Factors Associated with Postharvest Deterioration of Sweetpotato (*Ipomoea Batatas* L.) Roots in Kenya

By

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A Thesis Submitted in Fulfillment of the Requirements for the Award of the Degree of Doctor of Philosophy in Plant Pathology of the University of Nairobi, Kenya

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2004

DECLARATION

This thesis is my original work and has not previously been submitted to any other university, either in whole or in part, for the award of any degree, fellowship or any other similar title whatsoever.

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14 Sept. 2004

This thesis has been submitted for examination with our knowledge and approval as university supervisors.

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ACKNOWLEDGEMENTS

This study was part of a collaborative research initiative between the Kenya Agricultural Research Institute (KARI) and the International Potato Center (CIP), sub-Saharan Africa region. It was made possibly through a research grant from the Rockefeller Foundation (RF), to whom I am greatly indebted.

I am thankful to Dr. Edward Ewing Carey (formerly of CIP, Nairobi) for his keen interest in this work from its inception and to Dr. John Lynum of the RF, Nairobi, for recommending funding for this work. The administrative support from Drs. H. Zandstra, CIP Director General, and P. Ewell, immediate former CIP's representative for sub-Saharan Africa region, enabled me to access the research grant from the RF, New York.

I am grateful to the Director, KARI for granting me paid-study leave and for paying my tuition fees at the University of Nairobi. This support enabled me take the shortest time possible to complete the research project.

My university of Nairobi supervisors, Dr. R. D. Narla, Crop Protection Department, Dr. S. I. Shibairo, Crop Science Department and Prof. J. K. Imungi, Food, Technology & Nutrition, worked closely and tirelessly with me throughout the study, and provided much needed expert guidance and support.

The co-operation and support of staff members in the departments of Plant Pathology at the National Agricultural Research Laboratories (NARL) and Crop Protection, University of Nairobi is greatly appreciated. Others

DEDICATION

This thesis is lovingly dedicated to my mother, the late Mrs. Sofia W. Gachigua, who died in the course of this work. She single-handedly paid for my early education, under difficult circumstances, and constantly encouraged me to live to my full potential and to always trust in God. It is also dedicated to all those who, like my mother, support "girl-child" education.

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ACRONYMS AND ABBREVIATIONS

ACIAR	Australian Center for International Agricultural Research
AEZ	Agro-ecological zone
ANOVA	Analysis of variance
ARF	Agricultural Research Fund
BT	*Botyrodiplodia theobromae*
CAB	Commonwealth Agricultural Bureau
CABI	Commonwealth Agricultural Bureau International, UK
CIP	Centro Internacional de la Papa (International Potato Center)
CMI	Commonwealth Mycological Institute
COSCA	Collaborative Study of Cassava in Africa
CTA	Technical Center for Agricultural and Rural Cooperation,
CTCRI	Central Tuber Crops Research Institute, India
Ed(s)	Editor(s)
ESAP	East and Southeast Asia and the Pacific, CIP region
FAO	Food and Agriculture Organization of the United Nations.
Ha.	Hectares
ICAR	Indian Council of Agricultural research
IDRC	International Development Research Center
IITA	International Institute of Tropical Agriculture, Nigeria
ILRI	International Livestock Research Institute
ISTRC	International Society for Tropical Root Crops
ISTRC-AB	International Society for Tropical Root Crops-African Branch

KARI	Kenya Agricultural Research Institute
LSD	Least significant difference
MOA	Ministry of Agriculture
NRI	Natural Resources Institute
NARO	National Agricultural Research Organization
NARS	National Agricultural Research Systems
NAL	National Agricultural Laboratories
NARL	National Agricultural Research Laboratories
PHPD	Postharvest pathological deterioration
RCBD	Randomized complete block design
RO	*Rhizopus oryzae*
RS	*Rhizopus stolonifer*
SPFMV	Sweetpotato feathery mottle virus
TARDA	Tana River development authority
UNIFEM	United Nations Development Fund for Women
UPWARD	User's Perspective with Agricultural Research & Development
USDA	United States department of agriculture
WAP	Weeks after planting

ABSTRACT

Postharvest deterioration limits the production, marketing and utilization of sweetpotato (*Ipomoea batatas* L.). This study was conducted to identify the fungi associated with postharvest deterioration of sweetpotato roots in Kenya and to study how the deterioration is influenced by certain preharvest and postharvest cultural practices, varietal differences and some physical factors.

A baseline field survey was conducted in the main sweetpotato growing areas of Western, Nyanza and Central Provinces of Kenya. A short checklist was used to obtain information on sweetpotato management practices from farmers, traders and the local Ministry of Agriculture (MOA) field staff. Diseased sweetpotato root samples were also collected and used to isolate the causative fungi.

Preharvest experiments, each followed by postharvest laboratory evaluations, were set up to determine the effect of preharvest factors on postharvest pathological deterioration of sweetpotato roots. The factors investigated were vine removal at zero, one and two weeks before harvesting, time of harvesting at 16, 22 and 28 weeks after planting, cultivar effect using the cultivars, Yanshu 1, KSP 20, KEMB 10, KEMB 36 and soil pH using pH levels 4.6, 5.8, and 6.1. Disease development was evaluated on healthy sweetpotato roots which were artificially inoculated using circular agar plugs

from a two-day old Potato Dextrose Agar (PDA) culture of the most virulent single-spore isolate of each test pathogen.

Experiments were also conducted to determine the effect of postharvest washing and solar curing on postharvest deterioration of sweetpotato roots during prolonged storage (100 days) at room temperature (15.2^0C–26.7^0C) and relative humidity (31.4-81.7%) conditions. The effect of storage temperature on pathological deterioration was also studied using the following temperatures: 12^0C, 16^0C, 20^0C, 24^0C, 28^0C, 32^0C and 36^0C.

Six pathogenic fungi, *Botryodiplodia theobromae, Rhizopus oryzae*, *Rhizopus stolonifer*, *Fusarium oxysporum, Macrophomina phaseolina* and *Ceratocystis fimbriata,* and three saprophytic fungi, *Aspergillus niger, Mucor circinelloides* and *Penicillium spp.*, were identified on naturally infected roots. The pathogens *Rhizopus stolonifer, Rhizopus oryzae* and *Botryodiplodia theobromae* were selected and used for inoculating healthy sweetpotato roots in all subsequent experiments throughout the study.

Vine removal before harvesting, and especially at two weeks, and delayed harvesting at 28 weeks after planting significantly ($p<0.05$) enhanced postharvest pathological deterioration of sweetpotato roots, while early harvesting reduced deterioration. Cultivar differences in root susceptibility to postharvest pathological deterioration were significant ($p<0.05$) with cultivar KEMB 36 showing high disease resistance and cultivar KEMB 10 high disease susceptibility compared with the other cultivars. The different soil pH levels

did not significantly ($p<0.05$) influence postharvest pathological deterioration of sweetpotato roots.

Postharvest washing did not significantly ($p<0.05$) influence deterioration of sweetpotato roots, but solar curing significantly ($p<0.05$) reduced percent loss of marketable roots during prolonged storage at room temperature and relative humidity. Low temperature at 12-16^{0}C significantly ($p<0.05$) suppressed infection while temperature at 24-36^{0}C significantly ($p<0.05$) enhanced postharvest pathological deterioration.

The results showed that vine removal before harvesting and delaying harvesting predisposed sweetpotato roots to pathological deterioration. They also showed that differences in susceptibility to postharvest pathological deterioration occur in sweetpotato cultivars. In addition, it was showed that the influence of soil pH on root deterioration was not significant ($p<0.05$). Solar curing had potential in extending the storage life of sweetpotato roots, but the effect of washing such roots was not significant ($p<0.05$). The storage temperature influenced postharvest pathological deterioration of sweetpotato roots and the temperature range 24-36^{0}C was ideal for root infection, while infection was suppressed at 12-16^{0}C.

Postharvest pathological deterioration of sweetpotato roots result from naturally occurring fungal infections, and this study has also shown that preharvest vine removal and delayed harvesting are some of the cultural practices that could predispose sweetpotato roots to infection. Cultivar genotype, curing of roots after harvest and the regulation of temperature during

storage also play a significant role in the control of postharvest pathological deterioration of sweetpotato roots. Integrated strategies aimed at reducing postharvest fungal infections and subsequent losses in sweetpotatoes in Kenya are recommended.

1. INTRODUCTION

Sweetpotato (*Ipomoea batatas* (L.) Lam.) is the world's seventh most important food crop after wheat, rice, maize, potato, barley and cassava (FAO, 1992). More than 95% of the production is in developing countries, with approximately 92% in Asia, 5% in Africa and 3% in the rest of the world (FAO, 1992; CIP, 1999). Japan and United States of America are the only industrialized countries where significant amounts of sweetpotato are grown (CIP, 1999).

In Kenya, sweetpotato is the third most important root and tuber crop after Irish potato and cassava (MOA, 1991). It is grown in different agro-ecological zones, largely by small-scale farmers, for home consumption and surplus roots sold in the local markets (Mutuura *et al.,* 1992). In some parts of Western, Nyanza and Central provinces, however, sweetpotato has become a significant cash crop (Mutuura, 1990; Ngunjiri *et al.,* 1993; Low, 1996).

Previously, little attention was given to research and development of sweetpotato (Abubaker, 1990; Nderitu, 1991; CIP, 1994). Recently, however, it was realized that sweetpotato could bridge the growing national food deficit (Kamau, 1990) and it has been included in the list of crops in the national food security strategy (Abubaker, 1990). Consequently, research was initiated by the Kenya Agricultural Research Institute (KARI), in collaboration with the International Potato Center (CIP), to promote sweetpotato production and utilization (Abubaker, 1992).

Sweetpotato has a short storage life of less than four weeks in the tropics, an attribute that has been identified as a major limitation to its development as a food crop for the tropics (George, 1988; Abubaker, 1992; UNIFEM, 1993). The edible storage root is covered by a thin and delicate skin which is easily damaged during harvesting and postharvest handling leaving the roots highly perishable (UNIFEM, 1993). The resulting injuries become easy pathways for entry of spoilage microorganisms and moisture loss (Clark, 1992; Bashaasha *et al.*, 1995; NRI/NARO, 1996).

Under traditional production systems, "in-ground storage" is practiced where mature roots are harvested as needed, while the immature roots are left in the ground to continue bulking (Bashaasha *et al.*, 1995; Kapinga *et al.*, 1995; NRI/NARO, 1996). In commercial growing areas, on the other hand, roots are harvested once in bulk and transported to the market (Ngunjiri *et. al*, 1993; Low, 1996). During transit or at the market, the roots may begin to rot due to exposure to high temperature conditions that favour fungal growth and infection (Wills *et al.*, 1998; Jenkins, 1982). Consequently, postharvest pathological deterioration has now been recognized as a principal limiting factor in the marketing and the wider utilization of sweetpotato (Abubaker, 1990).

Soft rot is the most widespread and destructive disease of sweetpotato roots and it is caused by *Rhizopus stolonifer* (Syn. *R. nigricus*) and *R. oryzae* (Syn. *R. arrhizus* and *R. tritici*) (Clark, 1992; Clark and Moyer, 1988; Snowdon, 1990). The pathogens are soil-borne but disease symptoms usually

develop after the roots are harvested (Clark and Moyer, 1988). The affected roots turn soft and moist and in susceptible cultivars, a root of average size may be decayed entirely in less than five days (Spalding, 1969; Ray *et al.*, 1997; Holmes and Stange, 2002). The colour of the infected tissue is not significantly altered, but a pronounced oduor of fermentation is produced (Clark and Moyer, 1988). The infection usually progresses from the ends of the root or from other wound sites (Clark and Moyer, 1988; Ray *et al.*, 1997; Clark, 1992).

Curing of sweetpotatoes roots has been recognized as one of the most effective ways of increasing the storage life of the roots (Padmata, 1990; Clark, 1992). The process takes place when freshly harvested sweetpotato roots are promptly exposed to elevated temperature (27-33°C) and high relative humidity (85-95%) for 4-7 days (Padmata, 1990). It results in curing or healing of the wounds inflicted on the roots during harvesting (Wills *et al.*, 1998). A wound periderm forms that seals the wounds, thereby suppressing root infection and excessive moisture loss, as effectively as the intact skin does (Holmes and Stange, 2002). Curing is, unfortunately, not practiced in Kenya (Low, 1996).

Storage at low, non-freezing temperatures could also be used to maintain the quality of fresh sweetpotatoes by retarding disease development (Eckert and Ogawa, 1988). The recommended temperature range for sweetpotato storage is 13-16°C (Buescher, 1980; Picha, 1987; Snowdon, 1990). This low temperature storage technology is, however, not affordable by

the majority of sweetpotato producers in the tropics, since the crop is viewed as being of low market value (Jenkins, 1982).

A study on reduction of postharvest pathological deterioration and enhancement of shelf life of sweetpotato roots has not been conducted under Kenyan conditions.

The purpose of this study was to identify the fungi associated with postharvest deterioration of sweetpotato roots and to determine the influence of some preharvest and postharvest factors in the development of pathological deterioration .

1.1. Objectives

The overall objective of the study was achieved using the following specific objectives:

1. To conduct a baseline field survey in the main sweetpotato growing areas of Western, Nyanza, and Central provinces of Kenya in order to collect information on sweetpotato production, postharvest handling, postharvest pathological problems encountered by the farmers. and to collect naturally infected sweetpotato root samples.
2. To isolate and identify fungi associated with postharvest deterioration of sweetpotatoes from the naturally infected root samples collected from the main sweetpotato growing areas.
3. To study the effect of preharvest vine removal, time of harvesting, soil pH and cultivar on postharvest pathological deterioration of sweetpotato roots.

4. To study the effect of curing and washing on postharvest deterioration of sweetpotato roots during storage over a prolonged period.
5. To study the effect of storage temperature on infection of sweetpotato roots.

2. LITERATURE REVIEW

2.1. Origin and spread of sweetpotato in the world

The sweetpotato (*Ipomoea batatas* (L.) Lam.) is a dicotyledonous plant that belongs to the family *Convolvulaceae,* tribe *Ipomoeae,* genus *Ipomoea* and section *Batatas* (Clark and Moyer, 1988; Huaman, 1992). There are 13 wild species within the section *Batata* that are considered related to the sweetpotato and whose geographic distribution is within the Americas (Huaman, 1992).

Sweetpotato originated in Latin America, where it was grown for many millennia (Snowdon, 1990), but is now widely grown throughout tropical and subtropical regions of the world (UNIFEM, 1993). It was first introduced into Europe, Africa and the Far East by Spanish and Portuguese explorers in the 15th and 16th centuries (Snowdon, 1990). Today the largest plantings are in China and other Asian countries (Huaman, 1992).

2.2. Importance of sweetpotato

Sweetpotato is a herbaceous and perennial plant, grown as an annual, and since it does not have a definable maturity, it can be harvested following growing periods of widely varying lengths (Clark and Moyer, 1988). Its growth habit is predominantly prostrate with a vine system that expands rapidly horizontally on the ground (Huaman, 1992; Snowdon, 1990) (Figure 2.1).

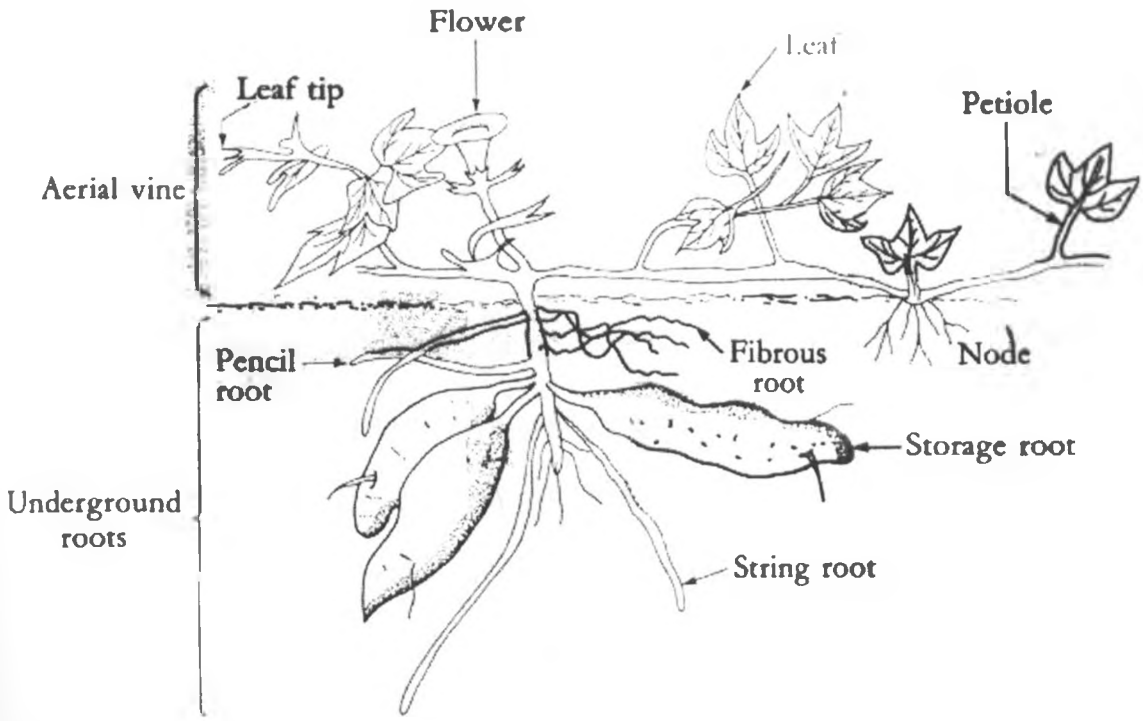


Figure 2.1: The gross morphology of the sweetpotato plant. In practice, the proportion of foliage to roots is usually greater than that shown here. (Source: Woolfe, 1992)

The sweetpotato crop combines many advantageous attributes that give it great potential as food (Woolfe, 1992). It has a broad genetic base with great variability that is increasingly being used for crop improvement, and it produces more energy per hectare per day than any other major food crop (Woolfe, 1992: CIP, 1999). It has a short growing period (Ngunjiri *et al.*, 1993) and does not normally require high levels of inputs to produce adequate yields (Woolfe, 1992; O'Sullivan *et al.*, 1997). It is also relatively easy to manage (Low, 1996).

