1	1	-		-
	Other varieties mentioned (with frequency) were: Juliasi (1), Nyamwisekeleja (1), Kiliona (1), Rangimbili (1), Tulabagenyi (1), Nyantaya (1), Lutambi (1), Mwiyangi (1), Kasamwa (1), Kinaje (1), Malya (1)						
Meatu ($N = 20$)	Sinia	5	4	4	-	-	-
	Kibuluu	4	2	3	-	3	-
	Serena	3	1	1	2	-	-
	Ngoshaga-gaga	3	3	1	-	-	-
	Tulwawima	2	2	2	-	1	-
	Suguti	1	1	1	-	-	-
	Other varieties mentioned (with frequency) were: Nzegamatolo (2), Ipembelyangholongo (2), Sengi (1), Ngoshaalaja (1), Ukerewe (Nyekundu) (1), Kenya (1), Sinia la Nyerere (1), Ndoleleji (1), Ngosha atenanemo (1), Polista (1), Koroboi (1), Mwijigumo (1)						
Ukerewe ($N = 20$)	Mzondwa	14	9	11	-	2	3
	Bilagala	8	3	7	5	-	-
	Chilile	7	5	7	4	3	3
	Sinia	5	2	4	1	1	1
	Lutambi	5	-	4	-	3	-
	Mwiyangi	4	1	-	-	1	-
	Other varieties mentioned (with frequency) were: Balozi (1), Sinia (mpya) (1), Malya (1)						

* Sweet refers to good taste rather than amount of sugar, preferred taste is usually described as neither bland nor very sugary.

† Good cooking qualities means soft when cooked, with a short cooking time.

‡ Good root flesh colour is generally considered to be yellow or white.

Table 3.5 Sweetpotato storage root characteristics preferred by urban consumers and their ranking in Lake Zone of Tanzania

Characteristic	Number of households mentioning characteristic				Mean household ranking *			
	Mwanza (*N* = 15)	Meatu (*N* = 20)	Ukerewe (*N* = 20)	Total (*N* = 55)	Mwanza (*N* = 15)	Meatu (*N* = 20)	Ukerewe (*N* = 20)	Overall†
Starchy/floury	15	10	12	37	1.4	1.4	1.6	1.5
Good taste	15	8	19	42	1.9	1.8	1.9	1.9
Good cooking qualities/less time to cook and soft when cooked	5	4	6	15	3.0	3.5	1.6	2.7
Non/less fibrous	1	2	4	7	4.0	2.8	2.0	2.9
Good storability	–	1	3	4	–	3.0	3.0	3.0
Good root appearance (shape, size and colour)	3	1	4	8	4.2	4.0	4.1	4.1

– = not mentioned.
* Calculated as the mean of the rankings (1 and upwards) given by individual interviewees.
† Calculated as an unweighted mean of the values for the three districts.

Unacceptable sweetpotato varieties and criteria for rejection as identified by urban consumers are presented in Table 3.6.

Table 3.6 Sweetpotato varieties considered unacceptable for buying by urban consumers and main criteria considered in Lake Zone of Tanzania

District	Variety	Frequency (number of households mentioning variety)	Bad characteristics (number of households)				
			Watery	Not tasty	Fibrous	Hard to cook	Unattractive root appearance
Mwanza (*N* = 18)	Mwejigumo	3	3	3	–	–	–
	Mzondwa	3	–	–	1	–	2
	Mwiyangi	2	–	–	–	2	–
	Dagaa	1	–	1	–	–	–
	Julius	1	–	–	–	1	–
	Bilagala	1	1	1	–	–	–
	Mayai	1	1	–	–	–	–
Meatu (*N* = 20)	I'lyangholongo	2	2	1	–	–	–
	Nzega matolo	1	–	1	–	–	–
	Serena	1	1	–	–	–	–
	Dundugala	1	–	1	–	–	–
	N'goshagagaga	1	1	1	–	–	–
	Pili	1	1	–	–	–	–
	Matungagoso	1	–	1	–	–	–
Ukerewe (*N* = 20)	Mwiyangi	9	–	8	–	4	–
	Mzondwa	5	–	2	–	–	–
	Sinia	2	1	1	–	–	–
	Mlenga	1	–	–	–	–	–
	Julius	1	–	–	–	1	–
	Bilaila	1	–	–	–	1	–
	Chigole	1	–	–	1	–	–
	Beritha	1	–	–	1	–	–

3.3.3 Selection criteria of sweetpotato varieties as identified by sweetpotato traders

The most important information obtained from traders is summarized in Tables 3.7, 3.8 and 3.9. Table 3.7 shows the sweetpotato varieties preferred for selling at different market locations. For Mwanza market, the variety Polista was most frequently mentioned followed by Sinia. Traders noted that the variety Simama/Suguti was preferred by consumers. However, traders indicated that this variety provided a problem in that it does not keep beyond a week, particularly if heavily damaged during transportation.

As for the survey of consumers, traders were asked to rank the characteristics of fresh roots according to their perception of the characteristics considered important by their customers. The ranking gave a similar trend to the characteristics mentioned by consumers. Thus high flour/starch content ranked first, followed by good/appealing root taste and attractive skin colour/root appearance. Varieties rejected and criteria considered by traders are presented in Table 3.9.

Table 3.7 Sweetpotato varieties most preferred for selling by traders in Lake Zone of Tanzania and the main criteria considered

District	Variety	Frequency (number of traders mentioning variety)	Preferred characteristics (number of traders)									
			Starchy/ floury	Good taste	Good skin and flesh colour	Good storability	Good processing quality	Good cooking quality	High yield*	Good root shape and size	Easily marketed	Pest resistant*
Mwanza ($N = 16$)	Polista	16	13	7	11	3	-	-	-	1	-	
	Sinia	13	10	1	4	2	-	-	-	2	-	
	Malya	6	3	4	4	-	-	-	-	-	-	
	Simama/Sugutu	4	4	1	3	-	-	-	-	1	-	
	Chilile	3	2	-	-	-	-	-	-	-	-	
	Mzondwa	2	1	1	-	1	-	-	1	-	-	
	Balozi	1	-	-	1	-	-	-	-	-	-	
Meatu ($N = 11$)	Sinia†	7										
	Nzega/Nzega matolo	6	5	4	2	-	-		-	-	1	-
	Kabululu/Kisasa†	5										
	Suguti/Simama†	3										
	Ipembelyangholongo	2	1	1	1	-	1	1	1	1	-	-
	Mbiti	2	-	-	-	-	-	-	-	1	-	-
	Siri	2	-	-	-	-	-	-	-	-	-	1
	Kagole	1	1	-	-	-	-	-	-	-	-	-
	Nihambagesengi	1	1	1	-	-	-	-	-	-	-	-
	Serena	1	-	-	-	1	-	1	-	-	-	-
	Ngolo	1	1	1	-	-	-	-	-	-	-	-
	Misonge	1	-	1	-	-	-	-	-	-	1	-
Ukerewe ($N = 8$)	Mzondwa	7	5	6	-	1	-	1	1	-	-	1
	Chilile	7	4	6	3	-	1	1	1	-	-	2
	Lutambi	1	1	1	-	-	-	-	-	-	-	-
	Bilagala	1	-	1	-	-	-	-	-	-	-	-
	Sinia	1	-	1	-	-	-	-	-	-	-	-

* These attributes were indicated by traders who also grew sweetpotatoes for marketing.
† Data on preferred characteristics missing for these varieties.

Table 3.8 Traders' perception and ranking of good sweetpotato root characteristics in Lake Zone of Tanzania

Root characteristic	Number of traders mentioning characteristic				Mean ranking given by traders *			
	Mwanza (*N* = 16)	Meatu (*N* = 11)	Ukerewe (*N* = 8)	Total (*N* = 35)	Mwanza (*N* = 16)	Meatu (*N* = 11)	Ukerewe (*N* = 8)	Overall† (*N* = 35)
Starchy/floury/ high dry matter content	11	5	5	21	1.1	1.0	1.8	1.3
Good taste	7	4	7	18	2.0	2.2	1.4	1.8
Attractive skin and flesh colour	7	5	3	15	1.7	1.7	2.0	1.8
Large size	5	0	1	6	2.8	-	2.0	2.4
Low/no fibre content	0	0	2	2	-	-	2.6	2.6
Good root shape	2	1	2	5	3.0	3.0	2.5	2.8
Good cooking qualities‡	0	1	1	2	-	3.0	3.0	3.0
Tolerant to bruises and rotting	1	1	1	3	3.0	4.0	4.0	3.7

- = not mentioned.
* Calculated as the mean of the rankings (1 and upwards) given by individual interviewees.
† Calculated as an unweighted mean of the values for the three districts.
‡ Less time to cook and soft when cooked.

3.4 Conclusions and implications

Until recently, although information was collected on the criteria by which farmers select sweetpotato varieties, very little information existed in Tanzania on the preferences of consumers (especially urban consumers) and traders. The methodology used by the Tanzanian national programme to obtain this information in the Lake Zone was presented in this chapter. Thus it was determined that the most common form in which sweetpotatoes are eaten is as boiled whole roots. The characteristics that consumers prefer are firstly, that roots be starchy/floury (high dry matter), secondly, that they have good taste, followed by good cooking quality, low fibre, good storability and good appearance. The criteria used by traders fit closely to those of the consumers, except that appearance is more important, ranking equally with good taste.

The methods described here could be used by national programmes in other countries, although it is important to adapt the questions asked to take account of the most common form in which the sweetpotatoes are eaten.

References

AGONA, A. (1998) *Studies on Aspects of the Biology and Control of Araecerius fasciculatus [De Geer (Coleoptera: Anthribidae)] on dried sweetpotato*. PhD thesis, University of Harare, Zimbabwe.

KAPINGA, R.E., EWELL, P.T. and JEREMIAH, S.C. (1995) *Sweet Potato in Tanzanian Farming and Food Systems: Implications for Research*. Nairobi: International Potato Center and Ministry of Agriculture, Tanzania.

KAPINGA, R.E., JEREMIAH, S.C., RWIZA, E.J. and REES, D. (1997) Preferences and Selection Criteria of Sweetpotato in Urban Areas of the Lake Zone of Tanzania. Chatham, UK: Natural Resources Institute. (unpublished)

NWEKE, F.I., KAPINGA, R.E., DIXON, A.G.O., UGGWU, B.O., AJOBO, O. and ASADU, C.I.A. (1998) *Production Prospects for Cassava in Tanzania*. Collaborative Study of Cassava in Africa (COSCA). Ukiriguru, Mwanza: Agricultural Research Station (ARI)/Ibadan: Resource and Crop Management Division, International Institute of Tropical Agriculture.

Table 3.9 Sweetpotato varieties rejected for selling by traders and main criteria considered in Lake Zone of Tanzania

District	Variety	Frequency (number of traders mentioning variety)	Disliked characteristics (number of traders)										
			Not starchy	Watery	Bad taste	Bad storability	Fibrous	Poor skin and flesh colour	Poor cooking quality	Not easily marketed	Late maturing*	Requires high rainfall*	Low yielding*
Mwanza ($N = 16$)	Mzondwa	9	2	5	2	3	1	3	2	2	-	-	-
	Bilagala	9	1	3	1	2	-	2	3	-	-	-	-
	Nzito	1	-	-	-	-	1	-	1	-	-	-	-
	Chilile	4	-	3	-	-	-	1	-	1	-	-	-
	Mwejigumo	1	-	-	1	-	1	-	-	-	-	-	-
	Malya	1	-	-	-	1	-	-	-	-	-	-	-
Meatu ($N = 11$)	Siri	3	-	2	-	-	-	-	-	-	-	-	-
	Mobili	1	1	2	1	-	-	-	-	1	-	-	-
	Ngosha	2	-	-	-	-	-	-	-	-	-	-	-
	Kaptula	1	-	-	-	-	-	-	-	-	1	-	1
	Maselena	2	-	-	-	-	1	-	-	-	-	1	-
	Mapembe	1	-	1	-	-	-	-	-	-	-	-	-
	Ntulawima	1	-	-	-	-	-	-	-	-	-	-	1
	Blanketi	1	-	-	-	-	-	-	-	-	1	1	-
	Serena	1	1	-	-	-	1	-	-	-	-	-	-
Ukerewe ($N = 8$)	Mwiyangi	2	-	-	-	1	-	-	-	-	-	-	-
	Mzondwa	2	-	-	-	-	-	1	-	-	-	-	-

* These attributes were indicated by traders who also grew sweetpotatoes for marketing.

CHAPTER 4

The use of consumer tests and trained taste panels to assess sensory characteristics

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4.1 Background

Many of the sensory criteria of sweetpotato cultivars identified by consumers and traders (see Chapter 3) are complex. 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.

The Tanzanian National Root and Tuber Crops Programme (TNRTCP) and NRI have been investigating 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 was asked to assess cooked sweetpotato samples for a range of pre-chosen characteristics as objectively as possible. The procedure depends upon the identification of 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 suggest that there is a degree of consistency (see section 4.3.3).

Thus the procedure would have the following stages.

1. Identification of 'ideal' sensory profile.
   - Use consumer tests to identify the most preferred cultivars for any region.
   - Use a trained taste panel to produce a sensory profile for the preferred cultivars.
2. Assessment of new cultivars.
   - Use a trained taste panel to produce a sensory profile for promising new cultivars and compare these with the 'ideal' profile.

This chapter describes a study carried out in the Lake Zone of Tanzania in 1998 to test these methods. Further information on the work presented here can be obtained from Tomlins (1998), Kapinga *et al.* (1998) and Rwiza *et al.* (2000). Further work was conducted in subsequent years but is not presented here. Information on this can be obtained by contacting D. Rees, K.I. Tomlins or T. Ndengello (see page vi). Effects of storage on sweetpotato sensory characteristics are described in van Oirschot *et al.* (2002).

4.2 Methods

4.2.1 Ranking consumer acceptability of locally available varieties

Consumer tests were conducted in three districts of the Lake Zone of Tanzania: Mwanza, Meatu and Misungwi. In each district, 5–6 locally available varieties were selected. Roots of these varieties were obtained and cooked using a standardized method, which as much as possible simulated the most common cooking method of the region. Consumers were then presented with samples of cooked roots (in random order) to examine and eat, ranking them in order of preference. Each sample was labelled with a three-digit random number so that the consumers did not know which varieties they were testing. In order to get an accurate picture of consumer preferences, tests were carried out using 100 consumers in each district. Additional socio-economic information was obtained on sweetpotato consumption using a questionnaire.

Further details of the testing method and analysis of results are given below.

Methods Used for Consumer Testing

Sweetpotato sample preparation

The objective was to prepare and cook samples by a standard method, which accurately reflected the preparation method usually used in the country. In this case, roots were peeled and cut into roughly equal sized portions (3–5 cm). They were placed in plastic bags in which holes had been made, and boiled until the texture, assessed by a fork, was considered right for eating.

Sample presentation to consumers

A full set of samples was presented to each consumer. The sample order was randomized and each sample coded with a random three-digit number. Figure 4.1 is an example of the random numbers and random order used, where the consumers were presented with five cultivars (e.g. as in Mwanza). **Note:** Where using random numbers in this way, it is important to keep careful and clear records relating the number to the actual sample.

Cultivar ranking and additional information from consumers

Each consumer interviewed was invited to assess the samples and rank them in order of preference. This was recorded on a report sheet as shown in Figure 4.2. (In this case six cultivars were assessed by 100 consumers.)

An interview was then carried out to gain an insight into the factors which affected their preference and purchasing decisions.

The information collected included the following:

- age category (10–19, 20–29, 30–39, 40–49, 50–60, over 60)
- gender category (male, female)
- which sample was the most preferred and why
- which sample was the most disliked and why
- how much would they be prepared to pay for the most preferred sample
- how often do they consume the product (never, once a year, once a month, once a week, every day)
- the ingredients usually included in the product that they eat
- where do they consume the product
- who purchases the ingredients
- who prepares it
- do they consume other sweetpotato products
- how much do they spend on food each month
- what is the monthly income.

Note: When carrying out such interviews, questions asked by the interviewer must be easy to understand with minimal possibility of misinterpretation. Questions must be clear and easily understood by the consumer. Open-ended questions should be avoided but the facility for recording spontaneous comments should be retained.

Equipment required for consumer testing

- Cookers and utensils for the preparation of sweetpotato samples.
- Cutlery.
- Table and cloth for sample preparation.
- Plates or bowls for presentation of samples. These preferably should be white in colour and plain in design.
- Score sheets.
- Temporary shelter (only required if a sheltered location for central location tests cannot be identified). Two temporary shelters might be required (consumer interview and product preparation).

Consumer	1st sample	Code	2nd sample	Code	3rd sample	Code	4th sample	Code	5th sample	Code
1	A	527	B	796	C	630	D	567	E	680
2	B	715	C	779	D	591	A	048	E	362
3	D	694	E	659	B	165	C	674	A	196
4	E	890	A	684	D	856	C	765	B	072
5	C	228	E	458	D	097	B	301	A	385
6	A	003	D	094	C	701	E	294	B	827
7	B	786	C	050	D	473	A	638	E	243
8	B	699	C	777	E	926	D	138	A	543
9	D	089	C	278	A	639	B	052	E	925
10	C	536	D	255	A	098	B	673	E	150

Where: A, B, C, D and E are sweetpotato cultivars.

Figure 4.1 Sample randomization and codes used for sample labelling for 10 consumers and five sweetpotato cultivars

Consumer testing score sheet Date_____

Name	Rank						
	No.	Cultivar A	Cultivar B	Cultivar C	Cultivar D	Cultivar E	Cultivar F
	1	1	2	6	3	4	5
	2	6	1	2	4	5	3
	3	4	1	2	6	5	3
	4	6	1	2	3	4	5
	5	1	2	6	4	5	3
	↓						
	99	5	2	1	3	6	4
	100	5	1	3	4	2	6

Figure 4.2 Example score sheet for consumer ranking of six sweetpotato samples

Analysis Using The Ranking Method

The ranking method for analysing data is described below but further details are given in Bainbridge *et al.* (1996).

Ranking is a test in which a series of three or more samples are presented to an assessor or consumer at the same time to be arranged in order of intensity, degree or preference. The simplicity of the method makes it valuable in consumer testing.

Calculation of the rank sums

The samples are decoded and the rank orders given by each assessor for each sample tabulated. (**Note:** 1 indicates favourite cultivar, 2 second favourite, etc.). Where there are tied rankings, the mean rank is recorded. The rank sum for each variety is then calculated by summing the ranks for all the assessors. This gives the overall ranking of the varieties. The calculation is demonstrated in Figure 4.3.

In the case shown, E is the favourite followed by F, D and A and C tie in 4th place and B is the least favourite.

By comparing the rank sums for the samples, it is possible to carry out a statistical analysis called the Friedman test for an evaluation of the significance of the differences between the samples. Details of this method are given in Bainbridge *et al.* (1996).

Note: Graphical techniques, such as frequency histograms, are useful for summarizing the results and picking out trends to understand how preferences might differ for different sectors of the population.

	Rank for each sample					
Consumer	Cultivar A	Cultivar B	Cultivar C	Cultivar D	Cultivar E	Cultivar F
1	5	6	4	3	1	2
2	6	5	3	4	2	1
3	4	5	6	3	1	2
4	5	4	6	1	3	2
5	5	4	6	3	2	1
6	4	5	6	3	1	2
7	5	6	4	3	1	2
8	4	5	6	3	1	2
9	4	5	6	1	3	2
10	6	4	5	1	2	3
Sum	48	49	48	25	17	19

Figure 4.3 Example calculation of rank sum

4.2.2 Training of on-station taste panels and obtaining sensory profiles of local cultivars

A taste panel was selected, trained and used on-station at the Lake Zone Agricultural Research and Development Institute (LZARDI), Ukiriguru to obtain sensory profiles of local varieties assessed by consumers. The process of setting up and training the panel included several stages.

Panel selection

It is important to be as consistent as possible and, therefore, to use the same people throughout a study. For that reason it was considered easiest to choose people from among local staff, preferably those that did not travel much as part of their work. Ten people were selected on this basis.

Selection of sensory attributes to be used

The panel members were presented with cooked samples of the roots of a few key cultivars, and group discussions were held to decide which were the most important sensory attributes in terms of appearance, odour, texture and taste. As a word may not have precisely the same meaning for all people, it was important to discuss sufficiently to ensure that there

were no misunderstandings and that the panel members reach a consensus. As much as possible, the terms chosen were objective, but in some cases this was difficult, so that some of the terms depended on the panellists' preferences and thus included a level of subjectivity.

Checking the effectiveness of a panel in distinguishing between cultivars

To check the consistency and sensitivity of the panel, a set of contrasting cultivars was chosen, and the panel used to create sensory profiles. Each panellist assessed each sample for all the sensory attributes previously chosen. The panellist recorded the intensity of that attribute by placing a mark on a line indicating the continuum between the extremes of the attribute (see Figure 4.4). The data obtained were analysed statistically to determine whether the panel was able to distinguish significantly between the cultivars.

Obtaining sensory profiles of the cultivars assessed by consumers

Once the panel had been trained and had been shown to be sufficiently sensitive, it was used to obtain sensory profiles of roots of the varieties assessed by consumers in each of the three districts. This involved several tasting sessions in which each panellist was presented with between 4 and 6 samples at random. Sessions were repeated until each cultivar was assessed twice by each panellist.

Methods Used to Train and Use On-station Taste Panels

Preparation of sweetpotato samples

The sensory character of the cooked material will depend on the method of preparation, so it is important that the method used is carefully standardized and reflects the usual local methods used. The following method was used.

The sweetpotatoes were peeled and approximately 10% of the root removed at each end since the texture at the ends significantly differs from the bulk of the storage root. The roots were peeled and cut into roughly equal sized portions (3–5 cm). The portions were placed in perforated plastic bags, and boiled until the texture, assessed by a fork, was considered right for eating. The cooking time varied between 15 min and 27 min.

Selection of sensory attributes to be used

The panel members were presented with cooked samples of the roots, and group discussions were used to decide the most important sensory attributes in terms of appearance, odour, texture and taste. The following terms were selected by the panel. Those marked with a * are subjective, in this case 50% of the chosen attributes.

- Appearance*
- External colour*
- Internal colour*
- Odour*
- Softness (using fingers)
- Taste*
- Chewiness
- Sweetness
- Mealiness
- Stickiness
- Fibre
- Overall acceptability*

Scoring samples for sensory attributes

Figure 4.4 shows a score sheet used for recording one panellist's assessment of one sweetpotato sample. Each attribute is scored using a mark on a line to record intensity.

During each panel session up to four test samples are randomly presented to each assessor, each labelled with a random number. Thus to assess more than four cultivars, several panel sessions may be needed, and in each session not all panellists will taste the same samples.

Name:_____ Date:_____

Sample number:_____

Score the sample in front of you for each of the qualities that it possesses in the list below by making a mark on the line at the position corresponding to the score that you perceive.

Appearance	bad	good
Colour (external)	bad	good
Colour (internal)	bad	good
Odour	bad	good
Softness (to touch)	hard	soft
Taste	bad	good
Chewiness	very chewy	soft
Sweetness	not sweet	very sweet
Mealiness	not mealy	very mealy
Stickiness	not sticky	very sticky
Fibre content	no fibre	very fibrous
Overall acceptability	very acceptable	not acceptable

Figure 4.4 Score sheet for sensory evaluation of sweetpotato

4.2.3 Obtaining profiles of elite cultivars within the breeding programme

Using the same methods as described above, the trained taste panel was used to assess the sensory characteristics of 12 elite cultivars that were being assessed for production characteristics by the TNRTCP at LZARDI, Ukiriguru.

4.3 Results and discussion

4.3.1 Consumer tests on local varieties in Mwanza, Meatu and Misungwi

Although the varieties, Polista, SPN/0 and Sinia B, were found at all three sites, the other varieties available at the sites were not the same. Table 4.1 lists the varieties and their ranking by consumers. In all cases, the ranking when analysed by rank sum was statistically significant.

Table 4.1 Ranking of local varieties at three locations in the Lake Zone of Tanzania

Ranking	Location of consumer study		
	Mwanza	Meatu	Misungwi
Most preferred	Polista	SPN/0	Ngikuru
	Sinia B	Ngosha	SPN/0
	SPN/0	Polista	Polista
	Mzondwa	Serena	Toniki
		Sinia B	Sinia B
Least preferred	Bilagala	Ipembe	Nguruka

4.3.2 Testing the consistency and sensitivity of the trained taste panel

The overall results of the sensory profiles created by the taste panel for three test varieties are represented graphically in the form of a 'spider diagram' (Figure 4.5). One way analysis of variance (ANOVA) indicated that the panel could significantly ($P = 0.05$) distinguish the three cultivars for 7 of the 12 sensory attributes. This was the first time that the panel had been used, and it was found that with experience precision increased.

4.3.3 Obtaining sensory profiles of the varieties from Mwanza, Meatu and Misungwi

The panel was then used as part of a study to determine consumer preferences for three sites in the Lake Zone. A sensory profile was created for each of the varieties ranked by the consumers. Figure 4.6a–c shows the profiles for the most and least preferred varieties at each site, while Figure 4.6d compares the profiles for the three most preferred varieties. An interesting and encouraging finding was that although the most preferred varieties were not the same, they had similar profiles. Although a more extensive study is needed, this may mean that in terms of sensory characteristics, varieties will not need to be bred for specific regions.

4.3.4 Profiles of elite cultivars within the breeding programme

Once the sensory profile relating to the sensory characteristics preferred by consumers had been established, it was possible to assess cultivars within the breeding programme to determine those close to this profile. A great range in profiles was obtained for the 12 elite cultivars assessed from the breeding programme at LZARDI, Ukiriguru, as illustrated by the 'spider diagrams' in Figure 4.7. Analysis of variance indicates that the panel was able to distinguish between the varieties for all attributes except *Fibre* (Table 4.2). This indicates a consistency between panel members, even for very subjective criteria. The inability to distinguish between varieties for *Fibre* may be because all varieties tested were considered low in *Fibre* by the panel and, therefore, the range was not sufficiently large.

The composition of the storage roots of the varieties profiled was analysed in terms of dry matter content and sugar content. The attribute described by *Starch*, refers to the texture of the root, and is sometimes described as *Mealiness* or *Flouriness*. Although a complex attribute, it is thought to be related to the dry matter of the roots. Figure 4.8 shows the *Starch* score obtained by the panel for each variety plotted against

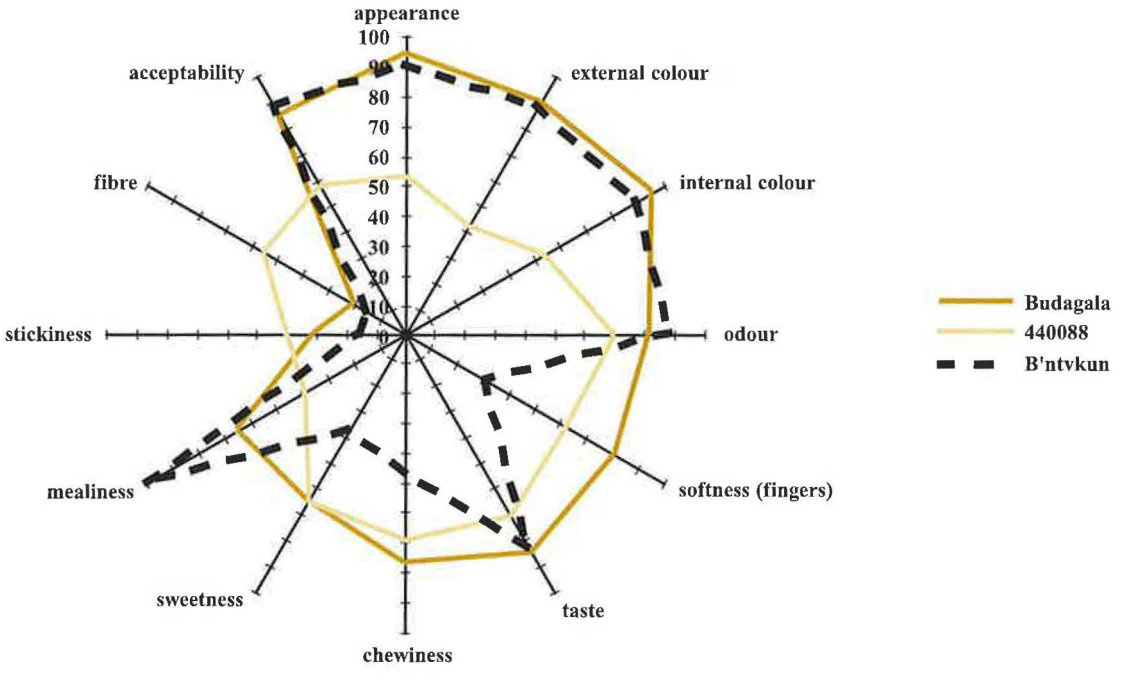


Figure 4.5 Spider chart of mean sensory scores for three sweetpotato cultivars

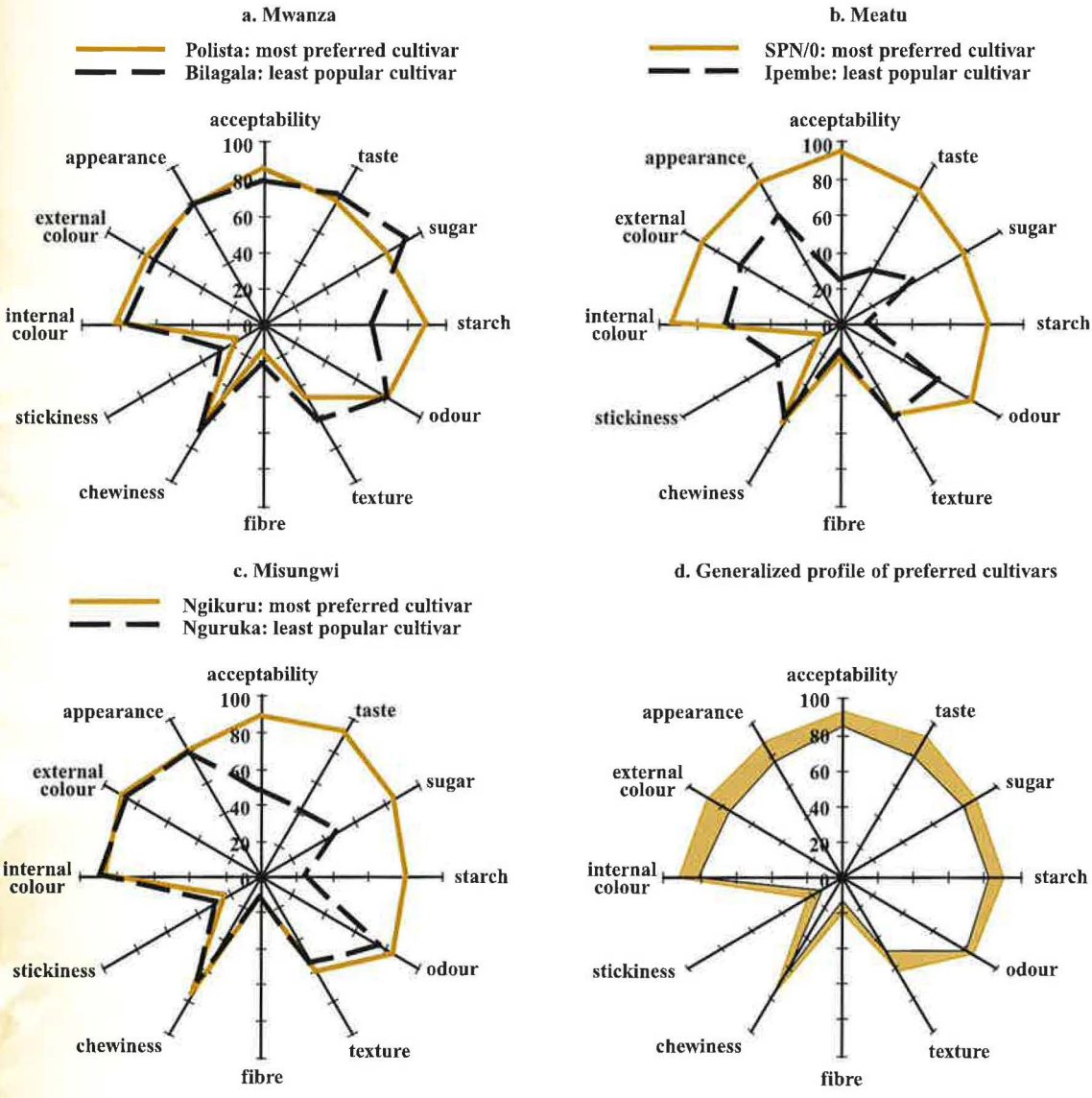


Figure 4.6 **Sensory profiles of the most preferred and least preferred variety for each location, and the generalized profile of preferred varieties**

Table 4.2 **Attributes used by the trained panel to assess varieties, and the level of significance for discrimination between the 12 cultivars**

Sensory attribute	Significance of discrimination between 12 cultivars as determined by the trained panel
Acceptability	***
Appearance	***
External colour	***
Internal colour	**
Taste	***
Sugar	***
Starch	***
Texture	***
Stickiness	**
Chewiness	***
Fibre	n.s.
Odour	***

n.s. = not significant.

, * significant to less than 1%, and less than 0.1%, respectively.

the measured dry matter content. Apart from one variety, Kagole, which has an exceptionally low *Starch* score, there is a significant relationship ($P<0.01$) between the two parameters.

Sugar, or sweetness, of the roots is considered an important taste attribute. It can also be a complex characteristic, not necessarily related directly to sugar content. The sugar content of roots increases during cooking, as the process promotes the breakdown of starch. Figure 4.9 shows the *Sugar* score obtained by the panel plotted against the actual sugar content of cooked roots as analysed by high performance liquid chromatography (HPLC) analysis. There is a significant ($P<0.05$) correlation between the two parameters.

The consistency of the panel's scores with the compositional analysis gives us further confidence in the validity of the assessments.

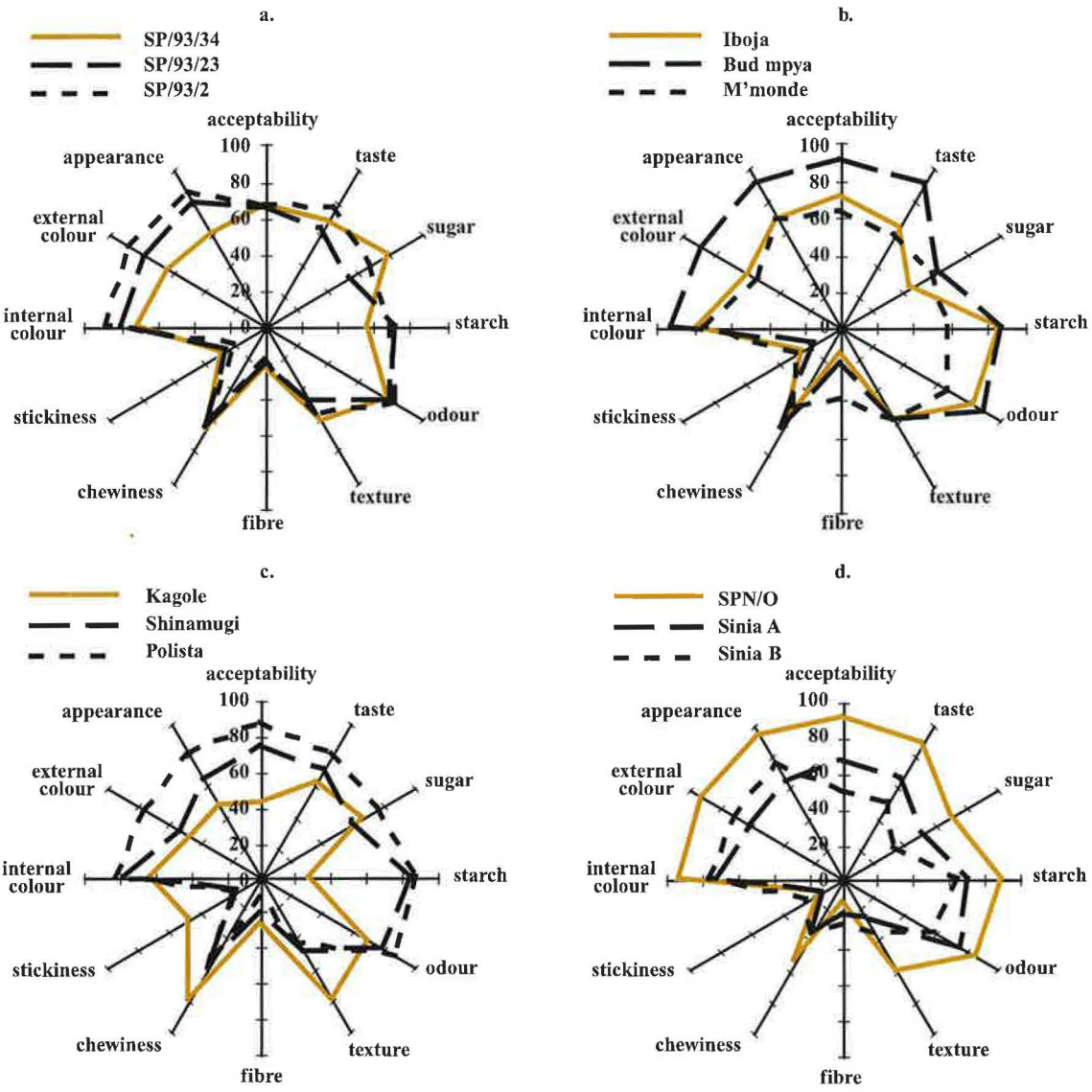
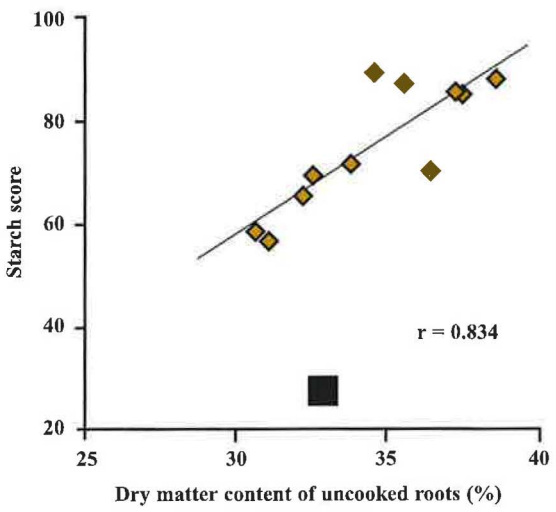


Figure 4.7 Sensory profiles created by the trained taste panel for 12 sweetpotato varieties (Bud mpya = Budagala mpya, Mmonde = Mwanamonde)



The square symbol indicates the data for Kagole.

