Participatory-based development of early bulking cassava varieties for the semi-arid areas of Eastern Kenya

by

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Thesis abstract

Cassava (*Manihot esculenta* Crantz) is an important food security crop in the semi-arid areas of Eastern Kenya. It provides food for more days in a calendar year than any other crop grown. Kenya has relied on varieties bred in other countries and because of this, local breeding methodologies and expertise are lacking. Access to appropriate varieties and adequate planting materials are major limiting factors to cassava production. Farmers grow late bulking landraces that take up to 18 mo to harvest. Efforts to introduce early bulking genotypes from IITA failed because of poor end-use quality. Local cassava breeding is necessary to alleviate the production constraints. Before a local breeding program can be established, farmers' preferences and production constraints must be identified and methodology appropriate to the Kenyan environment must be developed.

The aims of this study were to identify farmer production constraints and preferences, to develop methods appropriate for cassava breeding in the semi-arid areas of Kenya, develop a population segregating for bulking period to estimate genetic variances that would explain the gene effects controlling yield components, and through participatory selection identify varieties that combine early bulking and preferred end-user traits.

PRA tools, focus groups and individual interviews were used to identify production constraints and farmer preferences for cassava varieties. The PRA found that farmers grow 13 landraces in the area and 11 production constraints were identified and prioritised. The four most limiting in the order of importance were drought, lack of planting material, pests and diseases.

Crosses between cassava varieties often do not produce much seed and the seed produced does not germinate well. Germination studies were done with open pollinated seeds to identify conditions favourable for seed germination in Kenya. The highest germination of the seeds was at 36°C. The control seeds had a higher germination percent (77%) compared to the seeds which were pre-heated at 36°C (57%).

Crosses were made between selected IITA and local Kenyan genotypes following the NC II mating design to develop new genotypes which combine early bulking along with other farmer/end-user preferred characteristics. The hybrid progenies were evaluated in a seedling trial and clone genotypes advanced to a clonal trial and performance trial. The clonal trial was destroyed by red spider mites and cassava green mites, and only the

tolerant 225 genotypes were planted in a performance trial that was harvested at 6, 7 and 8 mo after planting. The SCA effects were estimated to be 57% to 75% for most of the traits, except root number, which was mainly controlled by GCA effects (55%). Participatory selection of genotypes that combined early bulking and end-user qualities at the 7 and 8 mo after planting was done by farmers. Thirty genotypes that combined early bulking and end-user qualities were identified and ranked according to their performance in both agronomic and end-use traits using a selection index. A number of selected genotypes yielded more than three times the yield of the best parents, showing strong progress in breeding. Combining the farmers' preference aggregate score and the selection index based on the agronomic data, assisted in the final identification of the best genotypes developed in the breeding process. These results clearly demonstrated that it is possible to breed early bulking varieties with good end-use quality in the semi-arid areas.

Declaration by the candidate

The work reported in this thesis is based on my original work and ideas. It has not been presented for a degree in any other university.

Signed ..... Date 1-12-2006

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Declaration by the university supervisors

This thesis has been submitted for examination with our approval as University of Kwazulu-Natal Supervisors

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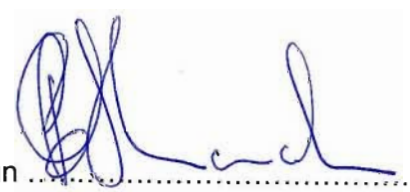

Sign ..... Date 26/4/2007

Dr. Paul Shanahan (Co-supervisor)

Dedication

This work is dedicated to my wife CATHERINE NJERI, my children EDWARD KAMAU,

PATRICIA WANGARI and JULIET WAMBUI, and parents,

NAFTALI KAMAU and the late PERIS WANGARI.