Sweetpotato is utilized in a diversity of ways which include preparation of the storage roots and leaves for human diets, processing of roots into flour, animal feed and industrial starch and alcohol (Woolfe, 1992). The leaves and vines are also important fodder for domestic animals (FAO, 1992; CIP, 1999).

Sweetpotatoes are grown mainly for their edible roots, which are high in dietary energy, and also contain minerals, such as calcium, phosphorous and iron, ascorbic acid (vitamin C), thiamin (B_1), riboflavin (B_2), niacin, folic acid and vitamin E (Woolfe, 1992). The yellow-orange varieties contain large quantities of provitamin A (Beta-carotene) the precursor of vitamin A, and their consumption is considered an important food-based approach to combat vitamin A deficiency (Low *et al.*, 1997; CIP, 1998; Woolfe, 1992).

The tender sweetpotato leaves are consumed as vegetables in Asia and Africa (Kapinga *et al.*, 1995; Woolfe, 1992). They are rich in iron, protein and vitamins A, B_2 and C (Amenyenu *et al.*, 1998; Villareal *et al.*, 1979). The proximate chemical composition of the sweetpotato is shown in Table 2.1.

Table 2.1 Proximate chemical composition of sweetpotato roots and other foods (per 100g of cooked or processed product)

Food	Moisture (%)	Energy (Kcal)	Energy KJ)	Protein (g)	Lipid (g)	Total Carbohydrate (g)	Dietary (fibre) (g)	Ca (mg)	P (mg)	Fe (mg)
Sweetpotato										
Boiled (in skin)	71	114	477	1.7	0.4	26.3	2.4	32	47	0.7
Baked (in skin)	64	141	590	2.1	0.5	32.5		40	58	0.9
Flour	12	336	1406	2.4	0.7	79.2		70	98	3.2
Maize										
Porridge	81	76	318	1.8	0.8	15.6		4	-	0.6
Meal (Flour)	12	354	1481	9.3	3.9	73.6		19	237	3.3
Wheat										
Chapati	46	202	860	7.3	1.0	43.7	3.4	60	-	2.1
Bread	33	278	1163	8.7	1.6	55.7	2.7	24	98	1.3
White rice (Boiled)	68	135	565	2.3	0.3	28.0	0.8	8	36	0.3

(Source:Woolfe, 1992)

2.3. Sweetpotato production in Kenya

Sweetpotato is an important secondary food crop that plays an important role in household food security in Kenya (Mutuura *et al.*, 1992). About 730,000 tonnes are produced annually on about 75,000 hectares (FAO, 1998). The average root yield in the farmers' fields is 7 tons per hectare (Horton, 1988; CIP, 1999) compared to a potential of 50 tons per hectare obtained under experimental conditions (Carey *et al.*, 1999). Over 75 percent production is concentrated at 1000-1600 meters above sea level in the densely populated lake Victoria basin in Western Kenya. Twenty percent is produced in the Central highlands and five percent in the Rift Valley and the coastal regions (Ngunjiri *et al.*, 1993; Carey *et al.*, 1999). The main sweetpotato growing areas in Kenya are shown in Figure 2.2.

Most producers are small-scale farmers who grow the crop mainly for home consumption and sell the surplus in local markets (Mutuura *et al.*, 1992; Carey *et al.*, 1999). However, a few areas in the lake Victoria basin and the Kibirigwi irrigation scheme in the Central highlands, have specialized in commercial production for sale to distant urban markets (Low, 1996; Carey, 1999).

Most sweetpotatoes are planted during the long rainy season in March, April and May, and in the short rainy season in September, October and November (Ngunjiri *et al.*, 1993).

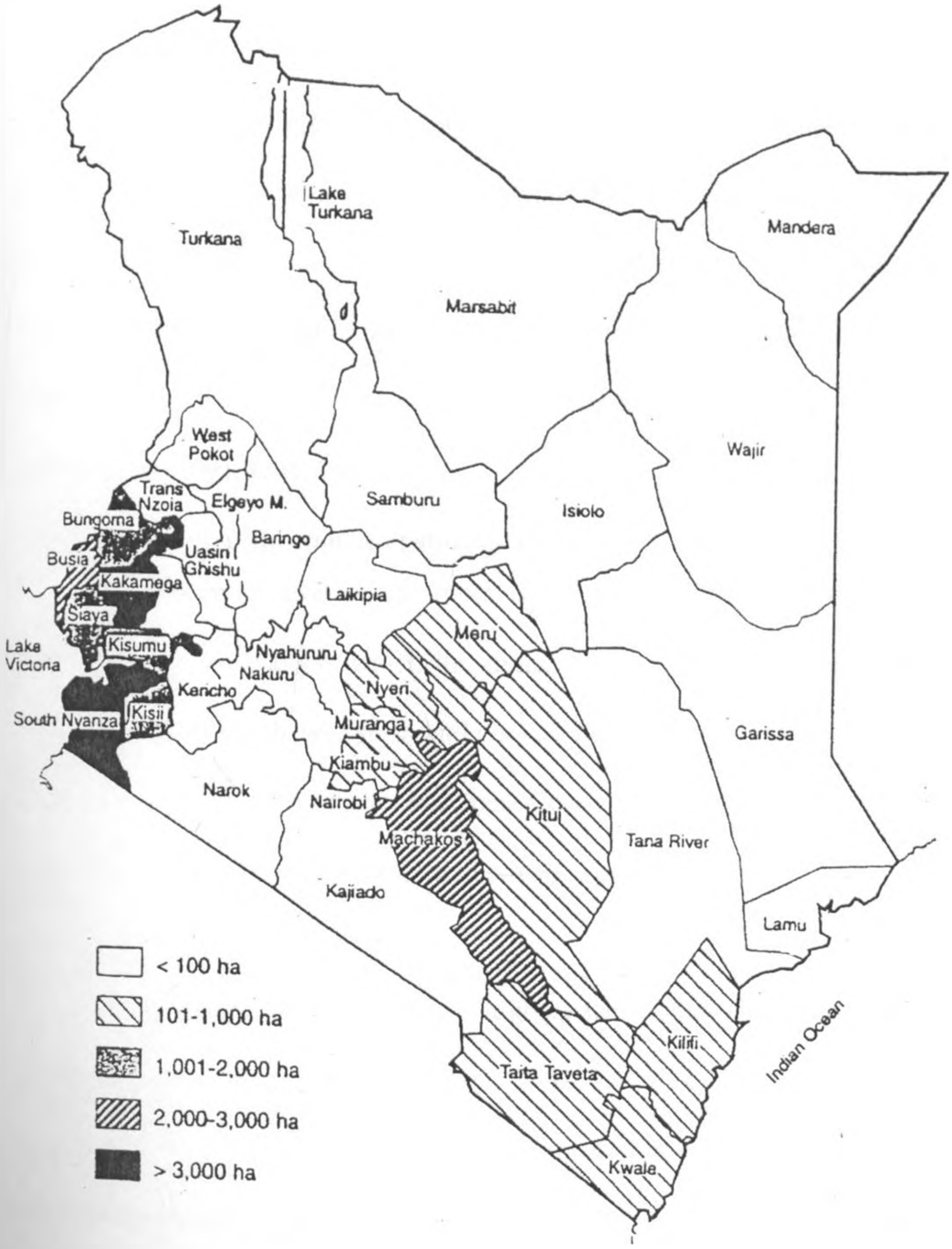


Figure 2.2: Map of Kenya showing the main sweetpotato growing areas.
Source: MOA, Kenya (provincial reports for 1989/91)

In some regions, however, planting is carried out almost continuously throughout the year whenever rain is sufficient (Mutuura *et al.,* 1992; Ngunjiri *et al.,* 1993). Some commercial producers time planting so that harvesting coincides with the Muslim holy month of Ramadhan celebrations, when demand for sweetpotatoes is greatest and prices are highest (Ngunjiri *et al*, 1993; Lenne, 1991; Low, 1996).

2.4. Sweetpotato utilization and storage in Kenya

Utilization of sweetpotato roots is not well developed in Kenya so there are very few ways in which the roots are used (Ngunjiri *et al.,* 1993). They are predominantly sold fresh and cooked by boiling or roasting and eaten with tea as a snack. Other dishes are occasionally prepared by frying the roots with other foods such as Irish potatoes, carrots, vegetables or meat (Mutuura *et al.*, 1990; Ngunjiri *et al.,* 1993).

Consumption of sweetpotato is highest when other foods are depleted or during the dry season (Mutuura *et al.*, 1992; Low *et al.*, 1997). Farm-level processing into other products is rare and industrial processing is nonexistent (Ngunjiri *et al.,* 1993; Low, 1996; Low *et al.,* 1997). Recently, however, some small-scale industrial processing of orange-fleshed sweetpotato into flour to combat vitamin A deficiency has been initiated in Nairobi (CIP, unpublished information).

Fresh sweetpotato roots have a short storage life, generally less than four weeks in the tropics (UNIFEM, 1993). In Kenya and most tropical

countries, roots are therefore harvested and consumed immediately or after very brief periods of storage (Karuri and Ojijo, 1994; Karuri and Hagenimana, 1995; Low, 1996). Harvesting is mainly "piecemeal" where the mature large roots are removed and the small immature roots are left in the ground to continue bulking (Bashaasha *et al.,* 1995; Kapinga *et al.*, 1995; NRI/NARO, 1996). In-ground storage is also practiced where roots are left in the ground after maturity and only harvested when needed for consumption or sale (Smitt and Ocitti p'Obwoya, 1994).

2.5. Postharvest deterioration

Postharvest wastage of produce between harvesting and final consumer is inevitable but actual losses depend on the type of produce, the season and production area (Eckert and Ogawa, 1988). The high moisture content of sweetpotato roots make them vulnerable to pathological and physiological deterioration after harvesting (Harvey, 1978). Losses are particularly high in the tropical and subtropical climates where high temperatures favour physiological and microbial activity (Wills *et al.,* 1998). The reduction of postharvest losses is more significant in increasing available food supply than what might be achieved through increasing primary production (Wills *et al.*, 1998; Booth and Burden, 1983).

Although postharvest losses are often substantial, they are difficult to quantify because deterioration is usually cumulative and it occurs at different stages between harvest and final consumption (Snowdon, 1990; Wills *et al.*, 1998). The losses may also be quantitative, qualitative, or both, and they may

physical, physiological or pathological in nature (Booth and Burden, 1983; Kader *et al.*, 1985). Pathological damage is possibly the commonest, most easily recognized and the greatest single cause of postharvest loss (Booth and Burden, 1983; Wills *et al.*, 1998). However, physical and physiological damage may contribute to postharvest loss by predisposing produce to infection (Booth and Burden, 1983; Kader *et al.*, 1985).

2.6. Postharvest pathological deterioration (PHPD)

Pathological deterioration results from frequently rapid and extensive breakdown of host tissue by microorganisms (Booth and Burden, 1983). Initial infection usually occurs at the sites of physical damage or at the point of root attachment to the plant (Wills *et al.*, 1998; Booth and Burden, 1983). The pattern of attack is usually initiated by a single or a few pathogenic microorganisms followed by several saprophytes that may greatly magnify the initial damage (Booth and Burden, 1983; Wills *et al.*, 1998). In root crop spoilage, fungi are often the most frequently involved causal agents (Booth and Burden, 1983). Careful handling of sweetpotato roots during and after harvesting minimizes injury and pathological deterioration (Lutz *et al.*, 1951; PRIS, 1986).

2.7. Microorganisms associated with postharvest deterioration of sweetpotato

Harvested sweetpotato roots are prone to infection by a wide range of microorganisms resulting in decay (Lenne, 1991; Thankappan and Nair, 1991; Clark, 1992). Most of the available information on postharvest pathological deterioration of sweetpotato roots pertains to temperate countries where only a

small percentage of the world's crop is produced (Lenne, 1991; Clark, 1992; Ray and Misra, 1995). This is because postharvest diseases are mostly recognized in stored sweetpotato roots and they are relatively unimportant where roots are rarely stored, which is the case in the tropics (Clark, 1992; Karuri and Hagenimana, 1995; Low, 1996). It follows, therefore, that the importance of postharvest diseases in sweetpotato roots has been recognized more in the temperate than in the tropical countries (Clark and Moyer, 1988; Clark, 1992). Storage of sweetpotato roots is important in the temperate countries because growing seasons are distinct and roots have to be stored during the cold winter months to ensure availability of roots for consumption and propagation throughout the year (Clark, 1992). In the tropics, on the other hand, storage of the roots is not as necessary since it is possible to grow sweetpotatoes all year round (Lenne, 1991; FAO, 1992; Clark, 1992).

In recent years, however, postharvest pathological deterioration has increasingly become an important limiting factor in the marketing and the wider utilization of sweetpotato in the tropics (Kay, 1987; George, 1988). This has been brought about by rapid urbanization that has created a demand for food in the urban centers and necessitated transportation of produce from the production areas, usually over long distances (Abubaker, 1990). Commercial sweetpotatoes are increasingly harvested in bulk in the main production areas of the lake Victoria basin and the Central Highlands and transported to distant urban market centres in Nairobi, Mombasa, Nakuru and Kisumu among others (Ngunjiri *et al.*, 1993).

Under tropical conditions of high temperature, and often with poor road networks, physical and physiological damage occurs to the roots and result in high postharvest losses (Wills *et al.*, 1998). Consequently, postharvest has been cited as a priority research topic by stakeholders in the sweetpotato sector (Abubaker, 1990). A national social-economic survey carried out in the main sweetpotato production areas has also shown that farmers rate rotting of roots as an important production constraint in Kenya (Mutuura *et al.*, 1992).

Many microorganisms can cause postharvest decay of sweetpotato roots as shown in Table 2.2. Their characteristic disease symptoms and possible control have been outlined by Clark and Moyer (1988), Snowdon (1990) and Ray and Misra (1995). Spoilage microorganisms are often specific to location and therefore their identification is an important fundamental step in the formulation of disease control strategies in any particular environment (Ray and Misra, 1995).

2.8. Preharvest factors affecting postharvest pathological deterioration of sweetpotato

Infection of sweetpotato roots may occur in the field, during harvesting, handling or in storage (Clark and Moyer, 1988; Wills *et al.*, 1998). Infections are facilitated by mechanical injuries that become entry points for the infecting microorganisms (Wills *et al.*, 1998). Environmental or cultural stress during root development that influences the physiology of the root may also affect susceptibility to infection (Balasubramanian and Srivastava, 1973; Clark and Moyer, 1988).

Table 2.2. Microorganisms associated with postharvest diseases during storage of sweetpotato roots

Microorganism	Disease	Reference
Fungi		
Rhizopus oryzae Went. & Prisen-Geerligs	Rhizopus soft rot	Clark and Moyer, 1988; Snowdon, 1991
R. stolonifer (Her. Ex Fr.) Lind	Rhizopus soft rot	Clark and Moyer, 1988; Snowdon, 1991
Botryodiplodia theobromae (Pat.)	Java black rot	Clark and Moyer, 1988; Snowdon, 1991
Ceratocystis fimbriata Ell. & Halst	Black rot	Clark and Moyer, 1988
Fusarium oxysporum (Schlecht) synd. & Hans.	Fusarium end rot	Clark and Moyer, 1988;
Fusarium solani (Sacc.) Mart. emend. Synd. & Hans.	Surface rot; Root rot	Snowdon, 1991
Fusarium pallidoroseum (Cooke) Sacc.)	Fusarium end rot	Ray and Misra, 1995
Aspergillus spp.	Black mold	Ray and Misra, 1995; Ray *et al.*, 1996
Diaporthe phaseolorum (Cooke & Ell.) Sacc. var *batatatis* (Harter & Field) Wehm.	Dry rot	Clark and Moyer, 1988; Snowdon, 1991
Macrophomina phaseolina (Tassi) Goid	Charcoal rot	Clark and Moyer, 1988; Snowdon, 1991
Plenodomus destruens Harter	Foot rot	Clark and Moyer, 1988
Botrytis cinerea Per. Ex. Fr.	Grey mold rot	Clark and Moyer, 1988
Monilochaetes infuscans Ell & Halst ex Harter	Scurf	Clark and Moyer 1988; Martin *et al.*,1976; Clark *et al.*,1992

Table 2.2. Continued.....