Figure 4.8 The relationship between *Starch* score given by the panel and dry matter content of roots of a range of sweetpotato varieties

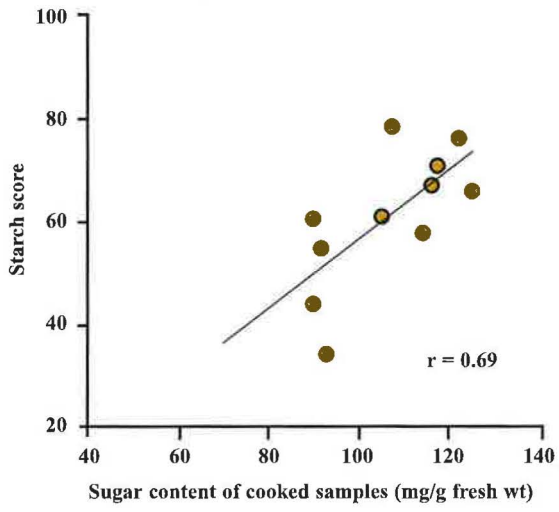


Figure 4.9 The relationship between *Sugar* score given by the panel and sugar content of cooked roots of a range of sweetpotato varieties

Comparison of the profiles with that of the preferred varieties (Figure 4.6) indicates that SPN/0, Polista and Budagala mpya should all be very acceptable. These varieties are all in fact already used by local growers. SP/93/2, SP/93/23 and SP/93/34 are new cultivars bred by the TNRTCP, and chosen for their good production characteristics. Their sensory profiles are reasonable but still less acceptable than the best available cultivars, particularly in terms of taste.

4.3.5 Advanced techniques for assessing cultivar acceptability over seasons

Recent analysis has explored the consistency of cultivar acceptability over seasons. This is important, as both the consumer preferences, and the cultivar characteristics could change between years.

In 2000, consumers were interviewed again and asked to assess sweetpotato samples using the same methods and in the same locations as for the study described above. Table 4.3 shows the cultivars in order of preference for the three regions over the two seasons. Although there was some difference in the cultivars found in the regions, many were common, and over both years (1998 and 2000), the cultivars, Polista and SPN/0, were consistently within the three most preferred cultivars. Other cultivars, such at Sinia B, were not liked in 1998 but were liked in 2000, while Mzondwa, Bilagala and Serena were consistently disliked.

All the cultivars were assessed for their sensory attributes in 2000 using the same taste panellists as used in 1998. With 11 attributes being assessed for each cultivar (overall acceptability was left out in 2000), the data can become very complex to interpret. For that reason, a mathematical technique called principal component analysis (PCA) was used to express the data. A full explanation of this technique is outside the scope of this publication, but some idea of the power of the method can be obtained by looking at Figures 4.10a and b. The data are mathematically *transformed* so that the 11 attributes can be expressed by *vectors* (lines) pointing in different directions on a two-dimensional graph (Figure 4.10a) that accounts for 78% of the 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 4.10b). Thus Serena (Meatu 2000) is very fibrous, whereas Sinia (Mwanza 2000) is not fibrous, but is sweet. Similar cultivars will be clustered together.

Hierarchical cluster analysis (Wards method; Figure 4.10b), shows that the most popular cultivars are all located in a cluster in the same area (lower right-hand quadrant) of the graph, indicating that the sensory panel found that all these cultivars had similar sensory profiles. The other thing that the graph shows is that SPN/0 and Polista had stable sensory characteristics, whereas Sinia was different in 1998 and 2000 (i.e. the position on the graph is different). This fits with the finding that the consumers tended to like Sinia more in 2000 than in 1998.

The PCA plot (Figure 4.10a) suggests that many sensory attributes are highly correlated and so the approach can be simplified. Analysis of variance (ANOVA) can be used to determine the significance of cultivar differences and, therefore, to give an indication of how useful a sensory attribute is for discriminating between cultivars. By selecting only those sensory attributes with the most significant cultivar differences and only those that are not correlated, the approach can be simplified to only two sensory attributes; *Starch* and *Stickiness*. That is, *Starch* and *Stickiness* have good discriminating power (highly significant cultivar differences) and are not significantly correlated with each other. This is illustrated in Figure 4.11 where the most preferred cultivars are in the upper left-hand quadrant of the *x-y* plot. The most preferred cultivars are starchy but not sticky and the least preferred are not starchy and not sticky.

More information on this study and on the PCA technique can be obtained from K.Tomlins. Examples

Table 4.3 Consumer acceptability – ranking sweetpotato cultivars by 100 consumers at Mwanza, Meatu and Misungwi over two seasons

Liking	Mwanza		Meatu		Misungwi	
	1998	2000	1998	2000	1998	2000
1 (most)	Polista	SPN/0	SPN/0	Polista	Ngikuru	SPN/0
2	Sinia B	Sinia B	Ngosha	Sinia B	SPN/0	Sinia B
3	SPN/0	Polista	Polista	SPN/0	Polista	Polista
4	Bilagala	Mzondwa	Serena	Serena	Toniki	Bukolu
5	Mzondwa	Bilagala	Sinia B		Sinia B	Hudi Shinyanga
6 (least)			Ipembe		Nguruka	Ngikuru

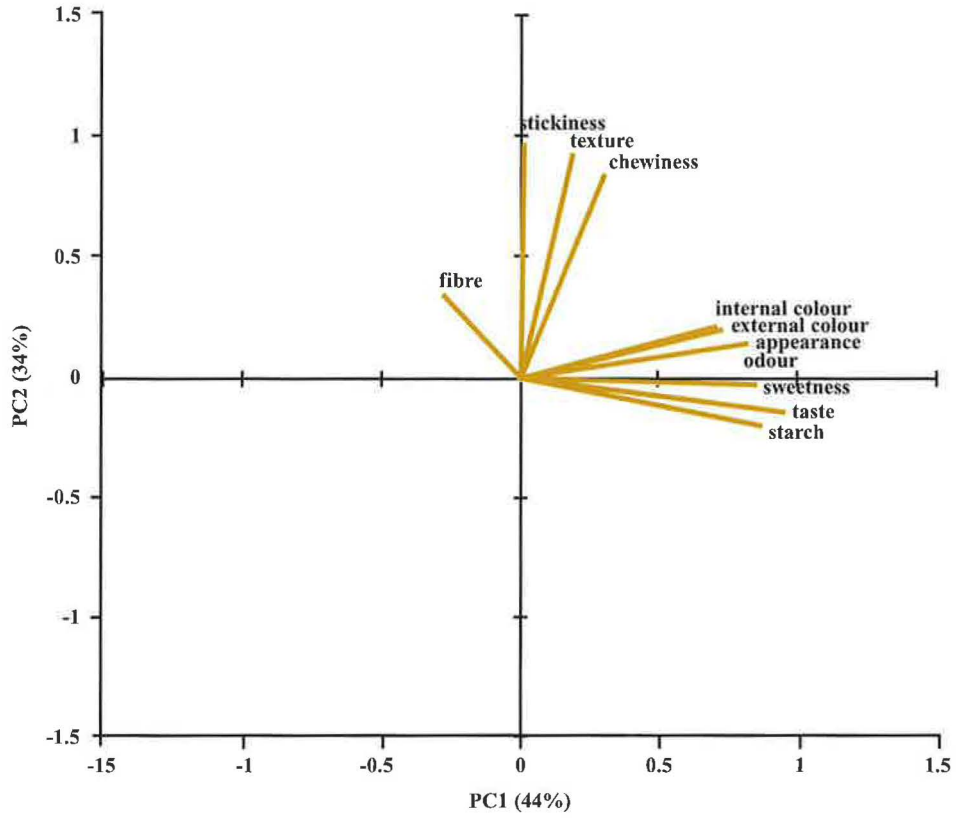
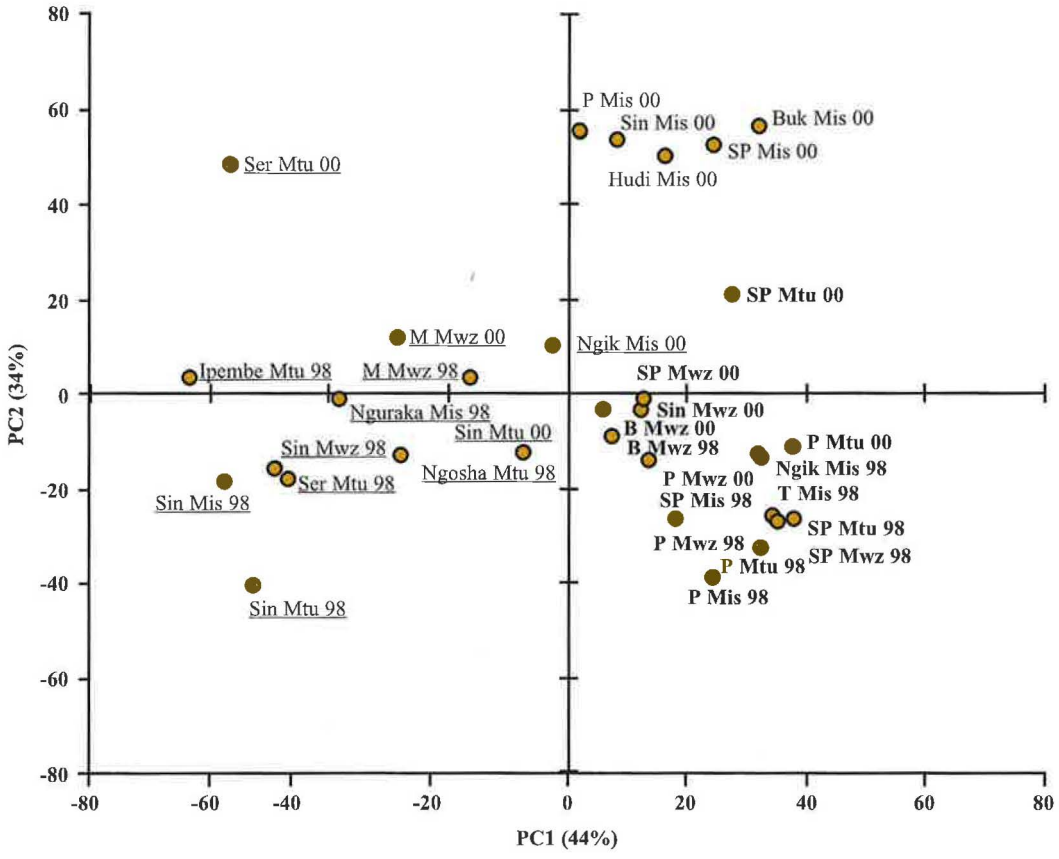
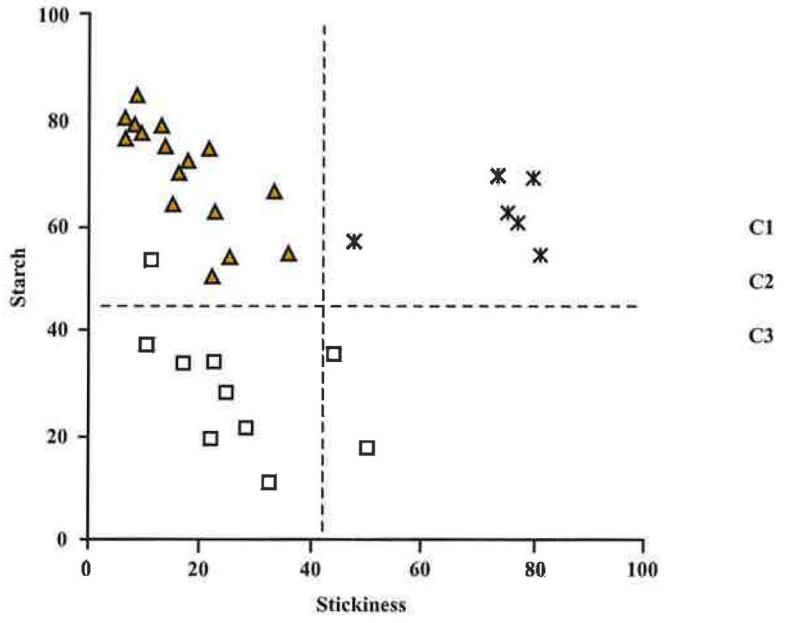


Figure 4.10a **Principal component plot showing relationship with respect to the sensory attributes**



Bold = most preferred cultivars, underlined = least preferred cultivars; normal text = Misungwi 2000 cultivars

Figure 4.10b **Principal component plot showing spacing of sweetpotato cultivars with respect to the sensory attributes**



Horizontal and vertical dotted lines are cut-off limits for selection criteria.

▲ most preferred cultivars

□ least preferred

✱ Misungwi 2000 cultivars

Figure 4.11 Discrimination of sweetpotato cultivars with respect to *Starch* and *Stickiness*

of the way in which sensory evaluation can be used in practice are given in Baker *et al.* (1994), Tomlins (2000a, b), Tomlins and Gay (1994) and Tomlins *et al.* (in press).

4.4 Conclusions and implications

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. The results presented in section 4.3.5 indicate that 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 it is important to screen using the entire spectrum of sensory attributes, the most important sensory attributes in selecting for consumer acceptability are *Starch* and *Stickiness*. The most preferred cultivars were starchy but not sticky while the least preferred were not starchy and not sticky. Non-sensory tests indicated that preferred cultivars (high starch) also had high dry matter and suggests measurement of dry matter content can assist screening studies.

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

References

BAINBRIDGE, Z., TOMLINS, K., WELLINGS, K. and WESTBY, A. (eds) (1996) *Methods for Assessing Quality Characteristics of Non-grain Starch Staples*. Part 4. *Advanced Methods*. Chatham, UK: Natural Resources Institute.

BAKER D.M., TOMLINS, K.I. and GAY, C. (1994) Survey of Ghanaian cocoa farmer fermentation practices and their influence on cocoa flavour. *Food Chemistry*, **51**: 425–431.

KAPINGA, R., RWIZA, E., TOMLINS, K.I. and REES, D. (1998) The Potential for Using On-station Trained Consumer Panels to Assess the Acceptability of Sweetpotato Cultivars in Tanzania. Chatham, UK: Natural Resources Institute. (unpublished)

RWIZA, E., NYANGO, M., MUNISI, R., KAPINGA, R., TOMLINS, K., REES, D., NDENGELLO, T. and WESTBY, A. (2000) The potential for using trained taste panels for screening sweetpotato varieties: experiences in Tanzania. pp. 521–526. In: *Fifth Triennial Congress of the African Potato Association, Kampala, Uganda 29 May–2 June 2000. APA Conference Proceedings* Volume 5.

TOMLINS, K.I. (1998) Methods for Evaluating the Sensory Properties and Consumer Preference of Sweetpotato Cultivars. Chatham, UK: Natural Resources Institute. (unpublished)

TOMLINS, K.I. (2000a) Methods for the Sensory Evaluation of Food and Drink Products. Chatham, UK: Natural Resources Institute. (unpublished)

TOMLINS, K.I. (2000b) Introduction to Sensory Evaluation and Consumer Acceptance. Chatham, UK: Natural Resources Institute. (unpublished)

TOMLINS, K.I. and GAY, C. (1994). Prediction of quality and origin of black tea and pine resin samples from chromatographic and sensory information: evaluation of neural networks. *Food Chemistry*, **50**: 157–165.

TOMLINS, K.I., MANFUL, J.T., LARWER, P. and HAMMOND, L. (in press) Urban consumer acceptability and sensory evaluation of locally produced and imported parboiled and raw rice in West Africa. *Food Quality and Preference.*

VAN OIRSCHOT, Q.E.A., REES, D. and AKED. J. (in press) Sensory characteristics of five sweetpotato cultivars and their changes during storage under tropical conditions. *Food Quality and Preference.*

CHAPTER 5

Extending root shelf-life during marketing by cultivar selection

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5.1 Introduction

5.1.1 The constraints imposed on sweetpotato marketing by 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 °C 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). The potential for long-term storage of sweetpotato and the behaviour of different cultivars under long-term storage conditions will be considered in Chapter 7.

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 have highlighted the problems of such a short shelf-life. These included surveys conducted both by NRI and the

Tanzanian National Root and Tuber Crops Programme (e.g. Fowler and Stabrawa, 1993; Kapinga *et al.*, 1995). Precise economic losses have not been quantified, although it has been estimated that post-harvest 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 3 days (R. Bancroft, personal communication).

5.1.2 The effect of mechanical damage on root shelf-life

Mechanical damage during post-harvest handling is detrimental to the shelf-life of fresh produce (Wills *et al.*, 1998), as the damaged areas form an avenue for moisture loss and an entrance for micro-organisms. Damage to sweetpotato is inevitable during handling and harvesting. This is certainly the case in East Africa where sweetpotatoes are often transported large distances over rough roads. In East Africa, sweetpotatoes are traditionally packed in large woven polypropylene sacks, each weighing between 100 kg and 140 kg. During transport, the roots are exposed to many minor impacts due to movement of the sacks on the vehicle, which result in skinning injury. The sacks are often dropped resulting in large impacts, causing the roots to break (Tomlins *et al.*, 2000). Susceptibility to damage has been shown to be variety-dependent in potatoes (*Solanum tubersosum*) (Blight and Hamilton, 1974) but, prior to these studies, little was known about sweetpotato cultivar differences in susceptibility to damage.

5.1.3 Shelf-life vs. long-term storability

Characteristics which give a root a long shelf-life during marketing are not necessarily the same as characteristics which make a root more suitable for long-term storage. For example, roots for long-term storage are not transported long distances, and are usually handled carefully, so that a cultivar which is susceptible to mechanical damage may be suitable for long-term storage, even though it would be unsuitable for marketing. Therefore, in order to avoid confusion, within this book we distinguish between 'shelf-life', which is used to describe keeping qualities under marketing conditions and 'storability', which is used to describe keeping qualities within long-term stores.

- Shelf-life = keeping qualities under marketing conditions
- Storability = keeping qualities within long-term stores

5.1.4 Objectives

Practically, an extension of shelf-life could be achieved by two strategies: improving handling techniques, or the introduction and promotion of cultivars with better keeping qualities. The first approach is often constrained by socio-economic factors outside the control of research and extension officers, whereas the introduction of improved cultivars causes minimal extra expense to farmers and traders. In this chapter, we describe a series of studies which were carried out to examine the potential for breeding for extended shelf-life. The specific objectives of these studies were:

- to determine the main forms of deterioration for sweetpotato roots during marketing
- to determine the extent to which sweetpotato cultivars vary in susceptibility to damage
- to determine the extent to which sweetpotato cultivars vary in their intrinsic perishability and the physiological factors that control root perishability
- to determine whether it is possible to breed for cultivars with longer shelf-life.

5.2 Methods

5.2.1 Assessing deterioration of roots in markets of Tanzania

A survey was carried out in 1996 and 1997 to assess the extent and type of damage to sweetpotatoes when they arrive at market, to assess the economic implications of damage, and to establish the most serious forms of damage affecting shelf-life.

Observations were made during months of peak and low supply in Dar es Salaam, Morogoro and Mwanza, and also on Ukerewe Island, a sweetpotato supply area. Further details are given below.

5.2.2 Storage trials to compare the shelf-life of a range of cultivars under simulated marketing conditions

Two things are desirable for breeding improved sweetpotato cultivars with extended shelf-life to be possible. Firstly, there should exist a sufficient range in shelf-life among existing germplasm, which is relatively stable across environments. Secondly, methods should be identified for selecting cultivars with better storability.

Trials were conducted on-station in Tanzania in 1997 and 1998 to assess a range of cultivars for their shelf-life under simulated marketing conditions. A range of other root characteristics were also examined, including dry matter content, sugar content, respiration rate, surface damage by rough weevil (*Blosyrus* spp.), latex production, cortex thickness and tissue hardness to obtain information on the physiological basis for cultivar differences. Further details are given below.

Survey Methods for Assessing Root Deterioration in Markets

For each urban centre, samples of wholesale sweetpotatoes were collected twice in each of the high and low seasons of sweetpotato supply (Table 5.1). For each sampling, three sacks of roots were bought as they arrived at the market, prior to any sorting by traders (for Mwanza, high season 1, only two sacks were bought). Each sack was treated as a separate replicate throughout the experiment. The roots in each sack were sorted into undamaged, superficial damage (scuffing) only, and more serious damage. The latter category was further classified as broken, cut, weevil (*Cylas* spp.) infested or rotting. Many roots suffered from more than one form of damage, but each was classified on the most obvious form. Where there was doubt as to which form of damage to use, classification was in the order: rotting, *Cylas* infested, broken and cut (determined by the seriousness of the damage in economic terms). The weight of roots in each class was recorded for each sack.

For each damage category, 15 roots were selected from each sack, and placed into separate sacks (clean polypropylene fertilizer bags) for storage. For categories with fewer than 15 roots, as many as possible were included. During storage, the sacks were kept open (rolled down to half height), in a well ventilated room. The extent of root deterioration was assessed weekly in terms of rotting and loss of fresh weight.

Rotting was scored on the extent observed on the external surface: 1 = 0%; 2 = 1–25%; 3 = 26–50%; 4 = 51–75%; 5 = 76–100%. After each assessment, those roots that scored 4 or 5 were discarded. In subsequent weeks, the previously discarded roots were still included with a score of 5 when the overall mean score was calculated.

Fresh weight loss was assessed by marking six random roots in each sack at the start of the trial and recording their weights weekly. Where roots were discarded due to rotting, only the remaining roots were considered when calculating the mean percentage weight loss.

Table 5.1 Markets and sampling seasons used for the survey of sweetpotato damage in the markets of Tanzania

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

Storage Trial Methods

Growth of roots

The trials were conducted at the Lake Zone Agricultural Research and Development Institute (LZARDI), Ukiriguru. Storage roots were obtained from two sets of cultivars grown in two field trials: Trial 1 (9/10 cultivars) and Trial 2 (22 cultivars) grown in consecutive years; 1997 and 1998. Cultivars (see Table 5.2) were selected from local landraces, new crosses and introduced germplasm to provide a wide range of root characteristics, but included only cultivars known to give reasonable yields. Two cultivars (SPN/0 and Mwanamonde) were common to both trials. For Trial 1, cultivar Sinia A was only included in the second year. For Trial 2, cultivar 440121(Naeshirazu) was replaced in the second year by cultivar 440144.

The trials for the first year were planted in the wet season on 28 December 1996, with planting of extra cuttings on 17 January due to poor establishment as a result of subsequent drought. Trials for the second year were also planted during the wet season, on 15 and 16 December 1997. Trials were harvested on 23 June 1997 and 15 May 1998, respectively. All field trials were planted as randomized complete block designs. Trial 1 had 4 replicates with plots of 6 m x 6 rows (3 plants/m), while Trial 2 had 2 replicates with plots of 6 m x 2 rows (3 plants/m). No fertilizers or chemicals were applied, and no irrigation was used.

Storage of roots

Following harvest, roots of marketable size (greater than 2.5 cm diameter) and low levels of visible damage were selected for post-harvest evaluation. For each cultivar, roots were divided into 3 replicates (not corresponding to field replicates) with 25 roots per replicate wherever possible.

To simulate normal marketing conditions, roots were stored in a well ventilated room in woven polythene sacks (one per replicate per cultivar), which were tied closed for 2 days, to simulate closed sacks during transport, then opened and rolled down to half height for the remainder of the storage period, to simulate the situation in the market and the home (see Figure 5.1).

Temperature and humidity within the room were recorded daily throughout. In 1997, recordings were taken at midday from a wet dry bulb thermometer on the wall of the room. In 1998, readings were recorded at 2–3 hourly intervals using two Vaisala temperature/humidity probes which were suspended approximately 30 cm above the top of the sacks in the centre of the room, and attached to a Grant squirrel data-logger.

Root assessment

Dry matter content

Immediately after harvest, three roots were selected for each cultivar and assessed for dry matter content by drying in an oven for 48 h at 80 °C.

Weight loss

For measurement of weight loss, six roots were selected at random from each sack and numbered using a permanent marker. The weight of each of these roots was recorded at the start of the trial and at weekly intervals.

Rotting

The extent of externally visible rotting for each sack was assessed at the start of the trial and at weekly intervals by sorting all the roots into six categories (0 = 0% surface showing visible rotting; 1 = 1–10%; 2 = 11–25%; 3 = 26–50%; 4 = 51–75%; 5 = 76–100%), and calculating the average root rotting score. After each assessment, those roots that scored 4 or 5 were discarded. In subsequent weeks, the previously discarded roots were still included with a score of 5 when the overall mean score was calculated. To assess internal rotting, roots were cut into quarters and the exposed surfaces scored for rotting, using the same scoring system as for external rotting.[1]

Surface insect damage

External insect damage was caused by the rough weevil (*Blosyrus* spp.), which grazes on the root surface. Damage was recorded using a 1–5 scale depending on the percentage of surface damaged (1 = 0%; 2 = 0–25%; 3 = 25–50%; 4 = 50–75%; 5 = 75–100%). This form of damage only occurs before harvest, so that damage for each sack can be calculated as the average of all roots assessed in the course of the trial (2/week).

Root hardness, cortex thickness, latex production

Hardness was measured using a hand-held penetrometer as the force required for an 8 mm probe to penetrate the tissue after a small portion of periderm had been removed. The root was cut and cortex thickness was measured in millimetres at the widest part of the root. Latex production was assessed on a freshly cut transverse surface using a subjective 1–5 scale (1 = none; 2 = low; 3 = moderate; 4 = high; 5 = very high).

[1]In most markets, roots with any significant levels of rotting would be unmarketable. Taking this into account another appropriate method of expressing rotting would be as a percentage of roots with more than a specified percentage (e.g. 10%) of rot. The data we collected can be recalculated in this way (see Rees *et al.*, in press).

Total soluble solids of root sap

Concentration of soluble solids in root sap was measured by refractive index using a hand-held refractometer. The root sap was extracted from a portion of grated tissue using a hand-held press.

HPLC analysis for sugar content

Freeze-dried samples were ground and extracted in water (1 g sample in 20 ml water) by shaking for 1 h at room temperature. The extract was filtered through muslin and filter paper, diluted with acetonitrile to 80% acetonitrile and further filtered through a 0.45 mm PTFE syringe filter. 10 ml samples were injected on to an amino-bonded high performance liquid chromatography (HPLC) column (Hypersil APS-2, 20 cm) maintained at 30 °C, using 80% acetonitrile running at 0.6 ml/min as the mobile phase. Sugars were detected using a refractive index detector (Hewlett Packard), and peak sizes were calculated using a Perkin Elmer LCI-100 Integrator.

Table 5.2 Cultivars included in storage trials conducted at LZARDI, Ukiriguru to compare cultivar shelf-life

Trial 1	Trial 2
1. SP/93/34	1. Kagole
2. SP/93/23	2. Polista
3. SP/93/2	3. Tula Omushako
4. Iboja	4. 440088 (NC 262)
5. Mwanamonde	5. Kombegi
6. Sinia B	6. 440037 (Imby 3102)
7. SPN/0	7. 440215 (Tainmg #65)
8. Budagala	8. 440025 (Xushu 18)
9. Budagala mpya	9. 440121 (Naeshirazu)[2]
10. Sinia A[1]	10. 440113 (Beniaka)
	11. Nyamwisekeleja
	12. Bagala
	13. Bilagala
	14. Ipembe
	15. Lutambi
	16. Shinamugi
	17. Tabu Waseki
	18. TIS 8250
	19. Luganza
	20. Itemve
	21. SPN/0
	22. Mwanamonde

[1]Included in second year of trials only.

[2]Replaced in second year of trials by 440144.

Figure 5.1 Sacks used to store roots during storage trial at LZARDI, Ukiriguru

Trial Methods for Assessing Germplasm Stability

In 1997 and 1998, trials were conducted at four sites around Tanzania, in addition to LZARDI, Ukiriguru. At each site, five key Tanzanian cultivars were included, together with additional local varieties. The sites and cultivars used are given in Table 5.3 (the trial at LZARDI is Trial 1 of the previous section). The five key cultivars are shown in bold. All field trials were planted as randomized complete block designs with 4 replicates and with plots of 6 m x 6 rows (3 plants/m).

The storage trial was carried out using essentially the same methods as described in the previous section.

5.2.3 Field trials to assess stability of germplasm across environments

For the introduction of cultivars with extended shelf-life, it is important to know not only whether cultivars with improved keeping qualities exist, but also how consistent their behaviour is across differing environments. The trial detailed (see below) was conducted to examine this issue.

5.2.4 Measurement of respiration rates

During the storage trials conducted at Ukiriguru in 1997, root respiration rates were measured by placing the roots in sealed jars and measuring the rate of increase in carbon dioxide levels). Further details are given below.

Table 5.3 Cultivars included in trials conducted at five sites in Tanzania to test the stability of cultivar shelf-life

LZARDI, Ukiriguru	Sugarcane Institute	HortiTengeru	MARTI-Uyole	Chollima-Dakawa[1]
1. SP/93/34	1. **SPN/0**	1. **SPN/0**	1. **SPN/0**	1. **SPN/0**
2. SP/93/23	2. **Sinia**	2. **Sinia**	2. **Sinia**	2. **Mwanamonde**
3. SP/93/2	3. **Mwanamonde**	3. **Mwanamonde**	3. **Mwanamonde**	3. Kasimama
4. **Iboja**	4. **Iboja**	4. **Iboja**	4. **Iboja**	4. Chanzuru
5. **Mwanamonde**	5. **Budagala**	5. **Budagala**	5. **Budagala**	5. **Budagala**
6. **Sinia**	6. Ukerewe	6. Tengeru R.	6. Mpufya	6. **Iboja**
7. **SPN/0**	7. Elias		7. Masyabala	
8. **Budagala**			8. Nyekundu	
9. Budagala mpya				

[1] Sinia failed to produce any roots at Chollima-Dakawa and, therefore, was omitted.

Respiration Measurements

Measurements were made after 5–7 days of storage. For Trial 1, 6 roots per cultivar (2/storage trial replicate) were assessed (replicates 1, 2 and 3 on days 5 and 6, days 5 and 7, days 6 and 7, respectively), while for Trial 2, 3 roots per cultivar (1/storage trial replicate) were assessed (replicates 1, 2 and 3 on days 5, 6 and 7, respectively). Only roots free of rot were selected. Each root was weighed and placed into a 3.2 litre sealed glass jar, with sealable inlet and outlet. After approximately 1 h, CO_2 was measured using a Combo Gas Analyser (David Bishop Instruments Ltd, Heathfield, UK).

Calculations

Respiration rate (R) [ml/kg/h] was calculated as:

$R = \%\ CO_2 * (V_{jar} - V_{root})/100*(W_{root} * t)$

where

$\%\ CO_2$ = $\%\ CO_2$ generated
V_{jar} = volume of jar (3.2 litre)
V_{root} = root volume (ml) calculated from root weight assuming a density of 1 kg/l
W = root weight (kg)
T = time (h)

Root weight loss due to respiration can be calculated assuming that carbohydrates were the only respiratory substrate and, therefore, that:

1 ml CO_2 generated/h = 1.24×10^{-3} g carbohydrate metabolized/h

(This calculation relies on the following: 1 mole CO_2 occupies 22.4 l, mol wt CO_2 = 44 g, generalized chemical structure of carbohydrate is $C_6H_{12}O_6$ (mol wt 180).)

5.2.5 Measurement of water loss through wounds using a porometer

During these studies, water loss through specific areas of the root periderm was measured using an instrument called a porometer adapted to fit on to the surface of a sweetpotato root (Figure 5.2). (A porometer is designed to measure the transpiration rate through the surface of leaves.) The leaf-chamber was adapted by replacing the rectangular aperture with a round aperture 1.5 cm in diameter. The lower clamp was removed and the head was padded with soft black foam to provide a seal and avoid damage to the sweetpotato surface during the measurement.

The Porometer

A porometer consists of a chamber that can be clamped around a leaf. Air is pumped through the chamber, where it is stirred by a small fan. By measuring the relative humidity of inflowing and outflowing air, the amount of water lost through the surface can be calculated. The calculation should also take into account parameters such as the temperature, flow rate of air through the chamber, area of periderm exposed in the porometer, atmospheric pressure, and saturated water vapour pressure at the ambient temperature.

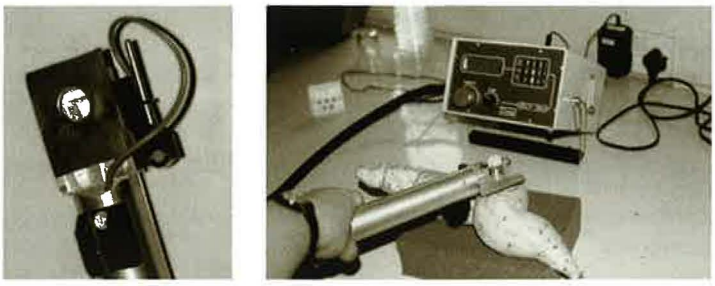


Figure 5.2 (a) Head of the porometer with round aperture and padding; (b) taking measurements of water loss from sweetpotato roots

5.2.6 Assessing cultivars for susceptibility to damage

The objectives of these trials were to assess the variability among sweetpotato cultivars in susceptibility to damage and to investigate the role of shape and periderm thickness. Two standardized damage treatments were developed: one which assessed a root for its susceptibility to 'scuffing' (surface abrasion), and a second, which assessed a root for its susceptibility to impact damage.

Scuffing damage treatment

A scuffing damage treatment was applied by placing 10 sweetpotato roots in a metal barrel (0.55 m x 0.38 m) which was then rolled a distance of 10 m, thus simulating the agitation in sacks during handling and transport. This method was adapted from a scuffing treatment developed by the Scottish Agricultural Research Institute to assess potatoes (Andrew Muir, personal communication).

Impact damage treatment

Impact damage was applied by dropping a sack of roots four times from a height of 1 m (Tomlins *et al.*, 2000).

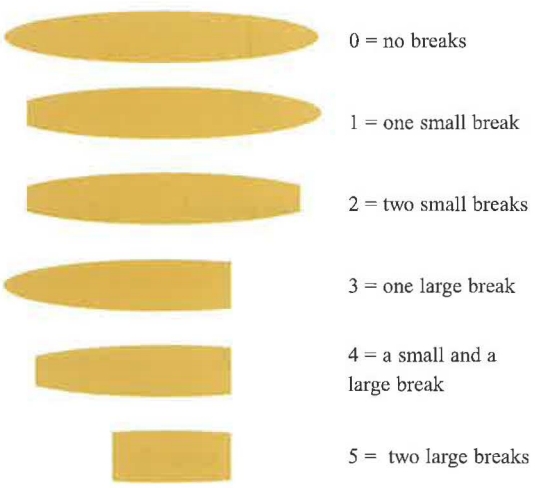


Figure 5.3 Scoring system for assessment of breakage (from Tomlins *et al.*, 2000)

Damage assessment

Breakage was assessed using the scoring system presented in Figure 5.3. Deep wounds were defined as wounds at least 5 mm deep, and the number of deep wounds per root was recorded. Superficial damage was defined as abraded root surface 0.5–5 mm deep, containing cortex tissue as well as periderm, and was scored visually by estimating the percentage of the total abraded surface area. Skinning injury was defined as an abrasion of the periderm only and was scored by visually estimating the percentage of total abraded surface area.

Trial Design Used to Assess Cultivars for Susceptibility to Damage

Ten cultivars of sweetpotato were grown by the International Potato Center (CIP) in Nairobi, Kenya. The cultivars Yan Shu 1, Kemb 10, KSP 20, Zapallo, SPK 004, BP1-SP2, Caplina, Salyboro, Yarada and Julian were planted in a randomized complete block design in 3 replicates using 30 plants per cultivar. The roots were harvested in December 1998 using hand hoes. The roots were then transported to the National Agricultural Research Laboratory (NARL), Nairobi, washed and kept in crates until artificial damage treatments were carried out. Scuffing damage was conducted separately for 10 roots of each cultivar. Impact damage was applied on 21–23 roots per cultivar. Standardized damage treatments were repeated in two trials.

5.3 Results and discussion

5.3.1 The main forms of deterioration in sweetpotato storage roots under East African marketing conditions

After harvest, a sweetpotato root will deteriorate in quality, becoming less acceptable to users in terms of appearance, taste and texture. The shelf-life of a sweetpotato can be defined as the period of time after harvest, for which a root is saleable. There are several ways in which the quality of a root might deteriorate and these are shown in Table 5.4.