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Abbreviations

ASAL	Arid and semi-arid areas of Eastern Kenya
C	Centigrade
CBS	Cassava brown streak
CBB	Cassava bacteria blight
CIAT	Centro Internacional de Agricultura Tropical
CIP	International Potato Centre
CGIAR	Consultative Group on International Agricultural Research
CGM	Cassava green mites
CNP	Cyanide content
COSCA	Collaborative study of cassava in Africa
CMD	Cassava mosaic disease
CMB	Cassava mealy bug
CSS	Cassava stem scales
DRC	Democratic Republic of Congo.
DM	Dry matter
DMC	Dry matter content
DMY	Dry matter yield
EAAFRO	East Africa Agricultural and Forestry Research Organisation
EARRNET	East African Root Crops Research Network
EMBRAPA	Empresa Brasiliera de Pesquisa Agropecuaria
F_1	First filial generation or the first hybrid generation after fertilisation
FAO	Food and Agricultural Organisation of United Nations
FSR	Farming system research
GCA	General combining ability
HCN	Hydrogen cyanide
HI	Harvest index
IAA	Indole acetic acid
IITA	International Institute of Tropical Agriculture
ITK	Indigenous technical knowledge
KARI	Kenya Agricultural Research Institute
LAI	Leaf area index
MOA	Ministry of Agriculture
NAA	Naphthalene acetic acid
NARS	National agricultural research systems
NC II	North Carolina II mating design
OPS	Open pollinated seeds
PRA	Participatory rural appraisal
PPB	Participatory plant breeding
ppm	Parts per million
®	Registered product
RCNP	Root cyanide content
RTW	Root weight plant $^{-1}$
RTN	Root number plant $^{-1}$
RTY	Root yield ha^{-1}
SCA	Specific combining ability
SHWT	Shoot weight plant^{-1}
sp	Species
sps	Several species

General Introduction

1. Production of cassava

Compared to other root and tuber crops grown in the tropics, cassava is the most widely utilised. It is grown for its starchy roots and its leaves, which are rich in protein (Latham, 1979; Hahn, 1989). In the last three decades, cassava production in the world has grown 2.2% per annum. This rate of increase in production is expected to continue up to 2020. The increase was largely a result of expanded acreage in Africa. In the early 1960s, cassava in Africa was cultivated on more than 5.6 million ha per annum, but by 2000 the area had increased to 10 million ha. During the same period, Africa's production increased from 42% of world production to 54% (Table 1).

Table 1: FAO 2006 cassava production data in million t

	Production years				
Regions	**2001**	**2002**	**2003**	**2004**	**2005**
South America	30	31	30	33	35
Asia	52	51	57	60	55
Africa	100	100	102	107	109
World	184	185	192	203	203

(Source: FAO 2006 Production Data, http://faostat.fao.org/faostat)

Nigeria is the largest cassava producer in Africa, and the world, producing 38 million tons of cassava in 2005 (FAO, 2006). In East Africa, Kenya was rated third in production after Tanzania and Uganda in the period between 1999 and 2005 (Table 2).

Table 2: Cassava production in selected Africa countries in million t

	Year of cassava production						
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Tanzania	7.18	5.76	5.65	6.89	6.89	6.89	7.00
Uganda	4.88	4.97	5.27	5.37	5.27	5.50	5.50
Kenya	0.93	0.95	0.95	0.60	0.42	0.64	0.63
Burundi	0.62	0.66	0.71	0.75	0.75	0.71	0.71
Rwanda	0.32	0.80	0.69	1.03	1.00	0.77	0.78

(Source: FAO 2006 Production Data, http://www.faostat.fao.org/faostat)

Most of the cassava in Kenya is produced in the low-lying areas that benefited from the 1930s' cassava breeding at Amani station in Tanzania, and later from the East African community research work up to the seventies. According to the provincial annual reports of the Ministry of Agriculture, the semi-arid areas produced 30% of the cassava in Kenya (MOA, 1999). At the farm level, the national average productivity for Kenya is 5 t ha^{-1} (MOA, 2004), which is among the lowest in Africa compared to 11 t ha^{-1} in Nigeria and

Ghana (Nweke *et al.,* 1994; FAO, 2006). The average productivity in the world is estimated at 10 t ha^{-1}. Farmers in Asia and Latin America produce on average 11 t ha^{-1} while in Africa the average is 8.4 t ha^{-1} (FAO, 2006). The low average productivity in Africa is attributed to droughts and lack of appropriate varieties for the semi-arid areas in many countries as well as lack of functional breeding programmes (Nweke *et al.,* 2002). In order to raise the national average cassava yield in Kenya, there is a need to establish breeding programmes based within the production zones. Such programmes would be responsible for developing and releasing cassava varieties with end-user preferences, which would be expected to spur the production and establishment of processing plants.