Microorganism	Disease	Reference
Sclerotium rolfsii Sacc	Circular spot	Jenkins 1982; Clark and Moyer 1988
Geotrichum candidum	Circular spot	Holmes and Clark, 2002
Alternaria spp.	Alternaria rot	Clark and Moyer, 1988
Rhizoctonia solani	Rhizoctonia	Snowdon, 1991
Pythium spp	Pythium rot	Snowdon, 1991
Gliomastix novae-zelandiae	Gliomastix	Snowdon, 1991
Cochliobolus lunatus [*Curvularia lunata* (Wakker)] Nelson & Haasis	Spongy rot	Ray and Misra, 1995
Mucor spp.	Mucor rot	Snowdon, 1991
Phymatotrichum omnivorum	Phymatotrichum root rot	Clark and Moyer, 1988
Pleospora herbarum	Stemphylium rot	Snowdon, 1991
Trichoderma koningii Oudem	Punky rot	Ray and Misra 1995; Clark and Moyer 1988
Geotrichum candidum	Circular spot	Holmes and Clark, 2002
Bacteria		
Erwinia chrysanthemi Burkholder, McFadden & Dimock	Bacterial soft rot	Clark and Moyer, 1988; Snowdon, 1991
Streptomyces ipomoea (Person & Martin) Waksman & Henrici	Soil rot (pox)	Clark and Moyer, 1988; Snowdon, 1991
Viruses		
A strain of sweetpotato feathery mottle virus (SPFMV)	Internal cork	Clark and Moyer, 1988; Snowdon, 1991
A different strain of SPFMV	Russet crack	Clark and Moyer, 1988; Snowdon, 1991

2.8.1. Effect of vine removal

Leaves and vines are usually removed during the growing period of the sweetpotato plant as green vegetables, planting materials or livestock feed. This may reduce root yields through the reduction of leaf area available for light interception for the process of photosynthesis (Dahniya *et al.*, 1985; Nwinyi, 1992; Amenyenu *et al.*, 1998). Leaf and vine removal may also accentuate the detrimental effects of flooding such as root decay at harvest and in storage (Corey and Collins, 1982). On the other hand, controlled vine removal can increase resistance of roots to mechanical injury (La Bonte and Amand, 1989) and thereby enhance root resistance to infection (Clark and Hoy, 1994).

The direct effect of preharvest vine removal on root susceptibility to microbial infection has not been documented.

2.8.2. Effect of time of harvesting

The sweetpotato plant has an indeterminate growth pattern and lacks definable maturity. Consequently, the roots are harvested following growing periods of widely varying lengths (Clark and Moyer, 1988). At the time of harvesting, they could either be growing vigorously or could have ceased growing altogether, or be at any stage between the two extremes (Ezell and Wilcox, 1952).

The optimum time of harvesting sweetpotato roots is determined by the rate of root bulking, upon which duration to maturity and the yield depends (Ashokan *et al.*, 1982; Madisa and Bok, 1997). The decision to harvest roots is

also influenced by factors such as cultivar, environmental conditions, pest infestation, market demand and the need to free land for a consecutive crop (Fliert and Braun, 1999).

Delaying harvesting may result in higher root yields, but also in loss of time for a consecutive crop (Fliert and Braun, 1999). It may also result in increased root infestation by pests and diseases (Venkatachalam, *et al.*, 1990; Kakaly *et al.*, 1992), sprouting (Missah and Kissiedu, 1994; P'obwoya and Mwanga, 1994) and development of fibrous tissue in the roots (Nawale, 1981). Early harvesting, on the other hand, may result in low yields, but also in higher financial returns from marketing early when prices are good, and by avoiding pest and disease infestation (Yanfu *et al.*, 1989; Reynolds *et al.*, 1994).

The effect of time of harvesting on root susceptibility to microbial infection has not been documented.

2.8.3. Effect of cultivar

Sweetpotato genotypes are known to vary widely in their susceptibility to postharvest diseases (Lo, 1986; Campbell and Collins, 1987; Clark and Hoy, 1994). However, neither the mechanism of resistance nor the correlation between resistance to one disease and another has been reported (Clark, 1992). The use of host resistance for disease management is appropriate because it ensures customer safety and minimum cost and labour to the producer.

Rhizopus soft rot is the most widespread and destructive postharvest disease of sweetpotato (Clark and Moyer, 1988). It is caused by the fungi *Rhizopus stolonifer* (Syn. *R. nigricus*) and *R. oryzae* (Syn. *R. arrhizus* and *R.*

tritici) (Clark and Moyer, 1988; Clark, 1992). The chief symptoms of the disease is a rapidly developing soft rot of the root tissue resulting from maceration by toxic enzymes (Spalding, 1969). Under favourable environmental conditions, a sweetpotato root of average size may be decayed entirely in 3-5 days (Spalding, 1969; Holmes and Stange, 2002).

Sweetpotato genotypes are known to vary widely in resistance to Rhizopus soft rot (Clark and Hoy, 1994). This has been shown by germplasm evaluation conducted in the United States of America (Harter and Weimer, 1921; Clark and Hoy, 1994) in Tanzania (Muhanna *et al.*, 2001) and in a preliminary evaluation of local Kenyan and introduced germplasm (Kihurani, 1997). A systematic study on the effect of cultivar on postharvest pathological deterioration has not been conducted in Kenya.

2.8.4. Effect of soil pH

Soil pH influences the availability of many essential nutrients to the plant (Bennett *et al.*, 1982; O'Sullivan *et al.*, 1997). The sweetpotato plant is tolerant to soil acidity (Abruna *et al.*, 1979) and is frequently cultivated in areas with moderate to high acid soils (O'Sullivan *et al.*, 1997; Ila'ava *et al.*, 2000). Sweetpotato may grow normally at pH values as low as 4.0 (Ila'ava *et al.*, 1996; Ila'ava *et al.*, 2000), but gives low yields in neutral and alkaline soils (Steinbauer and Kushman, 1971; Rasco Jr. *et al.*, 1986; Woolfe, 1992). Good growth and yields may be obtained in slightly to moderately acidic soils (Steinbauer and Beattie, 1938) and 5.6 to 6.6 is the optimum pH range for growing sweetpotato (Rasco Jr. *et al.*, 1986; Woolfe, 1992).

There is very little documentation on the effects of soil pH on sweetpotato growth (Ila'ava *et al.*, 2000). However, soil pH is known to influence plant growth through the effect of the hydrogen ion on root function and on its acid effect on soil properties (Rowell, 1988). Soil pH may also indirectly affect the suitability of the soil medium as a habitat for soil borne microorganisms (Person and Martin, 1940; Martin *et al.*, 1967). In sweetpotato, soil pH may affect root yield (Martinez *et al.*, 1992; Anuar *et al.*, 1996), dry matter and firmness (Constantin *et al.*, 1975) but may not influence root protein or carotenoid content (Constantin *et al.*, 1975).

The effect of sweetpotato cultivar on the susceptibility of the root to postharvest pathological deterioration has not been investigated.

2.9. Postharvest factors affecting postharvest pathological deterioration of sweetpotato roots.

The intact skin of the sweetpotato root acts as a barrier against pathogen entry and moisture loss. Therefore, there is need to practice good harvest and postharvest handling to ensure that injuries are minimized, thereby promoting keeping quality of roots, especially during prolonged storage (Kushman and Wright, 1969).

2.9.1. Effect of curing

Wounds inflicted on sweetpotato roots during harvesting undergo a curing or healing process when the roots are promptly exposed to elevated temperature of 27-33°C and high relative humidity at 85 - 95% for four to seven days (VanHooren, 1988; Padmata, 1990; Wills *et al.*, 1998). The process

weather with environmental temperatures similar or close to those recommended for conventional curing (Jenkins, 1982; Ojijo, 1991; Woolfe, 1992). Conventional curing is also expensive and not easily affordable by many small sweetpotato producers (Buescher, 1980; Clark, 1992). Fortunately, prolonged storage of roots is usually not necessary in the tropics (Karuri and Ojijo, 1994; Karuri and Hagenimana, 1995; Low, 1996) since production is possible through out the year (Mutuura, 1990). "In-ground" storage is also practiced where mature roots are not harvested until they are needed for consumption or sale (Smitt and Ocittip'Obwoya, 1994; Bashaasha *et al.*, 1995; Kapinga *et al.*, 1995).

In recent years, however, commercial sweetpotato production has become popular and roots are increasingly harvested in bulk and transported to distant markets (Bashaasha *et al.*, 1995; Low, 1996). During this brief storage period between harvesting and arrival at the market, the roots are inevitably exposed to high temperature conditions that favour microbial activity and high losses may occur (Jenkins, 1982; Abubaker, 1990). This need has necessitated development of simple and inexpensive curing structures and procedures which can be used effectively in different tropical environments (Gull and Duarte, 1974; Talatala and Quevedo, 1985; El-Sheikhl *et al.*, 1993). In Kenya, a simple curing method was used by Karuri and Hagenimana (1995) while studying the storage characteristics of 31 sweetpotato cultivars, but no systematic study on curing has been conducted.

2.9.2. Effect of storage temperature

Temperature is the single most important factor governing the maintenance of postharvest quality in fresh produce (Booth and Burden, 1983; Wills *et al.,* 1998). Consequently, transporting and storing produce under reduced temperatures is likely to maximize shelf life because of reduced rate of deterioration including development of infection (Eckert and Ogawa, 1988; Wills *et al.,* 1998). The inhibition of *R. stolonifer*, the causal agent of black mold disease, at low temperature is used as a method for prolonging storage of table grapes (Lisker *et al*, 1996). Similarly, the development of Java black rot, caused by *B. theobromae*, was reduced in sweetpotato roots that were cured and stored at 13-16^{0}C (Lo, 1986).

The recommendation for sweetpotato storage have been given as curing immediately after harvesting followed by storage at 12-16°C or 13-16^{0}C and 85-95% relative humidity (Picha, 1985; Snowdon, 1990; Kay, 1987). In tropical and subtropical regions, however, sweetpotato roots stored in ambient conditions without prior curing have recorded low disease incidence, a phenomenon attributed to the occurrence of natural curing (Jenkins, 1982; low, 1986; Ojijo, 1991). Storage of sweetpotato roots at lower temperature causes chilling injury characterized by root decay, internal discolouration and surface pitting (Clark and Moyer, 1988; Padmata, 1990). Storage at temperatures above 16^{0}C induces premature sprouting (Edmond and Ammerman, 1971) and pathological and physiological deterioration are undesirably accelerated (Kader *et al.,* 1985).

Until recently, little attention had been paid to postharvest diseases in the tropics (Clark, 1992). This may explain the absence of any systematic information for enhancing the shelf life of sweetpotato roots under tropical conditions. Information on the effect of storage temperature on sweetpotato roots is not available in Kenya and it is therefore common to find sweetpotato roots stored at room temperature even in situations where reduced temperature storage facilities could be available. Experiments were therefore set up to establish the enhancement of shelf life of sweetpotato roots by storage under a range of temperature from 12^0C–36^0C using a Kenyan cultivar.

3. METHODOLOGY

3.1. Study setting for baseline survey

The baseline survey was carried out in the main sweetpotato production areas of Western Kenya – Nyanza and Western Provinces and Kibirigwi irrigation Scheme in Kirinyaga district of Central Province.

Western and Nyanza production areas are characterized by continuous rainfall throughout the year with little distinction between the first and the second rainy season. Daily convergence of the western wind from Lake Victoria with the southeast trade wind produces heavy showers, especially in the afternoons. Soils are generally infertile because there is very little volcanic or other young parent material (Jaetzold and Schmidt, 1982). The area is also far from the main urban commercial markets of Nairobi and Mombasa.

Central province production area comprised the Kibirigwi irrigation scheme initiated in 1975 by the Tana River development authority (TARDA) and jointly implemented in 1977 by the ministry of agriculture and the Netherlands government. The scheme covers 482 ha., 93 ha of which are irrigated (Unpublished information). Household interviews were conducted within the irrigated part of the scheme, where commercial sweetpotato production was concentrated. The scheme enjoys easy communication with the main urban commercial markets of Nairobi and Mombasa.

The area is characterized by a bimodal rainfall pattern (Jaetzold and Schmidt, 1982). The long-rains are experienced in mid-march to mid-June and

the short-rains from mid-October to mid-December. Soils are friable clay to clay loams, very deep, fertile and well drained. The climatic characteristics of the study areas are given in Table 3.1.

Table 3.1. Climatic characteristics of the study areas

Province District	Farmers visited	AEZ	Annual Mean Temp. (^{0}C)	Annual Average Rainfall (mm)	Approx. Altitude (m)
Western					
Kakamega	1	UM4	18.9-20.9	1800->2000	1500-1900
Kakamega	1	UM4	18.9-20.9	1000-1600	1500-1900
Bungoma	1	UM3	18.8-20.6	1200-1600	1500-1800
Busia	1	LM2	21.4-22.3	1550-1800	1200-1350
Nyanza					
Kisii	1	UM1	18.0-20.5	1400-2100	1500-1900
Kisumu	1	LM2	20.9-22.3	1200-1400	1200-1400
South Nyanza	1	LM2	20.5-21.7	1300-1500	1300-1500
South Nyanza	1	LM3	20.8-22.7	1000-1400	1000-1400
Central					
Kirinyaga	12	UM3	20.6-22.1	1100-1250	1310-1400

AEZ= Agro Ecological Zone; UM = Upper Midlands; LM = Lower Midlands

Source: Jaetzold and Schmidt (1982)

3.2. Baseline survey

A baseline field survey was conducted in the study areas. Altogether, twenty farms were visited, four in Western, four in Nyanza and 12 in Central province. The farms were randomly selected.

Information on the existing knowledge on sweetpotato management practices was obtained from the farmers and the local Ministry of Agriculture (MOA) field staff. Farmers were interviewed using a short checklist shown in Appendix 1. The MOA field officers were interviewed through informal discussions using selected relevant questions from the same checklist used with farmers. At the Kibirigwi irrigation scheme, the local MOA field officers were the scheme manager and the technical officer.

3.3. Identification of fungi associated with postharvest deterioration of sweetpotato roots

3.3.1. Diseased root sample collection

Diseased sweetpotato root samples were collected from each area visited during the field survey mentioned in 3.2. The roots, sampled from farmers' fields and homesteads, markets and roadside selling points, were identified by the appearance of symptoms such as lesions and other abnormalities caused by the infecting fungus.

Where possible, a sample with three diseased roots with similar symptoms was considered sufficient. At the end of the survey, all the diseased root samples from the different areas visited were pooled, placed in Kraft

paper bags, and transported to the laboratory at the National Agricultural Research Laboratories (NARL) for pathological analysis.

3.3.2. Isolation and identification of fungi from the diseased root samples

The root samples were removed from the bags and washed under running tap water to remove adhering soil and facilitate observation of disease symptoms. The roots were then grouped according to similarity of symptoms.

For each group of samples, the main symptoms were described and recorded. The diseased roots were then surface-sterilized by cleaning with non-absorbent cotton wool dipped in alcohol (96% ethanol). Using a sterile carbon steel detachable surgical scalpel blade No. 24 (Ghia Surgiblades PVT Ltd.) fitted with a No.4 handle, three small root pieces were cut at the intersection of the diseased and healthy portions of the root. The root pieces were surface-sterilized by dipping them in a solution of sodium hypochlorite (0.5 percent available chlorine) for one minute, then thoroughly washed with sterile distilled water and air-dried. Each root piece was plated onto 2% Tap Water Agar (TWA) (See Appendix 2) in 90-mm petri dishes (Sterilin 90mm x 15mm Petri Dish Triple Vent, Bibby Sterilin Ltd., England) that were then incubated at 25^0C for 24 hours, when they were examined for fungal growth.

When growth was noticed, the fungal mycelia were allowed to grow one to two centimeters away from the root piece. At least three small TWA blocks containing mycelia were then cut out using a sterile carbon steel detachable scalpel blade No. 11 (Ruettgers Surgicals P Ltd., Bombay) fitted with a No.3 handle. They were each transferred onto Potato Dextrose Agar

(PDA) (See Appendix 2) contained in 90-mm petri dishes. The petri dishes were incubated at 25^0C and visually examined daily for fungal growth.

The characteristics of each developing fungal colony were described and recorded. The fungal isolates were examined under a compound microscope (Dialux 20, Leitz wetzlar, Germany) and identification made based on their morphological characters with the assistance of standard laboratory manuals (CAB-CMI, 1967; Ellis, 1976; Barnett and Hunter, 1987; Clark and Moyer, 1988). In addition, some of the fungal isolates were inoculated onto PDA slants (28ml glass universal container) and sent to the International Mycological Institute (IMI), plant pathology diagnostic laboratory, United Kingdom, for confirmatory identification.

3.3.3. Pathogenicity testing

Pathogenicity testing of all the fungi isolated and identified in 3.3.2 was done in order to verify whether they caused the diseases they were found associated with in the naturally infected root samples collected from the field. The testing was conducted using the method described by Agrios (1997). Inoculations were made using healthy freshly harvested roots of the sweetpotato cultivar, KSP 20, already known to be susceptible to postharvest pathological deterioration as reported by farmers at the Kibirigwi irrigation scheme, central Kenya study site. Before inoculations were made, the roots were surface sterilized and wounded at the median using a 9-mm cork borer.

Each of the isolated fungus was plated and grown on PDA and its cultural characteristics were described. Nine-mm agar discs supporting

mycelia and spores from a two-day old PDA culture of the fungus were aseptically introduced into the wounds previously created on healthy sweetpotato roots. The inoculated roots were incubated at room temperature and observed daily for development of disease symptoms.

The resultant disease symptoms, on the inoculated roots, were compared with the symptoms initially described on the naturally infected root samples from the field. The fungal isolate was then re-isolated from the inoculated roots, plated and grown on PDA, and its cultural characteristics compared again with those observed originally.

The fungus whose culture characteristics on PDA and whose disease symptoms on the inoculated roots were similar to those observed originally, were identified as pathogenic to sweetpotato. Those fungi that failed to cause disease symptoms when artificially inoculated onto healthy roots were identified as saprophytic or non-pathogenic.

Rhizopus stolonifer, *Rhizopus oryzae* and *Botryodiplodia theobromae* were among the pathogens identified, and they were the most frequently encountered during isolation of fungi from the naturally infected root samples obtained from the field. Consequently, these three pathogens were selected for root inoculations in all further experiments in this study.