Observations of roots bought from Tanzanian markets and stored under simulated marketing conditions (see section 5.2.1), indicated that the main forms of deterioration of sweetpotatoes under normal marketing conditions in Tanzania are weight loss and rotting. The relative importance of these forms of deterioration

Table 5.4 Forms of deterioration for sweetpotato storage roots

Weight loss	Roots can lose weight both by losing water, and also by metabolizing the starch reserves through the process of respiration. Under normal marketing conditions most weight loss (90%) is through water loss (Van Oirschot *et al.*, 2000; Rees *et al.*, in press). Water loss causes the root to become less attractive as it shrivels and, as described below, also appears to make the root more susceptible to rotting.
Rotting	Rotting of tissues occurs by both fungal and bacterial pathogens. When rotting starts a root quickly becomes unsaleable.
Sprouting	When a root sprouts, it will often become sweeter as starch is converted to sugar to provide energy for the growth of sprouts. The appearance of sprouts and loss of starch reduces the root value.
Loss of good taste	Many changes can occur in the root composition after harvest, which may affect the taste and texture of the cooked root.
Infestation by insects	The most important insect pest of the storage root is the sweetpotato weevil (*Cylas* spp.). Even if infestation is only slight, then the root can become completely unsaleable due to the production of bitter tasting phytoalexins as part of the defence mechanism of the root.

depends on storage temperature, humidity, and growth conditions. Figure 5.4 shows the weight loss and rotting of roots purchased on two occasions from each of three markets. The rates of deterioration do vary, but the weight loss was higher than anticipated, 10–17% over 7 days, and 67% over 3 weeks in one case (Morogoro, low season 2). In all but one case, roots showed on average more than 50% surface rotting after 3 weeks.

In the same study, the levels of root damage in the markets, and the effect on rates of deterioration were examined. Figure 5.5 summarizes the damage observed. In almost all cases, insect infestation was due to the larvae of sweetpotato weevils (*Cylas* spp.), which burrow deep into the root, and are a serious problem worldwide (Chalfant *et al.*, 1990; Sutherland, 1986). Levels of damage were variable, but were

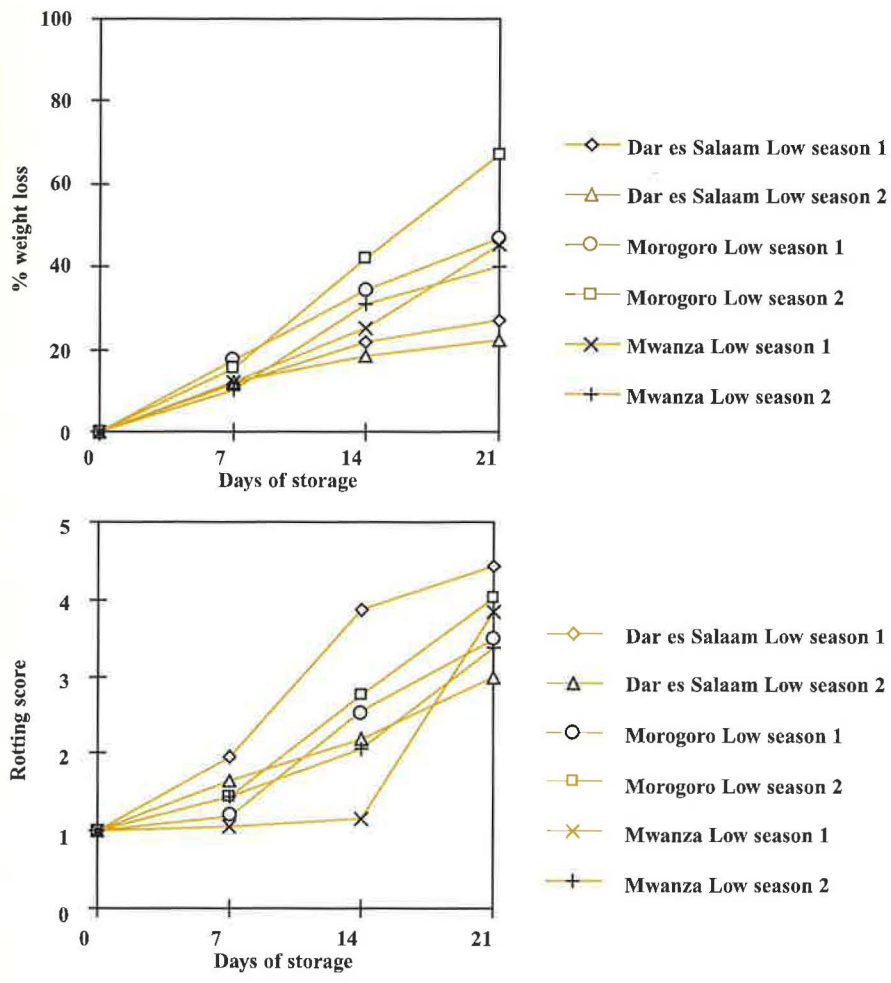


Figure 5.4 Rates of weight loss and rotting for roots bought from markets and stored under simulated marketing conditions (see section 5.2.1 for details of rotting score)

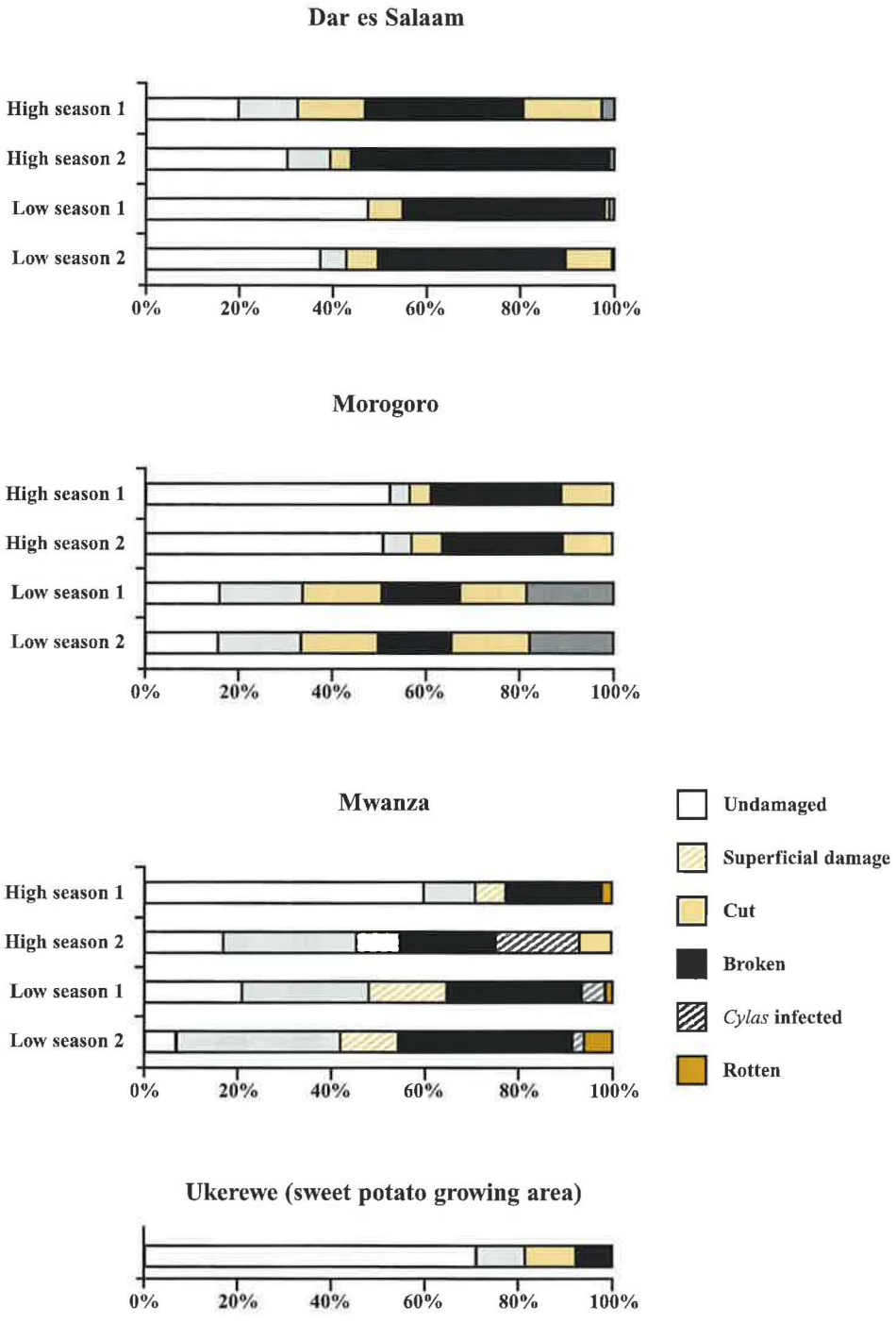


Figure 5.5 Levels and types of damage observed for sweetpotatoes in markets at four locations in Tanzania

generally high with 44–67% seriously damaged roots (including all but superficial damage) and total damage of 49–93%. There was a clear seasonal effect in Morogoro with more damage, mainly rotting, in the low season, but such clear seasonality was not observed in Dar es Salaam or Mwanza. The roots sampled from the rural market on Ukerewe Island showed the least damage.

The effect of damage on rates of deterioration was considerable. Figure 5.6 shows rates of weight loss for undamaged roots and for roots with various forms of damage. The data indicate that for broken roots the rate of weight loss in the first week was three times that of undamaged roots.

Further details of this study can be found in Rees *et al.* (2001).

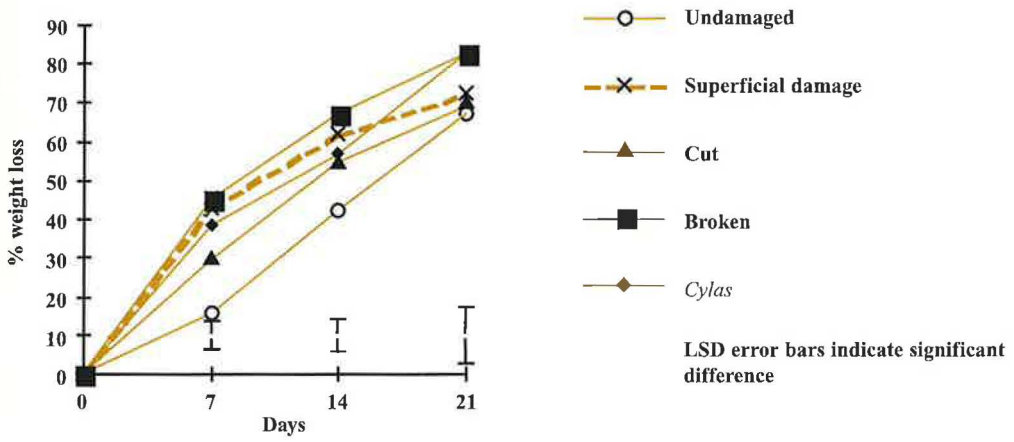


Figure 5.6 Rates of root weight loss in Morogoro during low season 2 and the effect of different forms of damage

5.3.2 Cultivar differences in keeping quality (weight loss and rotting) under simulated marketing conditions

The previous section underlines how short the shelf-life of sweetpotato is under marketing conditions. In order to determine the potential benefits of breeding for cultivars with longer shelf-life, trials were conducted in 1997 and 1998 to determine the keeping qualities of a wide range of sweetpotato cultivars (see section 5.2.2 for details of methods). As for the market studies described in the previous section, the main forms of deterioration observed were weight loss and rotting, while sprouting was not observed.

Figure 5.7a and b shows the extent of weight loss and rotting for a range of cultivars after 2 weeks of storage

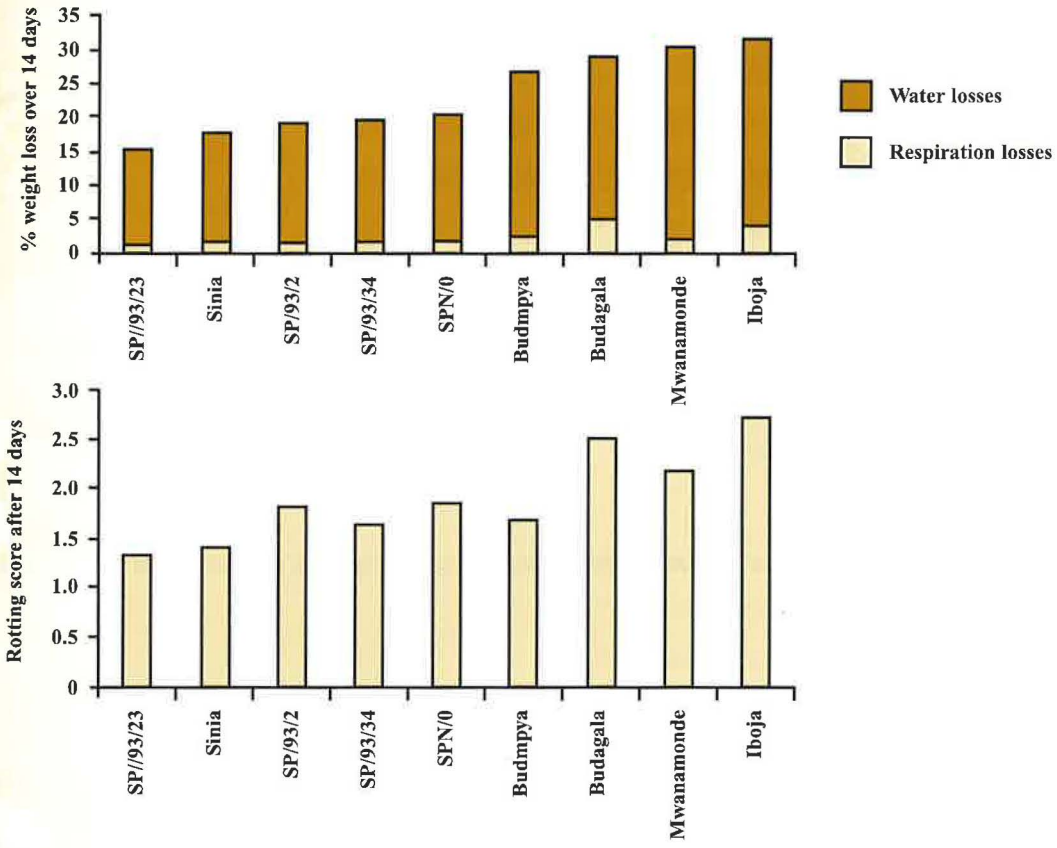


Figure 5.7a Rates of percentage weight loss (with estimated contribution from water loss and respiration) and rates of rotting for sweetpotato cultivars during storage under simulated marketing conditions – Trial 1, 1997, 9 cultivars

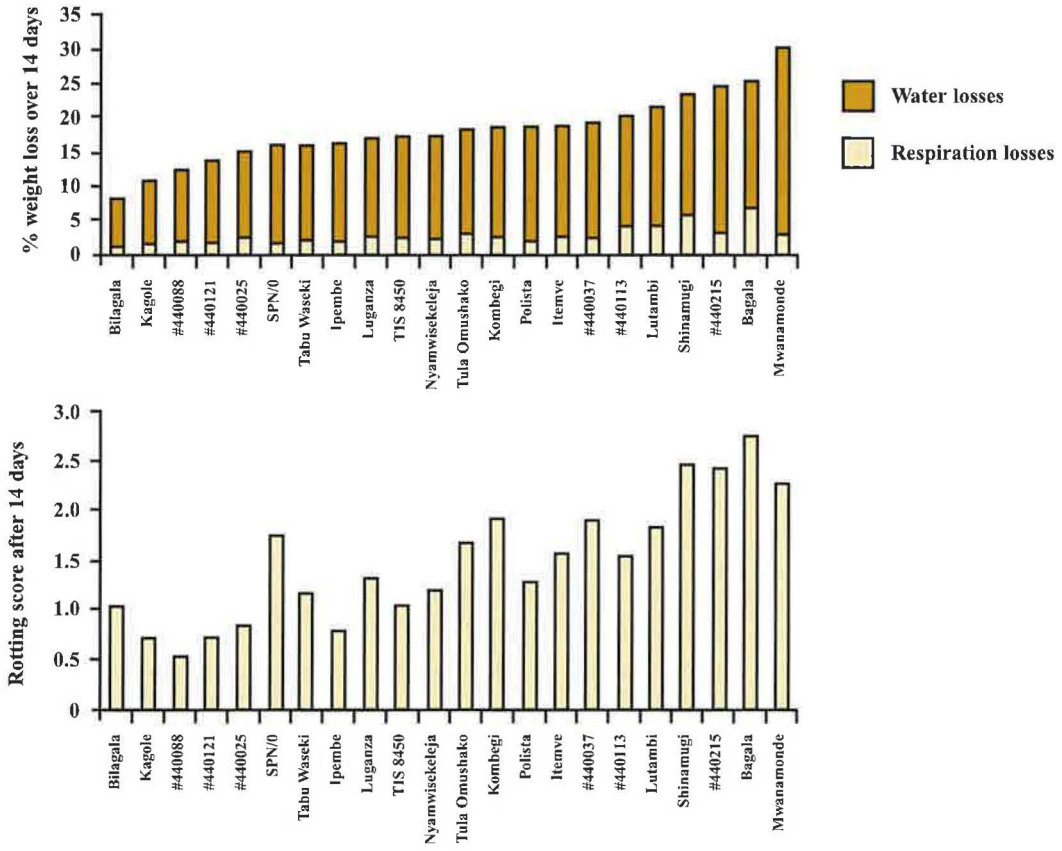


Figure 5.7b Rates of percentage weight loss (with estimated contribution from water loss and respiration) and rates of rotting for sweetpotato cultivars during storage under simulated marketing conditions – Trial 2, 1997, 22 cultivars

for the trials of 1997. A wide range in both parameters can be seen with more than a three-fold difference in weight loss among cultivars. Table 5.5 shows the weight loss data after 1 and 2 weeks for Trial 2. The data has been analysed by ANOVA, which confirms that there are cultivar differences significant to 0.1% after both 7 and 14 days. The least significant difference (LSD) can be used to get an indication of which cultivars differ significantly. For example, from this data it is reasonable to suppose that Kagole is significantly different from Kombegi, but not from Polista.

Table 5.5 Percentage weight loss during storage under simulated marketing conditions for roots from a range of sweetpotato cultivars

Cultivar	7 days	14 days	Cultivar	7 days	14 days
1. Kagole	5.98	11.27	14. Ipembe	9.67	16.59
2. Polista	8.42	18.88	15. Lutambi	10.16	21.88
3. Tula Omushako	8.50	18.44	16. Shinamugi	10.93	23.59
4. 440088 (NC 262)	6.94	12.49	17. Tabu Waseki	8.47	16.26
5. Kombegi	9.41	18.87	18. TIS 8250	9.00	17.42
6. 440037 (Imby 3102)	8.89	19.66	19. Luganza	8.96	17.21
7. 440215 (Tainmg #65)	11.83	24.88	20. Itemve	8.75	18.95
8. 440025 (Xushu 18)	7.68	15.11	21. SPN/0	7.80	16.09
9. 440121 (Naeshirazu)	6.90	13.94	22. Mwanamonde	12.93	30.62
10. 440113 (Beniaka)	10.35	20.54	Mean	9.01	18.36
11. Nyamwisekeleja	9.63	17.52	Cultivar effects	***	***
12. Bagala	12.39	25.41	LSD	3.21	5.11
13. Bilagala	4.53	8.38	CV%	21.6	16.9

*** Significant at 0.1% level of probability.

5.3.3 Water loss is the main driving force for deterioration under marketing conditions

The rates of root respiration measured during the first week of storage were used to estimate the contribution to weight loss of starch metabolism. For these trials we estimate that respiration is responsible for on average 14% (cultivars range from 8% to 27%) of root weight loss and, therefore, that weight loss is primarily due to water loss. This is indicated in Figure 5.7. Rates of respiration were greater for cultivars with higher weight loss, and this is probably an indication of the stress experienced by roots due to desiccation.

From Figure 5.7, it is possible to see that there is a tendency for the cultivars that lose weight rapidly to rot more. This is confirmed by a significant positive correlation between weight loss and rotting ($r = 0.79$, $P< 0.001$) for Trial 1. This trend was found for all four trials. We believe that under these conditions, water loss from roots weakens the tissues, and makes them more susceptible to rotting. The hypothesis that rotting is promoted by weight loss, rather than that weight loss is caused by rotting, is supported by the even stronger correlation of weight loss at 14 days with rotting at 21 days ($r = 0.841$, $P<0.001$). Again, the same trend was found for all trials.

Our overall hypothesis, therefore, is that one of the main factors affecting cultivar perishability under marketing conditions is the susceptibility of the root to lose water. The observation that cultivars differ widely in rates of water loss suggests that it may be feasible to breed cultivars with extended shelf-life.

Further details of this study can be found in Rees *et al.* (in press).

5.3.4 Stability of cultivars between years and between environments

For an improved cultivar to be successful, it should function well over all seasons and over a wide area and, therefore, over a range of environments. It is important to know how 'stable' is the low water loss characteristic. We found that the behaviour of the cultivars over the 2 years of trials was reasonably consistent. Figure 5.8 shows the weight loss for Trial 2 after 14 days plotted for 1998 vs. that for 1997. A correlation coefficient (r) of 0.619 was obtained, which is significant to 1%. For Trial 1, the correlation was even stronger (r = 0.912, significant to 0.1%).

Information on the consistency of cultivars between environments was tested in trials conducted at five sites throughout Tanzania (see section 5.2.3). The results obtained are less clear, but do indicate that certain cultivars are consistently better than others. Figure 5.9 shows the weight loss over 14 days for five cultivars assessed during seven different trials (including five

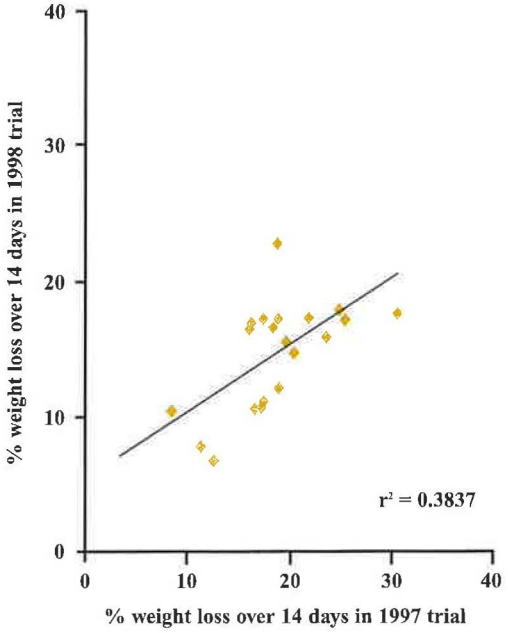


Figure 5.8 The relationship between weight loss over 14 days of storage under simulated marketing conditions in 1998 and 1997

sites and 2 years). The cultivars Iboja and SPN/0 are fairly stable; Iboja shows consistently high rates of weight loss, and SPN/0 shows relatively consistent low rates of weight loss (thus in six of the seven trials Iboja lost weight more rapidly than SPN/0). However, for the other cultivars the trends are less clear. Mwanamonde and Sinia in particular appear to have variable behaviour according to environment.

5.3.5 Most water loss occurs through wounds

Water loss and wound healing efficiency

Having established that water loss from roots is a key factor in their keeping quality during marketing, it is important to learn more about this process. A porometer was used to determine the pattern of water loss from a sweetpotato root, and the results obtained are illustrated in Figure 5.10. This indicates that water loss through undamaged periderm is low, while damaged areas show much higher rates of water loss. Deep wounds (see Figure 5.11) showed the highest rates of water loss. The rate of water loss for all areas declined over the first week after harvest and is particularly marked for wounded areas. As described in Chapter 6, this is primarily due to healing of wounds. Nevertheless, deep wounds continued to have a rate of water loss considerably higher than less severe forms of damage, even 7 and 14 days after harvest. Presumably wound healing is not completely efficient in this case.

The importance of root damage for weight loss is confirmed by the results shown in Table 5.6. Here, roots were damaged using the standardized scuffing and impact treatments described in section 5.2.6. The

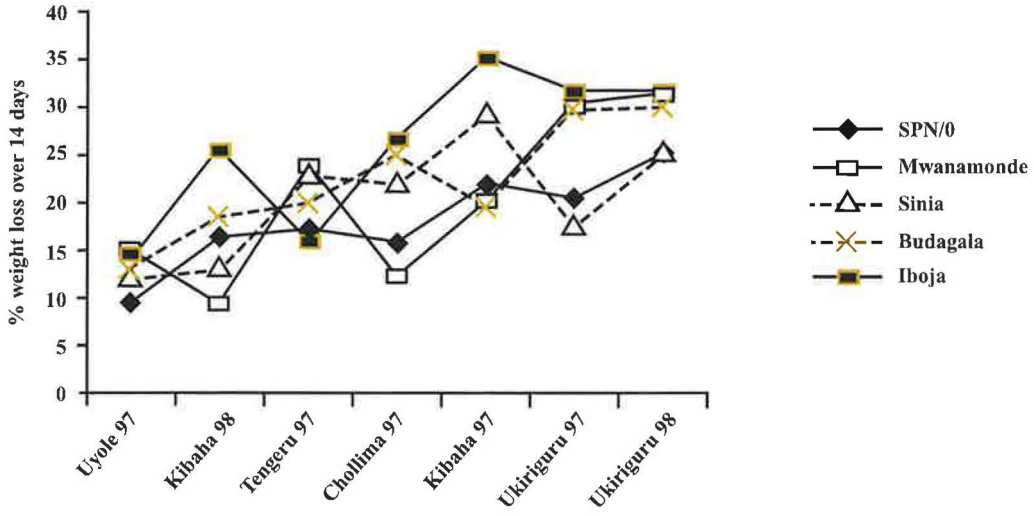


Figure 5.9 Weight loss over 14 days storage under simulated marketing conditions for five cultivars during seven trials. Trials have been ordered in terms of increasing rates of weight loss

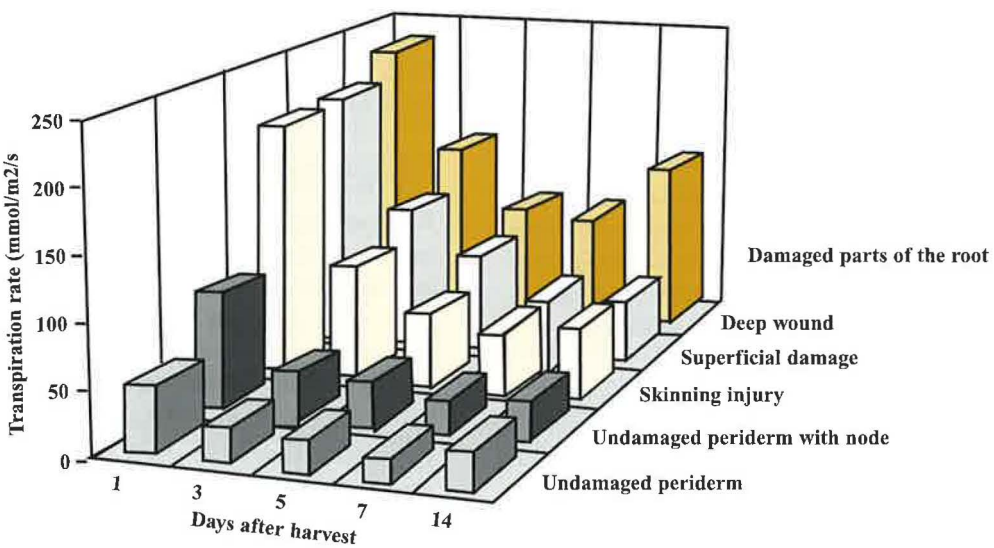


Figure 5.10 Transpiration rate through root surface with different kinds of damage measured at 1, 3, 5, 7 and 14 days after harvest (cultivar: KSP 20). (Note: Time scale is not linear)

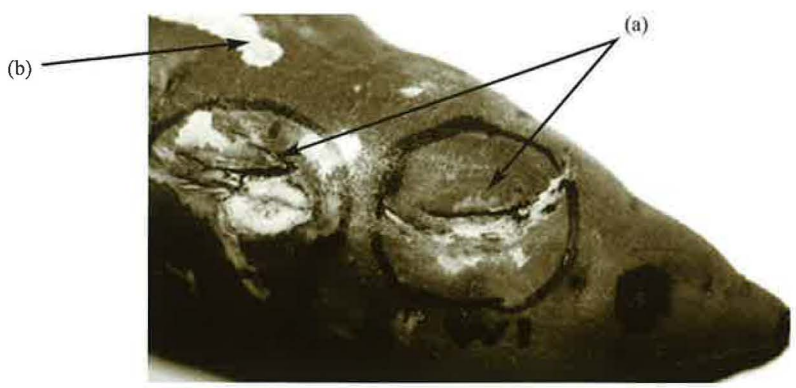


Figure 5.11 Deep wounds (a) and scuffing (b) on sweetpotato root surface (cultivar: KSP 20)

Table 5.6 Correlation coefficients between rate of weight loss and amount of damage for artificially damaged roots

Damage treatment	*N*	Damage type	Correlation coefficients: Days after damage treatments 1	2	7	14
Scuffing	100[A]	Skinning injury	0.348**	0.449**	0.050	ND
	230[B]		0.535**	0.426**	0.087	ND
Impact	217[C]	Breaks	0.480**	0.414**	0.541**	ND
	72[D]		0.549**	0.588**	0.712**	0.669**
Impact	217[C]	Skinning injury	0.253**	0.155*	0.053	ND
	72[D]		0.087	0.252*	0.172	0.046

[A, B, C, D] refer to four different experimental trials.
** Significant at $P < 0.001$; * significant at $P < 0.05$.
ND = not determined.

level of damage for individual roots was related to the rate of weight loss of each root.

There was a significant positive correlation between the level of skinning injury and weight loss and between the extent of breakage and weight loss indicating that roots with high levels of skinning injury and/or breaks also had higher weight losses. The correlation between breaks and weight loss remained highly significant until 14 days after impact damage. Breakage thus has a long-term effect on weight loss. Skinning injury caused significant weight loss for the first 2 days only and thus has a rather short-term effect on weight loss. These results indicate that breakage is a more severe form of damage than skinning injury.

These results support the findings from the studies of root market damage (section 5.3.1) that damage reduces shelf-life and that breakage is the most serious form of damage.

5.3.6 Cultivar variation in susceptibility to damage

It was found that cultivars varied in the kind of damage to which they were susceptible (Table 5.7). Thus, Yan Shu 1, Kemb 10 and SPK 004 were highly susceptible to breaks, while Zapallo and Caplina had the lowest susceptibility to breaks. The ranking of susceptibility to skinning injury was consistent for both the 'scuffing' treatment and impact damage. Both Zapallo and BP1-SP-2 were highly susceptible to skinning injury, while SPK 004 and Kemb 10 showed least susceptibility. The cultivars KSP 20 and Salyboro ranked intermediate for all forms of damage.

Susceptibility to breakages and root shape

By classifying roots by shape, it was demonstrated, not surprisingly, that breakage was strongly associated with long-shaped roots, while round or oblong-shaped roots were less susceptible to breakage. Although sweetpotato root shape can be variable within any cultivar, for the cultivars SPK004, Kemb 10 and Yan Shu 1, more than 70% of the roots belonged to the long-shaped category. As shape, therefore, is a cultivar characteristic and affects susceptibility to breakage, it would be useful to select for rounded root shape.

Susceptibility to scuffing and periderm thickness

Microscopy was used to measure the thickness of the root periderm for several roots of each cultivar. The

Table 5.7 Overview of the mean ranks obtained for 10 sweetpotato cultivars for various forms of damage

Treatment	Damage	Cultivars: Yan Shu 1	Kemb 10	KSP 20	Zapallo	SPK 004	BP1-SP-2	Caplina	Salyboro	Yarada	Julian
Scuffing barrel	Skinning injury	3.5	2.5	6.0	7.0	1.0	8.0	4.5	6.5	4.0	8.0
Impact damage	Breaks	9.0	7.0	5.0	1.0	7.5	3.0	2.0	5.5	6.0	4.0
	Deep wounds	3.0	7.0	6.5	4.5	8.5	6.0	4.0	4.0	1.0	2.0
	Skinning injury	4.5	2.5	6.5	7.5	1.0	8.5	4.0	5.5	4.0	6.0
	Superficial damage	3.5	5.5	5.0	9.0	1.0	8.0	5.0	4.0	4.0	4.0

A high rank corresponds to a high susceptibility to the particular form of damage, and is indicated by dark grey shading.

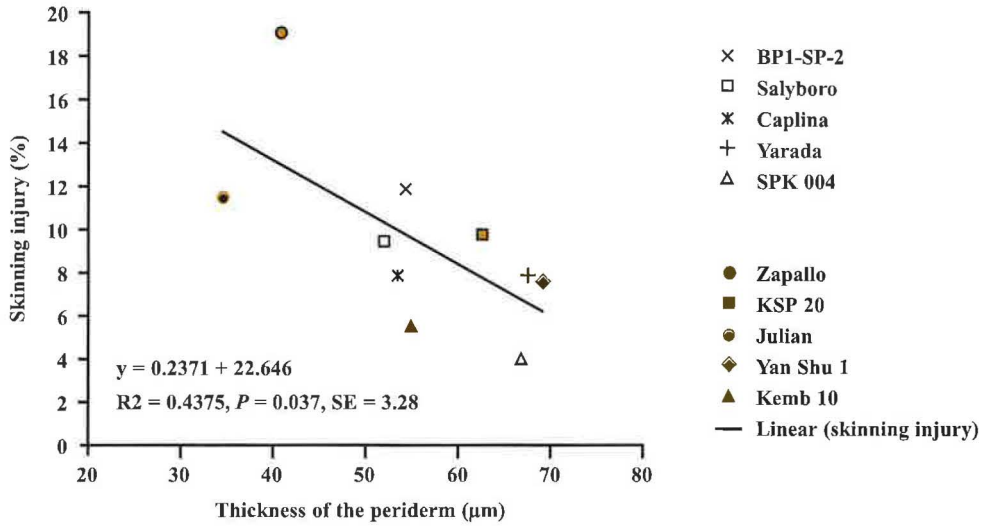


Figure 5.12 Relationship between periderm thickness and percentage skinning injury (percentage surface area of the root) after scuffing treatment; each point represents a cultivar

susceptibility to skinning injury was found to decrease with thickness of periderm (Figure 5.12) and this relationship was found to be significant ($P = 0.037$). The cultivars Yan Shu 1, Yarada and SPK 004 with the thickest periderms (65–70 mm) showed least susceptibility to skinning injury, while the cultivars Zapallo and Julian with a thin periderm (<40 mm) showed high susceptibility to skinning injury.

Further details of this study can be found in Van Oirschot (2000).

5.4 Conclusions and implications

- Under conditions typically experienced during marketing in East Africa, the main forms of deterioration in sweetpotato roots are water loss and rotting. Water loss appears to promote rotting and, therefore, if this can be reduced it should have an impact on the extent of rotting seen in the markets.
- There is a wide range in shelf-life among cultivars, which seems to be primarily due to differences in susceptibility to water loss.
- Susceptibility to water loss in cultivars is relatively consistent between seasons. The consistency between environments is less clear, but there are some cultivars that consistently do better than others.
- Greatest water loss from roots occurs through wounds. Damage, therefore, has a considerable effect in shortening root shelf-life.
- Two major factors controlling susceptibility to water loss are:
  - reaction of the root to wounding (this will be considered in the next chapter)
  - the susceptibility of roots to damage.
- Roots of rounded shape (i.e. not elongated) are less susceptible to breakages, and roots with thick periderms are less susceptible to surface damage (scuffing).

This chapter primarily considers the question of how cultivars could be selected with extended shelf-life for marketing. (This does not include suitability for long-term storage, which is covered in Chapter 7.) Although rotting is a serious restriction on shelf-life, we believe that water loss is more important. Although we would recommend that cultivar assessment includes measurement of water loss, rotting and also susceptibility to damage, where time/labour is restricted, a reasonably effective assessment of cultivar shelf-life can be obtained by measuring susceptibility to water loss alone. A simple test could be devised by placing roots of each cultivar on an open shelf, and measuring weight loss over 1 week.

Our data underline the effects of environment on cultivar behaviour. It is, therefore, very important that multi-site testing be carried out to cover the range of environments representative of the region for which breeding is being carried out.

References

BLIGHT, D.P. and HAMILTON, A.J. (1974) Varietal susceptibility to damage of potatoes. *Potato Research*, **17**: 261–270.

CHALFANT, R.B., JANSSON, R.K., SEAL, D.R. and SCHALK, J.M. (1990) Ecology and management of sweet potato insects. *Annual Review of Entomology*, **35**: 157–180.

FOWLER, M.H. and STABRAWA, A.M. (1993) Sweet Potato Marketing in Uganda: Results of a Rapid Appraisal. Chatham, UK: Natural Resources Institute. (unpublished)

HALL, A.J. and DEVEREAU, A.D. (2000) Low-cost storage of fresh sweet potatoes in Uganda: lessons from participatory and on-station approaches to technology choice and adapative testing. *Outlook on Agriculture*, **29**: 275–282.

KAPINGA, R., EWELL, P., JEREMIAH, S. and KILEO, R. (1995) *Farmers Perspectives on Sweet Potato and Implications for Research in Tanzania. A Case Study*. Dar es Salaam: Tanzanian Ministry of Agriculture and International Potato Center.

KAPINGA, R.E., JEREMIAH, S.C., RWIZA, E.J. and REES, D. (1997) Preferences and Selection Criteria of Sweetpotato in Urban Areas of the Lake Zone of Tanzania. Chatham, UK: Natural Resources Institute. (unpublished)

PICHA, D.H. (1986) Weight loss in sweet potatoes during curing and storage: contribution of transpiration and respiration. *Journal of the American Society for Horticultural Science*, **11**: 889–892.

REES, D., KAPINGA, R., MTUNDA, K., CHILOSA, D., RWIZA, E., KILIMA, M., KIOZYA, H., and MUNISI, R. (2001) Damage reduces both market value and shelf-life of sweetpotato: a case study of urban markets in Tanzania. *Tropical Science*, **41**: 1–9.

REES, D., VAN OIRSCHOT, Q.E.A., AMOUR, R., RWIZA, E., KAPINGA, R. and CAREY, T. (in press) Cultivar variation in keeping quality of sweetpotatoes. *Postharvest Biology and Technology*.

SUTHERLAND, J.A. (1986) A review of the biology and control of the sweetpotato weevil *Cylas formicarius* (Fab.). *Tropical Pest Management*, **32**: 304–315.

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

VAN OIRSCHOT, Q.E.A., REES, D., AKED, J. and KIHURANI, A.W. (2000) Cultivar variation in wound healing efficiency of sweet potato and Irish potato and the effect on shelf-life. Presented at the *International Society for Tropical Root Crops, Japan 2000.*

WILLS, R., McGLASSON, B., GRAHAM, D. and JOYCE, D. (1998*) Postharvest: An Introduction to the Physiology and Handling of Fruit, Vegetables and Ornamentals*. Wallingford, UK: CAB International.

CHAPTER 6

Curing and the physiology of wound healing

Q.E.A. van Oirschot, D. Rees, J. Aked, A. Kihurani, C. Lucas, D. Maina, T. Mcharo and J. Bohac

6.1 Introduction

6.1.1 The nature of wound healing

Damage is inevitable during handling and marketing of sweetpotato and is exacerbated by practices such as over-packing sacks as shown in the picture. Most plant tissues have mechanisms for healing wounds. This is exploited to improve storability of root crops after harvest by 'curing', where they are placed in an environment to promote healing of wounds incurred during harvesting and handling. Sweetpotato is similar in this respect to other root and tuber crops such as potato, cassava and yam (Lulai and Orr, 1995; Rickard, 1985; Passam *et al.,* 1976).

Descriptions of wound healing in sweetpotato date from the 1920s when Weimer and Harter (1921) described how moisture and temperature affect wound periderm formation and the efficiency of the wound cork in preventing infection. Artschwager and Starrett (1931) distinguished three stages of healing:

i) desiccation of surface cell layers
ii) thickening of cell walls (suberization or lignification) in underlying cell layers
iii) formation of a new 'wound' periderm underneath the lignified cells.

Each of these processes is described in more detail below.

Desiccation of surface cell layers

The first response after wounding is desiccation of the cell layers where the cells on the surface dry out and die. Under sub-optimal curing conditions (lower

humidities), this layer of desiccated cells may be thicker, which is unfavourable for the 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

Lignification is probably the most crucial step in the wound healing process. Cell walls below the desiccated cell layers become thickened. There is some uncertainty about the exact chemical nature of this thickening, i.e. whether the thickening is primarily due to the addition of lignin or suberin (Walter and Schadel, 1982, 1983). Both molecules are large polymers: lignin consists of phenolic sub-units, it is hydrophobic thereby reducing water movement and also has specific antifungal properties; suberin contains more aliphatic (lipid) components and so also reduces water movement. Artschwager and Starrett (1931) reported that the thickened cell layers absorb crystal violet which indicates suberization. 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. Thus, the cell wall thickening probably consists of both lignin and suberin. Once this 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.

Wound periderm

The wound periderm consists of cell layers stacked in a similar way to the native periderm, and conferring the same protective barrier. The thickness of the wound periderm may vary according to 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.

6.1.2 Conditions that promote wound healing

Wounds in sweetpotatoes cure 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, it is often assumed that it takes place naturally in the tropics (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.

6.1.3 Objectives

In the previous chapter, it was shown that in storage trials carried out under simulated marketing conditions in Tanzania, rates of root weight loss and rotting varied considerably among cultivars. The work reported in this chapter was conducted to determine whether this was due to the characteristics of root wound healing. Some variability has been found among sweetpotato cultivars in the rate of wound healing (Strider and McCombs, 1958; St Amand and Randle, 1991). However, prior to this study, little was known about the wound healing characteristics of African germplasm, how this relates to shelf-life and also how the process is affected by sub-optimal humidities. A better understanding of the wound healing process under sub-optimal conditions may contribute to efforts to extend shelf-life by improved handling and cultivar selection.

A rapid method to assess wound healing efficiency is described that can be used by sweetpotato breeding programmes in developing countries where sophisticated equipment is not available. This method was validated to establish the relationship between wound healing characteristics of sweetpotato cultivars and their keeping qualities, including water loss, susceptibility to micro-organisms and shelf-life.

Further details of these studies are given in van Oirschot (2000) and van Oirschot *et al.* (2001).

6.2 Methods

Artificial wounds were inflicted by peeling a portion of the root surface with a potato peeler. An area of tissue approximately 2 x 5 cm and 1.7 mm deep was removed. The wounds were then left to heal under conditions chosen to simulate the marketing environment. Several studies were then conducted to look at wound healing by microscopy. Staining lignin by phloroglucinol is simple and gives a red stain that can be seen by the naked eye. This was, therefore, developed into a means of assessing wound healing efficiency by a lignification index. This was tested as a measure of functional wound healing by comparing it with water loss through wounds and susceptibility to rots. Details of the root supply, healing environments and methods of microscopy are given below.

Root Supply and Wound Healing Trials

Eight storage trials were conducted. Table 6.1 presents relevant field and experimental information for each of the trials, while Table 6.2 presents the cultivars included. The storage conditions used were as follows.

Method A (Trials 1 and 2, based at NRI, UK)
Twelve plastic dustbins (B&Q) were placed in a controlled-temperature room at 26 °C. Within each of these, approximately 20 sweetpotato roots (weighing about 5 kg in total) were placed on a platform. The platform was constructed from a plastic plant support and plastic covered chicken wire, and was supported at a height of about 30 cm. In order to maintain high humidity, a layer of water (approximately 70 mm) was placed in the bottom of each bin, and air was bubbled through this at a rate of approximately 3 l/min/bin. A single pump (Charles Austin Pumps Ltd, UK) was used to provide an air flow which was divided using a manifold to supply all 12 bins. The humidity was measured at hourly intervals in 6 of the 12 bins using humidity probes (Vaisala, Helsinki, Finland), recorded by data-loggers (Grant Instruments Ltd, Barrington, Cambridge) and was found to remain between 76 and 100%.

Method B (Trial 3, based at NRI, UK)
One randomly selected root/cultivar/trial was placed in each of eight cardboard boxes (22 roots/box), and kept for 10 weeks in a controlled-temperature room at NRI, maintained at 25 °C and 60% RH. Temperature and relative humidity (25 ± 0.5 °C and 55% ± 6% RH) were recorded using Tinytalk data-loggers (Gemini, Chichester, UK). .

Method C (Trials 4, 5, 6 and 7 based at NARL, Nairobi, Kenya)
Roots were stored in crates. Each crate contained up to 30 roots with an equal number of roots for each cultivar. During the first 2 days, the boxes were lined with plastic sheets or dustbin liners to simulate the high humidity in closed sacks to which the roots would be exposed when transported to the market. In six boxes, the relative humidity was measured every 30 min, using RH probes and recorded using data-loggers as described above. The temperature fluctuated between 18 °C and 27 °C and relative humidity fluctuated between 45% and 95%.

Method D (Trial 8 based at NRI, UK)
The roots were maintained at three different levels of humidity, in three chambers located within a controlled-temperature room maintained at 25 °C. In one chamber, a high relative humidity was maintained by means of an air flow of 3.5 l/h through a layer of water in the base of the chamber. Humidification of the air was improved by using fish-tank stones for air dispersal; 97% relative humidity was achieved.

For the two other chambers, an intermediate humidity was maintained using two supplies of air, one of low humidity (sourced from outside the controlled-temperature room) and one of high humidity (obtained by bubbling through water). The supply of these two sources of air was controlled using an adjustable humidity sensor placed within the chamber. The humidities attained were in the range of 56.6–62.3% and 64.5–70.5%, with an average of 58% and 65%, respectively.

Root Supply and Wound Healing Trials

Both fresh and embedded tissue sections were studied. Fresh sections were hand cut with a razor blade (Wilkinson Sword) at a thickness of 2–7 cells. The sections were stained with phloroglucinol (1% in 95% ethanol) for 2 min, transferred to concentrated HCl for 30 s, then rinsed in water for 30 s. Four sections per wound were assessed.

For the preparation of embedded sections, tissue blocks of 7 x 7 x 7 mm, including both wound surface and native periderm, were cut and fixed in a formalin acetic acid solution (ethanol 70%, formalin 5%, acetic acid 5%). The tissue blocks were than dehydrated in toluene (99%) and embedded in paraffin wax (Paraplast Plus, Sigma). Sections of 15 mm thickness were cut using a microtome. Before staining, the embedded sections were dehydrated in a series of toluene (2 x 100%) and ethanol (2 x 100%, 1 x 90% (last)). Sections were stained for lignin with phloroglucinol and HCl as described above. The morphology of the lignified layer was assessed at 100x magnification using a microscope (Leitz, UK) equipped with a graticule. Micrographs were taken using a Minolta X-700 camera mounted on the microscope.

Method for Measuring the 'Lignification Index'

Four thin cross-sections with a depth of 10 mm and approximately 0.5 mm thick were cut from the wounds using a razor blade. The sections were stained with phloroglucinol as described above. Each wound was given a score between 0 and 1 based on the continuity of lignification across the wound (see Table 6.3 for examples). The average lignification score for the four sections of each wound was called the 'lignification index' (LI).

Table 6.1 Overview of location, field design, planting and harvesting dates, experimental set-up and conditions for each of the trials

	Field location	Number of cultivars	Field design	Date of planting	Date of harvesting	Storage during curing	Curing experiment location	Temperature	Relative humidity
Trial 1	CIP	5	-	15-7-96	22-1-97	Method A	NRI	26.1 ± 0.5 °C	82.2 ± 4%
Trial 2	CIP	5	-	15-7-96	17-3-97	Method A	NRI	26.1± 0.1 °C	73.2±-7.3%
Trial 3[†]	CIP	22[‡]	RCBD	Oct 2000	Mar 2001	Method B	NRI	25 ± 0.5 °C	60 ± 6%
Trial 4	CIP	10	CRD*, 3 rep, 90/120 plants per cultivar	25-5-98	27-10-98	Method C	NARL	21.1 ± 1.7 °C	71%
Trial 5	CIP	10	CRD*, 3 rep, 90/120 plants per cultivar	June 98	11-11-98	Method C	NARL	20.7 ± 1.9 °C	75.9%
Trial 6	CIP	8	-	July 98	1-12-98	Method C	NARL	21 °C	67.3%
Trial 7	CIP	10	-	July 98	7-1-99	Method C	NARL	26 °C	85–90%
Trial 8	CIP LZARDI (Lake Site)	10 3	-	Nov 98 Nov 98	March 99 March 99	Method D	NRI	26 °C	Low 58% Intermediate 65% High 97%

* CRD = Complete randomized design.

[†] Trial 3 was replanted in January 1997.

[‡] Trial 3 has two sets of cultivars as the roots were part of different experiments.

Location of growth of sweetpotatoes: CIP = International Potato Center, Nairobi, Kenya; LZARDI = Lake Zone Agriculture Research and Development Institute, main station and lake site station.

Experiment location: NRI = Natural Resources Institute, UK; NARL = National Agricultural Research Laboratories.

Table 6.2 Overview of the cultivars used in each of the trials

Trial	Cultivars	Cultivars	Cultivars	Cultivars	Cultivars
Trial 1	Kemb 10	KSP 20	SPK 004	Yan Shu 1	Zapallo
Trial 2	Kemb 10	KSP 20	SPK 004	Yan Shu 1	Zapallo
Trial 3	Jewel Budagala* Yanshu Beauregard	Sinia KSP 20* Sinia B Kemb 10*	Zapallo* SPN/0 Hernandez Polista	Kagole Iboja Bilagala Mwananmonde SPK 004	L-86-33
Trial 4	BP1-SP-2 Caplina	Julian Kemb 10	KSP 20 Salyboro	SPK 004 Yarada	Yan Shu 1 Zapallo
Trial 5	BP1-SP-2 Caplina	Julian Kemb 10	KSP 20 Salyboro	SPK 004 Yarada	Yan Shu 1 Zapallo
Trial 6	BP1-SP-2 Caplina	Julian Kemb 10	KSP 20 Salyboro	SPK 004 Yarada	Yan Shu 1 Zapallo
Trial 7	BP1-SP-2 Caplina	Julian Kemb 10	KSP 20 Salyboro	SPK 004	Yan Shu 1 Zapallo
Trial 8	BP1-SP-2 Caplina	Julian Kemb 10	KSP 20 Salyboro SPK 004	Yarada Yan Shu 1 Zapallo	Polista SPN/0 SP/93/2

* Roots of these cultivars grown in two separate field trials were considered separately.

Table 6.3 Scores for lignification of sweetpotato wound sections representing continuity of lignified layer

		Completeness of the lignin layer		
	Lignification score	Presence of lignin	Completeness of lignification	Distribution of lignin in wound (~ = lignin)
Complete lignification	1	1	1	
Patchy lignification	0.5	1	0	
No lignification at all	0	0	0	

The physiological purpose of wound healing is to prevent water loss and inhibit microbial invasion. The LI was tested for its validity as a measure of functional wound healing by comparing it with rates of water loss and the susceptibility of the wound to rotting. Water loss was measured using a porometer (as described in Chapter 5, section 5.2.5). Susceptibility to rotting was determined by artificially inoculating wounds with the rot, *Rhizopus oryzae* after specific periods of healing.

Method Used to Assess Susceptibility to Microbial Invasion

Roots with wounds were kept under sub-optimal conditions for 3, 6 and 10 days after which they were assessed for susceptibility to *Rhizopus oryzae*. Mycelial discs (9 mm) were cut from the border of a 2-day-old potato dextrin agar (PDA) culture of *R. oryzae* and placed on the wound with the mycelial side facing down. Roots were incubated for 2 days in transparent polyethylene bags (40 x 50 cm), which were perforated with 16 holes for ventilation. The relative humidity and temperature in the bags were recorded using electronic data-loggers (Onset Computer Corporation 1998) and were found to be 94.2–97.5% and 21.7–24.0 °C, respectively.

To assess the extent of tissue degradation by the inoculated pathogens, the roots/tubers were then cut longitudinally through the point of inoculation (Duarte and Clark, 1993) and measurements of the lesions taken. The wounds were further assessed for lignification as described above.

The results presented in this chapter include an assessment of wound healing efficiency using the LI for a wide range of sweetpotato germplasm. Details of the root supply and the screening trials are given below.

Cultivars Included in the Screening Programme for Wound Healing Efficiency

Set A: 16 cultivars were grown in Nairobi by CIP as part of a worldwide trial on germplasm by environment (GxE) interactions: Blesbok, Brondal, Mugande, Mafutha, Cemsa 74-228, Kemb 37, Jayalo, Naveto, Zapallo, Santo Amaro, Yan Shu 1, NC 1560, Xu Shu 18, Tainung No.64, Mogamba and Kemb 10. Five additional check cultivars (Yan Shu 1, Kemb 10, KSP 20, Zapallo and SPK 004) were planted in a separate field trial. Trials were planted in January 2000 and were harvested in May and July 2000.

Set B: 18 cultivars were grown by Janice Bohac of the US Vegetable Laboratory (USDA-ARS): Beau Regard, PI 538354, PI 595856, PI 595873, Picadito, Regal, SC 1149-19, Sumor, Tanzanian, Tinian, W287 Ruddy, W-308, W-317, W-325, W-341, W-345, W364 97k-11and White Regal. The first season trials were planted in May and harvested October 1999, then cured and stored for 2 months before being assessed in January 2000. The second season trials were planted May 2000 and harvested in November 2000.

Set C: cultivars were grown in Nairobi, Kenya by CIP. These included eight Tanzanian cultivars (Bilagala, Budagala, Iboja, Kagole, Mwanamonde, Polista, Sinia B and SPN/0), five check cultivars (Kemb 10, KSP 20, SPK 004, Yanshu 1 and Zapallo) and four cultivars from North and South America (Beauregard, Jewel, Hernandez and L-86-33). The first season trials were planted in May and harvested in September 2000; the second season trials were planted in November 2000 and harvested in February 2001.

The post-harvest experiments were conducted at the Natural Resources Institute (NRI), Chatham, UK. Assessment of wound healing efficiency at moderate humidity was conducted with the roots placed in three controlled environment chambers maintained at 65% RH and 26 °C. For assessment at high humidity, the roots were placed in an enclosed bin with a layer of water in the base; relative humidity was greater than 95% throughout the assessment. The humidity and temperature of the storage environment were recorded using Tinytalk miniature data-loggers (Gemini, Chichester, UK). A minimum of 12 roots per cultivar were assessed at moderate humidity and a minimum of four roots per cultivar at high humidity.

6.3 Results and discussion

6.3.1 Physiology of wound healing at sub-optimal humidities

Relative humidity affects the pattern of wound healing and reduces its efficiency in sweetpotato roots, but the effects vary by cultivar. Figure 6.1 shows the cross-section of roots of eight sweetpotato cultivars after wounding and subsequent storage for 3 days and 6 days at 97, 65 and 58% RH. Roots that were kept at lower humidity after wounding show sunken wound surfaces, presumably due to desiccation. The response of roots to lower humidities appears to be cultivar dependent, with tissue shrinkage more pronounced for the cultivars SPK 004, Kemb 10, KSP 20 and Caplina. A thick desiccated crust formed in these cultivars, which was difficult to cut. Less shrinkage and much thinner desiccated crusts were observed for the cultivars Zapallo, Salyboro, Yan Shu 1 and Julian. These cultivars appear to heal more efficiently at the lower humidities.

Figure 6.2 shows micrographs of sections through wounds healed at 71% RH for three contrasting cultivars – Zapallo, Kemb10 and KSP 20. Lignification started at the periphery of the wound under the periderm, and subsequently developed towards the centre of the wound (Figure 6.3c) All cultivars show surface layers of desiccated cells which are flattened and appear white due to the concentration of starch granules as the cells lose water. This has been described previously for sweetpotato by Artschwager and Starrett (1931) and for yam (*Dioscorea* spp.) by Passam *et al.* (1976). Consistent with the observations above, the micrographs show that Zapallo has a much thinner desiccated layer than Kemb10 or KSP 20.

Lignified layers started to develop below the desiccated layer from 2 days after wounding for most cultivars, although development started after 1 day in roots of some cultivars, notably Yan Shu 1 and KSP 20. Figure 6.3a–c shows micrographs of wounds from three contrasting cultivars. Zapallo developed lignified layers close to the surface (Figure 6.3a). For some cultivars, a continuous lignin layer never developed, the layer remaining patchy/discontinuous (Figure 6.3b), or even absent (Figure 6.3c) at the centre of the wound.

Thickness of desiccated and lignified layers

More detailed studies were carried out on five of the eight cultivars. The number of lignified cell layers observed by microscopy increased for 5 days after wounding and healing at 82% RH (Table 6.4). The mean number of lignified cell layers for the five cultivars was significantly different and varied between 0.47 and 3.65 layers after 4 days and 1.75 and 3.36 layers after 5 days. This is a thinner layer than reported for curing at high humidity by Walter and Schadel

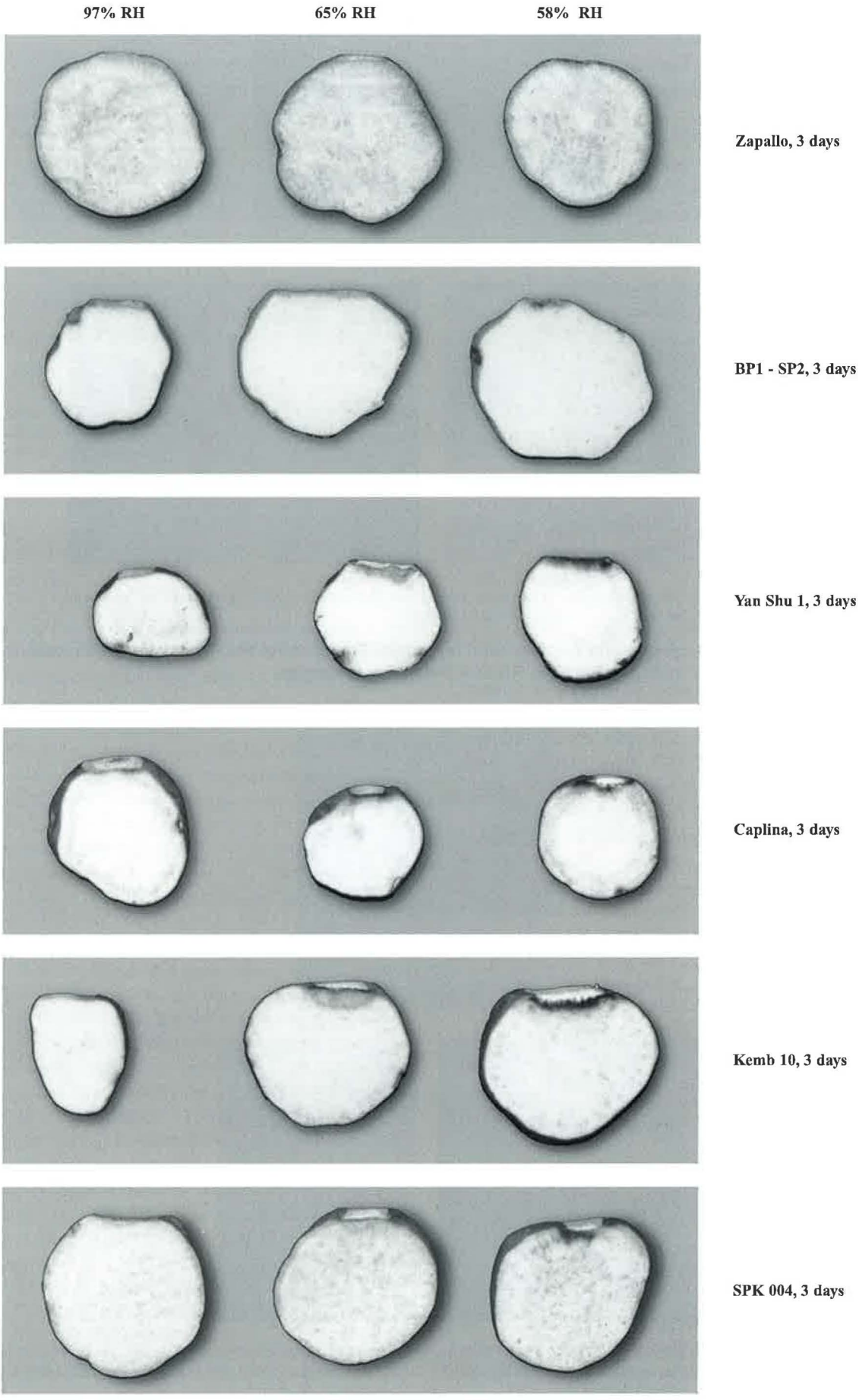
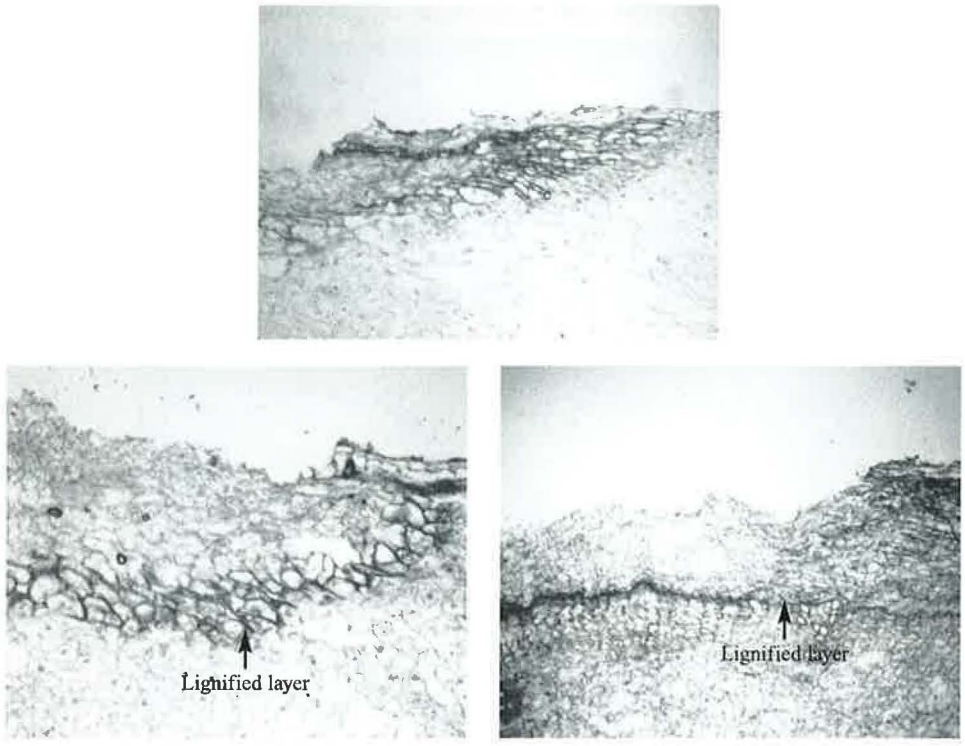
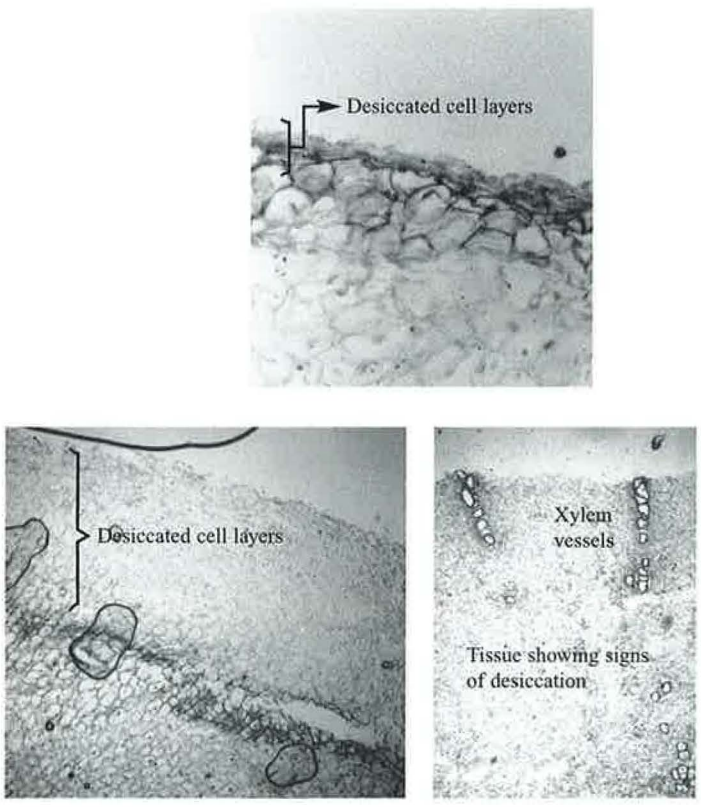


Figure 6.1 Slices of sweetpotato with wounds; variability in depth of desiccation depending on cultivar and relative humidity



The bar represents around 200 mm. Sections: 15 mm thick, stained with Phloroglucinol/HCl, which stains the lignin red. The sections were taken from (a) Zapallo, (b) Kemb 10 and (c) KSP 20.

Figure 6.2 Lignification starts at the wound boundary. The onset of the lignin layer in wounds of sweetpotato kept at 71% RH at 6 days after wounding



Sections were stained with phloroglucinol (1% in ethanol 95%) and concentrated HCl. Magnification: x 40 or x 100. The bar represents 100 mm. (a) Zapallo: thin desiccated cell layer (x 100), (b) KSP 20: 20 to 25 desiccated cell layers above patchy lignification (x40), (c) SPK 004: no lignified cell layers (x 40).

Figure 6.3 Variability in depth of desiccation. Typical sections through sweetpotato wounds at 6 days after wounding when the roots were kept at 71.1% RH and 20.9 ± 1.6 °C

Table 6.4 The number of lignified cell layers following artificial wounding and healing in roots of five cultivars of sweetpotato

Days after wounding	2	3	4	5
Yan Shu 1	1.41	1.29	2.04	2.28
Kemb 10	0.96	2.19	2.39	3.36
KSP 20	0.56	1.56	3.65	3.09
Zapallo	1.21	1.96	2.15	2.88
SPK 004	0.47	0.97	0.47	1.75
Cultivar effect (*P* value)	ns	ns	< 0.001	0.076
LSD	0.85	1.00	1.24	1.73

Roots were obtained from Trial 1 after 1 and 4 weeks of storage. Measurements were taken for five wounds per cultivar for each storage time. Healing conditions: 26 °C and 82% RH. No significant effects of storage time were found.

LSD = least significant difference.

(1983), who found on average 4.3 layers of suberized cells after 5–7 days.

Given that it is not possible to differentiate cells in the desiccated layer, a better indication of the thickness of both desiccated and lignified layers could be obtained by using a microscope fitted with a graticule to measure the actual dimensions. Table 6.5 shows data obtained for roots that had been stored for 1 and 6 weeks after harvest. For the lignified layer, highly significant differences among cultivars were observed for 2, 4, 6 and 10 days of healing. Results were less clear for the desiccated cell layers, but cultivar differences were significant after 4 days and highly significant after 10 days. An effect of storage time was only apparent after 10 days of healing, at which time SPK 004 and Kemb 10 had much thinner lignified layers, and thicker desiccated layers, while the other three cultivars showed no change. The cultivars SPK 004 and Kemb 10 had the thinnest lignified layers throughout healing with some roots completely failing to lignify. Yan Shu 1 and Zapallo had the thickest lignified layers. The results confirmed the findings of Walter and Schadel (1983) that after 4 days lignification is complete, but disagreed with the results of St Amand and Randle (1991), who described an almost linear increase in the number of lignified cell layers from 0 to 7 layers between 3 and 12 days after wounding (at 29 °C and 85% RH).

6.3.2 Continuity and depth of the lignified layer as an indication of wound healing efficiency

Average thickness of the lignified layer gives no indication of the completeness of the layer. As mentioned above, for some wounds, lignification occurred in a patchy pattern, with 5–6 lignified layers in some places, but no lignification in others, while some wounds completely failed to produce lignin. Failure to lignify was observed in 30 out of 46 roots of SPK 004 and 26 out of 42 roots for Kemb 10.

The thickness of the desiccated cell layer, and hence the depth of the lignified layer (Table 6.5), appears to be related to the efficiency of the healing process. Absence of a lignified layer usually coincided with a very thick desiccated layer and development of a hard wound surface. In these cases, the desiccated layer stained bright red with safranin-fast green, indicating the presence of phenolics, consistent with disruption of lignin synthesis. On the other hand, in those cultivars with efficient lignin synthesis, the desiccated layer tended to be thin and the lignified cell layers close to the surface (e.g. Zapallo, Figure 6.2). Strider and McCombs (1958) observed such a pattern when comparing roots cured at different humidities. Thus, they reported a thick desiccated layer (17 cell layers) where the roots were kept at 21 °C and 60% RH, compared to a depth of 4–6 layers where roots were healed at 95% RH. These authors did not compare different cultivars.

6.3.3 Lignification index as a measure of wound healing efficiency

A range of methods to measure progress of wound healing have been reported in the literature. Cell layers may be counted using microscopy (as above and Strider and McCombs, 1958). Walter and Schadel (1982) developed a rapid method in which artificially inflicted wounds are lifted off the tissue after healing and stained with phloroglucinol. The colour intensity was used to indicate the level of lignification. It was found that 1.4 layers of lignified cells stained pink, 2.6 layers stained red, and above 4 layers stained reddish-purple. Lulai and Orr (1995) measured the wound healing efficiency in potato by determining the transpiration rate through the wound surface using a porometer. These methods generally require sophisticated equipment, or are too time consuming to be used to screen germplasm. In addition, from our observations, we considered that the continuity of lignification is more important in the healing of wounds than the thickness of the lignified layer, and that there appears to be little relationship between thickness of the lignified layer and continuity. Thus Yan Shu 1 tends to have good continuity, but thin lignified layers. We, therefore, developed a rapid method to assess continuity of the lignified layer to determine the wound healing efficiency of cultivars at lower humidities. After staining lignin with phloroglucinol, the continuity of the lignified layer can be easily assessed and scored by the naked eye in tissue sections cut by hand from wounds left to heal for 5 days. The average score for each wound (0–1) was termed the lignification index (LI) (see section 6.2 for further details). This method is quick, as the staining is rapid

Table 6.5 The thickness of the desiccated and lignified cell layers (µm) during healing after artificial wounding of roots of five cultivars of sweetpotato

Days of healing		2 days		4 days		6 days		10 days	
	Storage time from harvest	Desiccated cells	Lignified cells	Desiccated cells	Lignified cells	Desiccated cells	Lignified cells	Desiccated cells	Lignified cells
Yan Shu 1	1 week	23.2	22.8	24.4	22.7	18.2	25.3	22.6	27.4
	6 weeks							20.5	29.2
Kemb 10	1 week	19.4	5.8	26.5	20	14.2	6.4	21	22
	6 weeks							75	2
KSP 20	1 week	19.4	13.7	38.6	28.4	22.7	38.4	44	34.2
	6 weeks							16	32.5
Zapallo	1 week	15.5	20.1	21.4	32.6	11.9	29.1	16.8	27.2
	6 weeks							16.2	19.8
SPK 004	1 week	19.8	3.9	46	5.3	24.8	12.4	58	19.6
	6 weeks							122.8	3.5
Storage effect *P* value		ns	ns	ns	ns	ns	ns	0.013	0.019
Cultivar effect *P* value		ns	< 0.001	0.045	0.011	ns	<0.001	< 0.001	0.001
Cultivar storage effect *P* value				0.004				<0.001	
LSD cultivar		16.95	7.76		16.36		12.76		
LSD cultivar storage								32.04	16.84

Measurements were taken using a microscope equipped with a graticule for four sections per root, after 1 and 6 weeks of storage. Five and four roots obtained from Trial 2 were assessed per cultivar after 1 and 6 weeks, respectively. In some cases it was not possible to determine the thickness of the desiccated cell layers, and this was treated as missing data. Healing conditions: 26 °C and 73% RH.
LSD = least significant difference.

(3 min), requires minimal equipment and can thus be used in developing countries of the tropics where laboratory facilities with microscopes are not available.

Table 6.6 shows the LI for the five cultivars, measured in seven trials. Consistently high LIs were observed for the cultivars Zapallo and Yan Shu 1, while SPK 004 was consistently poor. The cultivars Kemb 10 and KSP 20 were more variable, and appeared to show some dependence on relative humidity.

The relationship between LI and humidity is examined in more detail in Figure 6.4 which shows the LI for 13 cultivars measured at three relative humidities (58%, 65% and 97%). At high humidity, the LI is close to 1 for all cultivars but there is a wide range among cultivars in the ability to lignify at lower humidities.

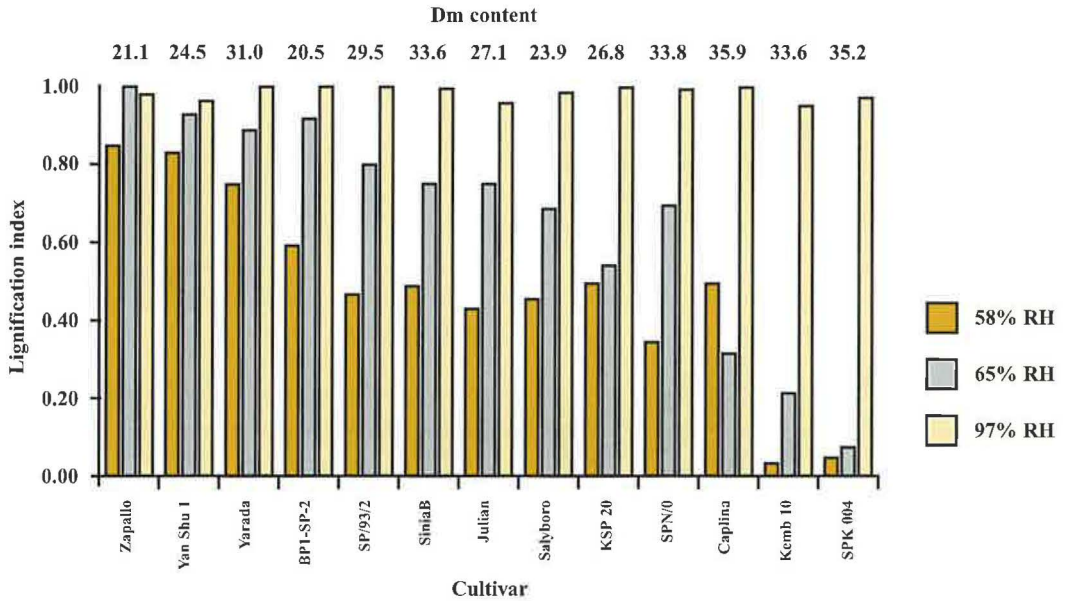
Testing the validity of the lignification index as an indicator of healing and storability

Wound healing is considered important both to reduce water loss through a wound, and also to prevent the entry of pathogens. We tested the validity of the LI as a measure of wound healing in terms of both these aspects.