3.3.4. Single spore isolation

Single spores cultures of each of the three selected pathogens, *R. stolonifer*, *R. oryzae* and *B. theobromae* were made using the semi-mechanical method described by Gregory (1983). A sparse spore suspension of the fungal

as described in section 3.3.3 above. The inoculated roots were placed at room temperature for 48 hours. Each inoculated root was then cut longitudinally through the inoculation point and the diameter and depth of the developing lesion was measured. Three roots, in three replicates, were inoculated with each isolate. The inoculated roots were arranged in a randomized compete block design (RCBD) and the data for the mean lesion diameter and depth was analyzed by analysis of variance (ANOVA) using Statgraphics Plus for windows Version 3.1 software, Manugistics, Inc. 1997. Significant differences between the different single-spore isolates for each pathogen were compared using Duncan's multiple range test (DMRT) at the 5% ($p<0.05$) significance level. The most virulent isolate of each pathogen was preserved in sterile soil by the Smith and Onions (1983) method and stored for use in subsequent experimentation.

3.4. Preharvest factors associated with postharvest pathological deterioration of sweetpotato roots

The preharvest factors considered were vine removal, time of harvesting, cultivar and soil pH. Each experiment was carried out in two consecutive years, 1998 and 1999 but the experiment to determine cultivar effect was conducted in 1999 and 2000.

In each experiment, the sweetpotato roots were produced in the field and after harvesting a postharvest evaluation was done in the laboratory. However, roots for evaluation of effect of soil pH were produced from potted plants, with similar postharvest evaluation with the other experiments.

Experimental design and data collection for each experiment was different and is described separately in section 3.4.6.

All the planting materials were obtained from the International Potato Center (CIP) germplasm conservation plot located at the Field Station, University of Nairobi, Kabete campus. They comprised 25-cm long, healthy apical-end vine cuttings. In the field, the vine cuttings were planted at a spacing of 30 cm on ridges 80 cm apart. No soil amendments like fertilizers or manure were applied and the field plots were kept weed-free by regular hand weeding.

Unless specified otherwise, all the roots used in these experiments were harvested at 22 weeks after planting, which was considered the normal harvesting time for sweetpotato. To minimize mechanical injury to the roots, an ordinary hand hoe was used for harvesting. Soon after harvesting, the roots were placed in sisal gunny bags that were previously labeled with cultivar name, treatment and replicate number and they were transported to the laboratory at NARL for postharvest laboratory analysis.

3.4.1. Selection of sweetpotato cultivars

For all the four preharvest factors considered, different combinations of the four sweetpotato cultivars, Yanshu 1 (CIP 440024), KSP 20 (CIP 440170), KEMB 10 (CIP 440169) and KEMB 36 (local cultivar) were used, unless stated otherwise. The four cultivars were selected based on their relative importance in the sub-Saharan region (Carey *et al.*, 1999), their relative

availability, and their reported susceptibility status to postharvest deterioration (Kihurani, 1997).

3.4.2. Inoculum preparation

All inoculations of healthy sweetpotato roots were made using nine-mm circular agar discs removed from the edge of an actively growing two-day old culture of the test pathogen. As stated earlier in section 3.3.5, only the cultures of the most virulent single-spore isolate of each of the three pathogens, *R. stolonifer, R. oryzae* and *B. theobromae* were used to inoculate healthy sweetpotato roots.

To retrieve isolates from storage in sterile soil (section 3.3.5), a few grains of the soil carrier was sprinkled onto PDA in a 90mm x 15mm petri dish. The petri dish was then incubated for 48 hours at 28^0C to allow the pathogen to grow. Using a sterile nine-mm-cork borer, circular agar discs were removed from the edge of the actively growing culture and used to inoculate healthy sweetpotato roots.

3.4.3. Inoculation of healthy sweetpotato roots

Soon after harvesting, the roots were taken to the laboratory and sorted out to remove and discard the undersized, mechanically damaged and diseased ones. The selected sound, healthy roots were washed in running tap water to remove adhering soil, and allowed to drip dry in air. They were then surface-sterilized by briefly dipping them in 96% ethanol to remove surface contaminants before they were spread out on a laboratory bench, previously sterilized by washing with 96% ethanol, to air-dry.

Each root was then wounded at the median as follows: A sterile nine-mm diameter cork borer was driven into the flesh of the root to a depth of 5-7 mm.

The cork borer was then withdrawn in a manner that ensured the bored tissue was removed, thereby creating a circular nine-mm diameter wound. Each root was then inoculated by introducing the inoculum (agar plug) prepared as described in 3.4.2, with mycelia side facing down. Sterile agar plugs were used to inoculate the control roots.

3.4.4. Postharvest evaluations

The inoculated roots were immediately placed in sterile sun-transparent bags (autoclavable, Sigma cell culture (440 x 205 mm) with 24 mm 0.02 micron filter disc) and incubated at room temperature for 48 hours. The bags were closed (using staples) to allow creation of high relative humidity around the roots and facilitate infection. To monitor temperature and relative humidity during incubation in this study, electronic data loggers (Onset® Computer Corp. 1998. U.S.A.) were used. The electronic data loggers were placed side by side with the roots in each case. Bags containing inoculated roots were then placed inside ordinary plastic stackable plastic crates (57 cm long, 39.5 cm wide and 22 cm deep, Model No. C-001, Acme Containers Ltd, Nairobi, Kenya.) to facilitate handling.

Each experiment was arranged in a RCBD with three or four replicates. Each replicate sample comprised 8-10 roots. The number of replicates and roots per replicate was dependent on the number of sound healthy roots available from each harvest.

3.4.5. Experimental sites

The field experiments were conducted at two sites, the Field Station, University of Nairobi, Kabete campus and NARL. The experimental sites have

similar characteristics, deep well drained friable clay soil (Nitosols)(Siderius, 1976) and lie at an altitude of 1740 m above sea level. They have a bimodal precipitation pattern of one main rainy season from mid-March to May and a secondary one from mid-October to December (Siderius, 1976; Siderius and Muchena. 1977).

The experiment for determination of effect of vine removal and time of harvesting were carried out at the Field Station, University of Nairobi, Kabete campus. In both experiments, experimental plots measured 3.2 m x 1.2 m.

The experiment for determination of effect of cultivar was conducted at NARL. There were no treatment application in the field in this experiment so all the cultivars were planted in a single experimental plot measuring 3.5 x 30m.

As stated earlier in section 3.4, the experiment for determination of effect of soil pH was conducted at NARL in an area sheltered from rain. This was to allow controlled watering and ensure uniformity. Vines were planted in 20-liter plastic pots in soils obtained from three sweetpotato production areas with different soil pH levels. To improve water uptake ballast, and sand were mixed with the soil at the ratio of 2:2:6 v/v. The soil mixture was maintained at field capacity moisture content throughout the growing period by can watering. To ensure that leaching of the soil did not occur water was placed in a small basin in which the pot stood, to allow it to diffuse upwards to the plants.

3.4.6. Specific preharvest experimental design and data collection for the different preharvest factor determination

3.4.6.1. Effect of vine removal

In this determination, there were three vine removal treatments: No vine removal (designated as zero weeks before harvesting or 22 weeks after planting), one week before harvesting (21 weeks after planting), and two weeks before harvesting (22 weeks after planting). These and the four cultivars, Yanshu 1, KSP 20, KEMB 10 and KEMB 36, were combined in a factorial experiment and replicated four times. Each vine removal treatment and cultivar combination was randomly allocated to plots. The plots were laid out in the field and arranged in a RCBD with four replications (See appendix 3).

At two weeks before harvesting, all the vines were cut off from all the plants in every plot allocated this treatment (vine removal at two weeks before harvesting). The vines were detached from the plant at one to two centimeters above ground level using a sharp knife. The procedure was repeated at one week before harvesting, for the plots with this treatment (vine removal at one week before harvesting). On the day of harvesting, 22 weeks after planting, the procedure was performed for the plots with a vine removal treatment at zero weeks before harvesting (no vine removal before harvesting).

3.4.6.2. Effect of time of harvesting

There were three time of harvesting treatments, 16, 22 and 28 weeks after planting. Postharvest inoculations were made with the pathogens *R. oryzae* and *R. stolonifer* in the first year. In the second year, roots were inoculated with *R. oryzae*. *B. theobromae* could not be used in both years and *R.*

stolonifer in the second year due to lack of sufficient roots for inoculation. The shortage of experimental roots in the second year was attributed to low yields resulting from drought conditions in that year coupled with early harvesting at 16 weeks.

The cultivars and time of harvesting treatments were combined in a factorial arrangement and randomly allocated to plots in a split-plot design in four blocks (See appendix 4). Time of harvesting was the main-plot factor and cultivar was the sub-plot factor.

All the plots were planted on the same day, but each was harvested according to its randomly allocated time of harvesting at 16 weeks (early harvesting), 22 weeks (normal harvesting) or 28 weeks (late harvesting) after planting.

3.4.6.3. Effect of cultivar

For this factor determination, apical-end vine cuttings of the four sweetpotato cultivars, Yanshu 1, KSP 20, KEMB 10 and KEMB 36 were planted on 30 m long ridges and 80 cm apart in an experimental plot at NARL.

In the first year, inoculations were made after roots had been solar cured and stored for two weeks, but in the second year, the roots were inoculated immediately after harvesting. *Rhizopus stolonifer* and *R. oryzae* were the pathogens used and the experiment was arranged in a RCBD with three replications.

3.4.6.4. Effect of soil pH

For this factor determination, there were three soil pH levels, 4.6, 5.8 and 6.1. The soil pH levels were selected based on soil pH levels found in

different sweetpotato growing areas. The soil with the lowest pH level of 4.6 was collected from the tea growing area of Nyeri district in Central province. The soil with pH level of 5.8 was from NARL and the one with pH level of 6.1 was from the forested area of Kikuyu division, Kiambu district.

Only two sweetpotato cultivars, Yanshu 1 and KSP 20 were used. The other two cultivars, KEMB 10 and KEMB 36 were dropped from the experiments since they produced very few roots under potted conditions. The two cultivars and the three soil pH levels were arranged in RCBD with four replications.

Two apical-end vine cuttings of the cultivars were planted in each pot that comprised 20-liter plastic containers of 34-cm diameter and 30 cm depth. Roots were harvested at 20 weeks after planting. During harvesting all the roots were detached from the plants, placed in a previously labeled bag and moved to the laboratory for postharvest analysis.

The harvested roots were inoculated with the pathogens *Rhizopus oryzae* and *Botryodiplodia theobromae*. *Rhizopus stolonifer* could not be used due to insufficient root production under potted conditions.

3.4.7. Measurement of disease development

Measurement of disease development on the roots was done 48 hours after inoculation. The inoculated root was removed from the incubation bag and cut-open longitudinally with a sharp knife through the inoculation wound. The diameter and depth of the developing internal lesion, shown by the extent of root tissue degradation, was measured in millimeters. The mean of the diameter and

depth was calculated to give the internal lesion dimension as in Duarte and Clark (1993).

3.5. Postharvest factors associated with postharvest deterioration of sweetpotato roots

The factors considered under this determination were; effect of washing and curing on loss of marketable roots during prolonged storage for 100 days, and effect of storage temperature on pathological deterioration of sweetpotato root slices. For each determination, two experiments were conducted in consecutive years. The experiments to determine the effect of washing and curing were conducted in a storage house at NARL using freshly harvested roots of the sweetpotato cultivar, KEMB 20. The first experiment was carried out in June 1999 and the second one in January 2000. The experiments to determine effect of temperature were conducted using roots slices of the sweetpotato cultivar, Yanshu 1. They were carried out in an incubator at NARL. The first experiment was carried out in June 1998 and the second one in April 1999.

3.5.1.Sweetpotato roots for the study

For the determination of the effect of washing and curing, roots were obtained from a commercial farm at the Kibirigwi irrigation scheme. The site has similar soil and climatic conditions with the other experimental sites used in this study. It also enabled availability of the large number of roots needed for the experimentation. The sweetpotato cultivar KEMB 20 was used and it was selected based on availability of a large number of roots of a commercial

variety, grown under similar soil and climatic conditions. For the determination of the effect of temperature, the cultivar Yanshu 1 was used and selection was based on the same criterion described in section 3.4.1. The roots were obtained from an experimental plot at NARL.

3.5.2. Effect of solar curing

Freshly harvested roots of the cultivar KEMB 20 were packed in two gunny bags weighing approximately 150 kilograms each and transported to the laboratory at NARL in Nairobi on the same day. The experiment was set up the following day. All severely damaged, diseased or undersized roots were discarded.

The healthy and sound roots were randomly distributed into ordinary stackable plastic crates to make four lots of 200 roots. Each lot was randomly assigned a treatment and then further sub divided into four batches of 50 roots, each of which was assigned a replicate number. There were four treatments as follows: Cured and Washed, Cured and Unwashed, Uncured and Washed and Cured and Unwashed and they were all replicated four times.

Roots in samples with a "washed" treatment combination were washed in running tap water to remove adhering soil and drip dried in air. Afterwards all the roots in the experiment were inflicted with a shallow wound measuring about $7cm^2$. The wound was created at the root median by scraping off the skin with a potato peeler.

Roots in samples with a "curing" treatment combination were cured as follows: They were placed in a large transparent polyethylene bag (1m x 0.6

m), previously punctured with 16 holes (using paper punch) to allow for aeration. The bag was closed well to ensure creation of high relative humidity around the roots. Each bag containing the sweetpotato roots was then placed in an ordinary plastic crate, and covered with a thick layer of green banana leaves. The crate was then placed outdoors, covered with a black polyethylene sheet and exposed to the sunshine. The black polyethylene sheet was used to help trap solar energy to raise the temperature of the environment around the roots in order to facilitate the process of curing. High relative humidity was retained due to moisture released by respiring roots. The roots were kept outdoors under the conditions for seven days and nights. Roots in samples with an "Uncured" treatment combination (control) were also placed in crates previously lined with a black polyethylene sheet and placed on a bench in the storage house at room temperature for the seven-day period.

After the seven-day curing period, all the replicate samples (cured and uncured) were each placed in an ordinary plastic crate previously lined with a black polyethylene sheet. The crates were then randomly arranged in a RCBD in the storage house and stored at room temperatures and relative humidity for 100 days.

The prevailing temperature and relative humidity conditions in the storage house and during curing were recorded using electronic data loggers (Onset® Computer Corp. 1998. U.S.A.) placed in close proximity with the roots. Fluctuations of room temperature and relative humidity during curing

were 20.6^{0}C to 37.9^{0}C and 39.3 to 104 per cent respectively, and 15.2^{0}C to 26.7^{0}C and 31 to 81.7 per cent respectively during storage.

The effect of washing and curing on loss of marketable roots during prolonged storage for 100 days was evaluated as follows: Periodically during storage at 7, 14, 21, 28, 40, 50, 60, 70, 80, 90, 100 days of storage, the stored roots were visually examined and individually assessed for salability in terms of appearance (shrinkage and rotting) and general acceptability. The individual root was then grouped into either of two categories as follows:

Category 1: Roots that would be accepted for sale at the local market.

Category 2: Roots that would **not** be accepted for sale at the local market.

Categorization of the roots was done by one person in order to ensure uniformity. The person was selected based on experience in handling sweetpotato roots. At each assessment time, the number of roots placed in each category was recorded and those in category 2 were immediately discarded.

3.5.3. Effect of storage temperature

One-centimeter thick root slices of sweetpotato cultivar Yanshu 1 were each inoculated at the center with a nine-mm diameter circular agar plug of the test pathogens, *R. stolonifer*, *R. oryzae* and *B. theobromae*. The agar plugs were removed from the edge of an actively growing two-day old culture of the test pathogen as described in section 3.4.2.

The root slices were prepared as follows: For each of the three test pathogens, seven healthy and freshly harvested roots of Yanshu 1 were washed and surface sterilized as described in section 3.4.3. From the middle portion of

each root, seven one-cm thick slices were cut using a manual vegetable slicer. The slices were further surface sterilized by dipping them for one minute in a calcium hypochlorite suspension (3% available chlorine). They were rinsed twice with sterile distilled water and air-dried. The slices were then inoculated by introducing the inoculum at the center with the side containing fungal mycelia facing down. Each inoculated root slice was then placed in a 90-mm petri dish. The dishes were previously lined with moist (sterilized) filter papers (Whatman medium fast qualitative circles 90mm) to create a humid environment. The inoculated root slices were incubated for 24 hours at each of the following temperatures: 12^0C, 16^0C, 20^0C, 24^0C, 28^0C, 32^0C and 36^0C.

At each temperature, the petri dishes containing root slices inoculated with each test pathogen were arranged in a completely randomized design (CRD) with seven replicates. The developing lesions were measured along two diameters across the center of the root slice. The mean of both measurements was used to calculate mean lesion diameter, the measure used to estimate infection on the root slice.

3.6. Statistical analysis

In the determination of preharvest factors associated with postharvest pathological deterioration of sweetpotato roots, data for mean internal lesion dimensions recorded on the inoculated roots was subjected to analysis of variance (ANOVA). Similarly, in the determination of the effect of washing and curing, the number of remaining roots at the end of the storage period was expressed as a percentage of the initial number of roots. The data was analyzed

by analysis of variance. In the determination of the effect of temperature, data for mean lesion diameter measured on the root slices was similarly analyzed. The analysis was done using Statgraphics Plus Version 3.1. (Statistical Software, Manugistics, Inc. 1997). Where significant differences occurred between or among treatments, comparisons were performed by Fisher's least significant difference (LSD) test at the 5% ($p < 0.05$) significant level.