(i) The relationship between the LI and water loss through a wound

Water loss through wounds was measured directly in terms of transpiration rate using a modified leaf porometer. Figure 6.5 shows the transpiration rate over time through wounds healed at 76% RH for the five key cultivars. The transpiration rate decreases during the wound healing process. This is partly due to desiccation of the top cell layers under the wound, and partly through lignification and formation of the wound periderm. Although cultivars showed a similar pattern, significant differences were observed among them at all time points. Consistent with the LI, the transpiration rates through wounds in Zapallo and Yan Shu 1 were always lower than for Kemb 10, KSP 20 and SPK 004.

In Figure 6.5, the transpiration rates are also shown for two potato cultivars. It is worth noting that the water loss profiles of potato were different from those of sweetpotato. The transpiration rate through wounds in potato decreased more rapidly after wounding, confirming the findings of Lulai *et al.* (1996). Thus the barrier under a potato wound forms more rapidly, or has a more effective sealing capacity than in



Roots were obtained from Trial 8. At least four roots were used for each measurement. Cultivar root dry matter content measured using three roots per cultivar is given at the top of the graph.

Figure 6.4 The LI of thirteen sweetpotato cultivars measured after healing at three relative humidities (58%, 65% and 97%)

Table 6.6 The lignification index of five sweetpotato cultivars as determined in five trials

	Trial 1	Trial 1 (4 weeks)	Trial 2	Trial 2 (6 weeks)	Trial 4 (6 weeks)	Trial 5	Trial 7
Temperature (°C)	**26**	**26**	**26**	**26**	**21**	**20**	**23**
RH (%)	**82**	**82**	**73**	**73**	**71**	**76**	**65**
Zapallo	1	0.82	1	0.95	0.89	1	0.79
Yan Shu 1	0.8	0.9	1	1	0.96	0.98	0.95
KSP 20	0.85	0.91	0.8	0.9	0.3	0.58	0.33
Kemb 10	1	0.6	0.45	0.16	0.39	0.79	0.25
SPK 004	0.29	0.35	0.38	0.3	0.15	0.31	0.15

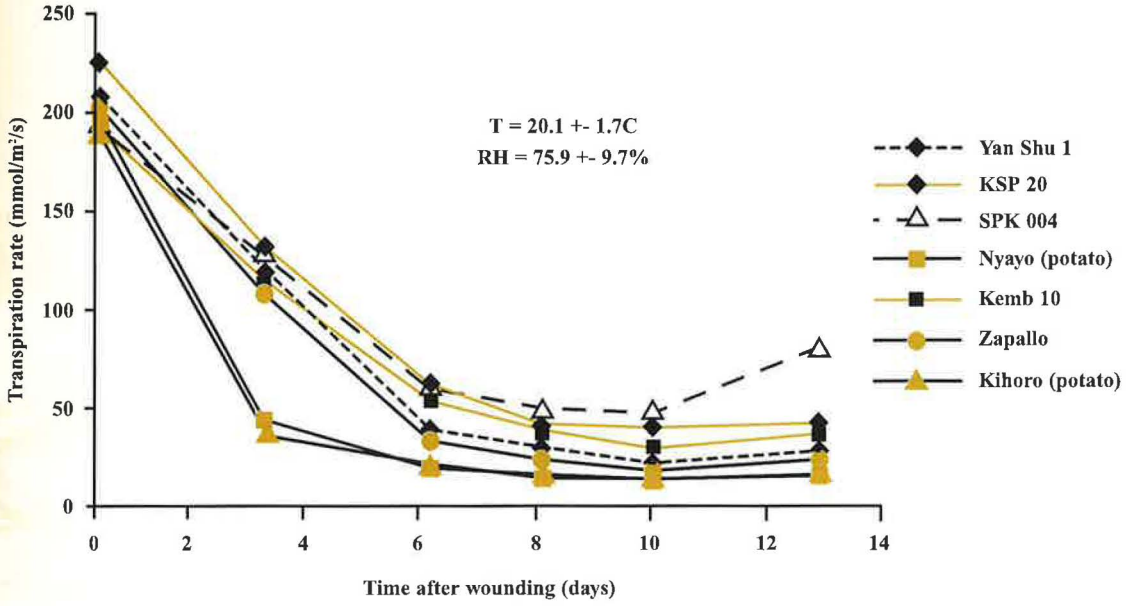
For Trials 1 and 2, measurements were repeated after 4 and 6 weeks of storage, respectively. At least four roots were assessed per cultivar in each trial.

sweetpotato. The barrier formed in potato does not stain with phloroglucinol/HCl, but stains with Sudan III and is assumed, therefore, to consist mainly of suberin (Lulai and Morgan, 1992). The barrier in sweetpotato on the other hand stains bright red with phloroglucinol/HCl and is believed to be a ligno-suberin-like substance with more lignin character (McClure, 1960).

The association between the presence/continuity of lignin and transpiration rate was assessed using statistical tests. These indicated that completeness of the lignified layer (high LI) was related to lower transpiration rates (Table 6.7). Thus, the distribution of the levels of transpiration rate were divided into three categories (i.e. low, intermediate and high) and lignification was divided into two categories, according to the completeness of lignification. Pearson chi square tests indicated that lignification was significantly associated with lower transpiration rates at 6, 8, 10 and 13 days after wounding. No association with transpiration rate was only indicated on day 3 when presumably the wound healing process was not completed.

(ii) The relationship between the lignification index and pathogen invasion of the wound

The effectiveness of wound healing in protecting the wound against pathogen invasion was tested by placing mycelia of *Rhizopus oryzae* directly on to wounds at various stages during the healing process. Figure 6.6 shows the dimensions of lesions allowed to develop over 2 days for twelve cultivars. SPK 004 is notable in the development of lesions on wounds even after 6 days of healing. A contingency table relating the incidence of rots to either the presence of lignin, or to the completeness of the lignified layer (Table 6.8), indicates that the latter is much more important in preventing rotting.



Roots were obtained from Trial 5. Each value is the mean of 5–10 measurements taken with a porometer at the wound site. Healing conditions: 20 °C, 76% RH.

Figure 6.5 Transpiration rate through artificially inflicted wounds for five sweetpotato and two potato cultivars

Table 6.7 Association between lignification and the rate of water loss through wounds after 3, 6, 8, 10 and 13 days of healing

					Counts of roots			
Time after wounding	Transpiration (T) (mmol/s/m²)				No lignin or patchy lignin	Continuous lignin layer	Chi square value	*P* value
3 days	Low	76.2	> T		5	9	3.26	= 0.196
	Intermediate	76.2	< T <	89.2	7	4		
	High		T >	89.2	10	5		
6 days	Low	43.2	> T		0	12	11.80	= 0.003
	Intermediate	43.2	< T <	57.8	8	4		
	High		T >	57.8	5	8		
8 days	Low	37.25	> T		3	9	17.20	< 0.001
	Intermediate	37.25	< T <	63.75	1	10		
	High		T >	63.75	10	1		
10 days	Low	29.6	> T		1	9	8.36	= 0.015
	Intermediate	29.6	< T <	69.4	3	8		
	High		T >	69.4	7	3		
13 days	Low	14	> T		2	9	8.71	= 0.013
	Intermediate	14	< T <	19.4	0	12		
	High		T >	19.4	6	6		

Data was collected from Trial 4. Healing conditions: 21 °C, 71% RH.

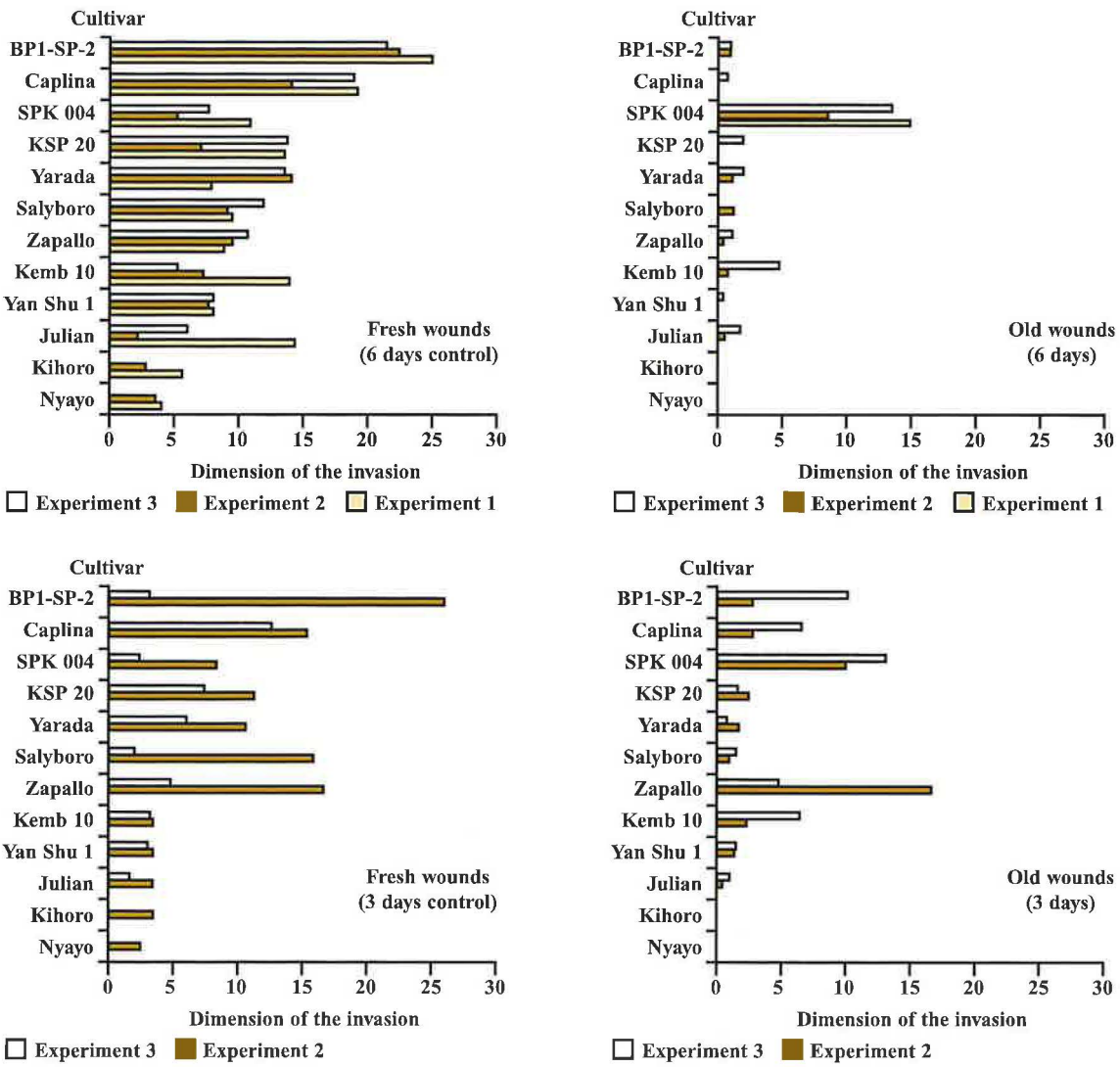
Lignification index and storability (weight loss)

The results above establish that continuity of the lignin layer and, therefore, the LI provide a valid indication of functional wound healing for sweetpotatoes at sub-optimal humidities. In Chapter 5, we postulated that water loss is the main cause of deterioration for roots during marketing in the tropics (Rees *et al.*, in press) and suggested that during marketing most water loss occurs through new or incompletely healed wounds (van Oirschot, 2000). This suggests that the LI for a cultivar could provide an important indication of the potential shelf-life during marketing. Consistent with this, we find that high weight losses occur during storage for cultivars with poor lignification efficiency

Table 6.8 Contingency table using the incidence of roots rotting and/or lignification

Time after wounding	Rotting	(A) Presence of lignin		(B) Completeness of lignified layer	
		No lignin	Patchy lignin Complete lignification	No lignin Patchy lignin	Complete lignification
Day 3	No rotting	11	26	14	23
	Rotting	18	31	28	21
		Pearson chi square = 0.46 $P = 0.496$ Fisher's exact test: $P = 0.6455$		Pearson chi square = 6.71 $P = 0.010$ Fisher's exact test: $P = 0.01544$	
Day 6	No rotting	5	28	5	28
	Rotting	15	19	26	8
		Pearson chi square = 3.14 $P = 0.076$ Fisher's exact test: $P = 0.0861$		Pearson chi square = 25.33 $P < 0.001$ Fisher's exact test: $P < 0.001$	

In (A) patchy lignified roots were grouped with complete lignified roots, and in (B) patchy lignification was grouped with 'no lignin'.



Freshly cut wounds were used as controls. Mycelial plugs were placed on the wound and the roots were incubated for 2 days in plastic bags to maintain humidity (at 21–25 °C, 95% RH) ($LSD_{3\ days} = 6.96$; $LSD_{6\ days} = 5.74$; $LSD_{10\ days} = 7.02$).

Figure 6.6 The dimensions of lesions of *R. oryzae* placed on 3, 6 or 10-day-old wounds

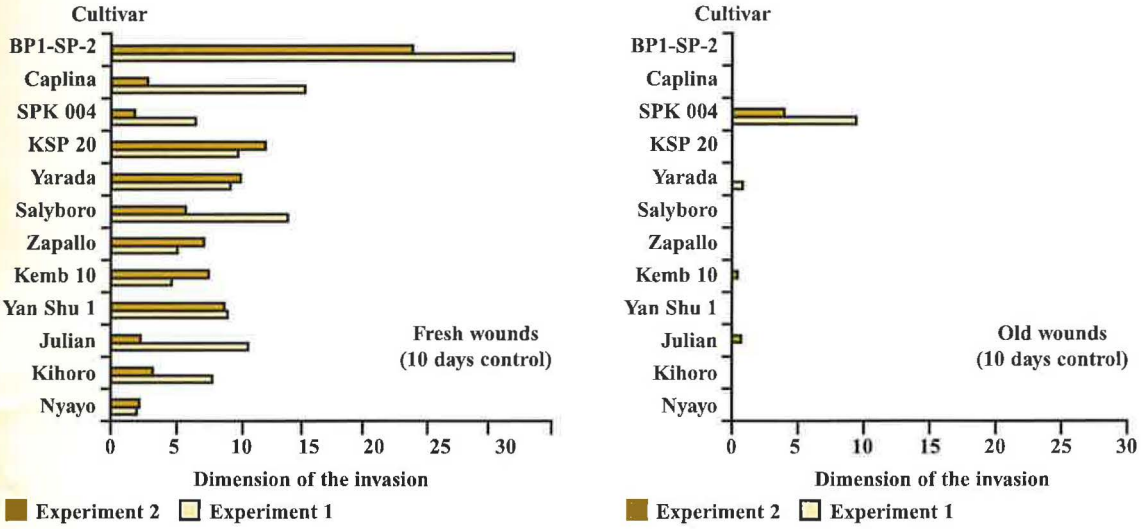


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Figure 6.6 ***cont.***

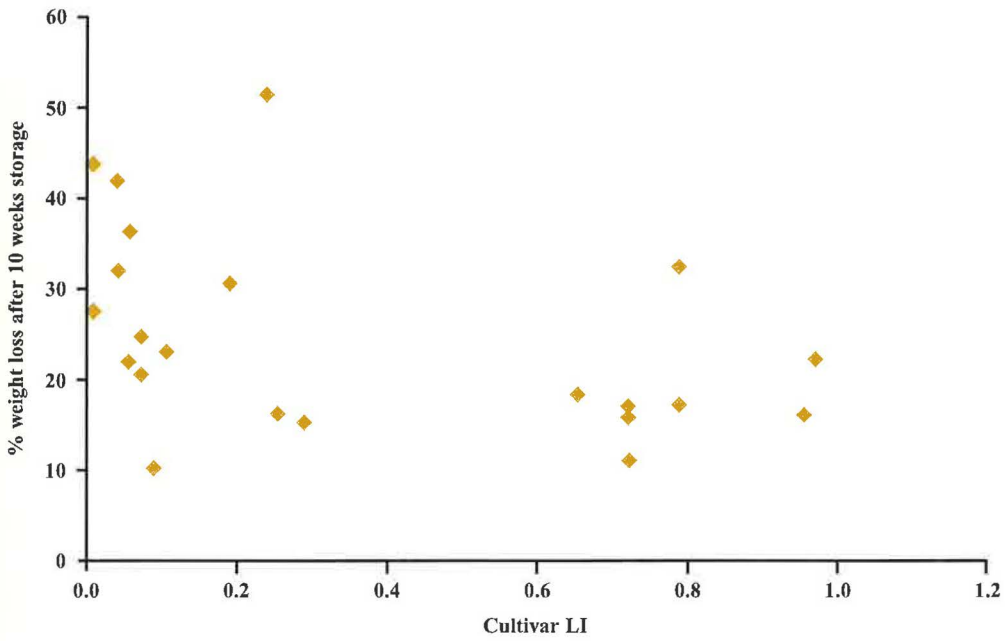

Figure 6.7 The relationship between cultivar LI and percentage root weight loss after 10 weeks of storage. Each point corresponds to a cultivar

(Figure 6.7, correlation coefficient -0.472, P = 0.027). This is in contrast with the findings of Walter *et al.* (1989) that the rate of lignification did not relate to storability.

6.3.4 Screening of sweetpotato germplasm using the lignification index

Once we were confident that the LI was a valid measure of wound healing efficiency, we initiated a screening programme of sweetpotato germplasm from all areas of the world to find cultivars that were particularly efficient at healing at lower humidities. These cultivars would be valuable in breeding programmes.

Three sets of cultivars were assessed (see section 6.2. for details). For all sets, a large range in LI was found. Moreover, a comparison of the results obtained for the two harvests of Set A, and for the two seasons for Sets B and C, indicated that cultivar behaviour was fairly consistent (Figure 6.8a–c). Correlation coefficients (r) of 0.80 (P< 0.001), 0.47 (P<0.001) and 0.82 (P<0.05)

were calculated for sets A, B and C, respectively. The lower correlation seen for Set B may be because the roots were stored prior to screening in the first season.

Table 6.9 presents the mean LI for each cultivar measured both at moderate and high humidity. As previously suggested (van Oirschot, 2000) almost all cultivars have high LI at high humidity, although there are a few exceptions, for example, Beauregard, Hernandez and L86-33.

Why does wound healing efficiency vary among cultivars?

A key question is what is the physiological basis for differences in wound healing efficiency among sweetpotato cultivars. If we could understand this, then it might help in the selection of better cultivars, and may even provide the basis for genetic modification in future decades. Research is ongoing in the investigation of this issue. We found a relationship between dry matter (DM) content and wound healing efficiency in several trials. High DM cultivars tended to be less efficient at wound healing at moderate humidities. This was in agreement with Rees *et al.* (1998) who reported that high dry matter is often related to short shelf-life.

The finding that cultivars with higher DM content have less efficient wound healing would be unwelcome. High DM is associated with sensory characteristics (*Flouriness*) important for consumer acceptability in East Africa (Kapinga *et al.*, 1997) and is a key attribute for processing. The characteristic is considered so important worldwide that CIP has a specific initiative to breed for higher DM cultivars. It thus becomes important to determine whether it is possible to breed for cultivars with high DM content and good wound healing characteristics.

Figure 6.9 classifies the cultivars screened according to their origin. It is apparent that the cultivars cluster by origin, for both DM and LI. For example, cultivars originating from East Africa had higher DM content and lower LI than cultivars from the USA or Central/South America. Although for the whole data set, there is a significant negative correlation between DM and LI, correlation analysis carried out separately for cultivars of each origin did not reveal any significant relationships between DM and LI.

To investigate this matter further, a set of five experiments was conducted on a selection of cultivars in which DM content and LI at moderate humidity was measured for each individual root. In this way it was possible to use multivariate linear regression analysis to model LI in terms of cultivar and DM content. The linear regression models obtained from the five experiments, with their significance levels, are presented in Table 6.10. In all cases, cultivar was the

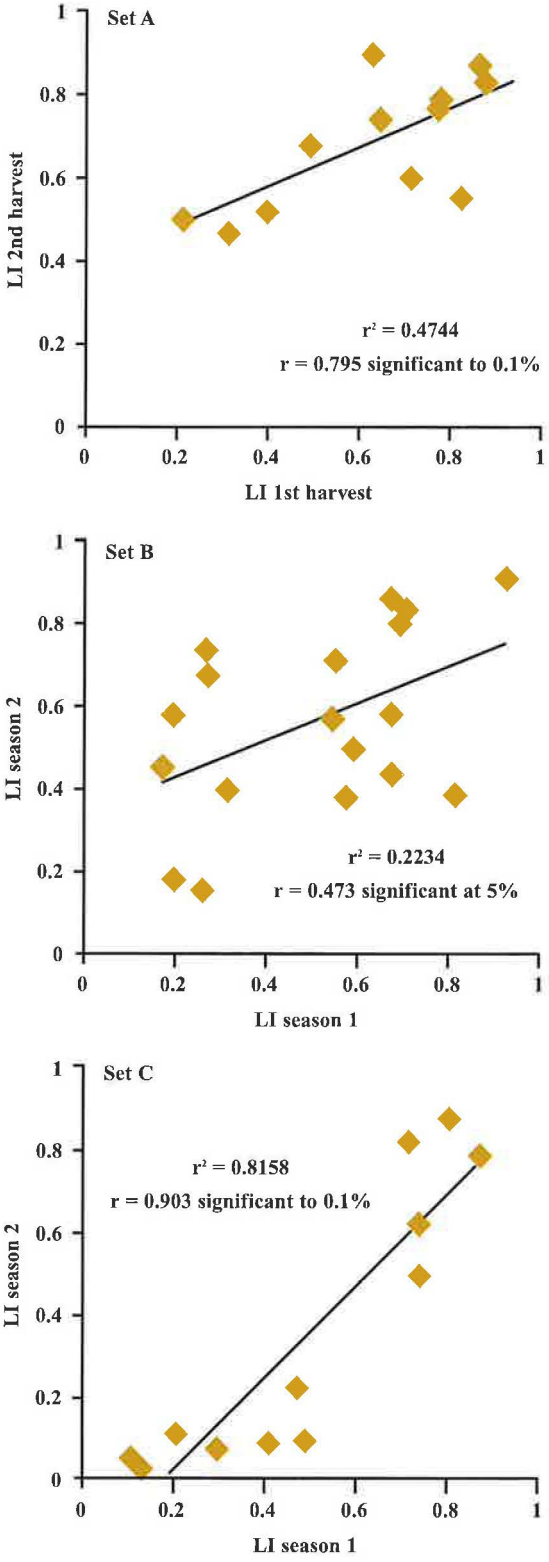

Figure 6.8 Comparison of the LI measured at moderate humidity by cultivar: (a) Set A, first and second harvest; (b) Set B, first and second season; (c) Set C, first and second season

most important factor. However, in each case, root DM content made an extra contribution, albeit a small one, to the strength of the model. The general conclusion from this data is that DM content does affect wound

Table 6.9 Mean LIs measured at high and moderate relative humidity, for all cultivars screened

Cultivar	LI high RH	LI moderate RH
W-308	0.99	0.93
Blesbok	0.83	0.87
Yan Shu 1	0.98	0.86
Zapallo	0.91	0.80
Jewel	0.78	0.78
Cemsa 74-228	0.90	0.77
Xu Shu 18	0.83	0.77
PI 595856	0.96	0.75
W-287	0.78	0.74
Sumor	0.93	0.71
Tainung No 64	0.78	0.71
Beauregard	0.64	0.68
Brondal	0.90	0.68
Jayalo	-	0.68
Naveto	0.90	0.68
W-325	0.91	0.67
Tinian	0.95	0.63
Sinia	0.95	0.60
W-317	0.94	0.57
L-86-33	0.64	0.57
PI 595873	0.97	0.56
Santo Amaro	0.90	0.55
W-341	1.00	0.55
W-345	0.94	0.48
Mafutha	0.93	0.45
Mugande	0.98	0.39
97K-11	1.00	0.38
Mogamba	0.90	0.37
Regal	0.98	0.35
SC 1149-19	0.95	0.33
Kemb 37	0.85	0.31
SPN/0	0.84	0.29
Bilagala	0.73	0.29
White Regal	0.96	0.27
Picadito	0.94	0.26
KSP 20	0.96	0.23
Kemb 10	0.94	0.22
Tanzania	0.98	0.20
NC 1560	0.95	0.20
PI 538354	0.96	0.18
Hernandez	0.61	0.13
Budagala	0.94	0.13
Polista	1.00	0.10
Kagole	0.96	0.08
SPK 004	0.94	0.05
Iboja	1.00	0.05
Mwanamonde	1.00	0.05

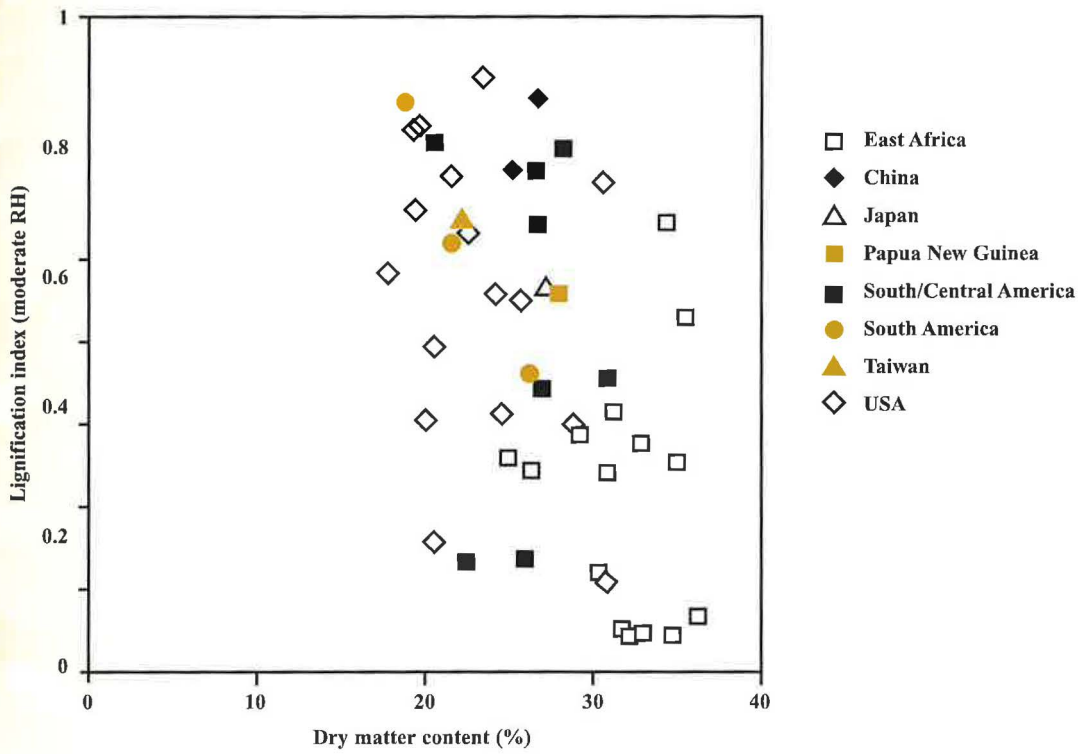

Figure 6.9 Relationship between LI (at moderate relative humidity) and dry matter content for all cultivars tested, classified by location

Table 6.10 Multivariate linear regression models for LI at moderate humidity

Experiment	Model (cultivar)	Model (DM and cultivar)
1	LI = 0.303 + constant* cultivar $P<0.001$ 34.3% variance accounted for	LI = 1.182–0.030 DMCi + constant* cultivar $P<0.001$ 36% variance accounted for
2	LI = 0.625 + constant* cultivar $P<0.001$ 23.1% variance accounted for	LI = 1.276–0.036 DMCi + constant* cultivar $P<0.001$ 28.2% variance accounted for
3	LI = 0.272 + constant* cultivar $P<0.001$ 40.0% variance accounted for	LI = 0.902–0.021 DMCi + constant* cultivar $P<0.001$ 41.7 % variance accounted for
4	LI = 0.224 + constant* cultivar $P<0.001$ 43.1% variance accounted for	LI = 1.075–0.027 DMCi + constant* cultivar $P<0.001$ 45.4% variance accounted for
5	LI = 0.37 + constant* cultivar $P<0.045$ 7.2% variance accounted for	LI = 1.59–0.058 DMCi + constant* cultivar $P<0.001$ 18.3% variance accounted for

DMCi = Initial DM content. For experiments 1–4, this was estimated using final DM content and weight loss during the experiment. For experiment 5, the root was cut in halves at the start of the experiment, and one half used to measure DMC.

Experiment 1: 18 roots each of 10 cultivars; Experiment 2: 13–18 roots each of 13 cultivars; Experiment 3: 182 roots each of 12 cultivars; Experiment 4: 17–18 roots each of 11 cultivars; Experiment 5: 12 roots each of 9 cultivars.

healing ability at moderate humidity, but there are other cultivar factors that are much more important.

This matter is still under investigation (further information can be obtained by contacting Q. van Oirschot or D. Rees).

6.4 Conclusions and implications

Under sub-optimal humidities (65% ± 10) the wound healing process in sweetpotato follows a similar pattern to wound healing under curing conditions. However, the thickness of the desiccated cell layer, and hence the depth of the lignified layer, is affected by both cultivar and humidity. Some cultivars consistently failed to produce a lignified layer while in others the layer is often not continuous. The continuity of the lignified layer is more important for effectiveness of wound healing than the actual thickness.

Wound healing efficiency as measured by lignification was found to be a major factor in the shelf-life of sweet potato cultivars. Lignification of wounds correlates with reduced rate of weight loss and fungal infection.

A method for assessing efficiency of wound healing termed the lignification index, based on assessing the continuity of lignified layers has been developed. This quick and simple method estimates the probability that wound healing occurs, and does not require a microscope. This could be a suitable method by which breeding programmes could assess their germplasm.

References

ARTSCHWAGER, E. and STARRETT, R.C. (1931) Suberization and wound-periderm formation in sweetpotato and gladiolus as affected by temperature and relative humidity. *Journal of Agricultural Research*, **43** (3): 353–364.

COLLINS, W.W. and WALTER, W.M. (1985) Fresh roots for human consumption. pp. 153–173. In: *Sweet Potato Products: A Natural Resource for the Tropics*. Bouwkamp, J.C. (ed.). Boca Raton: CRC Press Inc.

DUARTE, V. and CLARK, C.A. (1993) Interaction of *Erwinia chrysanthemi* and *Fusarium solani* on sweet potato. *Plant Disease*, **77**: 733–735.

JENKINS, P.D. (1982) Losses in sweet potatoes (*Ipomoea batatas*) stored under traditional conditions in Bangladesh. *Tropical Science*, **24** (1): 17–28.

KAPINGA, R.E., JEREMIAH, S.C., RWIZA, E.J. and REES, D. (1997) Preferences and Selection Criteria of Sweetpotato in Urban Areas of the Lake Zone of Tanzania. Chatham, UK: Natural Resources Institute. (unpublished)

KUSHMAN, L.J. and WRIGHT, F.S. (1969) Sweet potato storage. *USDA Agriculture Handbook*, No. 358.

LULAI, E.C., GLYNN, M.T. and ORR, P.H. (1996) Cellular changes and physiological responses to tuber pressure bruising. *American Potato Journal*, **73**: 197–209.

LULAI, E.C. and MORGAN, W.C. (1992) Histochemical probing of potato periderm with neutral red: a sensitive cytofluorochrome for hydrophobic domain of suberin. *Biotechnic and Histochemistry*, **67**: 185–195.

LULAI, E.C. and ORR, P.H. (1995) Porometer measurements indicate wound severity and tuber maturity affect the early stages of wound-healing. *American Potato Journal*, **72**: 225–241.

MCCLURE, T.T. (1960) Chlorogenic acid accumulation and wound healing in sweet potato roots. *American Journal of Botany*, **47**: 277–280.

MORRIS, L.L. and MANN, L.K. (1955) Wound healing, keeping quality, and compositional changes during curing and storage of sweet potatoes. *Hilgardia*, **24** (7): 143–183.

NIELSEN, L.W. and JOHNSON, J.T. (1974) Postharvest temperature effects on wound healing and surface rot in sweetpotato. *Phytopathology*, **64**: 967–970.

PASSAM, H.C., READ, S.J. and RICKARD, J.E. (1976) Wound repair in yam tubers: physiological processes during repair. *New Phytologist*, **77**: 325–331.

REES, D., KAPINGA, R., RWIZA, E., MOHAMMED, R., VAN OIRSCHOT, Q., CAREY, E. and WESTBY, A. (1998) The potential for extending shelf-life of sweet potato in East Africa through cultivar selection. *Tropical Agriculture (Trinidad)*, **75**: 208–211.

REES, D., VAN OIRSCHOT, Q.E.A., AMOUR, R., RWIZA, E., KAPINGA, R. and CAREY, T. (in press) Cultivar variation in keeping quality of sweetpotatoes. *Postharvest Biology and Technology*.

RICKARD, J.E. (1985) Physiological deterioration in cassava roots. *Journal of Science of Food and Agriculture*, **36**: 167–176.

ST AMAND, P.C. and RANDLE, W.M. (1991) Ethylene production as a possible indicator of wound healing in roots of several sweet potato cultivars. *Euphytica*, **53**: 97–102.

STRIDER, D.L. and MCCOMBS, C.L. (1958) Rate of wound phellem formation in the sweet potato. *American Society for Horticultural Science*, **72**: 435–442.

VAN OIRSCHOT, Q.E.A. (2000) *Storability of Sweet Potatoes (Ipomoea batatas (L.)) under Tropical Conditions: Physiological and Sensory Aspects*. PhD thesis, Cranfield University.

VAN OIRSCHOT, Q.E., REES, D., LUCAS, C., MAINA, D., MCHARO, T. and BOHAC, J. (2001) Sweetpotato: germplasm evaluation for wound healing efficiency. *Acta Horticulturae*, **584**: 31–40.

WALTER, W.M., HAMMETT, L.K. and GIESBRECHT, F.G. (1989). Wound healing in sweet potato and stability during subsequent storage. *Journal of the American Society for Horticultural Science*, **114**: 94-100.

WALTER, W.M. and SCHADEL, W.E. (1982) A rapid method for evaluating curing progress in sweet potatoes. *Journal of the American Society for Horticultural Science*, **107**: 1129–1133.

WALTER, W.M. and SCHADEL, W.E. (1983) Structure and composition of normal skin (periderm) and wound tissue from cured sweet potatoes. *Journal of the American Society for Horticultural Science*, **108**: 909–914.

WEIMER, J.L. and HARTER, L.L. (1921) Wound cork formation in the sweet potato. *Journal of Agricultural Research*, **21** (9): 637–647.

WOOLFE, J.A. (1992) *Sweet Potato. An Untapped Food Resource*. Cambridge: Cambridge University Press.

CHAPTER 7

Improving long-term storage under tropical conditions: role of cultivar selection

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7.1 Introduction

7.1.1 The potential for long-term storage under tropical conditions

Storage temperature has a large effect on the keeping qualities of sweetpotato. The ideal storage temperature is 13–15 °C; lower temperatures can cause physiological damage, whereas higher temperatures promote fast metabolic rates and, therefore, increase rates of deterioration. Thus, where temperature-controlled storage is feasible, roots can be stored for extended periods of time. For example, in the USA, sweetpotatoes are often stored for up to a year (Picha, 1986). In some cooler areas of the tropics, long-term fresh storage is also routinely practised. For example, in the highlands of south-west Tanzania, sweetpotatoes are traditionally stored in pits under banana trees for several months (Kapinga *et al.*, 1995).

Despite increased metabolic rates, it has been demonstrated that even in warmer regions, fresh storage for several months is technically feasible. This has been demonstrated in Uganda, where sweetpotatoes were stored for up to 4 months in pits and clamps (Hall and Devereau, 2000). At this time, there is still an element of risk in such storage; some of the trials failed with most of the roots rotting. Mbeza *et al.* (1997) reported that although sweetpotatoes can

be stored in pits for up to 5 months, the market value obtained thereafter is low and unattractive. The main reasons are losses in weight due to shrinkage and attack by moulds. To what extent success or failure is due to

the design of the store, or due to variations in climate during storage, has not yet been established.

7.1.2 Root characteristics desirable for long-term storage

In Chapter 5, we distinguished between root 'shelf-life' and 'storability', and discussed the fact that characteristics that make a cultivar suitable for long-term storage may not be the same as those that give a cultivar a long shelf-life and, therefore, make it suitable for marketing.

Resistance to rotting

We have established that for long shelf-life during marketing and handling, a cultivar should have a low susceptibility to water loss and efficient wound healing (Chapters 5 and 6). However, long-term storage structures are usually designed to maintain a high humidity. In the high temperatures experienced in the tropics, curing will occur naturally, and efficiency of wound healing is less of an issue. During marketing and handling, the main controlling factor is the extent of unhealed surface wounds through which pathogens causing rots can enter, whereas under storage environments, the intrinsic resistance of tissues to pathogen growth is likely to be more important.

Root respiration

Where ventilation is low, root respiration will lead to a decrease in levels of oxygen and an increase in carbon dioxide. If the change in atmospheric composition is too great, then roots may be unable to metabolize normally, and may switch to anaerobic respiration (see below), which in turn leads to root damage. Thus, cultivars with low respiration rates and resistance to switching to anaerobic respiration would be advantageous.