4. RESULTS

4.1 Baseline Survey

This section presents the results of the baseline study in the two sweetpotato production areas studied, Western Kenya and Central Kenya. For both areas, descriptions of sweetpotato production and marketing practices are presented. The baseline survey provided important information on different aspects in sweetpotato production, postharvest handling and marketing.

4.1.1. Western Kenya study area

The western Kenya production area comprised Western and Nyanza Provinces. The majority (87.5%) of the farmers were women and there was no clear distinction between farmer and trader since some farmers were also directly involved in the sale of their own sweetpotatoes. Around 62.5% of the farmers had experience in sweetpotato production of more than five years. Sweetpotato plot sizes were small with 50% of the farmers having plot size not exceeding 0.4 ha. However, each farmer planted more than one sweetpotato plot per season

Most (87.5%) of the farmers planted the sweetpotato crop as a pure stand (mono cropping) and grown in rotation with maize. Other farmers (37.5%) rotated sweetpotato with sugarcane, groundnuts, cassava and millet.

About 12.5% of the farmers intercropped sweetpotato with maize. The majority (87.5%) of the farmers grew more than one sweepotato cultivar in a single plot and added no soil amendments like chemical fertilizers or manure

to the soil throughout the growing season. However, a small percentage (12.5%) of farmers reported applying animal manure. The characteristics of the sweetpotato cultivars commonly grown by the farmers in the western Kenya production area are shown in Table 4.1.

The majority (87.5%) of the farmers planted sweetpotato between September and December. The planting material comprised apical-end vine cuttings about 20-25 cm long but whenever there was a shortage of apical-end vine cuttings, any other part of the vine was utilized. 75% of the farmers obtained planting material from their previous sweetpotato crop, while 25% were given by their neighbours and friends.

The sweetpotato was planted on ridges or moulds and weeding was mainly done twice (87.5%) per growing season. During weeding, the lower parts of the growing plants were covered with soil to ensure that the developing roots were not exposed to the surface.

Few farmers (25%) indicated harvesting whole plots at once or row by row. However, the main harvesting method was "piecemeal" (75%) where large mature roots are removed, while the small immature ones are covered again with soil to continue bulking. Harvesting was done using a wooden hand held tool in order to minimize mechanical damage to the roots. The harvested roots were often tossed from the harvesting point into a heap from where they were bagged for the market.

Table 4.1. Sweetpotato cultivars commonly grown in Western Kenya showing skin and flesh colour and farmer perception of relative susceptibility to rotting

Production area	Cultivar grown	Skin colour	Flesh colour	Relative susceptibility to rotting
Western Province				
	Mwezi Tatu	White	Yellow	Susceptible
	Mwezi Sita	Red	White	Resistant
	Bungoma	Red	Yellow	Resistant
	Namaswakhe	Red	White	Unsure
	Ondiake	Pink	Cream	Unsure
Nyanza Province				
	Jayalo	Red	White	Unsure
	Wera	Dark Red	White	Unsure
	Kalamu Nyerere	Red	White	Resistant
	Lodha	White	Cream	Unsure
	Sinia	Red	White	Unsure
	Nylon	White	Yellow	Unsure
	Kwar	Red	White	Susceptible
	Oduoko	Pink	White	Resistant

The majority (87.5%) of the farmers reported that postharvest rotting of roots was a major problem in sweetpotato production, and 62% indicated that the problem was cultivar dependent (See Table 4.1).

Soon after harvesting, roots were separated into two or three grades. The first grade comprised healthy, undamaged or slightly damaged.roots meant for sale. The second grade comprised undersized (< 2-cm diameter) and the severely damaged roots that were used for home consumption or as livestock feed. The third grade comprised diseased roots, which were usually discarded. In most (62.5%) cases, the roots were washed, then packed in woven polypropylene sacks for delivery to the market. Little care was exercised during packing, a practice that resulted in unnecessary injuries to the roots. About 50% of the farmers used handcarts to transport the roots from the farm to the market while about 25% used bicycles and wheelbarrows. The rest carried the roots on human backs. The roots were mainly (75%) sold in the local market directly to retailers (87%). A few farmers (25%) transported the roots to the nearest roadside point and sold them to traders who transported them to major markets in Kisumu, Eldoret, Nakuru, Nairobi and Mombasa (See Figure 4.1).

4.1.2. Central Kenya study area

In central Kenya, the study was concentrated in Kibirigwi irrigation scheme. As the case in the western Kenya production area, the majority (66.7%) of the farmers were women, and most (75%) had experience of more

Figure 4.1. A scene at a roadside shopping center in Nyanza province, Western Kenya, showing the sweetpotatoes packed in polyethylene sacks waiting to be loaded onto a waiting truck for transportation to distant markets

than five years in sweetpotato production. Sweetpotato plot sizes were small in most cases (83.3%) not exceeding 0.4 ha. However, the farmers planted more than one sweetpotato plot per season.

Most (91.7%) of the farmers planted sweetpotato as a pure stand (mono cropping) but sometime grew two or three varieties together. The sweetpotato was grown in rotation with commercial vegetables such as tomatoes, onions, capsicums, crucifers and French beans. In most cases (66.7%), no soil amendments like chemical fertilizers or manure was added to the soil throughout the growing season, but some (33.3%) farmers reported applying animal manure. The characteristics of the sweetpotato cultivars grown at the Kibirigwi irrigation scheme are shown in Table 4.2.

Planting was done on ridges and the majority (75%) of farmers timed planting to coincide with onset of the short rains season in October and November. Planting material, which comprised any part of the vine, was obtained from the farmer's previous crop. The crop was mostly (58.3%) weeded twice during which time the plants were covered with soil to ensure that the developing roots were not exposed to the surface.

Whole plots were harvested at once using a wooden hand held tool that helped to minimize mechanical damage to the roots. The vines were not uprooted but left in the field to provide planting material for the next sweetpotato crop. Most (66.7%) of the farmers indicated that rotting of roots

Table 4.2. Sweetpotato cultivars commonly grown at the Kibirigwi Irrigation Scheme showing skin and flesh colour and farmer perception of cultivar relative susceptibility to rotting

Cultivar grown	Alternative name	Skin colour	Flesh colour	Relative susceptibility to rotting
Ngorofu	KEMB 36	Red	White	Resistant
Kiguruki	KEMB 20	Red	White	Susceptible
Kaboko	KSP 20	Red	White	Susceptible

was a problem and most (75%) reported that root susceptibility to rotting was cultivar dependent. Among the three cultivars grown in this area, KEMB 20 and KSP 20 were susceptible to rotting while KEMB 36 was resistant (Table 4.2).

The harvested roots were collected (tossed) into a heap at a central point from where they were sorted and placed into two or three groups (grades). The first group comprised large roots with minimum mechanical damage, which were sold for a premium price. The second had healthy but smaller sized roots (2-4cm diameter) which sold at a reduced price. The third group consisted of the undersized (< 2-cm diameter), diseased and severely damaged roots. These were further sorted for home consumption and livestock feed, while others were discarded. The sweetpotato roots were sold unwashed.

Soon after harvesting, the roots were put in various types of containers and transported on human back to the roadside where they were repackaged mostly (91.7%) into woven polypropylene sacks weighing about 150 Kg. The roots were then sold to middlemen in the local market (66.7%) and the rest was transported to major markets in Nairobi and Mombasa.

4.2. Fungi isolated from diseased sweetpotato root samples

Nine different fungi were isolated from the diseased root samples collected from the study areas. Laboratory tests revealed that six of the fungi: *Botryodiplodia theobromae*, *Rhizopus oryzae*, *Rhizopus stolonifer*, *Fusarium oxysporum*, *Macrophomina phaseolina* and *Ceratocystis fimbriata* were

pathogenic. The other three fungi, *Aspergillus niger, Mucor circinelloides* and *Penicillium spp* were saprophytic to sweetpotato roots. Table 4.3 shows the isolated fungi, the disease they are associated with and the IMI identification number given for the fungi sent for confirmatory diagnosis at the International Mycological Institute (IMI). Figure 4.2 shows micrographs of some of the isolated fungi and Figure 4.3 shows disease symptoms on sweetpotato roots associated with some of the fungi.

4.2.1. Description of disease symptoms caused by fungi isolated from diseased sweetpotato roots

The fungi *Rhizopus stolonifer* and *R. oryzae* caused similar soft rot on sweetpotato roots. The affected roots rapidly developed a soft, moist and stringy rot, which decayed a sweetpotato root of average size entirely in 3-5 days. A pronounced fermentation odour was also produced. Mycelia appearing like whiskers sometimes grew out through breaks in the periderm to produce sporangia which subsequently raptured and released numerous sporangiospores.

Disease symptoms caused by *Botryodiplodia theobromae* were observed on sweetpotato roots about 14 days after harvesting. Initially, the affected roots were firm and brown, then they darkened to solid black before drying out and becoming mummified. Many black pimple-like or wart-like growths were sometimes observed on the surface of affected roots. These later broke down with age and released conidia that appeared like black powder.

The fungus *Fusarium oxysporum* caused surface rot symptoms on the affected sweetpotato roots characterized by circular, light to dark brown lesions. The lesions were firm and dry and sometimes contained white mycelium. The root tissue within and around the lesions became shrunken as the decay progressed.

Macrophomina phaseolina infection began as a light brown discoloration of various sizes and shapes on the affected sweetpotato roots. Upon cutting the root in half, there was a sharp contrast between the diseased and the healthy tissue. The affected tissue comprised three zones: the advancing edge of the lesion was pale brown and spongy, the intermediate zone reddish brown and firm while the oldest part of the lesion was black. The rot was initially restricted to the root cortex, but eventually the entire affected root dried up.

Sweetpotato roots infected by the fungus *Ceratocystis fimbriata* developed circular, brown, firm, slightly sunken lesions that later became greenish-black. Mature lesions were covered with small black fungal fruiting bodies that appeared like bristles. Over time, the lesions continued to increase in size, but remained shallow.

Infection by the weakly parasitic molds occurred in roots stored under high relative humidity. *Aspergillus niger* appeared on the sweetpotato roots as a black mold and lesions remained generally firm over time. *Mucor circinelloides* caused rotting especially at the ends of the sweetpotato root. Symptoms were similar to those caused by *Rhizopus* sp. with the affected

tissue becoming moist and whitish with production of a distinct starchy oduor and becoming spongy as decay progressed. *Penicillium spp.* infection on the sweetpotato roots appeared as a blue and green mold rot usually on cut or damaged surfaces of the root.

4.2.2. Virulence test

The most virulent isolates among those tested were K36/KIB/R37S2.3 for *R. oryzae,* RS/UON/SS5 for *R. stolonifer* and KGK/KIB/DS13 for *B. theobromae.*

4.3. Preharvest factors associated with postharvest pathological deterioration of sweetpotato roots

This section contains the findings of the study on the effect of vine removal, time of harvesting, cultivar and soil pH on postharvest pathological deterioration of sweetpotato roots.

4.3.1. Effect of vine removal

The results showed that the three-way interaction: vine removal treatment x pathogen x cultivar was not significant ($p<0.05$) but the two-way interaction: cultivar x pathogen was significant ($P < 0.05$) in both years of the study.

In the first trial (1998), roots from plants with vines removed two weeks before harvesting had significantly ($p<0.05$) larger mean internal lesion dimensions (MILD) than roots from the control plants. However, the MILD in

Table 4.3. Fungi isolated from diseased sweetpotato root samples collected from the study areas and associated diseases

No.	Fungi Isolated	Pathogenicity	Sweetpotato Disease	IMI identification number
1	*Botryodiplodia theobromae*	Pathogenic	Java black rot	*
2	*Rhizopus oryzae*	Pathogenic	Soft rot	W57779 (1998)
3	*Rhizopus stolonifer*	Pathogenic	Soft rot	*
4	*Fusarium oxysporum*	Pathogenic	Surface rot	W5778 (1998)
5	*Macrophomina phaseolina*	Pathogenic	Charcoal rot	W5957 (1999) & W5781 (1998)
6	*Ceratocystis fimbriata*	Pathogenic	Black rot	W5958 (1999)
7	*Aspergillus niger*	Not Pathogenic	Black mold rot	W5782 (1998)
8	*Mucor circinelloides*	Not Pathogenic	Mucor rot	W5783 (1998)
9	*Penicillium spp*	Not Pathogenic	Blue mold rot	*

*Isolates not identified at the International Mycological Institute

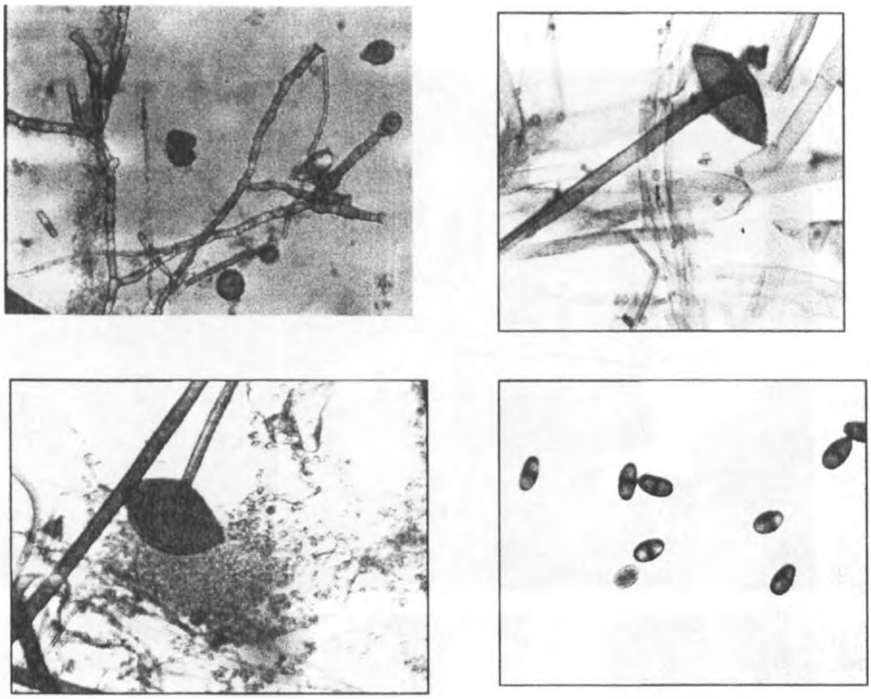


Figure 4.2. Micrographs of some fungi associated with postharvest pathological deterioration of sweetpotato roots: *Ceratocystis fimbriata* (Top left), *Rhizopus oryzae* (Top right), *Rhizopus stolonifer* (Bottom left) and *Botryodiplodia theobromae* (Bottom right).

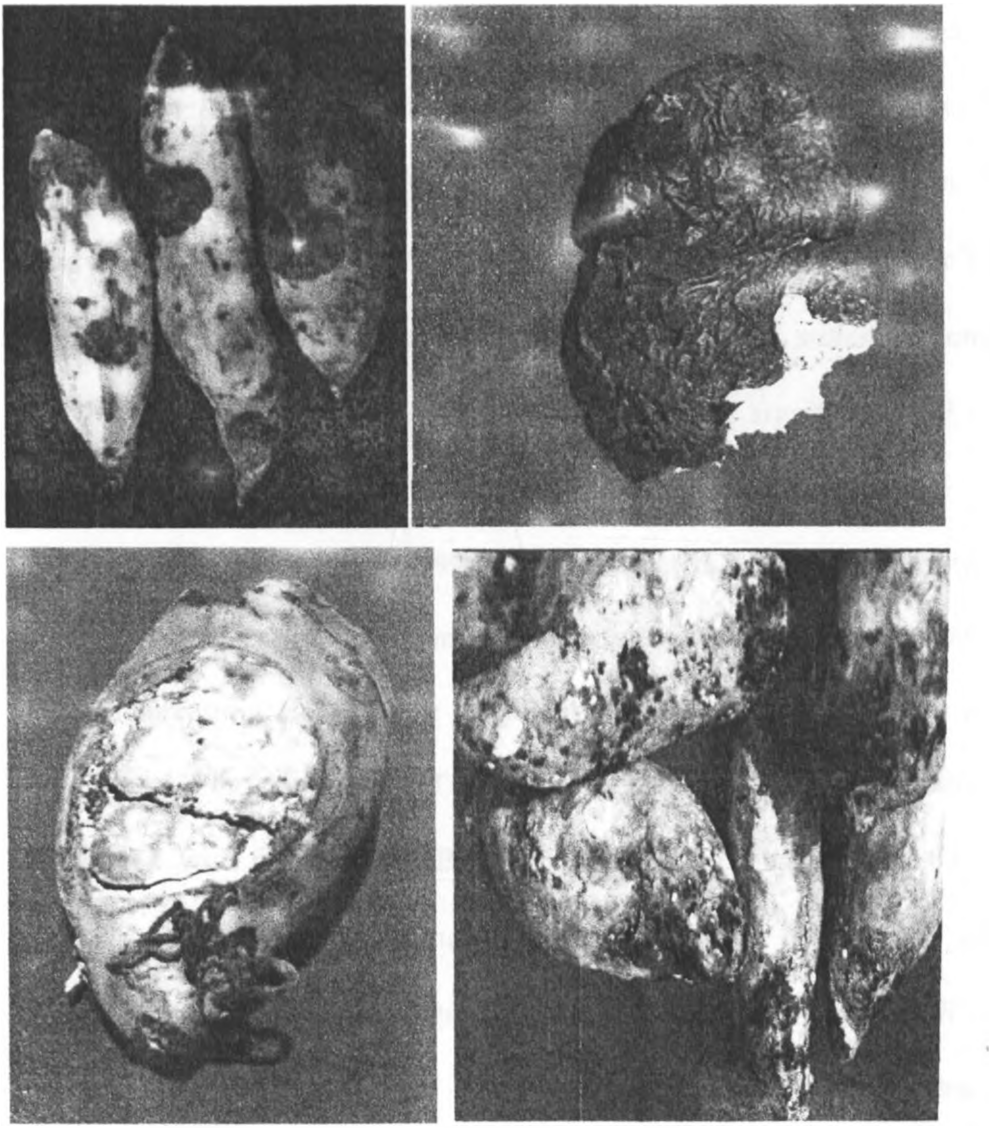


Figure 4.3. Symptoms of postharvest pathological deterioration of sweetpotato roots caused by fungi: Black rot (*Ceratocystis fimbriata)* (Top left), Soft rot (*Rhizopus oryzae* and *Rhizopus stolonifer)* (Top right), Surface rot (*Fusarium oxysporum*) (Bottom left) and Java black rot (*Botryodiplodia theobromae)* (Bottom right).

roots from plants with vines removed one week before harvesting did not differ significantly from the control roots (Table 4.4).