Anaerobic respiration in sweetpotato roots

For all plant tissue, when oxygen levels fall below a certain level or carbon dioxide rises above a certain level, the tissues switch to anaerobic respiration. The subsequent build-up of ethanol and acetaldehyde leads to the build-up of off-flavours and eventually leads to irreversible tissue damage and death. Compared to other root crops, sweetpotato is particularly susceptible to anaerobiosis, as the switch in metabolism occurs at a higher oxygen and lower carbon dioxide level. This becomes a particular problem given the elevated rates of respiration during storage at tropical temperatures. The susceptibility to low oxygen levels in sweetpotato is probably also an important reason why the sweetpotato crop is particularly susceptible to waterlogging.

Little work has been carried out to determine the range of characteristics in storage roots (such as rates of respiration and susceptibility to anaerobiosis) that would affect long-term storage under tropical conditions. However, studies on US cultivars have indicated not only a large range of respiratory rates, but significant variation in the level of oxygen at which roots switch to anaerobic respiration, and their ability to re-metabolize the products of anaerobic respiration on return to normal atmospheric composition (Kays, 1985). The fact that cultivars differ in susceptibility to waterlogging is also noteworthy (Paul Thompson, University of Mississippi, personal communication).

7.1.3 Objectives

While work is still ongoing in the improvement of store design, the main emphasis in this chapter is to examine the extent to which cultivar selection might affect the success of long-term storage. The main characteristics identified as being desirable for long-term storage are intrinsic resistance to rots, low respiration rates, and a reduced tendency to switch to anaerobic respiration. Trials conducted to examine cultivar effects on all of these parameters are presented, with some discussion as to the relationship with storability. (For information on store design contact K. Tomlins, Q. van Oirschot, T. Ndengello or E. Rwiza.)

7.2 Methods

7.2.1 Laboratory trials to test cultivar reaction to storage environment

A study was conducted at Sokoine University of Agriculture to examine the effect of storage environment on the keeping qualities of key Tanzanian sweetpotato cultivars. Five cultivars, namely Budagala, Iboja, Mwanamonde, Sinia and SPN/O, were harvested and subjected to four different storage environments. These differed in degree of ventilation, i.e. an open sack rolled down, a closed sack, a double layered closed sack and a lined closed sack (waterproof polythene bag closed in closed sack).

Roots were assessed weekly throughout the experiment for a range of quality attributes such as weight, external appearance (rotting) and internal appearance, by cutting the roots into longitudinal and cross-sections. The methods used are similar to those described in Chapter 5.

7.2.2 Trials conducted to assess sweetpotato cultivars for susceptibility to rots (*Rhizopus oryzae*)

In order to assess the intrinsic resistance of roots to rot growth (as distinct from rot entry through wounds, see section 7.1), trials were conducted in which roots were artificially inoculated with pathogens causing rots. Inoculation was carried out by removing a disc of root tissue and inserting a disc of mycelia obtained from the edge of a culture grown on agar. Roots were then stored under controlled conditions and the growth of the pathogen assessed in terms of lesion size and weight.

Trials Conducted to Assess Susceptibility to Rots

Initial trials were conducted in 1998 and 1999 on Tanzanian cultivars grown on-station at Sokoine University of Agriculture, Tanzania. Later experiments were conducted at Silsoe College, UK using roots which had been grown by the International Potato Center (CIP) in Nairobi, and air-freighted to the UK. A summary of the cultivars used is given in Tables 7.1 and 7.2.

Table 7.1 Cultivars grown in Tanzania used in trials to assess susceptibility to rots

Experiments 1, 2 and 3 conducted in 1998	Experiments 4, 5 and 6 conducted in September 1999	Experiments 7 and 8 conducted in November/December 1999
Mwanamonde	Mwanamonde	SPN/0
SPN/0	SPN/0	Iboja
Iboja	Iboja	Sinia
Budagala	Sinia	Budagala
Sinia	Ukerewe	
Hali ya mtumwa		
Chenzeru		
Sindano		
Elias		
Ukerewe		

7.2.3 Assaying for antifungal compounds by testing growth of pathogens on agar produced from sweetpotato extract

In order to determine the nature of tissue resistance to pathogens, experiments were conducted in which tissue extracts were taken from infected roots at various locations, and used to make agar, on which the growth of *Rhizopus oryzae* was tested.

Table 7.2 Cultivars grown by CIP used in trials conducted in the UK to assess susceptibility to rots

Experiments 9, 10 and 11 conducted in May/August 2000
KSP 20
SPK004
Kemb 10
Yan Shu 1
Zapallo

Experiments to Assay for Antifungal Compounds

Sweetpotato roots were inoculated using the method described in section 7.2.2 and kept in plastic bags for 3 days. After 3 days, roots were removed from the plastic bags. Using a sharp knife, the infected sweetpotato root tissue (2 mm thick) was cut at points 0.5 cm (border tissue), 5 cm (middle tissue) and 10 cm (healthy tissue) from the edge of the lesion. The sweetpotato tissues were then freeze-dried, and ground into a fine powder. Thus, for each cultivar there were three powder types: border tissue powder, middle tissue powder and healthy tissue powder. Different sweetpotato meal agar (SMAs) were then prepared as follows.

(i) A mixture of powdered sweetpotato (7.5 g) and water (250 ml) was boiled over a water bath for 1 h.

(ii) The contents were filtered through a muslin cloth.

(iii) Sterile distilled water was then added to make up the volume to 250 ml.

(iv) Oxoid agar (5 g) was added and the mixture boiled until the agar dissolved.

(v) Sterilization was carried out at 15 psi for 15 min.

(vi) After cooling the agar was poured into petri dishes.

During the assessment of the rate and extent of growth of *R. oryzae* on different SMAs, a 3 mm disc of mycelia was cut at the periphery of a 2-day-old culture of *R. oryzae* on PDA using a 3 mm diameter sterile corkborer. The disc was placed at the centre of the SMA media in the petri dish (about 4.5 cm from the periphery). The petri dishes containing SMAs and the pathogen were then put in sterile ventilated bags. The pathogen was allowed to grow for 1 day on SMA. The rate of growth of *R. oryzae* was estimated by measuring the diameter of the circle of pathogen mycelia after every 6 h, taking the initial point of placement of the agar disc as the reference. After 1 day, the form of growth on different SMAs was estimated using the following scale.

Class	Description
1	No growth
2	Weak growth (very sparse and slender mycelia)
3	Good growth (relatively thick and compact mycelia)
4	Very good growth (very thick and compact mycelia)

7.2.4 Laboratory trials to assess respiration rates

A set of experiments was carried out at the Natural Resources Institute (NRI) to examine the respiratory characteristics of three cultivars, as it was hypothesized that these characteristics would be important for the storability of the cultivars. In particular we were interested in the rates of respiration, and the susceptibility of the roots to switch to anaerobic respiration as the storage atmosphere became modified (i.e. decreased oxygen levels, increased carbon dioxide levels). The scientific literature suggests that there is variation among sweetpotato cultivars in the levels of oxygen at which the switch to anaerobic respiration occurs.

7.3 Results and discussion

7.3.1 Cultivar differences in keeping qualities under long-term storage conditions

Significant cultivar differences in susceptibility to rotting were found. This is illustrated in Figure 7.1, which shows the rate of rotting for roots stored in the highest humidity treatment (lined closed sacks).

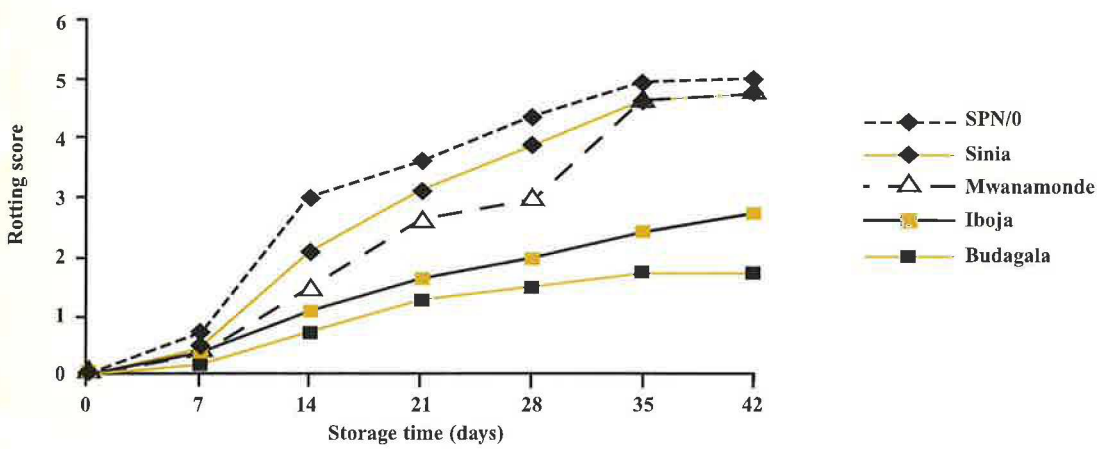
The ranking of cultivar storability was not the same as that when roots were stored under simulated marketing conditions (low humidity). At the highest humidities, the cultivar Budagala appeared to be the least susceptible to rotting, but at lower humidities it did not keep well.

Respiration Rate Trials

Roots of three sweetpotato cultivars were transported from the Lake Zone Agricultural Research and Development Institute (LZARDI), Ukiriguru to NRI in the luggage hold of a commercial airline. The roots were well insulated during the flight. A tinytalk data-logger recorded the temperature continuously. The minimum and maximum temperatures to which the roots were exposed were *x* and *y*, respectively. Once at NRI, the roots were stored under ambient temperatures at high humidity (>80%).

Two experiments were conducted to measure the rates of respiration. For each, six good roots (low levels of damage, free from rots or insect damage) were selected for each cultivar. Each root was weighed and placed in a 3 litre jar, in a controlled-temperature room set to 25 °C. The 18 jars containing roots were left open in the controlled-temperature room for 1 h to allow temperature equilibration, and were then closed with an air-tight seal. Air samples were removed at intervals from each jar through a rubber septum using an air-tight syringe. Levels of carbon dioxide and oxygen were measured by gas chromatography using a molecular sieve (to separate carbon dioxide from oxygen/nitrogen) and poropak column (to separate oxygen and nitrogen), arranged so that they could be run alternately in series and with the poropak bypassed. Levels of the gases were measured using a thermal conductivity detector. Oxygen and carbon dioxide concentrations were approximated by assuming that nitrogen comprised 78% air, and that the thermal conductivity of the three gases is identical. (This leads to inaccuracies, but does not affect the validity of comparisons.)

The first experiment was terminated after 30 h while the second continued to 180 h.



Source: Mbilinyi *et al.* (2000).

Figure 7.1 The rate of rotting for five key Tanzanian cultivars stored under high humidity conditions

7.3.2 Susceptibility of sweetpotato cultivars to rotting

A detailed study of the susceptibility of sweetpotato cultivars to rot was carried out in the Morogoro region of Tanzania using artificial inoculation methods. In that region, the main storage rot was identified as *Rhizopus oryzae*. Screening of cultivars over successive seasons indicated that cultivar differences in susceptibility did exist. For many cultivars, susceptibility varied with growing conditions, but some cultivars were more stable. Budagala, mentioned above, and Sinia were consistently resistant, while SPN/0 was consistently susceptible (Table 7.3).

7.3.3 Tissue defence mechanisms against rotting

There are a variety of ways in which plant tissues protect themselves against attack by pathogens causing rot. Healing of surface wounds is an important defence mechanism, but other mechanisms come into force once infection has occurred.

It has been observed in a number of tuber crops that infection can lead to hypersensitive cell death. In this case, following infection, a barrier is created by cell death that effectively halts pathogen growth. This has been studied in potato (e.g. Doke and Chai, 1985), but currently there is no information on a hypersensitive reaction in sweetpotato roots as a result of pathogen infection.

Other defence mechanisms involve antifungal chemicals. Some of these are present in tissues prior to infection, but most appear to be induced afterwards.

Kojima and Uritani (1974, 1978) studied some pre-existing compounds of high molecular weight, including a spore agglutinating factor composed primarily of polygalacturonic acid, which agglutinates germinating spores of certain fungi and inhibits growth. Latex in some plants acts as a natural defence system against certain insects. The roots of some sweetpotato cultivars produce substantial quantities of latex when cut. The potential of latex as a defence mechanism against the sweetpotato weevil, *Cylas formicarius*, has been demonstrated, and it is likely that it is also involved in resistance to some post-harvest pathogens.

Phytoalexins are low molecular weight antimicrobial compounds which are synthesized by, and accumulate in, plant cells after microbial infection (Paxton, 1981). In sweetpotato, the phytoalexin, ipomeamarone, a furanoterpenoid, has been identified. Accumulation of ipomeamarone has been found to occur in sweetpotato roots infected by a range of pathogens. Imaseki and Uritani (1964) reported that ipomeamarone accumulated in roots after infection by the black rot fungus (*Ceratocystis fimbriata*).

Arinze and Smith (1980) observed that ipomeamarone concentrations were greater in restricted lesions than expanding lesions caused by fungal post-harvest pathogens, which is consistent with its defensive role.

As well as acting as precursors in the formation of physical barriers such as lignin and suberin, phenolics also contribute to resistance through chemical inhibition of pathogen growth and cell wall degrading enzymes. Arinze and Smith (1982) found elevated levels of phenolics, polyphenol oxidase and peroxidase, both within the lesions of five fungal rots and the surrounding healthy tissue. A greater accumulation of these compounds was found in fungal rots with limited lesions. Inhibition of the fungal polygalacturonase by extracts of infected sweetpotato roots was also demonstrated.

7.3.4 The physiological basis for differences in sweetpotato cultivars in susceptibility to rotting

In order to determine the basis of the cultivar differences in resistance to rots under high humidity (sections 7.3.1 and 7.3.2), experiments were conducted

Table 7.3 Ranking of cultivars in terms of decreasing susceptibility to *Rhizopus oryzae* as measured by rot weight following artificial inoculation

Experiments 1, 2 and 3 conducted in 1998	Experiments 4, 5 and 6 conducted in September 1999	Experiments 7 and 8 conducted in November/December 1999
Ukerewe	SPN/0	Iboja
SPN/0	Iboja	SPN/0
Elias	Mwanamonde	Sinia
Chenzeru	Ukerewe	Budagala
Sindano	Sinia	
Iboja		
H/mtumwa		
Budagala		
Sinia		
Mwanamonde		

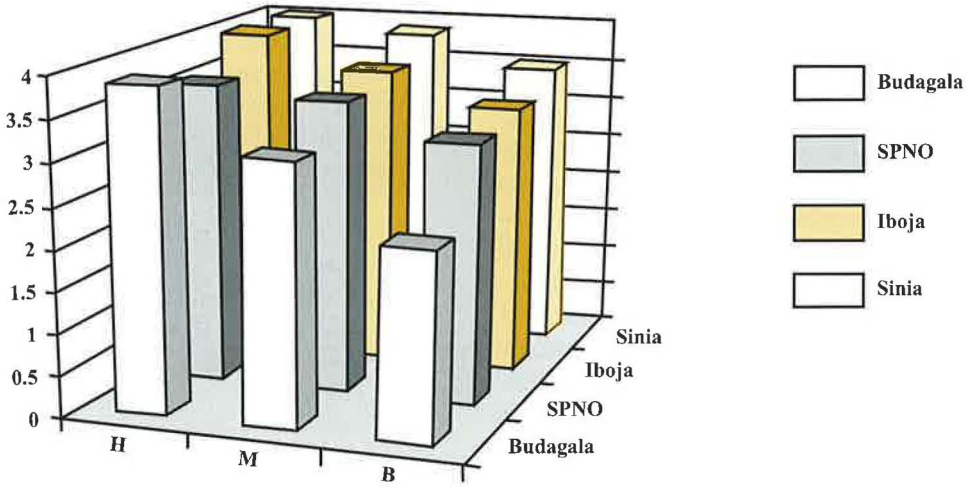


Figure 7.2 Relative growth rates of *R. oryzae* on SMA agar made with tissue extracts taken 10 cm (H), 5 cm (M) and 1 cm (B) from the disease lesion on roots of four cultivars. LSD = 0.8. Interaction significant at 5% level of probability. Growth was scored as described on page 89

to distinguish whether resistance was due to tissue mechanical characteristics, barrier formation or chemical characteristics.

Figure 7.2 shows the results of an experiment in which extracts were made of tissue isolated from infected sweetpotato roots, and used to make agar on which the rate of pathogen growth was assessed. It was found that agar made from tissue extracted from the border of lesions inhibited growth of *Rhizopus oryzae*, and that the effect was cultivar specific. The greatest effects were seen for Budagala, a cultivar noted for its resistance to *R. oryzae*. This suggests that the resistance is at least partly due to the induction of an antifungal chemical. This chemical (or chemicals) must be heat resistant, as it survived autoclaving during the production of the agar. This agrees with previous studies in which antifungal compounds have not been destroyed by heating at 100 °C for 5 min (Kojima and Uritani, 1976) and are stable under autoclaving (Jenkins, 1981).

7.3.5 Assessment of cultivar respiration rates

The results of two experiments to compare the respiration rates for three cultivars: SPN/0, Sinia and Polista are summarized in Table 7.4. The rate of respiration was calculated for each root from the rate of increase of carbon dioxide over the first 4–9 h (Respiration 1) and over the first 24–30 h (Respiration 2) in an enclosed jar. Due to wide variability among roots, cultivar effects were not significant for either individual experiment, but a combined analysis indicates that Polista had a significantly higher rate of respiration than SPN/0 and Sinia, with no significant difference between the latter two cultivars.

When measuring respiration rates in a closed system, as here, the atmosphere becomes modified over time, and can affect the behaviour of the roots. For the first measurement (Respiration 1), it is unlikely that the modification of the atmosphere would have significantly affected the rates of respiration. However, for the second measurement, carbon dioxide levels

Table 7.4 Rates of respiration for roots of three sweetpotato cultivars

Cultivar	Experiment 1		Experiment 2		Combined analysis	
	Resp 1	Resp 2	Resp 1	Resp 2	Resp 1	Resp 2
SPN/0	35.6	34.7	56.6	51.2	46.1	43.0
Sinia	44.2	41.0	45.8	44.5	45.0	42.8
Polista	80.6	70.3	75.3	69.0	77.9	69.7
Cultivar effect (*P* value)	0.098	0.111	n.s.	n.s.	0.032	0.043
LSD	43.8	36.1	38.5	35.5	27.3	23.7

Respiration rates are given in ml CO_2/kg/h. Respiration 1 is calculated from CO_2 levels measured after 4–8 h, assuming the initial CO_2 level was 0. Respiration 2 is calculated from CO_2 levels measured after 24–30 h, assuming the initial CO_2 level was 0. For Experiments 1 and 2, each value is the mean of data measured for six roots.

could be as high as 16%, and oxygen levels as low as 7%, so that some decrease in rate of oxygen consumption might be expected. Respiration 2 was in fact lower that Respiration 1 for all three cultivars in both experiments, but the effect was small.

7.3.6 Assessment of cultivar susceptibility to switch to anaerobic respiration

In Experiment 2, the roots were kept in sealed jars for 6 days, and the modification of the atmosphere monitored for this period. This allowed calculation of the respiratory quotient (carbon dioxide produced/oxygen consumed) for each root over a range of oxygen and carbon dioxide levels. This data can give information about the atmospheric composition at which the roots switch from aerobic to anaerobic respiration, because at the switch point, the respiratory quotient will rise.

Figure 7.3a–b shows the respiratory quotient for each root at each time interval, plotted against the average oxygen level and average carbon dioxide level for that time period. This indicates that sweetpotatoes switch metabolism at 2–3% oxygen and 23–24% carbon dioxide. There is, however, no indication from this data of any differences between the cultivars.

7.4 Conclusions and implications

From studies of East African germplasm, we have demonstrated that sweetpotato cultivars differ in their susceptibility to pathogens responsible for rotting when maintained at high humidity, and that this is at least partly due to the induction of antifungal chemicals. We have also demonstrated that differences in respiration rate exist, although we have no evidence of a difference in tendency to switch to anaerobic respiration.

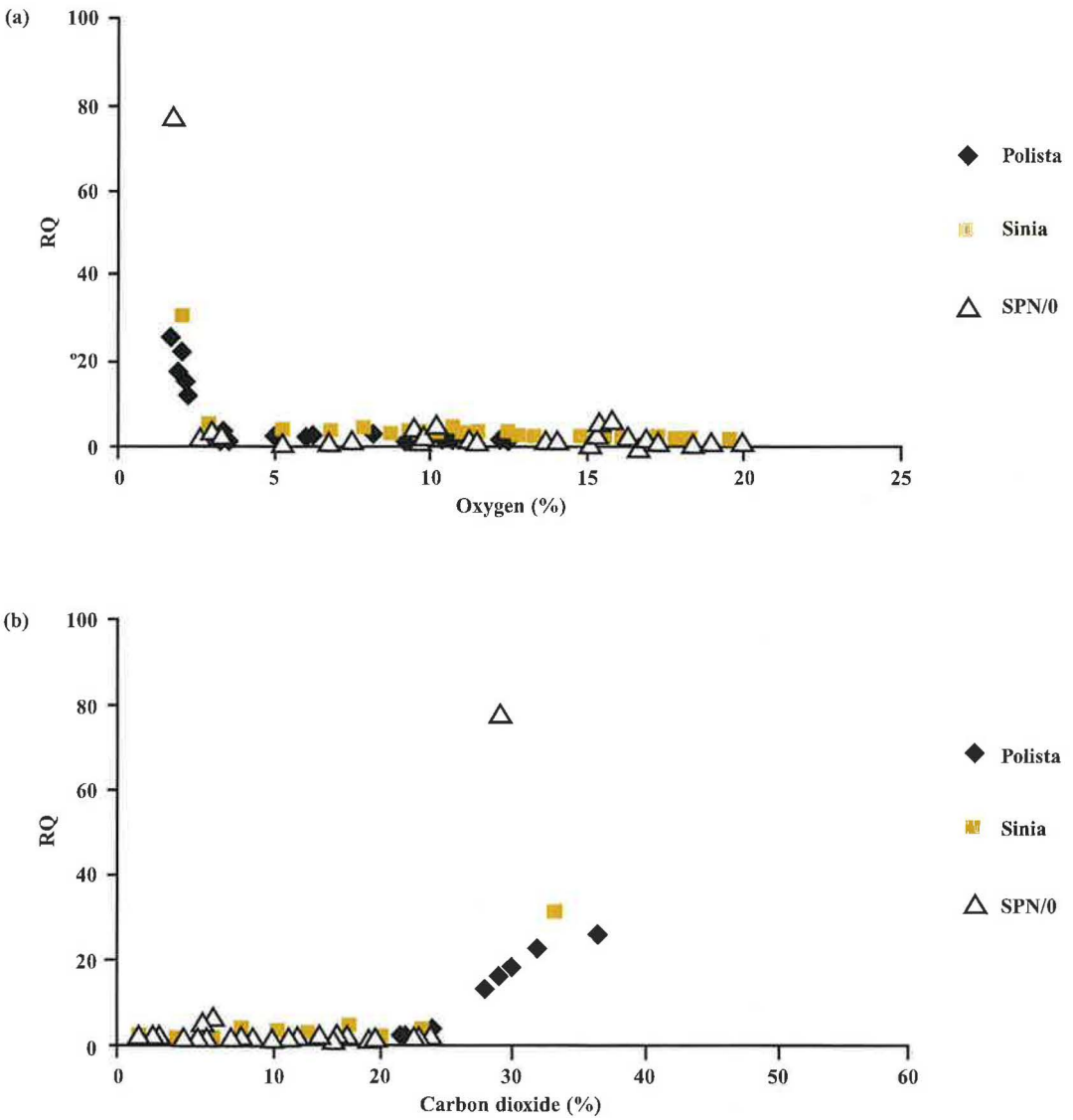


Figure 7.3 **Respiratory quotient plotted against (a) oxygen concentration and (b) carbon dioxide concentration for each individual root over each time period of measurement in Experiment 2**

At the time of writing, a set of storage trials is underway in Tanzania to test different storage designs, and to determine the relative importance of storage design and cultivar selection. These storage trials are using three cultivars: Sinia, SPN/0 and Polista. So far we have no information on the susceptibility of Polista to rot pathogens, and the information we have for SPN/0 and Sinia is confusing. In section 7.3.2, SPN/0 appeared to be consistently more susceptible to rotting than Sinia, but this was contrary to the findings of section 7.3.1. With respect to respiratory characteristics, we have found that Polista has a higher rate of respiration than the other two cultivars.

From this data, if cultivar effects are important for successful storage, we might predict that Polista would be a poor storer due to its higher respiration rates. Indeed, consistent with this, initial results suggest that Polista shows higher rates of shrivelling. However, until these trials are complete, we cannot make firm conclusions as to the value of selecting cultivars for long-term storage on the basis of respiratory characteristics or resistance to rotting.

References

ARINZE, A.E. and SMITH, I.M. (1980) Antifungal furanoterpenoids of sweet potato in relation to pathogenic and non-pathogenic fungi. *Physiological Plant Pathology*, **17**: 145–155.

ARINZE, A.E. and SMITH, I.M. (1982) Distribution of polygalacturonase, total phenolics substances, polyphenol oxidase and peroxidase in root zones in sweet potato. *Plant Pathology*, **31**: 119–122.

DOKE, N. and CHAI, H.B. (1985) Activation of superoxide generation and enhancement of resistance against compatible races of *Phytophthora infestans* in potato plants treated with digitonin. *Physiological Plant Pathology*, **27**: 323–334.

HALL, A.J. and DEVEREAU, A.D. (2000) Low-cost storage of fresh sweet potatoes in Uganda: lessons from participatory and on-station approaches to technology choice and adapative testing. *Outlook on Agriculture*, **29**: 275–282.

IMASEKI, H. and URITANI, I. (1964) Ipomeamarone accumulation and lipid metabolism in sweet potato infected by the black rot fungus. Accumulation mechanism of ipomeamarone in the infected region with special regard to contribution of the non-infected tissue. *Plant and Cell Physiology*, **5**: 133–142.

JENKINS, P.D. (1981) Differences in susceptibility of sweet potato cultivars to infection by storage fungi in Bangladesh. *Phytopathologische Zeitschrift*, **102**: 247–256.

KAPINGA, R.E., EWELL, P.T., JEREMIAH, S.C. and KILEO, R. (1995*) Sweetpotato in Tanzanian Farming and Food Systems: Implications for Research.* Nairobi: International Potato Center (CIP) and Ministry of Agriculture, Tanzania.

KAYS, S.J. (1985) The physiology of yield in sweet potato. In: *Sweet Potato Products: A Natural Resource for the Tropics.* Bouwkamp J.C. (ed.). Boca Raton: CRC Press Inc.

KOJIMA, M. and URITANI, I. (1974) Possible involvement of spore agglutinating factors of the host plants in manifestation of host specificity by various strains of black rot fungus, *Ceratocystis fimbriata*. *Plant Cell Physiology*, **15**: 733–737.

KOJIMA, M. and URITANI, I. (1976) Possible involvement of furanoterpenoid phytoalexins in establishing host parasite specificity between sweet potato and various strains of *Ceratocystis fimbriata*. *Physiological Plant Pathology*, **8:** 97–111.

KOJIMA, M. and URITANI, I. (1978) Studies on factor(s) in sweet potato which specifically inhibits germ tube growth of imcompatible isolates of *Ceratocystis fimbriata*. *Plant and Cell Physiology* **19:** 71–81.

MBEZA, H.F. (1997) Storage of Sweet Potato in Malawi – Second Year Report. Bunda College of Agriculture, PO Box 219, Lilongwe, Malawi. (unpublished)

MBILINYI, L.B., MULUNGU, L.S., REUBEN, S.O.W.M., SENKONDO, F.J., MABAGALA, R.B., REES, D. and KAPINGA, R. (2000) The effect of storage environment on the shelf-life of sweetpotato. pp. 513–519. In: *Fifth Triennial Congress of the African Potato Association, Kampala, Uganda, 29 May–2 June 2000. APA Conference Proceedings,* Volume 5 (A).

MUHANNA, M. (2001) *Physiological and Biochemical Factors Determining Resistance of Sweetpotatoes to Post-harvest Pathogens in Tanzania.* M.Phil thesis, Cranfield University.

PAXTON, J.D. (1981) Phytoalexins – a working redefinition. *Phytopathologische Zeitschrift*, **101**: 106–109.

PICHA, D.H. (1986) Weight loss in sweet potatoes during curing and storage: contribution of transpiration and respiration. *Journal of the American Society for Horticultural Science*, **11**: 889–892.

CHAPTER 8

Damage to storage roots by insect pests

T.E. Stathers, D. Rees, S. Kabi, L.B. Mbilinyi, N. Smit, H. Kiozya, S.C. Jeremiah, A. Nyango and D. Jeffries

8.1 Background

Damage to sweetpotato storage roots by insect pests, even when it occurs before harvest, can be considered a post-harvest problem as it reduces both the nutritional and economic value of the storage roots and can reduce shelf-life.

The most important insect pest of sweetpotato storage roots worldwide is the sweetpotato weevil (*Cylas* spp., Coleoptera: Apionidae). In certain areas of East Africa, the so-called rough weevil (*Blosyrus* spp.), which damages the surface of the root, is also starting to gain economic importance.

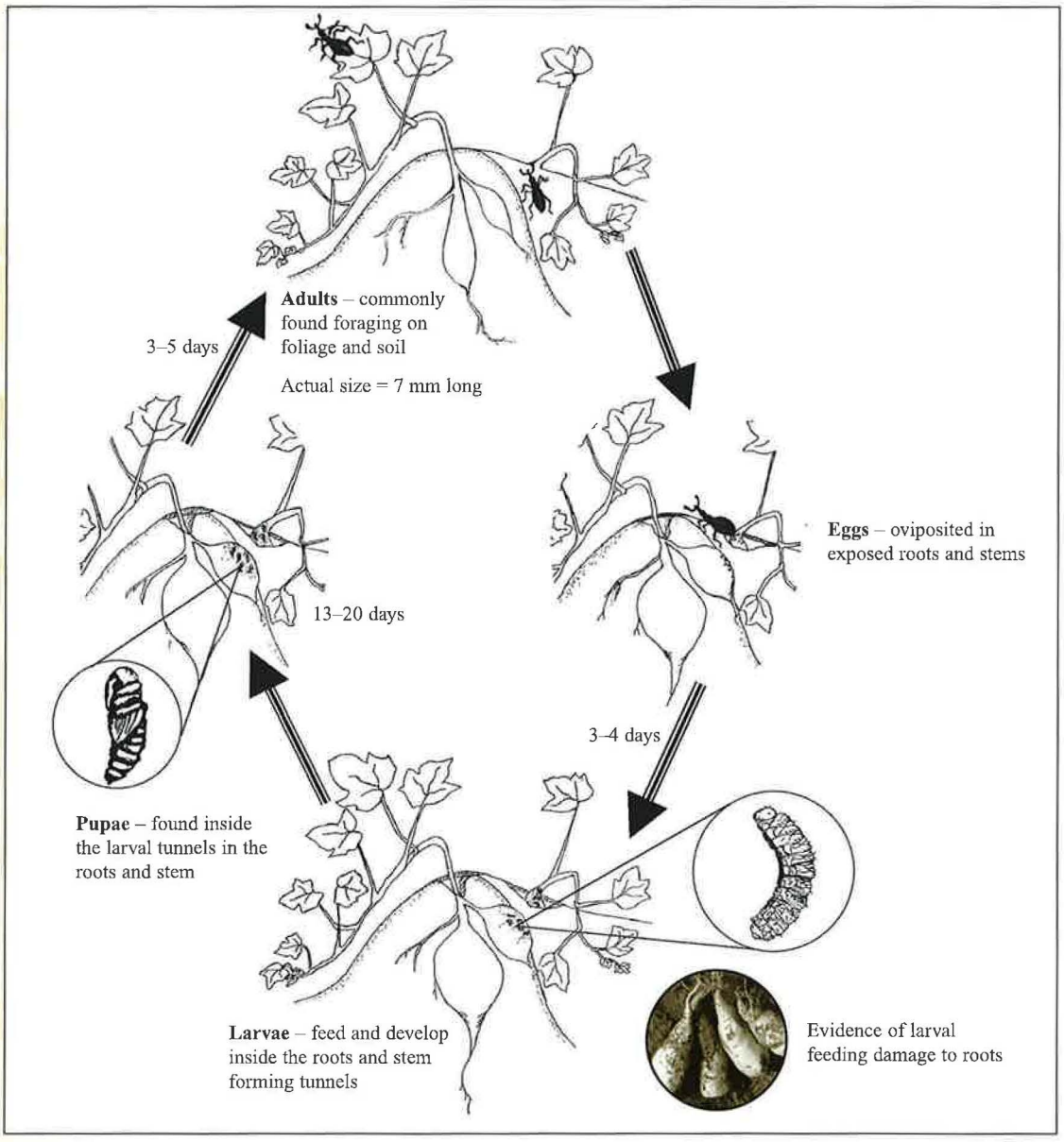
8.1.1 Sweetpotato weevils (*Cylas* spp.)

Sweetpotato weevils constitute a major constraint to sweetpotato production and utilization worldwide (Villareal, 1982; Sutherland, 1986; Chalfant *et al.*, 1990; Lenne, 1991). Yield losses as high as 60–97% have been reported (Ho, 1970; Subramanian *et al.*, 1977; Mullen, 1984; Jansson *et al.*, 1987; Smit, 1997). Even low levels of infestation can reduce root quality and marketable yield because the plants produce unpalatable terpenoids in response to weevil feeding (Akazawa *et al.*, 1960; Uritani *et al.*, 1975) and consumers will pay only reduced prices for roots damaged by *Cylas* spp. (Ndunguru *et al.*, 1998).

Sweetpotato weevils are a particularly serious problem under dry conditions, because the insects, which cannot dig, can reach roots more easily through cracks that appear in the soil as it dries out. In much of East

Africa, the sweetpotato crop matures after the end of the rains, and root bulking, which has a tendency to shift the soil, often exposes roots providing easy access for *Cylas* spp. It is for this reason that during the dry season, unlike cassava, sweetpotato roots cannot be stored in-ground for any significant period of time. Given the perishability of the root once it has been harvested, this critically limits the potential of the crop as a secure food supply. Initial surveys of root quality in the markets of Tanzania have shown that, at certain times of the year, 15–20% of roots that are sent to the market may be spoiled by infestation (Kapinga *et al.,* 1997). This is an underestimation of the total levels of loss, since farmers usually leave infested roots in the field.

There are a number of species of sweetpotato weevil; *Cylas puncticollis* and *C. bruneus* are the most prevalent species in East Africa, while *C. formicarius* is the most abundant in North and South America and the Far East. The female sweetpotato weevil lays eggs singly in cavities excavated in either the vines or exposed/easily accessible roots (Figure 8.1). The developing larvae tunnel while feeding inside the vine or root and are the most destructive stage. Pupation takes place within the larval tunnels and adults emerge after a few days. Plants may wilt or even die as a result of extensive stem damage, and damage to the vascular system can reduce the size and number of storage roots. While external damage to roots can affect their quality and value, internal damage can lead to complete loss. As sweetpotato weevils fly infrequently and generally only for short distances (Chalfant *et al.*, 1990), newly planted fields are most likely to be infested through planting material, immigrating *Cylas* spp. weevils from neighbouring fields or alternative host plants (Sutherland, 1986), or survivors in crop debris from a preceding crop (Talekar, 1987).



Source: Adapted by T.E. Stathers, NRI, UK from original artwork by W. Temu, MATI Mwanza, Tanzania.

Figure 8.1 Lifecycle of *Cylas puncticollis* and its association with sweetpotato plants

8.1.2 Selecting cultivars for resistance/ tolerance to root insect infestation

Several attempts have been made to breed for resistance to *Cylas* spp. The most likely resistance mechanisms include: escape via deep rooting (as weevils can only burrow short distances); or early maturity (enabling farmers to harvest roots before the onset of the dry season and the subsequent increase in *Cylas* spp. populations); or non-preference related to the chemical composition of the roots of different cultivars. However, the rate of success in breeding for non-preference has been slow, leading some breeders to conclude that an adequate source of resistance may not exist within the sweetpotato germplasm. Nevertheless, there are numerous reports of variation among varieties in susceptibility to weevil attack. Among East African germplasm, for example, one cultivar, which is particularly popular throughout the region (known as SPN/0 in Tanzania and Tanzania in Uganda), appears to be highly susceptible compared to other less popular varieties (S. C. Jeremiah, personal communication). There is no evidence of cultivar differences in susceptibility to attack by the rough weevil.

It has been standard practice to assess insect damage to roots as part of the yield trials conducted within breeding programmes throughout East Africa. In practice, the data obtained have not provided consistent information on cultivars. This is probably because the timing of trials, with harvests at the start of the dry season, is arranged to avoid weevil infestation. Studies have shown that where weevil infestation is either low or very high, cultivar differences cannot be observed (Stathers *et al.*, in press a). This is illustrated in Table 8.1, which summarizes the results of nine trials conducted in Tanzania and Uganda in 1997/98. Significant cultivar effects could be seen in all cases, except those where infestation was very high, or low. Despite this, observations on insect infestation during yield trials may be useful in picking out any varieties with particularly high susceptibility and is, therefore, recommended.

A recent study has been carried out as a collaborative venture between the Tanzanian National Root and Tuber Crops Programme (TNRTCP), National Agricultural Research Organization (NARO), Natural Resources Institute (NRI) and the International Potato Center (CIP) with the following objectives:

- to determine the extent to which sweetpotato cultivars presently available in East Africa differ in their susceptibility to field infestation by *Cylas* spp.
- to examine the factors that determine the susceptibility of sweetpotato cultivars to this pest
- subsequently, to use the above information to establish strategies for selection of suitable cultivars for East Africa with reduced susceptibility.