The cultivar KEMB 10 showed significantly ($P < 0.05$) higher MILD with *R. oryzae* than with *B. theobromae* and *R. stolonifer* and had larger MILD with *R. oryzae* and *R. stolonifer* compared with the other three cultivars. MILD did not differ significantly ($P < 0.05$) amongst the pathogens in cultivar Yanshu 1. Cultivar KEMB 36 showed the smallest MILD with *R. stolonifer* compared to the other cultivars, while cultivar KSP 20 showed significantly ($P < 0.05$) larger MILD with *R. oryzae* than with *B. theobromae* and *R. stolonifer*.

In the second trial (1999), MILD did not differ significantly ($p<0.05$) amongst pathogens in roots from plants with vines removed one and two weeks before harvesting. However, the MILD was significantly ($p<0.05$) larger in these roots than in the control roots (Table 4.5). MILD also differed with cultivar and pathogen with cultivar KEMB 10 developing significantly ($p<0.05$) larger MILD with all pathogens than the other cultivars. MILD also differed significantly ($p < 0.05$) amongst the pathogens. It was largest with *R. oryzae* but did not differ significant ($p < 0.05$) between the other two pathogens.

4.3.2. Effect of time of harvesting

The two-way interaction: time of harvesting x pathogen and time of harvesting x cultivar, were significant ($P < 0.05$) in 1998. Time of harvesting, pathogen and cultivar effects were all significant ($P < 0.05$) (Table 4.6).

Table 4.4. Effect of time of preharvest vine removal on mean internal lesion dimensions (MILD) (mm) in four sweetpotato cultivars inoculated with the pathogens *Botryodiplodia theobromae* (BT), *Rhizopus oryzae* (RO) and *Rhizopus stolonifer* (RS) in 1998.

Preharvest Vine Removal Time	Yanshu 1			KSP 20			KEMB 10			KEMB 36			Vine Removal Time means
	BT	RO	RS	BT	RO	RS	BT	RO	RS	BT	RO	RS	
0 weeks	5.57	7.50	4.07	5.66	9.67	6.05	10.30	28.48	5.36	8.00	5.79	0.05	8.04
1 week	3.97	6.55	10.31	5.90	14.86	4.14	10.27	26.76	13.75	4.55	11.41	2.09	9.55
2 week	7.94	8.62	10.70	8.23	12.98	5.66	12.53	28.17	20.90	7.96	6.84	1.11	10.97
Cultivar means		7.25			8.13			17.39			5.31		

LSD (P=0.05) for comparing vine removal time means = 2.01 Standard Error = 3.66

LSD (P=0.05) for comparing cultivar means = 2.32

LSD (P=0.05) for comparing pathogen means = 2.01

LSD (P=0.05) for cultivar X pathogen interaction = 4.20

Table 4.5. Effect of time of preharvest vine removal on mean internal lesion dimensions (MILD) (mm) in four sweetpotato cultivars inoculated with the pathogens *Botryodiplodia theobromae* (BT), *Rhizopus oryzae* (RO) and *Rhizopus stolonifer* (RS) in 1999

Preharvest Vine Removal Time	Yanshu 1			KSP 20			KEMB 10			KEMB 36			Vine Removal Time means
	BT	RO	RS	BT	RO	RS	BT	RO	.RS	BT	RO	RS	
0 weeks	13.42	7.29	10.22	8.06	22.48	8.94	25.88	35.34	11.37	9.67	16.96	9.42	14.92
1 week	15.51	11.23	10.97	19.79	25.35	12.23	43.12	34.91	19.02	11.13	12.55	12.75	19.05
2 week	7.70	34.44	11.79	14.79	18.98	12.02	24.71	36.76	23.05	10.36	21.40	13.75	19.15
Cultivar Means		13.62			15.85			28.24			13.10		

LSD (P=0.05) for comparing vine removal time means = 4.53

LSD (P=0.05) for comparing cultivar means = 5.23

LSD (P=0.05) for comparing pathogen means = 4.53

Standard Error = 6.94

LSD (P=0.05) for cultivar X pathogen interaction = 7.94

Table 4.6. Effect of time of harvesting on mean internal lesion dimension (MILD) (mm) in four sweetpotato cultivars inoculated with *Rhizopus oryzae* (RO) and *R. stolonifer* (RS) in 1998

Time of harvesting	Yanshu 1		KSP 20		KEMB 10		KEMB 36		
	RO	RS	RO	RS	RO	RS	RO	RS	Time of harvesting means
16 weeks	9.18	12.91	9.44	15.94	42.46	45.40	7.36	3.45	18.29
22 weeks	8.61	16.79	13.16	15.25	42.58	60.13	4.23	9.53	21.29
28 weeks	36.65	80.19	18.42	58.19	46.10	74.55	9.15	54.89	47.27
Cultivar Means	27.39		21.73		51.87		14.77		

LSD (P=0.05) for comparing Time of harvesting means = 3.79

LSD (P=0.05) for comparing cultivar means = 4.37

LSD (P=0.05) for Time of harvesting x cultivar interaction = 4.42

Standard Error = 4.47

LSD (P=0.05) for Time of harvesting x pathogen interaction = 3.12

Roots harvested at 28 weeks after planting (WAP) had significantly ($P < 0.05$) larger MILD than those harvested at 16 WAP and those harvested at 22 WAP with all pathogens (Table 4.6). In *R. oryzae*, MILD did not differ significantly ($P < 0.05$) between roots harvested at 16 and those harvested at 22 WAP in all the cultivars except cultivar KSP 20. With *R. stolonifer*, however, MILD was significantly ($P < 0.05$) larger in roots harvested at 22 WAP compared to those harvested at 16 WAP in all cultivars except in KSP 20.

Mean internal lesion dimension (MILD) differed between the pathogens in roots harvested at 22 WAP and those harvested at 28 WAP in all cultivars, with *R. stolonifer* showing significantly ($P < 0.05$) larger MILD than *R. oryzae*.

Roots of all the cultivars harvested at 28 WAP had significantly ($P < 0.05$) larger MILD than those harvested at 16 and 22 WAP. The MILD did not differ significantly in roots harvested at 16 WAP and 22 WAP in Yanshu 1 and KSP 20. However, in KEMB 10 and KEMB 36 MILD was significantly larger in roots harvested at 22 WAP compared to those harvested at 16 WAP.

Cultivar KEMB 10 developed significantly ($P < 0.05$) larger MILD compared to all other cultivars at all times of harvesting except with Yanshu 1 at 28 WAP. Cultivar KEMB 36, on the other hand, had significantly ($P < 0.05$) smaller MILD compared to the other cultivars at all times of harvesting.

Time of harvesting x cultivar interactions was not significant ($P < 0.05$) in 1999, but the MILD differed significantly ($P<0.05$) amongst

harvesting times and amongst cultivars. The MILD did not differ in roots harvested at 28 WAP and those harvested at 22 WAP. However, the MILD was significantly ($P<0.05$) smaller in roots harvested at 16 WAP compared to those harvested at 28 weeks and 22 weeks.

The MILD was significantly ($P<0.05$) larger in cultivar KEMB 10 compared to the other cultivars except cultivar Yanshu 1. There was no significant difference ($P<0.05$) in MILD amongst the cultivars Yanshu 1, KSP 20 and KEMB 36 (Table 4.7).

4.3.3. Effect of cultivar

Roots artificially inoculated with *R. oryzae* and *R. stolonifer* showed typical soft rot symptoms with the root tissue rotting around the inoculation point within two days. When cut longitudinally into two halves through the inoculation point, the roots of the different cultivars showed variation in tissue degradation (Figure 4.4). The control roots showed no tissue degradation.

Cultivar x pathogen interaction was significant ($P < 0.05$) in 2000 but not in 1999 (Table 4.8). In both years, the MILD differed significantly ($P < 0.05$) among cultivars. It also differed significantly ($P < 0.05$) between the two pathogens in 1999 but not in 2000.

With *R. stolonifer*, cultivar Yanshu 1 developed significantly ($P < 0.05$) larger MILD compared with cultivars KSP 20, KEMB 10 and KEMB 36. MILD did not differ significantly ($P<0.05$) among the latter three cultivars.

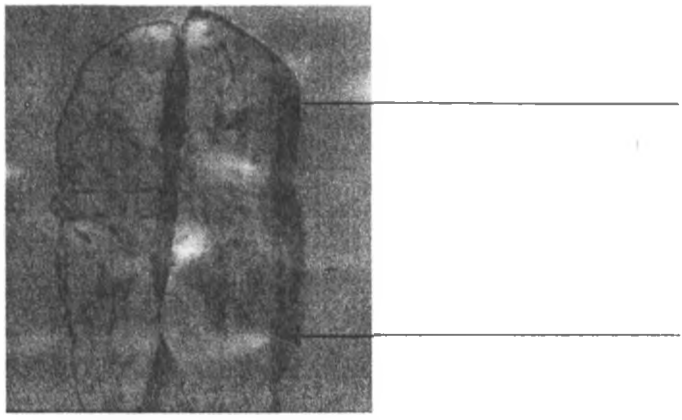
Table 4.7. Effect of time of harvesting in weeks after planting on mean internal lesion dimension (MILD) (mm) in four sweetpotato cultivars inoculated with *Rhizopus oryzae* in 1999

Time of harvesting	Yanshu 1	KSP 20	KEMB 10	KEMB 36	Time of harvesting means
16 weeks	2.70	0.42	5.75	1.37	2.56
22 weeks	26.73	19.25	26.82	18.12	22.73
28 weeks	29.20	23.42	32.77	20.20	26.40
Cultivar Means	19.54	14.36	21.78	13.23	

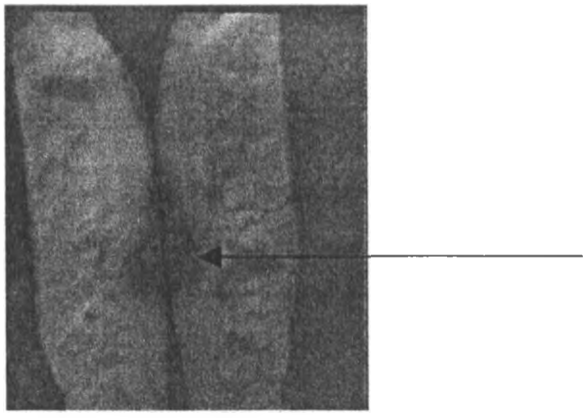
LSD (P=0.05) for comparing Time of harvesting means = 11.09

LSD (P=0.05) for comparing cultivar means = 7.08

Standard Error = 3.99



Cultivar Yanshu 1
The arrows show a large rotted section of the root around the inoculation point



Cultivar KEMB 36
The arrows show restricted rotted section of the root around the inoculation point.

Figure 4.4. Sweetpotato roots showing different severity of root rot 48 hours after artificial inoculation with *Rhizopus stolonifer*.

Table 4.8. Effect of cultivar on mean internal lesion dimension (MILD) (mm) in sweetpotato cultivars inoculated with *R. oryzae* and *R. stolonifer* in 1999 and 2000.

Cultivars	*R. oryzae*		*R. stolonifer*		Cultivar means	
	1999	2000	1999	2000	1999	2000
Yanshu 1	37.33	20.25	58.43	32.94	47.88	26.60
KSP 20	25.60	16.60	44.80	7.30	35.20	11.95
KEMB 10	23.53	16.00	45.80	7.00	34.67	11.50
KEMB 36	24.70	12.56	39.05	9.81	31.86	11.18
Pathogen Means	27.79	16.35	47.01	14.26		

	1999	2000
LSD (P=0.05) for comparing cultivar means	9.12	8.25
LSD (P=0.05) for comparing pathogen means	6.45	5.83
LSD (P=0.05) for cultivar x pathogen interaction	Ns	11.66
Standard Error	5.27	4.77

Ns – Not significant

This also occurred with *R. oryzae* in 1999, but not in 2000. The MILD also differed significantly ($P < 0.05$) between the pathogens in 1999 but not in 2000. In 1999, MILD was higher with *R. stolonifer* compared to *R. oryzae*. It was also higher in 1999 compared to 2000 in all cultivars with both pathogens, except in cultivar KSP 20 and KEMB 36 with *R. oryzae* where the difference was not significant ($P < 0.05$) (Table 4.8).

4.3.4. Effect of Soil pH

In both years of the study, the MILD did not differ significantly ($p < 0.05$) amongst soil pH treatments. However, the two-way interaction: soil pH x pathogen interaction and pathogen x cultivar were significant ($p < 0.05$) in 1998 but not in 1999. Cultivars and pathogens also differed significantly ($p < 0.05$) in 1998 but not in 1999.

The MILD did not differ significantly ($p < 0.05$) amongst soil pH levels in both test cultivars with *B. theobromae* (Table 4.9). With *R. oryzae,* however, MILD in both cultivars was significantly larger at soil pH level 6.1 compared to soil pH levels 4.6 and 5.8.

In cultivar Yanshu 1, the MILD differed significantly ($p < 0.05$) between the pathogens at pH levels 5.8 and 6.1, but not at 4.6. In cultivar KSP 20. however, the MILD differed significantly ($p < 0.05$) only at pH level 6.1.

Table 4.9. Effect of soil pH on mean internal lesion dimension (MILD) (mm) in two sweetpotato cultivars Yanshu 1 and KSP 20 inoculated with the pathogens *Rhizopus oryzae* (RO) and *Botryodiplodia theobromae* (BT) in 1998

Soil pH Level	Yanshu 1		KSP 20		Soil pH Level means
	Rhizopus oryzae	*Botryodiplodia theobromae*	*Rhizopus oryzae*	*Botryodiplodia theobromae*	
4.6	16.40	12.89	7.00	10.37	11.67
5.8	21.09	14.38	9.41	11.41	14.07
6.1	24.36	10.26	15.94	10.08	15.16
Cultivar Means	16.56		10.70		

LSD (P=0.05) for comparing soil pH means = 3.65

LSD (P=0.05) for comparing cultivar means = 2.98

LSD (P=0.05) for comparing pathogen means = 2.98

LSD (P=0.05) for pathogen X cultivar interaction = 4.06

LSD (P=0.05) for soil pH level X pathogen interaction = 4.98

Standard Error = 3.44

Mean internal lesion dimension differed significantly ($p < 0.05$) between the cultivars with larger MILD developing in cultivar Yanshu 1 than in cultivar KSP 20.

4.4. Postharvest factors associated with postharvest pathological deterioration of sweetpotato roots

This section presents the results of postharvest factors associated with postharvest pathological deterioration of sweetpotato roots. The specific factors presented are curing and washing and storage temperature.

4.4.1. Effect of solar curing

Curing treatments were significantly different ($p<0.05$) at all storage times in both years, except at seven days in 1999, with the cured roots having higher percent marketable roots than the uncured roots (Table 4.10).

There was no difference between washed and unwashed roots in both cured and uncured roots at all storage times in both years. However, at 70, 80, 90 and 100 days of storage, percent marketable roots was significantly ($p<0.05$) higher in cured-washed roots than in cured-unwashed roots in 1999.