Some of the results obtained are presented here, while further details can be found in Stathers *et al.* (1999, in press a, b). The main purpose of this chapter is to present the methods used to assess levels of insect damage.

8.2 Methods

8.2.1 Assessment of storage root damage by *Cylas* spp.

Within a breeding programme, methods for measurement of insect infestation need to be simple and rapid. Two methods are described here. A non-destructive scoring system relies on scoring each root

Table 8.1 Percentage yield without *Cylas* spp. infestation and significance of cultivar effects for trials conducted in Tanzania and Uganda in 1997 and 1998

Trial			Percentage clean marketable yield (by weight)	
			Overall mean	Cultivar effect *P* value
Ukiriguru 1997			53.5%	*
Ukiriguru 1998			71.1%	**
Kibaha 1997			95.1%	n.s.
Kibaha 1998			14.4%	n.s.
Serere 1997	Season 1	4 months	66.8%	+
Serere 1997	Season 1	6 months	77.7%	***
Serere 1997	Season 2	4 months	99.5%	***
Serere 1997	Season 2	6 months	89.8%	+
Serere 1998			85.3%	***

+ $P<0.1$, * $P<0.05$, ** $P<0.01$, *** $P<0.001$.

At Serere, percentage clean total yield was measured.

for visible signs of infestation. A second method is more precise and measures the extent of damage by cutting the roots into clean and infested portions. *Cylas* spp. are cryptic, i.e. they spend much of their lifecycle inside the storage root or vine, so that some damage may not be visible from the outside. Precise assessment of insect numbers and damage, therefore, requires the storage root to be carefully taken apart. However, this is very time consuming. We present data, however, that show that the scoring method relates well with destructive methods of measurement, and is of practical use in breeding programmes.

8.2.2 Non-destructive damage scoring

Following harvest, roots are separated into those of marketable size (in Tanzania this typically includes roots with a root diameter >25 mm), and those which are unmarketable (root diameter <25 mm). Only marketable roots are assessed for weevil damage. However, as the criteria for determining whether roots are marketable or not differs between countries, these categories will need to be adjusted as appropriate in individual countries.

Roots are separated into different categories depending on the percentage of the external surface showing infestation (Figure 8.2). The damage within each plot is expressed as the weighted mean (Table 8.2).

Figure 8.2 Sweetpotato roots sorted by *Cylas* spp. infestation category

8.2.3 Measurement of percentage infested portion of roots by cutting

For this assessment, marketable roots are separated into infested and non-infested (clean) groups. The infested portion of the infested roots is removed by cutting to separate the clean and infested parts (Figures 8.3 and 8.4). This provides three parts of the harvest:

- completely clean (non-infested) roots, which are suitable for marketing
- clean parts of infested roots (edible) which can be used by the household, but will not keep for long
- infested portions of roots that are useless for most purposes.

This is the more time consuming of the methods, but we believe that it provides the most accurate representation of the way the sweetpotato harvest is used by farmers.

8.2.4 Comparison of the two methods of measurement

The two methods of assessment are compared in Figure 8.5. Data from two trials with very different levels of infestation are included.

The two methods produced strongly related values (Figure 8.5), but the degree of scatter is also quite high. This is an indication of the degree to which roots without much external signs of damage often have greater internal damage as a result of burrowing and feeding by developing *Cylas* spp. larvae. Thus, we have confidence in the non-destructive damage scoring method as an approximation of levels of infestation, but believe that for detailed studies where extra effort is justified, the destructive method (infested portion of roots by cutting) is more appropriate.

8.2.5 Assessment of storage root damage by other insect pests

Where roots are to be assessed for damage by pests other than *Cylas* spp., for example, *Blosyrus* (Figure 8.6), it is easy to use a scoring system similar to that used for *Cylas* spp. (see Table 8.2).

Table 8.2 Example of scoring method calculation

	Percentage damage seen on root surface Number of roots in each damage category							
	1 (0%)	2 (1–10%)	3 (11–25%)	4 (26–50%)	5 (51–75%)	6 (>75%)	Calculation	Weighted mean score
SPN/0 Rep1	4	5	8	2	0	0	= ((1*4)+(2*5)+(3*8)+ (4*2)) /(4+5+8+2)	2.42

Figure 8.3 Removal of *Cylas* spp. infested portion of root

Figure 8.4 Cut sweetpotato roots showing edible and *Cylas* spp. infested portion of roots

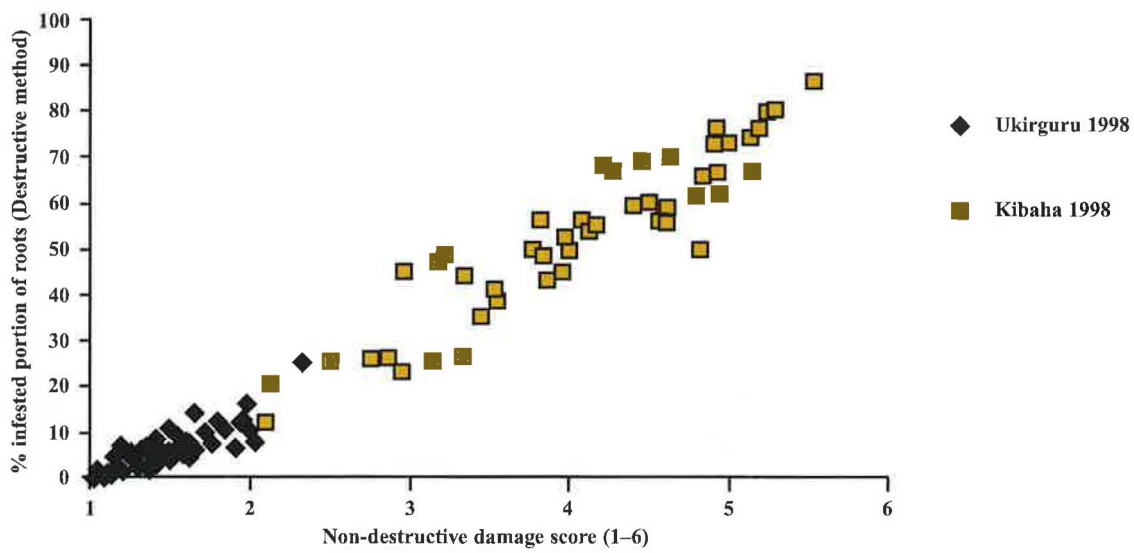


Figure 8.5 A comparison of two methods for assessing damage by *Cylas* spp. during sweetpotato trials at Kibaha and Ukiriguru, Tanzania in 1998

Figure 8.6 Surface damage caused by the rough sweetpotato weevil *Blosyrus* spp.

8.3 Results and discussion

Using the methods of damage assessment described above, trials were conducted at two sites in Tanzania (Lake Zone Agricultural Research and Development Institute (LZARDI), Ukiriguru and the Sugarcane Institute, Kibaha) and one site in Uganda (Serere Agricultural and Animal Production Research Institute) to assess a range of cultivars for their susceptibility to infestation by *Cylas* spp. In Tanzania, natural levels of *Cylas* spp. infestation were supplemented by artificial infestation (full details are given in Stathers *et al.*, in press a).

There was a notable range in both yield and infestation levels between cultivars within trials. An ANOVA established that the cultivar effect on infestation levels (percentage of clean marketable yield) was significant to less than 10% in all but two trials (see Table 8.1), which had the highest and lowest percentage clean marketable yield, respectively. The results for LZARDI, Ukiriguru are illustrated in Figure 8.7.

The consistency of cultivar behaviour between seasons (i.e. genotype effect) is indicated by correlating infestation levels (clean marketable yield and percentage clean marketable yield) for the two seasons considered for each site (Table 8.3). Significant correlations were obtained for Ukiriguru and Serere, but not for Kibaha, where (as mentioned above) extreme levels of infestation were recorded.

Four cultivars, Mwanamonde, Budagala, Sinia and SPN/0, were included in the trials at both Kibaha and Ukiriguru. A degree of consistency was seen; at both sites, Budagala and Mwanamonde were less susceptible than Sinia and SPN/0 (Figure 8.8).

These results indicate that significant and reasonably consistent differences in susceptibility to *Cylas* spp. exist among East African sweetpotato germplasm. In order to determine what factors might be associated with reduced infestation levels, we measured a wide range of plant characteristics. Attempts to model infestation levels in terms of these characteristics produced the linear regression models given in Table 8.4.

These models indicate that most of the cultivar variation observed could be explained by relatively few characteristics: root yield (root number, root weight), foliage yield, crown diameter, soil cracking, exposed roots and shortest weevil distance. (Shortest weevil distance refers to the shortest distance from soil surface to root. Details of measurement are given in

Table 8.3 Correlations for cultivar clean (marketable) yield and percentage clean (marketable) yield between years at three locations

		Correlation coefficient (R)	
	Number of cultivars	Clean (marketable) yield	Percentage clean (marketable) yield
Ukiriguru 1998 vs. Ukiriguru 1997	16	0.57 *	0.67 **
Kibaha 1998 vs. Kibaha 1997	10	n.s.	n.s.
Serere 1998 vs. Serere 1997 (at 6 m.a.p)	21	n.s.	0.49*

* $P<0.05$, ** $P<0.01$, n.s. = not significant.

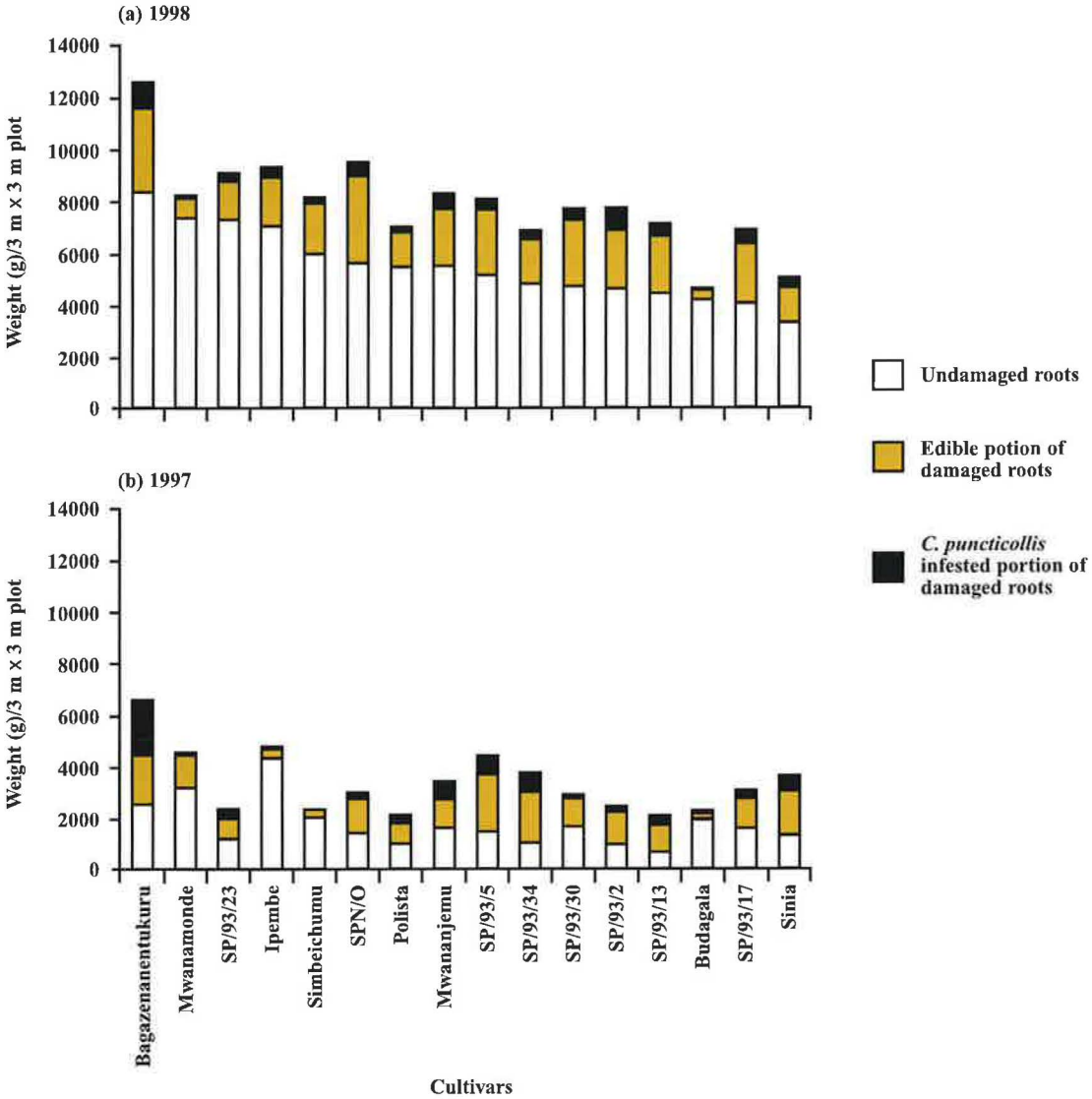


Figure 8.7 Comparison of *Cylas puncticollis* damage on the mean marketable yield of 16 sweetpotato cultivars at Ukiriguru, Tanzania in (a) 1998 (n = 5), and (b) 1997 (n = 4). Damage assessment was carried out by cutting (see section 7.2.3)

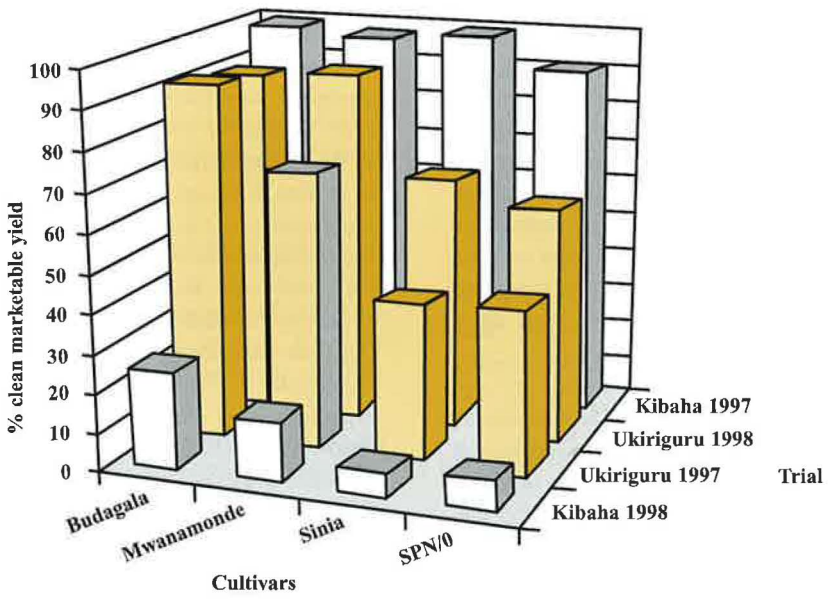


Figure 8.8 Percentage clean yield for four key sweetpotato cultivars in trials at Ukiriguru and Kibaha in 1997 and 1998

Table 8.4 Models of *Cylas* spp. infestation in terms of plant characteristics

Location and season of trial	Percentage clean yield*		Percentage infested portion of roots **		Non-destructive damage score ***	
	Model	var.	Model	var.	Model	var.
Ukiriguru 1997	60.0+5.0FW-0.6R	69 (29)	5.9-1.1FW+0.2R	29 (24)	1.5-0.06FW+0.008R	57 (26)
Ukiriguru 1998	94.0+0.6FW-1.6ER 0.4SC	88	1.6 0.2FW+0.4ER+0.07SC	68	1.2-0.02FW+0.02ER+0.007SC	74
Kibaha 1997	No meaningful models could be constructed					
Kibaha 1998	No meaningful model could be constructed		30.4-2.4FW+7.8RW+4.7ER	88 (46)	3.1-0.2FW+0.4RW+0.2ER	75 (49)
Serere 1997	97.4-0.9RW	30	No meaningful model could be constructed		ND	
Serere 1998	23.0+7.5SWD+4.5CD-0.9RW	70 (37)	25.7-2.3SWD-1.8CD+0.1RW	74 (25)	ND	

FW = foliage weight (t/ha); RW = root weight (t/ha); R = root number (/ha); ER = percentage of plants with exposed roots; SC = percentage of plants with soil cracks; SWD = shortest weevil distance (cm); CD = crown diameter (mm); ND = no data.

var. = percentage variance accounted for by model. Where models include a root yield term (R or RW), the variance accounted for by this term alone is given in brackets.

* Percentage clean yield refers to weight of roots completely clear of infestation.

** For measurement of percentage of infested portions, roots were cut and separated into clean and infested portions as described in section 8.2.3.

*** Non-destructive damage score as described in section 8.2.2.

Stathers *et al.*, in press a.) It is not unexpected that higher root yield is associated with increased levels of infestation, but clearly this is not a useful relationship in the context of breeding for reduced susceptibility. Soil cracking, exposed roots and shortest weevil distance all relate to root architecture. In all but one location, we approximated root depth by measuring neck length. Although this was related to infestation levels in several trials, we could not find any strong models containing this parameter. 'Root neck length' measures the distance from the crown (soil level on plant stem) to the tip of the root when the harvested plant is held above ground. This measurement gives no indication of whether the roots have gone straight down into the soil or spread sideways (possibly close to the edge of the ridge) and, therefore, is not a realistic measurement of accessibility of roots to *Cylas* spp. The shortest distance to the root is a much more time consuming method, but future fieldwork studying cultivar differences in *Cylas* spp. infestation levels would benefit from using this more accurate indicator of how accessible roots are to the infesting *Cylas* spp. weevils.

In several models, high foliage weight was associated with reduced levels of infestation. This suggests it might be advantageous to select for cultivars that have increased foliage or whose foliage persists longer into the dry season. Increased foliage cover may maintain moisture in the soil and prevent the formation of soil cracks, or make them less accessible to weevils. In addition to maintenance of soil moisture, two alternative hypotheses are firstly, that *Cylas* spp. damage to the crown may reduce foliage growth (a significant negative correlation was observed between foliage yield and external damage to crowns), or secondly, that there may be complex links between *Cylas* spp. feeding behaviour and oviposition, or foliage and predatory insect numbers.

Although the results are not presented here, laboratory experiments were conducted at all three sites to determine if the harvested storage roots of sweetpotato cultivars differed in their acceptability to *C. puncticollis* or if any root antibiosis (toxicity) towards *C. puncticollis* existed (for details see Stathers *et al.*, in press b). For all experiments, cultivar effects on the number of new adults emerging were significant to at least 10% and in most cases were much more significant. At Ukiriguru and Kibaha, the results showed reasonable consistency between years and, of the four cultivars used at both sites, fewer *C. puncticollis* adults emerged from roots of Sinia and Budagala than from SPN/0 and Mwanamonde on all occasions. A relationship between laboratory experiments and crown damage by *Cylas* spp. in the field suggests that cultivar differences in attraction/deterrence for *Cylas* spp. exist. However, correlations between adult emergence in laboratory experiments and field infestation levels were generally not strong. Although this indicates that cultivar selection by laboratory experiments is not a useful strategy for reducing field infestation, there may be

potential for using such techniques to select cultivars that are resistant to attack during long-term storage.

8.4 Conclusions and implications

Two methods for assessing cultivars for susceptibility to *Cylas* spp. infestation have been introduced. The best strategies for assessing cultivars may differ by location. In countries where sweetpotatoes are grown almost exclusively for marketing, roots infested by *Cylas* spp. have virtually no economic value. In contrast, in many developing countries the clean portion of partially infested roots can act as a food source, either fresh if consumed immediately, or sliced and sun-dried. Comparison of the methods indicated no great difference in subsequent ranking of the cultivars. For detailed studies, the destructive measurement of the percentage of infested portion of roots is the most accurate representation of the way the sweetpotato harvest is used by farmers in East Africa. However, our data suggests that non-destructive damage scores can be used as a rapid approximation.

Although attempts to breed for resistance to *Cylas* spp. infestation have so far shown little success, results presented here on the differences among cultivars in East Africa, indicate the value of continuing to assess cultivars for their levels of susceptibility to the pest, as indeed most breeding programmes continue to do.

References

AKAZAWA, T., URITANI, I. and KUBOTA, H. (1960) Isolation of ipomoeamarone and two coumarin derivatives from sweet potato roots injured by the weevil, *Cylas formicarius elegantulus*. *Archives of Biochemistry and Biophysics,* **88**: 150–156.

CHALFANT, R.B., JANSSON, R.K., SEAL, D.R. and SCHALK, J.M. (1990) Ecology and management of sweet potato insects. *Annual Review of Entomology,* **35**: 157–180.

HO, T.H. (1970) Studies on some major pests of sweet potato and their control. *Malaysian Agricultural Journal*, **47**: 437–452.

JANSSON, R.K., BRYAN, H.H. and SORENSEN, K.A. (1987) Within vine distribution and damage of sweet potato weevil, *Cylas formicarius elegantulus* (Coleoptera: Curculionidae), on four cultivars of sweet potato in southern Florida. *Florida Entomologist*, **70** (4): 523–526.

KAPINGA, R., MTUNDA, K., CHILLOSA, D. and REES, D. (1997) An Assessment of Damage of Traded Fresh Sweet Potato Roots in Mwanza, Dar es Salaam and Morogoro Markets. Roots and Tuber Crops Research Programme, Progress Report for 1996. Ministry of Agriculture and Co-operatives, Research and Training Department, Tanzania. (unpublished)

LENNÉ J.M. (1991) Diseases and pests of sweet potato: south-east Asia, the Pacific and East Africa. *Natural Resources Institute Bulletin,* No. 46.

MULLEN, M.A. (1984) Influence of sweetpotato weevil infestation on the yields of twelve sweet potato lines. *Journal of Agricultural Entomology*, **1** (3): 227–230.

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

SMIT, N.E.J.M. (1997) *Integrated Pest Management for Sweetpotato in Eastern Africa*. Thesis, Landbouwuniversiteit Wageningen.

STATHERS, T.E., REES, D., JEFFRIES, D., KABI, S., SMIT N., MBILINYI, L., KIOZYA, H., JEREMIAH, S., NYANGO, M., MOSS, C. and ODONGO, B. (1999) Investigating the Potential of Cultivar Differences in Susceptibility to Sweetpotato Weevil as a Means of Control. Final Technical Report. Chatham, UK: Natural Resources Institute. (unpublished)

STATHERS, T.E., REES, D., KABI, S., MBILINYI, L., SMIT, N., KIOZYA, H., JEREMIAH, S., NYANGO, A. and JEFFRIES, D (in press a) Sweetpotato infestation by *Cylas* spp. in East Africa: I. Cultivar differences in field infestation and the role of plant factors. *International Journal of Pest Management.*

STATHERS, T.E., REES, D., NYANGO, A., KIOZYA, H., MBILINYI, L., JEREMIAH, S., KABI, S., and SMIT, N. (in press b) Sweetpotato infestation by *Cylas* spp. in East Africa: II. Investigating the role of root characteristics. *International Journal of Pest Management.*

SUBRAMANIAN, T.R., DAVID, B.V., THANGAVEL, P. and ABRAHAM, E.V. (1977) Insect pest problems of tuber crops in Tamil Nadu. *Journal of Root Crops,* **3**: 43–50.

SUTHERLAND, J.A. (1986) A review of the biology and control of the sweetpotato weevil *Cylas formicarius* (Fab.). *Tropical Pest Management*, **32**: 304–315.

TALEKAR, N.S. (1987) Feasibility of the use of resistant cultivars in sweetpotato weevil control. *Insect Science and its Application,* **8**: 815–817.

URITANI, I., SAITO, T., HONDA, H. and KIM, W.K. (1975) Induction of furanoterpenoids in sweet potato roots by the larval components of the sweet potato weevils. *Agricultural and Biological Chemistry,* **37**: 1857–1862.

VILLAREAL, R.L. (1982) Sweet potato in the tropics – progress and problems. pp. 3–15. In: *Sweet Potato. Proceedings of the First International Symposium. Asian Vegetable Research and Development Center, Shanhua, Tainan, Taiwan, Republic of China.*

CHAPTER 9

Assessment of sweetpotato cultivars for suitability for different forms of processing

C. Owori and A. Agona

9.1 Introduction

Sweetpotato storage roots are bulky and perishable. The main forms of deterioration have been discussed in Chapter 5. The bulkiness and perishable nature of the roots are major constraints on the marketing and availability of the crop. One way in which these constraints have been addressed is through processing. Processing is defined as the transformation of the raw material (fresh root) into the end product. The end product, which is usually a value-added product, may be more attractive, palatable, nutritious, less bulky and less perishable to permit continuous use. The major part of processed sweetpotato in sub-Saharan Africa is utilized for human consumption and the methods are limited. Two main types of sweetpotato processing, traditional and commercial processing, are discussed in this chapter.

9.1.1 Traditional processing

Traditional processing methods are simple and are practised at household level to produce products for direct use as human food. Boiling or steaming (cooking) roots is the main method used for the preparation (processing) of sweetpotato for home consumption.

In some dry areas of Uganda and Tanzania, sun-drying sliced pieces is practised during the dry season, primarily as a means for storing the roots. At maturation,

sweetpotato roots are subject to deterioration that lowers quality and quantity adversely if they are not harvested timely. The primary causes of root deterioration, as discussed earlier, include physiological processes: tissue

metabolism and sprouting; mechanical factors due to poor harvesting, packaging, transportation and storage that result in bruises and wounds; and biotic factors, i.e. insects, nematodes, rodents and microbes (Hill, 1984; Chalfant *et al.*, 1990). At present there are few appropriate storage and curing methods, especially at smallholder subsistence farm levels, that could enhance the shelf-life of roots during post-maturation (Agona, 1998). One strategy to ensure the availability of sufficient food, especially during the lean seasons and where sweetpotato cultivation is limited to only one season in a year, is to process the roots into dried chips and store them in this form. The dried chips are either reconstituted by boiling or are ground into flour which may or may not be mixed with millet/sorghum flour for making thin and thick porridge. Methodologies for the improvement of traditional drying at farm level to produce higher quality primary products that can either be stored without spoilage or used to process value-added products are being explored.

9.1.2 Commercial processing

Sweetpotato processing for human consumption in many countries is not yet commercialized. Studies in some countries have, however, investigated the feasibility of sweetpotato as a partial substitute for imported wheat flour in snack products. Substitution of wheat flour, either with fresh, grated roots or sweetpotato flour, is gaining a foothold in the snack product market in Kenya and Uganda. Promotion of commercial processing of primary products would increase the utilization of sweetpotato flour as an ingredient in snack product processing.

There is great variation in the processing characteristics of sweetpotato cultivars but generally dry matter is an important characteristic.

9.1.3 Objectives

In this chapter, we will consider the development of methods to assess and evaluate cultivars for cooking quality and suitability for processing into crisps, dried chips and sweetpotato flour.

9.2 Methods

9.2.1 Assessing cultivars for cooking quality

In Chapter 2, we reported that farmers usually prefer varieties that take a short time to cook. Cooking sweetpotatoes for the correct time is important, since over-cooking reduces nutrient content, while under-cooking results in high levels of anti-nutrients (such as proteinase inhibitors) which can cause indigestion or illness. The simplest method to assess cultivars for cooking quality is thus to measure cooking time. When the root is boiled, it softens and if over-cooked it may disintegrate. Variation in cooking time is closely related to dry matter content. Therefore, in assessing cultivars for cooking quality, determination of cooking time, dry matter content, and sensory evaluation of the *cookedness* of the roots are all important.

A study was carried out in Uganda in which a wide range of cultivars were assessed for cooking qualities. Cooking time was evaluated instrumentally using the matson bar drop cooker method. This is a simple, reproducible and rapid method. The matson bar cooker, illustrated in Figure 9.1, consists of sharp metal rods that puncture and drop through the product being tested as the product becomes soft during cooking. The cookedness of the sweetpotato pieces was determined using sensory evaluation methods.

9.2.2 Assessing cultivars for crisp production

During frying, sugars usually contribute to the darkening of the final product due to the maillard reaction which occurs between reducing sugars and amino acids at high temperatures. It is known that dry matter content affects yield and oil content of the final product as roots with a high water content produce crisps with a higher oil content. Oiliness has been found to be one of the most important problems affecting the acceptability of sweetpotato crisps, and economically, as oil is expensive, it will affect the cost. The simplest and most sound method for assessing cultivars for suitability for crisp processing is to measure sugar and dry matter content. However, it is also important to take

Methods Used in Assessing Cooking Qualities of Cultivars in Uganda

Sweetpotato storage roots used in the experiments included local and released varieties. The sweetpotatoes were planted in farmers' fields in Dokolo sub-county, Soroti, during the long rains of 2000 and harvested after 5 months.

Immediately after harvesting, dry matter of sweetpotato varieties was determined by the oven method. Chopped pieces of sweetpotato roots were dried to a constant weight in a forced air oven set at 60 °C. Dry matter was calculated as dry weight/fresh weight x 100.

The middle portion of average sized sweetpotato roots was cut into cubes of 1.5 cm in height and diameter. The prepared samples were placed under the sharp metal rods of a matson bar drop cooker which was put in a saucepan containing 1 litre of boiling water. The time that each rod took during the cooking process to drop down after penetrating the piece of sweetpotato was recorded as cooking time.

For the sensory evaluation, the cooked pieces of sweetpotatoes were presented to regular consumers of sweetpotato to assess the degree of cookedness. The five panelists were staff from the research institute. Assessment involved scoring for the degree of cookedness on a nine point scale shown in Table 9.1. Clean water was provided to rinse the mouth between variety testing.

Figure 9.1 The matson bar cooker

Table 9.1 Sensory scale for evaluation of cooked sweetpotato pieces

1	Extremely raw
2	Very slightly cooked
3	Slightly cooked
4	Nearly cooked
5	Sufficiently cooked
6	Very slightly overcooked
7	Slightly overcooked
8	Overcooked
9	Extremely overcooked

into account consumer acceptance of the final product. Important characteristics that influence consumer acceptance of products are colour, taste and texture.

A study was carried out in Kenya to assess cultivars for their suitability for processing into crisps. Crisps were made by a standardized method, and then assessed for oil content and consumer acceptability. The findings were also related to the original root dry matter content.

Methods Used in Assessing Cultivars for Processing into Crisps in Kenya

Sweetpotato storage roots used in the experiment were grown at the University of Nairobi, Kabete Campus farm during the long and short rains of 1994 and at the Regional Research Centre in Kakamega during the long rains of 1994. All roots were harvested at a maturity age of 5 months.

Dry matter was determined by drying chopped root samples at 65 °C for 72 h in a forced air oven. Percentage dry matter was calculated as dry weight/fresh weight x 100.

Processing of sweetpotato into crisps was done by cutting peeled and washed sweetpotato roots into 1–1.5 mm slices. The slices were washed in cold tap water to remove surface starch and dried on a clean towel. Frying was carried out in a domestic deep fat fryer containing about 3 litres of Elianto corn oil at a constant temperature of 170 °C for 5 min. The crisps were removed from the oil and drained for 30 s. Oil content in the crisps was determined using the method described by Lulai and Orr (1979). Crisps were finely ground in a blender. A 5 g portion of powder was put into a thimble and a 6 h soxhlet extraction conducted using petroleum ether as described. Percentage oil content was calculated as weight oil/weight original sample x 100.

Acceptability of the crisps was determined by the sensory evaluation method. Crisps were presented to a panel consisting of staff of the National Potato Research Centre, Tigoni to score for flavour and texture on a 1–5 scale (i.e. 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = excellent).

9.2.3 Assessing cultivars for dried chip processing and subsequent susceptibility to insect infestation

Dried chip processing involves the selection of big and undamaged roots, peeling, wilting in the sun for a few hours, slicing and drying on stabilized drying yards. Sweetpotato cultivars that are high yielding, have big roots, store well in the ground after attaining maturity, are not easily damaged by insects and are 'delicious' are particularly preferred for dried chip processing (Agona, 1998). The dried chips are considered 'inert materials' and thus not liable to biochemical and physiological deterioration factors. The main constraints of dried chips are losses associated with poor drying and inefficient storage practices that encourage insects and microbial infection (Hall *et al.*, 1998). Damaged chips are characterized by pulverization, tunnelling and mouldiness (Fowler and Stabrawa, 1993). This is accompanied by production of powdery wastes, development of bitter and pungent off-flavours and tunnels packed with larval faecal droppings.

Farmers' practices of mitigating losses involve regular inspection and re-drying in the sun and, to a lesser extent, opening the granary roof to allow the photophobic insects to escape. Although farmers are aware of differences between varieties in susceptibility to storage insect pests, all sweetpotato varieties are processed and stored in the same unit indiscriminately. Farmers define susceptible cultivars as those that are easily damaged within a few months of storage, while the 'resistant' ones as those that store for long periods with insignificant damage. The main reasons for non-varietal selection during processing include good food blend, differences in varietal yields, limited planting materials for suitable varieties, preventing further insect damage, development of root sponginess and difficulty in providing each variety with its own storage structure (Agona, 1998).

Methods Used in Assessing Cultivars for Processing into Dried Chips in Uganda

Source of roots and processing into dried chips

Roots of 13 different sweetpotato cultivars were harvested at about 180 days after planting at Kawanda Agricultural Research Institute. The optimal growth period was 6 months for all the cultivars to ensure synchrony in maturity (Badillo and Lugo, 1977; O'Hair *et al.*, 1986).

Farmers' traditional methods of dried chip processing were simulated. The chips were dried under the sun for 4 days until a constant moisture content (MC) of 11–12% was attained in all the cultivars processed. Chip MC was monitored twice at 4-h intervals during the day, by drying 10 g of ground sweetpotato slices in a ventilated oven at 130 °C for 1 h.

Screening chips for susceptibility to insect infestation

The dried chips were packed separately in waterproof polyethylene bags and kept in a deep freezer for 3 days to disinfest the chips of any prior infestation during drying. The frozen chips were removed and placed in 2 litre plastic bottles fitted with perforated lids and conditioned under prevailing ambient conditions in the laboratory for 1 week. After conditioning, the dried chips were divided into two 500 g lots. The first lot was retained for varietal screening for resistance, and the second lot was sub-divided into two sub-lots of 250 g each and used for conditioning 0–3-day-old *A. fasciculatus* females and males for 3 weeks. The females and males were kept separately to allow acclimatization of the different varieties and synchrony with the maximum oviposition period (Agona, 1998).

The 500 g samples conditioned for varietal screening for resistance were weighed into three different 100 g sub-lots and kept in 1 litre Kilner jars fitted with perforated lids with the neck coated with Fluon® (this provides a slippery surface which prevents the insects from climbing out). The chips in each jar were infested with six female- and three male-acclimatized adults aged 18–21 days. Gravid females were allowed 3 days to oviposit and then removed. The use of older adults, lower number of males and shortened oviposition period was to ensure maximum oviposition (Sayed, 1935), to avoid oviposition interference (Kumar and Karnavar, 1986) and to reduce the duration between the first and last adult emergence dates (Agona, 1998), respectively. The infested chips were retained in the jars under ambient conditions until all the F1 progeny had emerged. The total number and time taken by 50% of the F1 progeny to emerge was determined. The data were used to calculate the susceptibility indices (Dobie, 1974, 1977) of the sweetpotato varieties under test using the formula:

$$SI = \frac{\text{Log}_e (F1) \times 100}{D}$$

where SI = susceptibility index

F1 = total number of adults that emerged

D = time taken by 50% of the progeny to emerge from mid-oviposition

The data of susceptibility indices, development time and emergent adult numbers were analysed as completely randomized design using the MSTATC statistical package. Each sweetpotato variety constituted a treatment and was replicated three times.

A study was conducted in Uganda to determine the development and infestation rate of the coffee bean weevil, *Araecerus fasciculatus* (Degeer), on dried chips made from a range of different sweetpotato cultivars. The cultivars were obtained from farmers' fields in Kumi district (Agona, 1998), which are enriched with a large germplasm collection of sweetpotato and where dried chip processing and utilization are predominant. *Araecerus fasciculatus* is a major pest of dried sweetpotato chips in storage (Agona, 1995).

9.2.4 Assessing cultivars for flour processing (low browning)

Sweetpotato flour is a raw material for various processed food products. One major constraint associated with sweetpotato is the browning reaction which takes place when the roots are exposed to air during processing. This results in an undesirable discoloration. In traditional processing, browning is not considered a disadvantage, however, it is a major obstacle in some products incorporating sweetpotato flour.

A study was conducted in Kenya in which roots were assessed for their tendency to brown when cut.

9.3 Results

9.3.1 Cultivar cooking qualities

Results obtained from the case study are shown in Table 9.2. Among the varieties evaluated, SPK 004, Naspot 1 and Haraka were considered to have particularly good cooking qualities as they had a high dry matter content and yet did not take long to cook. The sensory scores indicated that in this study all the samples were considered to be cooked for about the right amount of time (a score of 5 indicated 'sufficiently cooked', see Table 9.1). (**Note:** Cooking time of the small tissue pieces was shorter than would be expected for whole roots or large pieces.)