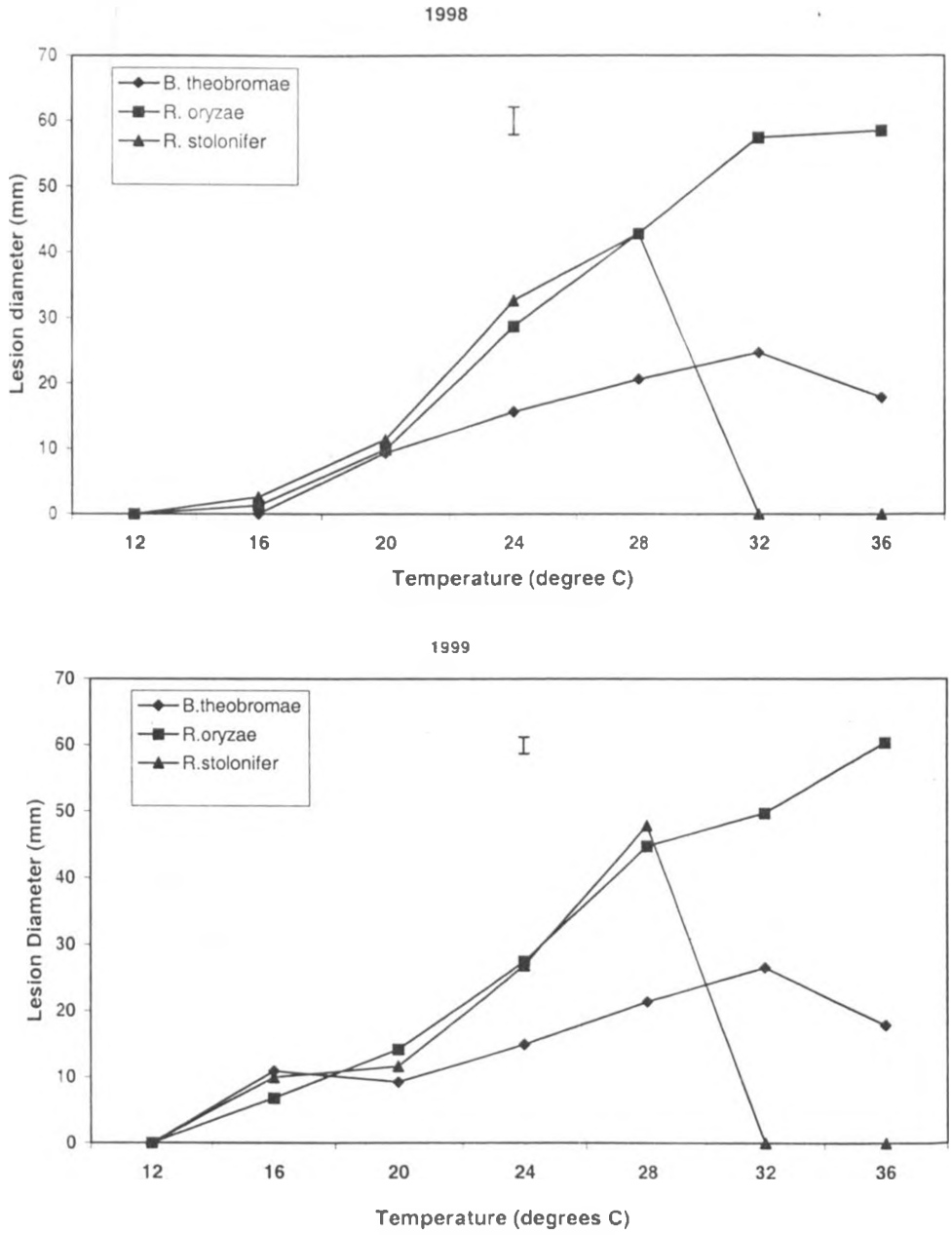
4.4.2. Effect of storage temperature

Temperature x pathogen interaction was significant ($p<0.05$) in both years. With all the pathogens, there was no infection at 12^0C, but above this temperature, infection increased with increase in temperature (Figure 4.5).

Table 4.10. Effect of curing and washing on percent marketable roots (percent of initial number) of sweetpotato cultivar KEMB 20 during storage at room temperature and relative humidity in 1999 and 2000

Treatment	Year	Storage time (days)										
		7	14	21	28	40	50	60	70	80	90	100
Washed Cured	1999	97.5	97.5	93.8	87.7	84.6	71.4	64.7	64.2	61.6	61.6	61.1
	2000	98.9	95.3	83.7	77.3	77.3	56.9	51.7	47.6	47.0	44.4	39.7
Unwashed Cured	1999	98.0	98.0	95.9	89.7	78.1	63.7	55.4	43.7	38.4	37.3	36.2
	2000	97.4	94.2	88.9	85.3	79.0	59.0	52.1	46.8	46.8	42.7	37.9
Washed uncured	1999	98.0	53.7	16.0	8.5	3.5	2.0	2.0	1.5	1.5	1.5	1.5
	2000	56.6	25.9	15.0	12.0	3.6	2.1	0.5	0.5	0.5	0.5	0.5
Unwashed uncured	1999	95.4	63.3	9.2	6.6	3.0	1.0	1.0	1.0	1.0	1.0	1.0
	2000	63.1	36.6	17.0	14.7	6.7	0.6	0.0	0.0	0.0	0.0	0.0
P-Value	1999	NS	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	2000	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	1999	5.7	11.7	8.9	8.3	11.6	8.7	12.5	11.5	10.8	10.7	9.6
	2000	12.5	11.6	5.5	6.5	8.9	17.1	16.0	13.9	14.5	15.7	14.7

Figure 4.5. Effect of storage temperature (degree C) on lesion diameter (mm) in root slices of sweetpotato cultivar Yanshu1 inoculated with *Botryodiplodia theobromae*, *Rhizopus oryzae* and *Rhizopus stolonifer* and incubated for 24 hours in 1998 and 1999. The vertical bar in each graph represents the LSD (P = 0.05).



In 1998, there was no infection with *B. theobromae* at 16^0C, and infection was very low with *R. oryzae* and *R. stolonifer*. With *B. theobromae*, lesion diameter increased with temperature to a maximum of 24.71mm at 32^0C, then decreased to 17.86mm at 36^0C. With *R. oryzae*, it increased to 58.50mm at 36^0C, and with *R. stolonifer* to a maximum of 42.79mm at 28^0C, then dropped to zero at 32^0C.

In 1999, infection increased to 26.43mm at 32^0C, then decreased to 17.71mm at 36^0C with *B. theobromae*. With *R. oryzae* it increased to 60.36mm at 36^0C and with *R. stolonifer* to a maximum of 47.86mm at 28^0C, then dropped to zero 32^0C. These results are shown in Figure 4.5.

5. DISCUSSION

5.1. Baseline survey

Postharvest handling of food crops at the farm and during marketing should be the concern of everybody irrespective of gender. However, in this study it was observed that in both study areas, women comprised the majority of the people directly involved in sweetpotato production and trade and they had several years of experience in sweetpotato production. Similar findings on women involvement have been reported by Hagenimana *et al.* (1999) and Mutuura *et al.* (1992). This suggests that women have been playing an important role in sweetpotato production and trade in Kenya and are likely to continue doing so. Consequently, women comprise a crucial target group during implementation of programmes aimed at improving sweetpotato production, utilization and trade.

A wide range of sweetpotato cultivars are commonly grown in a single plot, a practice that has also been reported by Mutuura *et al.* (1992) and Ngunjiri *et al.* (1993). Some of the farmers' sweetpotato cultivars have a long maturity period and the others a short one, and this ensures that the farmer can harvest piecemeal over an extended period. Planting of different varieties could also have been caused by the problem of insufficient planting material of one cultivar, as has already been reported (Mutuura *et al.*, 1992). Farmers may also prefer to grow a combination of different varieties with different root qualities such as in-ground

and postharvest storage capacity, use, taste and marketability, in order to meet their food and cash needs (Ngunjiri *et al.*, 1993).

Most farmers were aware of the problem of postharvest fungal infection and recognized it as a main production constraint. The problem had also been identified during earlier studies, but it was considered of minor importance compared to root destruction by moles and weevils (Mutuura *et al.*, 1992; Ngunjiri *et al.*, 1993). Some farmers associated root rots to certain cultivars, and this shows that a farmer-based strategy to reduce postharvest losses through growing relatively resistant cultivars would be acceptable. The strategy should be augmented with education of the farmers on careful harvesting and handling of the roots to minimize physical injury. Lutz *et al.* (1951), has demonstrated that carefully placing roots directly into market crates, compared to tossing them into a heap, would result in roots having low percentage decay, low weight loss and low total postharvest loss.

5.2. Fungi associated with postharvest pathological deterioration

Six pathogenic fungi were associated with postharvest pathological deterioration of sweetpotato roots in Kenya.

The Java black rot fungus, *B. theobromae*, was the first postharvest pathogen of sweetpotato to be reported in Kenya (Nattrass, 1961). Later *Rhizopus stolonifer* and *Fusarium oxysporum* were identified (Gatumbi *et al.*, 1990; Kihurani *et al.*,1994). The other three pathogens identified in this study, *Rhizopus*

oryzae, Macrophomina phaseolina and *Ceratocystis fimbriata,* had previously not been reported.

These findings were consistent with a report by Harrison *et al.* (2001) that many postharvest diseases in sweetpotato are incited by fungi. However, one virus disease, internal cork, and two bacterial pathogens, *Erwinia chrysanthemi* and *Streptomyces ipomoea,* have been reported in the U.S.A. (Clark and Moyer, 1988; Clark, 1992) and India (Ray and Misra, 1995). There are other postharvest fungal pathogens not yet reported in Kenya. They include; *Diaporthe phaseolorum* which causes dry rot, *Trichoderma koningii* which causes punky rot, *Botrytis cinerea* which causes grey mold, *Monilochaetes infuscans* which causes Scurf (Clark and Moyer, 1988) and *Curvularia lunata* which causes spongy rot (Ray and Misra, 1995).

Postharvest losses in sweetpotatoes commonly range from 15-35% (Booth, 1974). Contribution of this figure by microorganisms can be controlled through management of diseases caused by pathogens already known to be present in the country. In addition, regulatory controls of movement of sweetpotato planting materials across our national borders could help to prevent entry of new pathogens into the country.

5.3. Preharvest factors affecting postharvest pathological deterioration

5.3.1. Effect of vine removal

The study showed that vine removal before harvesting predisposed sweetpotato roots to postharvest pathological deterioration. The yearly difference

between vine removal at one week and two weeks may be attributed to differences in the weather conditions in 1998 compared to 1999. In 1998, shoot re-growth after the vines were removed was more favourable compared to 1999. Also, in both years, there was more shoot regrowth at the time of harvesting in plots where the vines were removed two weeks before harvesting than in the plots where the vines were removed one week before harvesting.

The exact physiological base for the observed higher deterioration of roots harvested from plants with vines removed two weeks before harvesting compared to one week or no vine removal before harvesting, was not determined in this study. However, it is possible that the difference in root deterioration occurred because of the observed differences in the vigor of shoot re-growth between the time of vine removal and harvesting of roots. This may have been brought about by starch hydrolysis to sugar to support new shoot re-growth (Missah and Kissiedu, 1994), leading to accumulation of sugar in the root. The accumulation of reducing sugar in the root has been reported to play a significant role in the establishment of fungi at the inoculation site thereby enhancing colonization of the host (Balasubramanian and Srivastava, 1973).

The interaction between cultivar and vine removal treatment was not significant in both years of the study and this showed that all four cultivars essentially responded in a similar way to vine removal. This would be expected since respiratory processes that support new shoot growth in the root are likely to be similar irrespective of cultivar.

Since vine removal before harvesting predisposed roots to postharvest pathological deterioration it is important that vines are not cut from sweetpotato plants before roots are ready for harvesting in order to minimize postharvest pathological deterioration.

5.3.2. Effect of time of harvesting.

Delaying harvesting predisposed sweetpotato roots to postharvest pathological deterioration with susceptibility to infection increasing with increase in the time of harvesting. This gave an indication that delaying the time of harvesting resulted in a reduction of root resistance to infection.

An increase in simple sugars is known to occur in the later developmental stage of the sweetpotato root and in roots that are harvested late (Noda *et al.*, 1997; Reynolds *et al.*, 1994). The increase has been attributed to enzymatic hydrolysis of the root starch reserves (Reynolds *et al.*, 1994) and it has been associated with root susceptibility to fungal infection (Balasubramanian and Srivastava, 1973). Sugar and starch contents of the roots were not determined in this study, but it is possible that the late harvested roots accumulated higher sugar levels than the early harvested roots, leading to their greater susceptibility to infection.

The cultivar KEMB 36 was the least susceptible, and cultivar KEMB 10 the most susceptible to fungal infection. With a maturity period of 90 - 120 days after planting, cultivar KEMB 10, is considered an early maturing cultivar (Ndolo

et al., 2001) compared with cultivar KEMB 36 with a maturity period of 150 – 180 days after planting. Both cultivars were harvested after the same growing period. It follows that at each time of harvesting, the roots of cultivar KEMB 10 were at a later developmental stage compared to roots of cultivar KEMB 36. Since sweetpotato roots accumulate simple sugars in the later stages of development (Noda *et al.*, 1997), cultivar KEMB 10 roots may have accumulated higher sugar levels compared with cultivar KEMB 36 roots. This may have resulted in roots of cultivar KEMB 10 becoming more susceptible to infection than those of KEMB 36 since sugar accumulation is associated with susceptibility to infection (Balasubramanian and Srivastava, 1973).

The findings further showed the need to determine and standardize the optimum harvesting time for both early and late maturing sweetpotato cultivars in order to minimize postharvest pathological deterioration.

5.3.3. Effect of cultivar

Varietal differences occurred in postharvest deterioration of sweetpotato cultivars caused by *Rhizopus oryzae* and *Rhizopus stolonifer* with the cultivar Yanshu 1 showing higher susceptibility compared to the other cultivars, KSP 20, KEMB 10 and KEMB 36. Similar varietal differences have previously been reported (Clark and Hoy, 1994; Muhanna *et al.* 2001). The results showed the possibility of reducing postharvest infection through identification and selection

of sweetpotato cultivars with relative resistance to infection, as a means of reducing postharvest losses from Rhizopus soft rot disease.

All the cultivars were more susceptible to infection by both pathogens in 1999 compared with 2000. This may be attributed to higher prevailing temperature during incubation which were 22-28^{0}C in 1999 compared to 20-25^{0}C in 2000. The higher incubation temperature conditions were more favourable for root infection by both *R. stolonifer* and *R. oryzae.*

These results show the importance of the prevailing environmental conditions in influencing fungal infection of roots leading to postharvest deterioration. This is in agreement with results previously reported by other researchers (Clark and Moyer, 1988; Snowdon, 1990; Clark, 1992). The results further showed that root infection could be suppressed through the regulation of temperature to ensure that low temperature conditions prevail during transportation and marketing of sweetpotatoes. Wills *et al.* (1998) has recommended the same as a means of maximizing shelf life of fresh produce.

5.3.4. Effect of soil pH

As per the results of this study, different soil pH levels at 4.6, 5.8, and 6.1, did not significantly ($p<0.05$) influence postharvest infection of sweetpotato roots by the fungal pathogens, *Rhizopus oryzae* and *Botryodiplodia theobromae*. There was no difference in the extent of deterioration amongst roots harvested from the soils at the different pH levels.

The significant interaction between soil pH and pathogen indicated that soil pH influenced the way the different pathogens infected the roots. The magnitude of the influence was, however, not large enough to significantly affect overall root deterioration. Similarly, the interaction between pathogen and cultivar was significant, but only in the first trial. This showed that the pathogen infected roots of the different cultivars differently, although the magnitude of the effect was not large enough to significantly influence the level of root deterioration.

The inability of the different soil pH levels to significantly influence infection level may be attributed to the tolerance of the sweetpotato plant to variations in soil conditions (O'Sullivan *et al.*, 1997; Abruna *et al.*, 1979; Ila'ava *et al.*, 2000).

These results suggest that it is possible to grow sweetpotatoes in soils at varying pH levels without significantly influencing postharvest pathological deterioration of the storage roots. This is important because sweetpotatoes are frequently cultivated on previously marginal areas with wide variations in soil conditions.

5.4. Postharvest factors affecting postharvest pathological deterioration

5.4.1. Effect of solar curing

Solar curing was effective in reducing losses of sweetpotato roots stored under tropical room temperature and relative humidity.

In both years of the study, the percentage of marketable roots were significantly ($P<0.05$) higher in cured compared to the uncured roots. These findings are consistent with reports from other studies which show that curing is significantly effective in the control of postharvest deterioration of sweetpotato roots (Padmata, 1990; Clark, 1992).

Although curing is currently not practiced in Kenya and in most tropical developing countries (Woolfe, 1992; Low, 1996), advocacy for the practice would be an effective way of reducing postharvest losses of sweetpotato roots in Kenya. Further, the results showed it would be inadvisable to assume that natural curing always takes place in sweetpotato roots harvested and stored at tropical room temperature and relative humidity as reported (Prasad *et al.*, 1981; Jenkins, 1982; Ojijo, 1991, Woolfe, 1992).

The postharvest losses in marketable roots were high in both the cured and uncured roots with more than 10 per cent loss after 21 days of storage. This was attributed to the unregulated temperature and relative humidity conditions in the storage environment, which was different from what is recommended for sweetpotato storage. The recommended conditions for sweetpotato storage is 12 - 16^{0}C and relative humidity of 85 to 90 per cent (Kay, 1987). However, in the present study, room temperature was higher and fluctuated from 15.2^{0}C to 26.7^{0}C while the relative humidity was lower ranging from 31.4 to 81.7 per cent during storage. The recommended conditions for sweetpotato storage ensures the intact

root skin and the wound periderm are maintained in a healthy state, and influences the extent of the decay that occurs during storage by determining the character and rate of the root physiological responses (Cooley *et al.*, 1954).

The results also showed that in general washing did not significantly influence loss of marketable roots at all storage times. Cured and uncured roots could be stored with or without washing without significantly influencing loss of marketable roots. This is contrary to results of Tereshkovich and Newsom (1965) who found that sweetpotato roots stored best when cured and stored without washing where temperature and relative humidity are unregulated.

5.4.2. Effect of storage temperature

The results of this study have shown that the storage temperature significantly influenced infection of sweetpotato by all the three postharvest pathogens, *B. theobromae*, *R. oryzae* and *R. stolonifer*. Infection was low at low temperature and it increased with increase in temperature. With *B. theobromae* and *R. oryzae*, infection was high at the temperature range of 24^0C to 36^0C and with *R. stolonifer* at 24^0C to 28^0C. The temperature range between 24^0C to 36^0C was therefore ideal for infection by all the three pathogens, *B. theobromae, R. oryzae* and *R. stolonifer*. This agrees with other reports that infection and decay of sweetpotato root is influenced by the prevailing environmental conditions (Clark and Moyer, 1988; Snowdon, 1990; Wills *et al.*, 1998). It has been found that the optimum temperature for infection by *B. theobromae* is between 28^0C and 32^0C

(Lo. 1986; Ray and Punithalingam, 1996) while that for *R. oryzae* is 36^{0}C (Ray *et al.*, 1997) and about 20^{0}C for *R. stolonifer* (Clark and Hoy, 1994; Srivastava and Walker, 1959).