9.3.2 Cultivar suitability for crisp production

Table 9.3 presents the variation among cultivars in root dry matter content and in the oil content and acceptability of the fried crisps. There is a significant negative correlation between oil content and dry matter content of fried sweetpotato crisps (Figure 9.2). However, there was no significant trend observed between acceptability in terms of texture or flavour and the crisp oil content. A slight trend was observed between acceptability in texture and dry matter content, with high dry matter content having slightly

Methods Used to Assess Cultivars for Browning

Sweetpotato storage roots used in the experiment were grown at the University of Nairobi, Kabete Campus farm during the long and short rains of 1994 and at the Regional Research Centre in Kakamega, during the long rains of 1994. All roots were harvested at 5 months. Sweetpotato clones were screened for flour processing by recording the browning rate. The roots were cut into slices using a stainless steel kitchen knife and exposed to air at room temperature. The change in colour was observed at intervals of 0.5 h, 1 h, 3 h, 6 h, 18 h and 24 h. At the end of each interval, the rate of browning in sweetpotato was evaluated using a hedonic scale of 1–5 as follows: 1 = no discoloration; 2 = light discoloration; 3 = fair discoloration; 4 = heavy discoloration; 5 = very heavy discoloration.

Table 9.2 Dry matter content, cooking time and mean scores for sensory evaluation of cooked sweetpotato pieces

Variety	Dry matter content (%)	Cooking time (min)	Sensory scores
Naspot 5	27.7	2.8e	5.8
Naspot 1	36.0	3.3*d	5.2
SPK 004	32.2	3.3d	5
Haraka	31.4	3.5d	5.3
Osopat	29.4	3.6cd	5.3
Ateseke	33.1	3.6cd	5.4
Sowola	38.6	4.1*bc	5.2
Naspot 3	33.4	4.5ab	5
Tanzania	34.3	4.6a	5
Naspot 2	30.3	4.8a	5.1

* Small sized roots were used in the experiment.

Means with different letters within columns are significantly different at $P = 0.05$.

Table 9.3 Dry matter content, oil content and crisp acceptability of sweetpotato clones and varieties

Clone	Dry matter (%)	Oil content (%)	Flavour acceptability	Texture acceptability
440006	15.8	27.72	2.8	2.5
440111	17.4	33.98	3	3
440243	18.4	22.59	3.4	3.3
440185	18.4	31.55	3.8	3.5
420029	18.5	27.84	3.5	3.5
400005	20.7	26.70	2.6	2.8
KSP 20	21.2	21.91	2.6	3.1
440186	21.5	25.14	4.2	4.1
440062	23	24.2	3	3.6
440198	23.4	25.28	4	3.4
440089	23.4	22.53	3.1	3.8
440098	23.5	21.87	3	3.6
440050	25.4	18.99	3.7	3.4
420024	25.4	25.53	4.2	3.5
420014	29.3	29.5	3.3	3.8
KSP 11	29.5	21.04	3.6	3.3
440024	29.8	25.53	2.3	3.5
440103	30.5	21.4	4.1	3.6
Mwezi Tatu	31.5	21.77	3.9	3.2
440129	32.2	19.65	3	3.9
420026	32.2	27.05	3.1	3.9
Kemb 33	32.3	13.95	3.2	3.7
Kemb 23	32.5	19.68	3.3	3.4
Kemb 36	32.9	15.25	3.7	3.4
SPK 004	33.4	20.88	3.1	3.3
Kemb 10*	33.6	19.86	3.1	3.2
SPK 013*	34.5	18.51	3.2	3.2
Kemb 20	36.1	17.15	3.5	3.9

*Local checks.

higher scores, but this was barely statistically significant ($r = 0.355$ significant to 10%). The varieties that we consider to have greatest potential for processing into crisps were those with a high dry matter and crisps of low oil content and high acceptability. These varieties were identified as SPK 013, Kemb 36, Kemb 33, Kemb 20, Kemb 23, SPK 004, 440050 and 440129.

9.3.3 Cultivar suitability for dried chip processing in terms of resistance to insect infestation

Significant differences ($P<0.05$) occurred between varieties for the number of *Araecerus fasciculatus* F1 progeny that emerged from the dried chips (Table 9.4). Similarly, the median development periods of *A. fasciculatus* varied between varieties (Table 9.4). The results further showed significant variation in the susceptibility (SI) of the varieties to *A. fasciculatus* in which varieties with the highest number and shortest median development period of the pest were classified as the most susceptible (Category III). Those with low numbers of emergent adults and with protracted development periods were classified as less susceptible (Category I). Those varieties with intermediate qualities were placed in Category II. The results showed that all the dried chips of the 13 varieties screened were susceptible to *A. fasciculatus* infestation, but to varying

Table 9.4 Varietal effects on *A. fasciculatus* emergent numbers and median development period and susceptibility indices

Sweetpotato variety	Number of adults emerged*	Median development time (days)*	SI*	Category
Mbiyombiyo	11.0 ± 3.2	57.5 ± 1.5	4.00 ± 0.65	III
Ecuru	10.3 ± 1.3	60.5 ± 1.2	3.84 ± 0.21	III
Emaderait	11.3 ± 2.2	63.2 ± 0.9	3.78 ± 0.38	III
Tanzania	10.7 ± 5.2	63.8 ± 0.9	3.34 ± 0.78	III
Oceger	6.3 ± 1.5	61.5 ± 2.3	2.94 ± 0.46	II
Odopelap	7.3 ± 2.3	65.2 ± 1.2	2.87 ± 0.64	II
Ojeite-edula	6.0 ± 1.5	62.2 ± 0.9	2.76 ± 0.53	II
Ateseke	5.7 ± 0.9	64.8 ± 0.7	2.64 ± 0.28	I
National	4.7 ± 0.7	58.2 ± 0.3	2.62 ± 0.23	I
Epura-amojong	6.3 ± 2.4	67.2 ± 1.2	2.52 ± 0.51	I
Ebyoloto	4.3 ± 0.3	61.5 ± 0.3	2.36 ± 0.11	I
Ebokorait	4.0 ± 0.6	65.5 ± 1.5	2.09 ± 0.22	I
Haraka	3.3 ± 0.3	65.2 ± 0.9	1.83 ± 0.13	I
CV (%)	53.7	3.2	26.73	
SED (26 d.f.)	3.1	1.7	0.63	

* Each datum is given as mean ± SE.

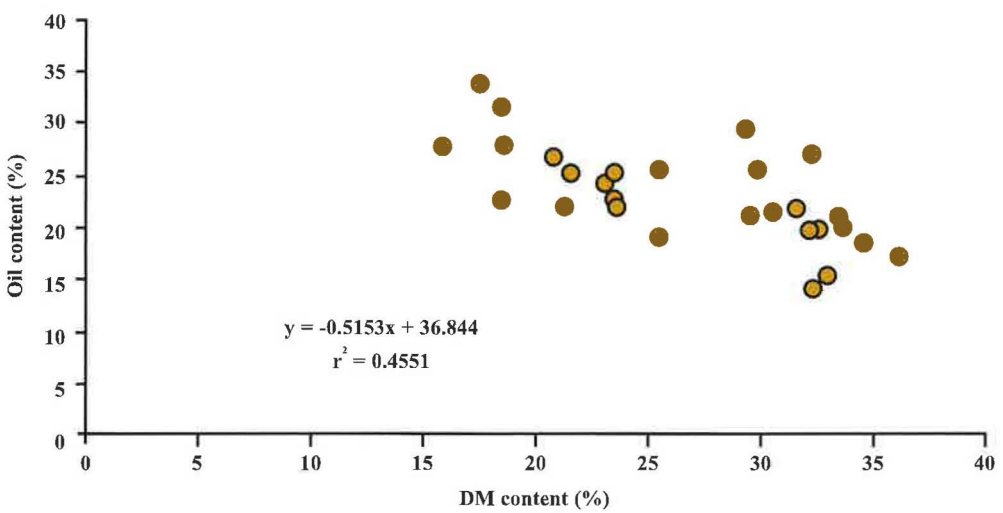


Figure 9.2 The oil content of deep fried sweetpotato crisps in relation to dry matter content for 28 sweetpotato varieties

degrees. The results agree with the farmers' belief that there are differences between varieties, especially in the onset of infestation and damage levels (Agona, 1998).

9.3.4 Variation in root browning among cultivars

Results from the study showed that there was a wide range in browning among cultivars (Table 9.5). There was no relationship between dry matter content and rate of browning. Cultivars with a high dry matter content which showed lower browning, i.e. SPK 004, Wendo, Modhial, 188001.2 and 440078, were considered as having the greatest potential for processing into flour.

Table 9.5 Rates of browning (oxidation) of sweetpotato roots after slicing

Clone	Percentage dry matter	0.5 h	01 h	3 h	6 h	24 h
KSP 20	21.2	2.5	2.9	2.9	3.0	3.4
SPK 013*	34.5	2.0	2.4	2.6	3.2	3.0
Kemb 36	32.9	1.5	1.5	1.8	1.8	2.4
Kemb 10*	33.6	2.1	2.0	2.1	2.4	3.0
KSP 11	29.5	2.2	2.0	2.1	2.5	2.8
Mwezi tatu	31.5	4.6	4.9	5.0	5.0	5.0
Kemb 23	32.5	1.0	1.9	2.0	2.2	3.7
Ogur Iwe*	35.0	1.0	1.5	1.8	3.0	3.2
Kemb 33	32.3	1.0	1.4	1.0	3.0	3.2
Kemb 20	36.1	2.8	3.0	3.0	3.4	3.2
SPK 004	33.4	1.2	1.8	2.4	2.8	2.9
Wendo modhial*	34.5	2.4	2.4	2.2	2.5	2.8
188001.2	35.4	1.0	1.2	1.4	1.8	2.2
420009	28.1	2.4	2.4	2.4	2.6	3.0
Sandak*	30.1	2.0	2.2	2.0	2.4	3.0
Ex diani	29.8	2.4	2.7	2.5	3.0	3.2
Mafuta	37.0	2.8	3.0	3.2	3.3	3.5
440078	29.0	2.2	2.2	2.1	2.2	2.5
Mtw13	24.0	1.7	1.9	2.4	2.5	2.7
440078	29.0	2.2	2.2	2.1	2.2	2.5
Mtw13	24.0	1.7	1.9	2.4	2.5	2.7
440037	26.5	2.5	2.9	2.8	2.9	2.9
440062	23.0	4.4	4.9	5.0	5.0	5.0
420026	32.2	2.9	2.8	3.1	3.2	3.0
420027	21.7	2.1	2.9	3.3	3.4	3.3
440024	29.8	2.5	2.8	3.2	3.3	3.4
440098	23.5	2.1	2.6	3.2	3.3	3.4
440009	26.2	2.5	3.1	3.4	3.5	3.6
420025	28.7	4.3	4.8	5.0	5.0	5.0

* Local checks.

Note: Work is underway to determine the effect of chemical composition and functional properties of cultivars on quality and consumer acceptability of products made using sweetpotato flour. Further information can be obtained from C. Owori.

References

AGONA, J.A. (1995) Survey on the storage pest complex of dried sweetpotato chips in Uganda. pp. 479–483. In: *Root Crops and Poverty Alleviation. Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch), 22–28 October 1995, Lilongwe, Malawi.* Akoroda, M.O. and Ekanaye, I.J. (eds).

AGONA, J.A. (1998) *Studies on Aspects of the Biology and Control of Araecerus fasciculatus Degeer (Coleoptera: Anthribidae) on Dried Sweet Potato Chips*. PhD thesis, University of Zimbabwe.

BADILLO, J.F. and LUGO, M.A. (1977) Sweet production in oxisols under a high level of technology. *University of Puerto Rico Agricultural Experimental Station Bulletin,* No. 256.

CHALFANT, R.B., JANSSON, R.K., SEAL, D.R. and SCHALK, J.M. (1990) Ecology and management of sweetpotato insects. *Annual Review of Entomology*, **35**: 157–180.

DOBIE, P. (1974) The laboratory assessment of the inherent susceptibility of maize varieties to post-harvest infestation by *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae). *Journal of Stored Products Research*, **10**: 183–197.

DOBIE, P. (1977) The contribution of the Tropical Stored Products Centre to the study of insect resistance in stored maize. *Tropical Stored Products Information*, **34**: 7–17.

FOWLER, M.H. and STABRAWA, A.M. (1993) Sweet Potato Marketing in Uganda. Result of a Rapid Appraisal [R 1905 (S)]. Chatham, UK: Natural Resources Institute. (unpublished)

HALL, A., BOCKETT, G. and SILIM, M.N. (1998) Sweetpotato post-harvest systems in Uganda: Strategies, constraints and potentials. *A Social Science Working Paper,* No. 1998–7. Lima: International Potato Center.

HILL, D.S. (1984) *Agricultural Insect Pests of the Tropics and their Control*. Second edition. Cambridge: Cambridge University Press.

KUMAR, G.A. and KARNAVAR, G.K. (1986) Reproductive biology of the stored product pest *Araecerus fasciculatus* (Coleoptera: Anthribidae), *Entomonograph*, **11** (4): 309–310.

LULAI, E.G. and ORR, P.H. (1979) Influence of potato specific gravity on yield and oil content of chips. *American Potato Journal*, **56**:379–390.

O'HAIR, S.K., DANGLER, J.M., EVERETT, P., FORBES, R.B., LOCASCIO, S.J., OLSO, S.M., SCHUMAKER, J.R. and WHITE, J.M. (1986) Cruciferous and root crops for year-round biomass production. pp. 173–184. In: *Biomass Energy Development*. Smith, W.H. (ed.). New York: Plenum.

SAYED, M.T. *et al.* (1935) On the biology of *A. fasciculatus* De Geer (Coleoptera: Anthribidae) with special reference to the effects of variations in the nature and water content of the food. *Annals of Applied Biology*, **22**: 557–577.

Sweetpotato breeding methodologies and targets in sub-Saharan Africa

R.E. Kapinga and E.E. Carey

I.1 Introduction

Plant breeding can be defined as the art and science of changing plants genetically (Allard, 1960). It is crop evolution directed by man through a conscious decision to keep the progeny of chosen parents similar in performance to ideotypes (Jones *et al.*, 1986). Steps involved in plant breeding are:

- finding or developing populations from which selections can be made
- selection
- the use of selections in commercial/useful production.

Root and tuber crops are vegetatively propagated, thus the breeding methods most suitable for these crops are somewhat different from those used for seed propagated crops. Vegetatively propagated crops are characterized by the following advantages:

- as long as they are propagated vegetatively and in the absence of spontaneous mutation, no genetic segregation takes place even if they are genetically heterozygous
- superiority of F1 plants results from both additive and non-additive effects
- heterosis can be vegetatively fixed, it lasts permanently and it is, therefore, possible to select individuals having desirable traits in the F1 generation.

Vegetatively propagated crops have their own disadvantages in breeding which include:

- many cultivars do not flower under natural conditions
- the inheritance of characters is usually complicated due to heterozygosity and polyploidy
- exchange of breeding materials is difficult because of local quarantine regulations: these govern the export and import of vegetative materials to restrict the spread of pests and diseases which are transmitted through vegetative propagation.

The appropriate method of population improvement must, therefore, be chosen to suit facilities, available funds and the variation (both genetic and environmental) in the population under improvement. The basic requirements of prolonged progress are common to all crops and methods: good parents, good derived populations, adequate number, adequate genetic variability and efficient selection.

It is important to involve the end-user in the selection process. This can be done by identifying the farmers' needs and incorporating them into the selection

process or involving the farmers themselves in the selection process so that they pick what they want. It is important for the researcher and farmer to come to a compromise since, for example, the farmer may choose a variety which, unknown to him, is susceptible to disease or insect attack, while the researcher with his additional knowledge can discount such a variety.

I.2 Sweetpotato breeding objectives

A plant breeding programme must have well defined objectives which are both economically and biologically reasonable. Economic objectives are important, even if not stated in strictly monetary terms, because the breeder must be assured that he/she is trying to produce varieties that farmers and end-users want. The 'biological objectives' are determined by scientific and general knowledge of the crop. Biological objectives are dominated by yield and quality factors (fitness for purpose), although a few additional features that do not fall under either of these headings can also be recognized.

I.3 Obtaining and evaluating new sweetpotato clones

I.3.1 Justification for new varieties

The selection of new varieties is an important aspect of sweetpotato crop improvement. New varieties can provide farmers with improved yields, early maturity, control of diseases and pests, and quality characteristics, at little or no additional cost. Those interested in the selection of new varieties include agricultural researchers, development and extension workers and, of course, farmers.

I.3.2 Sources of starting material

The starting material for a sweetpotato variety selection programme may be either sexual seed or previously existing clones. Sweetpotato is a vegetatively (also called clonally or asexually) propagated crop, but new varieties come principally from seeds produced by cross-pollination. While large populations of seeds are the starting material used by established breeding programmes, the process of their initial evaluation takes longer, and thus is more expensive than the evaluation and selection of previously existing clones. Previously existing clones are the logical first step for evaluation and selection by newly established variety selection programmes, and are also valuable to established breeding programmes as a source of potential new parental material and varieties.

Several sources of previously existing clonal germplasm are available for testing, including experimental clones and varieties released from breeding programmes, as well as farmer-selected landrace varieties. Within a country, sources of clones for testing may include breeding programmes, germplasm collections (gene banks) and farmers, or clones may be obtained internationally. The International Potato Center (CIP) maintains a large collection of pathogen-tested sweetpotato clones available for international distribution and testing. This collection includes important landrace and released varieties from many countries, and elite experimental clones from leading sweetpotato breeding programmes around the world. The decision on which source(s) of clonal germplasm to use and how to proceed with evaluation should be based on an understanding of current and previous sweetpotato varietal selection efforts in the target area.

Key elements in variety evaluation

In any standard procedure, the following should be considered for a successful breeding programme.

i) Multiply clones for trial and verify their identities.

Pathogen-tested sweetpotato clones may be distributed internationally as *in vitro* plantlets or, in some cases, as cuttings. Take care to verify and maintain the identity of clones during multiplication and evaluation.

ii) Conduct preliminary evaluations of adaptation and acceptability.

Although some introduced clones will probably perform well in the target environment, many probably will not, because they will be poorly adapted to climate, soils or agronomic practices, or susceptible to diseases and pests. In addition, introduced clones may not have desired root or foliage quality characteristics. We recommend that introduced clones should initially be evaluated in observational trials with small plots, replicated once or twice, under agro-ecological and agronomic conditions representative of the target environment.

iii) Incorporate clones into a routine selection scheme.

In an ongoing breeding programme, we suggest that introduced clones be incorporated directly into your standard trial scheme as explained in section I.4.

I.4 Sweetpotato standard trial scheme

The trial scheme described below involves teamwork where breeders, pathologists, entomologists, agronomists, food technologists, socio-economists, extension/farmers and industrial participation are equally important. All the breeding trials are conducted with no fertilizer application to simulate farmers' cropping systems in Africa. Although selections are made on monocrops, attention should be paid to morphological characteristics suitable to the predominant cropping system of the area/region.

Every breeding trial should include one local variety and one improved standard variety as checks. The local variety should be that most cultivated by farmers in the area. These two checks provide the basis for selection of new varieties which must be superior at least to the local check (genetic progress *vis a vis* local population) and to the standard improved variety (genetic gain *vis a vis* the breeding programme).

Basically, sweetpotato breeding involves sowing the F1 seeds obtained by full-sib (two known parents) and/or half-sib (only the female parent known, i.e. open pollinated [OP] seeds) progenies. As sweetpotato is heterozygous, there is a segregation of traits in the F1 population. Clonal selection is applied from F1 for identification of superior clones. Thus, there is no rationale in going to F2 before starting the selection.

Below is a summary of breeding stages taking into consideration the prevailing climatical and biological conditions. The breeding procedures provided here have some limitations considering the time taken to develop good acceptable varieties, and also the availability of resources within many national programmes in sub-Saharan Africa. The *CIP Research Guide* No. 6 by Carey and Reynoso (1997) provides an explanation of flexible procedures that should be used to take on-board evaluation of existing pathogen-tested germplasm. This can be used at different stages as explained, hence reducing the breeding cycle and maximizing available resources.

The following steps are taken after a sufficient number of seedlings have been raised and cloned from the source population. The selected clones must have been screened for resistance to viruses, weevils, root conformation and other desirable characteristics.

Step one: sweetpotato seedling nursery

Approximately 10,000 to 50,000 seedlings are raised, but 5000–15,000 seedlings are adequate depending on availability of resources. During the growing period, the seedlings are screened monthly for 4 months for resistance to major diseases and pests. The seedlings are harvested after 5 months. This is done for one season. Root conformity, shape and weevil damage are assessed. The selection should be rigorous. All selected clones are advanced to step two: sweetpotato clonal evaluation trial.

Step two: sweetpotato clonal evaluation trial

The selected seedlings from each station (which may number up to 2000) are cloned and planted in a single row plot of 5 x 1 m or 5 x 0.8 m (where land is scarce). Spacing between plants is 0.3 m in most countries. Two standard local varieties are planted after every 10 clones for comparison (check-plot design). At this stage, the observations made during the first year on diseases and pests are confirmed for each clone. At harvest (4–5 months after planting), individual clones are again assessed on the basis of the number of plants which have survived, the number of roots, root shape and size, total root yield (kg/plot), and the overall appearance of the roots. The clones which perform poorly in terms of establishment and other qualities are discarded. Only promising clones are further evaluated for dry matter, yield potential and other quality characteristics. Data collection procedure is explained in section I.5. The trial is always conducted at one site and for only one season.

Step three: sweetpotato preliminary yield trial

The best 20–50 clones selected through clonal evaluation in the previous year are put through a preliminary yield trial (PYT) in 2–3 rows, 3.0 m long, with 2–3 replications depending on availability of planting materials. In most parts of the world, the PYT is planted in 1–3 distinct locations for two seasons. In sub-Saharan Africa, due to unavailability of resources, PYT is planted for one season at one location. Clones are evaluated again for yield, disease and pest resistance, root characteristics, conformity, dry matter and consumer acceptance qualities. Participatory varietal selection could start from this step with only a few native station workers per location.

Step four: sweetpotato advanced yield trial

The most promising 5–15 clones selected from the preliminary yield trial carried out in the third stage progress to an advanced yield trial (AYT) in plots with 4 rows by 3.6–4.5 m in 3 replications. Only the two inner rows are harvested for yield estimation. The AYT trial is conducted in 2–3 locations representing a wide range of environments of specific agro-ecology and/or locations of different agro-ecology, but within the research centres. The trial is repeated for 2–3 seasons. The clones are further evaluated for root yield, disease and pest resistance, dry matter content, consumer acceptance qualities and adaptation. At this stage, it is important to involve farmers in the assessment of the varieties on-station for both agronomic characteristics and post-harvest qualities such as taste. Details for farmer participation in variety selection on-station and evaluation on-farm is presented in Chapter 2 and *CIP Research Guide* No. 5 (Fonseca *et al.,* 1994).

Step five: sweetpotato uniform yield trial

Based on performance in the AYT of the previous year, the best 5–10 clones are advanced to the uniform yield trial (UYT). The number of test sites is increased from three to six. The clones are thoroughly evaluated for yield, dry matter content, consumer acceptance qualities and ecological adaptation. The trial is planted in plots of 4 rows by 4.5 m with 4 replications at each location. Only the central two rows in each plot are harvested for yield estimate. Farmers' assessment is also crucial here and the best 4–5 varieties selected in

this trial can be tested on-farm. To ensure yield stability and adaptability the trial should be repeated for 2–3 seasons.

Step six: national sweetpotato variety trial

The UYT in the second year is referred to as UYT2 and the trial is planted in 5 row plots (10 plants/rows) with 4 replications at each location. Only the central three rows are harvested for yield estimation. Promising clones from UYT2 are advanced to farm level testing with farmers' participation. While carrying out on-farm testing, nucleus multiplication of breeder seed is initiated so as to have a sizeable quantity of material if any promising lines have to be pushed forward. This happens alongside the national variety trial (NVT). The best clones selected from AYT and from different main agro-ecologies are pooled and tested in a UYT design throughout the country. This will help to identify clones with a wide adaptation to many environments contrary to those which have a specific adaptation to a particular environment.

Step seven: sweetpotato on-farm variety evaluation

As mentioned earlier, farmers participate in the assessment of trials at the AYT stage. In order to obtain more information on performance at farm level where soil conditions, land quality, management practices, etc., differ, it is important to test the varieties on-farm. For this evaluation, the participatory research methodology (Ashby *et al.*, 1989) is used. The key basic elements come together, i.e. experimental materials + research team + farmer. This evaluation can be included in every type of advanced trial, and must be adapted to the conditions characteristic of each trial zone. The farmers (women and men) who participate in the evaluation carry out two types of test: taste tastes and agronomic evaluations. Details on the procedure is presented in Chapters 2 and 3 and *CIP Research Guide* No. 5 (Fonseca *et al.*, 1994).

Summarized sweetpotato standard trial procedures

Year	Season	Breeding stage	Number of clones, plots and replications	Major tasks and evaluations
1	1st	Source population	10,000 seedlings	Raise seedlings in the nursery for 1 month
	2nd	Preliminary observation (optional)	10,000 clones Plant 2 plants per clone	Screen for resistance to virus, weevil, root conformity and characteristics
2	1st	Clonal evaluation I	500 clones Plant single row plots, 1 replication	Confirm the first year's evaluation Evaluate yield potential and dry matter
	2nd	Clonal evaluation II (optional)	250 clones Plant single row plots, 1 replication	Screen for resistance to weevils, virus and drought (where important) Evaluate yield potential
3	1st and 2nd	Preliminary yield trial	100 clones Plant single row, with 20–30 plants per plot, 2 replications, two dates of harvest	Evaluate for yield and preliminary consumer acceptance by station workers **Note:** To reduce inter-plot competition effects, plant the same number of cuttings, in shorter 2-row plots, or by grouping clones according to their growth habit
4	1st and 2nd	Advanced yield trial (AYT)	25 clones Plant 3 rows, 60 plants per plot with 3 replications, one date of harvest (150 days), repeated over several locations and seasons	Evaluate agronomic and yield potential Conduct assessments by farmers of agronomic and yield performance Conduct consumer acceptance by farmers
5	1st and 2nd	Uniform yield trial (UYT)	5–10 clones Plant 4 rows, 60 plants per plot, 4 replications, repeated over several locations	All other assessments as in AYT Select varieties for on-farm testing

Note: At this stage a national variety trial can be established with several distinct agro-ecologies.
Adapted from *CIP Research Guide* No. 6 (Carey and Reynoso, 1997).

I.5 Data collection

The following forms were designed by CIP for data collection when testing sweetpotato clones distributed by CIP. However, they are also suitable for testing locally derived clones.

To facilitate analysis and decision-making, raw data should be transformed into reference units of general acceptance. For instance, the number of harvested plants divided by the number of planted cuttings will give the rate of cutting survival, yield measured in g/plot can be converted into kg/ha, etc. Once the data have been standardized, sorting, analysis of variance and mean comparisons become useful tools for clonal selection.

Within each country, data for selected outstanding varieties generated from both on-station and on-farm trials should be compiled and submitted to the National Variety Release Committee for review and approval for release where appropriate.

Form 1 General Trial Information

This form requests essential information on trials, such as location, plot size and trial management practices. It also provides space for the results of soil analyses and meteorological data which, if available, will help in the interpretation of trial results.

1. Name of scientist(s) conducting trials_____

2. Institution and address_____

3. Trial location latitude____ Agro-ecology longitude____ Altitude (m)___

4. Trial name_____ Design_____

   No. replications_____ No. clones____ No. checks____

5. Date of planting_____ Date of harvest_____ Duration_____ Season_____

6. Plot size_____ No. cuttings_____ No. rows_____

   Length (m)_____ Spacing (m)_____

7. Trial planted on ridges, mound or flat?_____

   Irrigation volume_____ Fertilization_____

   Pesticides_____ Previous crop_____

8. Soil type_____

   Texture_____ pH_____ Organic matter %_____

   CEC meq/100g_____ Aluminium saturation %_____

   EC mmhos/cm _____ $CaCO_3$ %_____

   Nutrient analysis_____

9. Meteorological data during trial (means by month or fraction of month)

	Month					
Meteorological data	1	2	3	4	5	6
Mean temperature (°C)						
Mean maximum temperature (°C)						
Mean minimum temperature (°C)						
Rainfall (mm)						
Radiation (MJ/m^2)						

10. Other_____

Form 2 Agronomic Data

Trial location_____ Trial name_____

Date of planting_____ Date of harvest_____ Name of check(s)_____

		Clone														
Plot	Replication	CIP number	Name	Cuttings	NPH	YT	NPWSR	NLR	NSR	YLR	YSR	CRACK	RD	ER	RSC	RFC

a) To be filled out at time of planting:

Plot = Plot number
Replication = Replication number (if any)
Clone = CIP number and name of clone
Cuttings = Number of cuttings planted

b) Data to be taken at harvest:

YT = Yield of the tops of the plants (leaves + stems) in grams
NPH = Number of plants harvested
NPWSR = Number of plants with storage roots
NLR = Number of large roots
NSR = Number of small roots
YLR = Yield of large roots in grams
YSR = Yield of small roots in grams
(A cut-off value for considering a root as large or small may be 100 g.)

CRACK = Root cracking, scale 1-9.

RD = Root defects: 1 = alligator-like skin; 2 = veins; 3 = shallow horizontal constrictions, 5 = shallow longitudinal grooves; 7 = deep constrictions and grooves; 8 = other (specify).

This trait combines information on root size, shape, uniformity and smoothness. Use a 1-9 scale. Points should be taken off for each defect.

Root colour can refer to skin or flesh as follows:

Root skin colour (RSC)	Root flesh colour (RFC)
1 = White	1 = White
2 = Cream	2 = Cream
3 = Yellow	3 = Dark cream
4 = Orange	4 = Pale yellow
5 = Brownish-orange	5 = Dark yellow
6 = Pink	6 = Pale orange
7 = Red	7 = Intermediate orange
8 = Purple-red	8 = Dark orange
9 = Dark purple	9 = Strongly pigmented with anthocyanins

Form 3 Evaluation of Diseases, Pests and Abiotic Stresses

Diseases, pests and abiotic stresses vary among locations and seasons, and may not even occur in some trials. We provide a flexible form, which allows the scientist to fill in the reaction against them and the corresponding date. A standard scale of 1-9 is suggested for all evaluations.

Trial location_____ Date of planting_____

		Clone		Disease		Pest		Abiotic stress	
Plot	Replication	CIP number	Name	1	2	1	2	1	2
Date of evaluation									

Form 4 Post-harvest Quality Evaluations

Clones with acceptable agronomic performance should be evaluated for post-harvest quality traits important in your target region. These may include eating quality and dry matter content. Detailed methods on the evaluation of these traits to suit the existing conditions are given in Chapter 4.

Trial location_____ Date of planting_____ Date of harvest_____

		Clone		Dry matter		Eating quality					Industrial quality	
Plot	Replication	CIP number	Name	Fresh weight	Dry weight	Appearance	Texture	Sweetness	Fibre	Other	1	2

Form 5 Storage Evaluation and Production of Cuttings from Bedded Roots of Selected Clones

Trial location_____

Date of storage_____

Curing conditions: Temperature (°C)_____ Time_____ RH (%) _____

Storage conditions: Temperature (°C)_____ Time_____ RH (%) _____

				Sprouting		Rotting		Production of cuttings	
Plot	Replication	CIP number	Name	1	2	1	2	1	2
Date of evaluation									

Storage characteristics

In some tropical areas, storage may be of interest, and in temperate regions, storage of roots is necessary. Columns are provided to evaluate sprouting and rotting periodically. Use a 1-9 scale. Indicate the trait evaluated, date, and curing and storage conditions used. (For a description of curing see Chapter 6.)

Sprout production

This is an important trait for those regions where roots are used to produce cuttings. The evaluation should use a 1-9 scale (1 = bad; 9 = excellent; 2 to 8 indicate intermediate values) to answer the question: "How good is the production of cuttings by this clone?" Total numbers, early maturity, uniformity and sturdiness of cuttings should be considered in making this evaluation.

Form 6 Summary of Clonal Evaluation

Clone			Selected			Comments
CIP number	Name	Discarded	Varietal	Breeding	Use	

This form is designed to summarize results of trials and indicate whether experimental clones are discarded or selected.

List clones and indicate whether the clone has been rejected (will not be evaluated again) or selected for further evaluation. Note whether you consider that selected clones have potential for varietal release, or for use as parents in a breeding programme. In addition, note the main end-use, i.e. table, industry, feeding, or other, for which you think a selected clone has potential. Important strengths or weaknesses of clones should be noted in the comment column.

Details on data analysis and clonal selection can be obtained from *CIP Research Guide* No. 6 (Carey and Reynoso, 1997).

References

ALLARD, R.W. (1960) *Principles of Plant Breeding*. Chichester: John Wiley.

ASHBY, J., QUIROS, C. and RIVERS, Y. (1989) Farmer participation in technology development: work with crop varieties. pp. 115–122. In: *Farmer First. Farmer Innovation and Agricultural Research*. Chambers, R., Pacey, A. and Thrupp, L. (eds). London: Intermediate Technology Publications.

CAREY, E.E. and REYNOSO, D.M. (1997) Procedures for the evaluation of pathogen-tested sweetpotato clones. *CIP Research Guide*, No. 6. Lima: International Potato Center.

FONSECA, C., MOLINA, J.P. and CAREY, E. (1994). Farmer participation in the selection of new sweetpotato varieties. *CIP Research Guide,* No. 5. Lima: International Potato Center.

JONES, A., DUKES, P.D. and SCHALK, J.M. (1986) *Sweetpotato Breeding. Breeding Vegetable Crops*. AVI Publishing Co.

APPENDIX II

Measurement of dry matter content

D. Rees

II.1 Background

In Africa, mealiness or starchiness, has been identified as an important consumer criterion. There have been several cases where cultivars with acceptable production characteristics have been rejected because they are not sufficiently mealy for African tastes. Mealiness is closely, although not completely, associated with root dry matter content. Studies have indicated that the mealiness of cooked sweetpotato is also associated with the extent to which cells break apart when cooked sweetpotato is bitten. This in turn relates to the extent to which starch grains swell during cooking, causing cells to deform and detach from neighbouring cells. In those cultivars with amylases which are stable to heat, much starch is broken down during cooking, such that swelling and cell separation are less. These cultivars tend to have a moist taste. Thus, when determining consumer acceptability, although the measurement of dry matter content is a useful indicator of mealiness, it is not completely reliable, and for advanced cultivar testing should be supported by taste tests (see Chapter 4).

In cases where sweetpotato is processed for starch, dry matter content is of direct relevance, as most of the dry matter is starch.

II.2 Measurement of dry matter content

Dry matter content is generally measured by oven-drying.

Dry matter content can vary between roots, and also for different parts of the same root. In addition, the growth environment can have a significant effect. Thus, measurements for each cultivar should be made at least in duplicate, using two different roots. Where roots are obtained from a replicated field yield trial, a measurement should be made for each plot (i.e. for each cultivar in each replicate).

II.2.1 Suggested procedure

(i) For each variety and replicate, cut thin transverse slices of the root material. Cut the slices again into small sticks or 'matchsticks'. If large roots are used, such that there is excess material, the slices should be taken from the central part of the root. Mix the pieces thoroughly. Small pieces are used, as these will dry more easily.

(ii) Each sample requires a suitable container (such as an aluminium foil tray or weighing tray). The container should be labelled with date, treatment, variety and an additional label such as *a* or *b* to distinguish samples

wherever more than one measurement is taken for each replicate. **Note**: Paper bags are not good containers as they absorb moisture and, therefore, will lose weight during drying.

(iii) Weigh the container [C].

(iv) Add *approximately* 100 g of material and record the exact total weight [FW] + [C].

(v) If possible dry the samples in an oven at 70–80 °C. If an oven is not available, it is possible to get consistent results by sun-drying. This can be especially effective in a greenhouse (glasshouse) or solar dryer.

(vi) After 48 h of drying, reweigh the sample in the container [DW] + [C], and return the sample to the oven (or greenhouse). **Note**: Do not remove the sample from its container.

(vii) Reweigh the sample in the container every 24 h, recording the weight each time, until no further weight loss is seen.

(viii) Calculate the percentage dry weight as 100 x {[DW] +[C] - [C]}/{[FW] + [C] - [C]}.

An example of a form for recording the data for dry matter measurement is given below.

Dry Matter Content Data Sheet

Variety and replication	Weight of container [C] (g)	Fresh weight of container and sample [FW] + [C] (g)	Date and time of measurement				DMC
			Dry weight of container + sample [DW] + [C] (g)	Dry weight of container + sample [DW] + [C] (g)	Dry weight of container + sample [DW] + [C] (g)	Dry weight of container + sample [DW] + [C] (g)	

ABBREVIATIONS

AYT	advanced yield trial
ANOVA	analysis of variance
CIP	International Potato Center
COSCA	Collaborative Study of Cassava in Africa
DM	dry matter
FSR-NCU	Farming Systems Research-National Co-ordination Unit
HPLC	high performance liquid chromatography
IITA	International Institute for Tropical Agriculture
ISAR	Institut Des Sciences Agronomique du Rwanda
LI	Lignification Index
LSD	least significant difference
LZARDI	Lake Zone Agricultural Research and Development Institute
MC	moisture content
NARL	National Agricultural Research Laboratory
NARO	National Agricultural Research Organization
NRI	Natural Resources Institute
NVT	national variety trial
OP	open pollinated
PCA	principal component analysis
PDA	potato dextrin agar
PRAPACE	Programme Regional de la Pomme de terre et de la Patata douce en Afrique Centrale et de l'Est
PYT	preliminary yield trial
SADC	Southern Africa Development Community
SARRNET	Central Africa and Southern Africa Root Crops Research Network
SI	Susceptibility Index
SMA	sweetpotato meal agar
SPVD	sweetpotato viral diseases
TNRTCP	Tanzanian National Root and Tuber Crops Programme
USDA	US Department of Agriculture
UYT	uniform yield trial