At 25^{0}C (KMD, 1984), the room temperature in Kenya falls within the range for optimum fungal infection and decay of sweetpotato roots. This means that in the absence of temperature regulation, sweetpotato roots are inevitably exposed to conditions likely to encourage infection and decay, and this explains the occurrence of high pathological deterioration of roots during transportation and marketing in Kenya.

The results also showed that root infection by all the pathogens was low at low temperature range of 12^{0}C to 16^{0}C, an indication that infection and decay could be suppressed through storage of roots at reduced temperature conditions. This agrees with reports by Eckert and Ogawa (1988) and Wills *et al.* (1998) that transporting and storing fresh produce under reduced temperatures is likely to maximize shelf life because of reduced rate of deterioration including development of infection. Kay (1987) has also reported that the recommended conditions for sweetpotato storage is 12 - 16^{0}C and relative humidity of 85 to 90 per cent. Similarly, Snowdon (1990) has given the recommended temperature range for sweetpotato storage at the range of 13^{0}C to 16^{0}C.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

- Women comprised the majority of the people directly involved in sweetpotato production and trade in the study areas. Most of the farmers were aware of the problem of postharvest spoilage and recognized it as an important production constraint that was cultivar dependent.
- During harvesting, the common practice of tossing roots into a central place, instead of carefully placing them directly into containers, resulted in high degree of mechanical injury and led to unnecessary postharvest pathological deterioration.
- Six fungal pathogens were identified as the causal agents of postharvest pathological deterioration of sweetpotato roots in Kenya. They include *Botryodiplodia theobromae, Rhizopus stolonifer, Rhizopus oryzae, Fusarium oxysporum, Macrophomina phaseolina* and *Ceratocystis fimbriata.*
- Preharvest vine removal predisposed sweetpotato roots to postharvest pathological deterioration. The effect was more pronounced when vines were removed at two weeks before harvesting compared to one week before harvesting.
- Delayed harvesting predisposed sweetpotato roots to postharvest pathological deterioration with root susceptibility to infection increasing with increase in the length of the growing season.

- Sweetpotato cultivars differed significantly in susceptibility to postharvest pathological deterioration.
- The magnitude of the effect of soil pH on sweetpotato root susceptibility to infection was not pronounced.
- Solar curing effectively reduced postharvest deterioration of sweetpotato roots during prolonged storage at room temperature and relative humidity, but the effect of washing the roots was insignificant.
- The storage temperature influenced postharvest infection and decay. The temperature range at 24^0C to 36^0C enhanced infection while low temperature at 12^0C to 16^0C suppressed infection. Suppression of infection at low temperature was uniform in all the test pathogens but enhancement of infection differed among the pathogens. While infection by *Botryodiplodia theobromae* and *Rhizopus oryzae* was highest at the temperature range of 24^0C to 36^0C, infection by *Rhizopus stolonifer* was highest at 24^0C to 28^0C.

6.2. Recommendations

- The majority of Kenyan sweetpotato farmers and traders are women and should be targeted for implementation of programmes aimed at improving the sector.
- The farmers should be educated on careful harvesting and postharvest handling of sweetpotato roots in order to reduce postharvest losses through mechanical injury and postharvest pathological deterioration. In addition, provision of suitable sweetpotato cultivars that are disease resistant would further help reduce losses.
- Formulation of effective control strategies for control of postharvest diseases of sweetpotato roots in Kenya should target the six fungal pathogens identified as the causal agents of postharvest pathological deterioration: *Botryodiplodia theobromae, Rhizopus stolonifer, Rhizopus oryzae, Fusarium oxysporum, Macrophomina phaseolina* and *Ceratocystis fimbriata.*
- Removal of vines from the sweetpotato plant before the roots are harvested should be avoided since the practice is likely to predispose the roots to postharvest pathological deterioration. It is also recommended that studies be carried out to establish the physiological base for the enhancement of infection by preharvest vine removal.

- Sweetpotato farmers should be advised on the optimum maturity stage of harvesting their sweetpotato roots in order to minimize postharvest pathological deterioration and at the same time optimize yields. Studies should also be undertaken to determine optimal maturity for the most widely grown sweetpotato cultivars in Kenya and to determine the physiological base for the enhancement of pathological deterioration by delayed harvesting.
- Studies should be done to establish the status of the most widely grown sweetpotato cultivars in terms of their susceptibility/resistant to postharvest diseases.
- Growing sweetpotatoes would be a prudent way of utilizing moderately or strongly acidic soils without enhancing postharvest infection since the crop does not appear to be strongly influenced by soil pH.
- Farmers should be encouraged to adopt solar curing in order to prolong the shelf life of sweetpotato roots. Solar curing should be carried out irrespective of whether the roots are washed or unwashed.
- Fresh sweetpotato roots should be held under low temperature conditions at 12^0C to 16^0C whenever possible during transportation and marketing in order to prolong shelf life. Attempts should also be made to provide basic shading to ensure some cooling effects where conventional air temperature regulation is not feasible.

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APPENDIX

Appendix 1. Checklist

1. Province/ District/ Division/ Location/ Sublocation
2. Nearest town/ main road
3. Agro-ecological zone
4. Altitude
5. Farmer's name/ Gender (Female / Male)
6. Farmer's experience in sweetpotato growing:
7. Number of sweetpotato plots per season
8. Estimated size of plot(s)
9. Planting method (Monocrop/ Intercrop/ Relay cropping)
10. Soil amendment (manure /chemical fertilizer)
11. Number and names of varieties grown
12. Time of planting
13. Part of the plant used as planting material
14. Source of planting materials
15. Rehilling /Weeding
16. Harvesting method and tools
17. Handling of roots during harvesting (Tossing / using container)
18. General weather condition during the growing season

19. Frequency and occurrence of root rots in the last five years

20. Correlation of root rot with variety (less/ more rotting)

21. Grading roots and method

22. Cleaning roots after harvest and method used

23. Market delivery container

24. Means of transport to the market

25. Time taken from harvesting to market delivery

26. Type of market (Local / Regional)

27. Method of sale (to consumer/ to retailer/ to middleman)

Appendix 2. Media used in this study.

Tap-Water Agar (TWA)

Agar Technical (Oxoid No. 3)	12 g
Tap water	1000 ml

Potato Dextrose Agar (PDA)

Potato dextrose agar (Oxoid)	39g
Tap water	1000ml.

Appendix 3 Field experimental plot design (RCBD) to test the effect of vine removal at 0 weeks (P_0) one week (P_1) and two weeks (P_2) before harvesting on postharvest pathological deterioration of roots of sweetpotato cultivars Vanshu 1 (V_1) KSP 20 (V_2) KEMB 10 (V_3) and KEMB 36 (V_4)

BLOCK I

$P_o V_3$	$P_1 V_4$	$P_1 V_3$	$P_2 V_3$
$P_o V_4$	$P_2 V_4$	$P_o V_1$	$P_2 V_1$
$P_1 V_1$	$P_1 V_2$	$P_o V_2$	$P_2 V_2$

BLOCK II

$P_o V_1$	$P_o V_3$	$P_1 V_2$	$P_1 V_3$
$P_1 V_4$	$P_2 V_3$	$P_o V_4$	$P_2 V_1$
$P_o V_2$	$P_1 V_1$	$P_2 V_2$	$P_2 V_4$

BLOCK III

$P_o V_2$	$P_1 V_2$	$P_1 V_1$	$P_o V_4$
$P_2 V_2$	$P_2 V_3$	$P_o V_3$	$P_2 V_1$
$P_2 V_4$	$P_1 V_3$	$P_o V_1$	$P_1 V_4$

BLOCK IV

$P_1 V_2$	$P_o V_2$	$P_o V_4$	$P_o V_1$
$P_2 V_4$	$P_1 V_3$	$P_o V_3$	$P_2 V_3$
$P_1 V_1$	$P_2 V_1$	$P_1 V_4$	$P_2 V_2$

Appendix 4. Field experimental plot (Split Plot Design) to test the effect of time of harvesting at 16 weeks (P_{16}) 22 weeks (P_{22}) and 28 weeks (P_{28}) after planting on postharvest deterioration of roots of sweetpotato cultivars Yanshu 1 (V_1) KSP 20 (V_2) KEMB 10 (V_3) and KEMB 36 (V_4).

BLOCK I

P_{28}	P_{22}	P_{16}
V_3	V_4	V_3
V_1	V_2	V_1
V_4	V_3	V_2
V_2	V_1	V_4

BLOCK II

P_{22}	P_{28}	P_{16}
V_2	V_1	V_2
V_3	V_3	V_1
V_1	V_4	V_3
V_4	V_2	V_4

BLOCK III

P_{16}	P_{22}	P_{28}
V_3	V_1	V_1
V_2	V_4	V_3
V_4	V_2	V_2
V_1	V_3	V_4

BLOCK IV

P_{22}	P_{28}	P_{16}
V_4	V_2	V_3
V_1	V_4	V_4
V_2	V_1	V_1
V_3	V_3	V_2

Appendix 5. Analysis of variance (ANOVA) for MILD (mm) on roots of sweetpotato cultivars, Yanshu 1, KSP 20, KEMB 10, and KEMB 36 harvested from plants with vines removed at 0, 1 and 2 weeks before harvesting, then inoculated with the pathogens, *Rhizopus oryzae*, *R. stolonifer* and *Botryodiplodia theobromae* in 1998.

Source of variation	Sum of Squares	Df	Mean Square	Computed F-Value
Block	143.38	3	47.79	1.78 *
A: Vine removal treatment	203.16	2	101.58	3.78 *
B: Pathogen	1546.73	2	773.36	28.79 *
C: Cultivar	3117.42	3	1039.14	38.68 *
A x B	127.49	4	31.87	1.19 ns
A x C	76.71	6	12.784	0.33 ns
B x C	1234.45	6	205.741	7.66 *
A x B x C	316.11	12	26.34	0.98 ns
Error	2820.58	105	26.86	
Total	10432.30	143		

MILD = Mean Internal Lesion Dimension

ns = not significant;

* = Significant at 95% confidence level ($P < 0.05$)

Appendix 6. Analysis of variance (ANOVA) for MILD (mm) on roots of sweetpotato cultivars, Yanshu 1, KSP 20, KEMB 10, and KEMB 36 harvested from plants with vines removed at 0, 1 and 2 weeks before harvesting, and inoculated with the pathogens *Rhizopus oryzae*, *R. stolonifer* and *Botryodiplodia theobromae* in 1999.

Source of variation	Sum of Squares	Df	Mean Square	Computed F-Value
Block	759.17	3	253.06	2.63 ns
A: Vine removal treatment	558.41	2	279.20	2.90 ns
B: Pathogen	2522.17	2	1261.09	13.10 *
C: Cultivar	5481.43	3	1827.14	18.97 *
A x B	907.55	4	226.89	2.36 ns
A x C	509.75	6	84.96	0.88 ns
B x C	940.28	6	156.71	1.63 *
A x B x C	1609.70	12	134.14	1.39 ns
Error	10110.65	105	96.29	
Total	23399.10	143		

MILD = Mean Internal Lesion Dimension

ns = not significant;

* = Significant at 95% confidence level ($P < 0.05$).

Appendix 7. Analysis of variance (ANOVA) for MILD (mm) on roots of sweetpotato cultivars, Yanshu 1, KSP 20, KEMB 10 and KEMB 36 harvested at 16, 22 and 28 weeks after planting and inoculated with the pathogens, *Rhizopus oryzae* and *R. stolonifer* in 1998.

Source of variation	Sum of Squares	Df	Mean Square	Computed F-Value
Block	224.96	3	74.9853	
A: Weeks	16267.80	2	8133.9	135.52*
Error (a)	239.32	6	39.89	
B: Pathogen	6657.84	1	6657.84	113.62 *
A x B	6334.91	2	3167.46	54.06 *
C: Cultivar	18740.80	3	6246.95	106.61 *
A x C	3260.40	6	543.40	9.27 *
B x C	27.86	3	9.29	0.16 ns
A x B x C	710.52	6	118.42	2.02 ns
Error (b)	3691.58	63	58.60	
Total	56156.0	95		

MILD = Mean Internal Lesion Dimension

ns = Not significant

* = Significant at 95% confidence level ($P < 0.05$)

Appendix 8. Analysis of variance (ANOVA) for MILD (mm) on roots of sweetpotato cultivars, Yanshu 1, KSP 20, KEMB 10 and KEMB 36 harvested at 16, 22 and 28 weeks after planting and inoculated with the pathogens, *Rhizopus oryzae* and *R. stolonifer* in 1999

Source of variation	Sum of Squares	Df	Mean Square	Computed F-Value
Block	127.52	2	63.76	
A: Weeks	3954.13	2	1977.07	20.70 *
Error (a)	2382.03	4	95.51	
B: Cultivar	452.594	3	150.86	2.96 *
A x B	81.56	6	13.59	0.27 ns
Error (b)	917.65	18	50.98	
Total	5915.47	35		

MILD = Mean Internal Lesion Dimension

ns = Not significant

* = Significant at 95% confidence level ($P < 0.05$)

Appendix 9. Analysis of variance (ANOVA) for MILD (mm) on roots of sweetpotato cultivars, Yanshu 1, KSP 20, KEMB 10, and KEMB 36 and inoculated with the pathogens *Rhizopus oryzae* and *R. stolonifer* in 1999.

Source of Variation	Sum of Square	Df	Mean Square	Computed F-Value
A: Cultivar	917.529	3	305.843	5.51 *
B: Pathogen	2216.64	1	2216.64	39.97 *
A x B	55.2895	3	18.4298	0.33 ns
Error	887.432	16	55.4645	
Total	4076.89	23		

MILD = Mean Internal Lesion Dimension

ns = not significant;

* = Significant at 95% confidence level ($P < 0.05$)

Appendix 10. Analysis of variance (ANOVA) for MILD (mm) on roots of sweetpotato cultivars, Yanshu 1, KSP 20, KEMB 10, and KEMB 36 and inoculated with the pathogens *Rhizopus oryzae* and *R. stolonifer* in 2000.

Source of Variation	Sum of Square	Df	Mean Square	Computed F-Value
A: Cultivar	1021.56	3	340.519	7.49 *
B: Pathogen	26.1807	1	26.1807	0.58 ns
A x B	478.121	3	159.374	3.51 *
Error	727.26	16	45.4537	
Total	2253.12	23		

MILD = Mean Internal Lesion Dimension

ns = not significant

* = Significant at 95% confidence level ($P < 0.05$)

Appendix 11. Analysis of variance (ANOVA) for MILD (mm) on roots of sweetpotato cultivars, Yanshu 1 and KSP 20 grown in soil at pH 4.6, 5.8 and 6.1 and inoculated with the pathogens, *Botryodiplodia theobromae* and *Rhizopus oryzae* in 1998.

Source of variation	Sum of Squares	Df	Mean Square	Computed F-Value
Block	151.25	3	50.42	
A: Soil pH	102.31	2	51.15	2.16 ns
B: Pathogen	205.10	1	205.10	8.65 *
C: Cultivar	412.54	1	412.54	17.39 *
A x B	215.26	2	107.63	4.54 *
A x C	18.37	2	9.19	0.39 ns
B x C	189.45	1	189.45	7.99 *
A x B x C	1.82	2	0.91	0.04 ns
Error	782.74	33	23.72	
Total	23399.10	143		

MILD = Mean Internal Lesion Dimension

ns = not significant

* = Significant at 95% confidence level ($P < 0.05$).

Appendix 12. Analysis of variance (ANOVA) for MILD (mm) on roots of sweetpotato cultivars, Yanshu 1 and KSP 20 grown in soil at pH 4.6, 5.8 and 6.1 and inoculated with the pathogens, *Botryodiplodia theobromae* and *Rhizopus oryzae* in 1999.

Source of variation	Sum of Squares	Df	Mean Square	Computed F-Value
Block	42.40	3	14.13	
A: Soil pH	87.92	2	43.96	2.53 ns
B: Pathogen	2.23	1	2.23	0.13 ns
C: Cultivar	17.65	1	17.65	1.02 ns
A x B	59.04	2	29.52	1.70 ns
A x C	32.79	2	16.39	0.94 ns
B x C	2.05	1	2.05	0.12 ns
A x B x C	66.34	2	33.17	1.91 ns
Error	572.67	33	17.35	
Total	883.09	47		

MILD = Mean Internal Lesion Dimension;

ns = not significant at 95% confidence level ($P < 0.05$)

Appendix 13. Analysis of variance (ANOVA) of lesion diameter (mm) on root slices of sweetpotato cultivar Yanshu 1 inoculation with the pathogens, *Botryodiplodia theobromae*, *Rhizopus oryzae*, and *R. stolonifer* at different temperatures in 1998.

Source of Variation	Sum of Square	Df	Mean Square	Computed F-Value
A: Temperature	24557.20	6	4092.87	257.96 *
B: Pathogen	8110.55	2	4055.28	255.59 *
A x B	19484.70	12	1623.72	102.34 *
Error	1999.19	126	15.87	
Total	54115.00	146		

* = significant at 95% confidence level (P<0.05).

Appendix 14. Analysis of variance (ANOVA) of lesion diameter (mm) on root slices of sweetpotato cultivar Yanshu 1 inoculation with the pathogens, *Botryodiplodia theobromae*, *Rhizopus oryzae*, and *R. stolonifer* at different temperatures in 1999.

Source of Variation	Sum of Square	Df	Mean Square	Computed F-Value
A: Temperature	20531.40	6	3421.89	601.22 *
B: Pathogen	7353.88	2	3676.94	646.03 *
A x B	18592.00	12	1549.33	272.21 *
Error	717.14	126	5.69	
Total	47194.3	146		

* = significant at 95% confidence level (P<0.05).