2. Cassava in modern markets

Considering cassava as a poor man's crop is a misconception because it is a source of income to many and a raw material for the feed, adhesives, starch and other industries (Nweke, 1995). A collaborative study in Africa (COSCA) found that cassava was more of a cash crop than a subsistence crop (Nweke, 1996). Processed and packaged cassava products such as flour, gari[1] and starch are penetrating markets outside the production regions (Hershey and Henry, 1997). Thailand exports dried cassava chips to Europe for animal feed, amounting to 80% of products processed from cassava in that country (Munyikwa, 1997; FAO, 2000). Kenya has a starch factory (Tapioca Limited) at Mazeras, in the coastal region that operates below capacity because of a shortage of cassava roots. It processes 30 t of cassava roots per day into flour, starch and modified starch, which are sold to local industries (Ferris *et al.,* 2002). However, the factory cannot satisfy the local requirement of 113 000 t of starch per year (Table 3).

Table 3: Potential uses of cassava starch in Kenya

Industry category	**Quantity (metric t y^{-1})**	**Value (Kshs '000)**
Food	1,668.8	58,408
Brewery	14,000	490,000
Pharmaceuticals	20	700
Textiles	50	1,750
Packaging	72,815	2,548,525
Paper	800	28,000
Glues/Adhesives	24,012	840,420
Total	**113,365.8**	**3,967,803**

(Source: Kariuki et al., 2002)

The local landraces grown by farmers are late bulking because they have not been improved and have low yield potentials, which cannot support a starch factory. If Kenya

[1] Gari –fermented cassava flour boiled into a paste

is to satisfy the local market and enter the international market, improved varieties are a prerequisite. These varieties should be developed within the production region where they will be grown. This would enable them to express their maximum yield potential, which would translate into higher earnings for the farmers.

3. Importance of cassava in the semi-arid areas

According to El-Sharkawy *et al.* (1993), cassava produces more root yield than any other food crop in the semi-arid areas. Under drought conditions and in low input agriculture, cassava produces reasonable root and leaf yields (Romanoff and Lynam, 1992). It also has the ability to store its roots underground for over 24 mo, allowing for harvesting on demand, which adds to the crop's importance in food security.

Kenya is 80% arid and semi-arid and more than half of the Kenyan population lives in these areas. In the semi-arid areas crop failure occurs in three or more years in a five year cycle (Mavua and Kusewa, 1989). Cassava is the only crop that the communities rely on when other crops fail. The roots and leaves are utilised throughout the year. However, most of the roots are consumed during the long dry period from June to December, when there are no others crops available. In the middle of December, when the green grain legumes start coming off the farms, cassava is harvested and sold to raise school fees for the children. So cassava is also very important as a cash crop in the semi-arid communities.

4. History of variety improvement in Kenya

Cassava was introduced into Kenya in the nineteenth century by Arab and Portuguese traders (Ross, 1975). It was transported to the interior by the Arab and European settlers for their farm workers. By 1900, cassava was a food security crop along the Kenyan coast and around Nairobi (Herlehy, 1984). In spite of the long history in the country, Kenya has relied on varieties bred in other countries. For instance, from the 1920s to the Second World War, the Amani breeding programme in then Tanganyika (Tanzania), produced varieties grown in the low and medium altitude high rainfall areas in coastal and western Kenya (Storey and Nichols, 1938). Because of the narrow adaptation of cassava varieties (Cock, 1987; Lawson, 1988), the Amani varieties were not well adapted to the medium to high altitude low rainfall regions. After the war, the breeding work at Amani station continued to benefit the targeted production areas (Mailu, 1997). In the 1970s, the Ministry of Agriculture started the first adaptation trials of cassava in the semi-arid areas of Kenya with genotypes bred in other countries. This was followed in the 1980s by organised local germplasm collections. Introductions of tissue culture

germplasm from IITA and characterisation of the germplasm was also started (Shakoor, *et al.*, 1983; Kiarie *et al.,* 1991). From this programme, two varieties 820001 and 880058 of local origin, and one, 880061, from IITA germplasm, were released. Unfortunately, the two local varieties were late bulking, and roots of 880061 were waxy instead of the preferred "mealy" (floury) roots (Kiarie *et al.*, 1991). From 1994 to 2001, open-pollinated seeds were introduced from IITA. This germplasm was assessed for early bulking, tolerance to cassava mosaic diseases and general adaptation. Superior genotypes identified were multiplied and tested on the farmers' fields in different ecological zones. Palatability tests were done with the farmers and, despite being early bulking, these varieties were also rejected by farmers because the roots were waxy and not mealy (Kamau *et al.,* 1998b). These materials were conserved at KARI-Katumani as a source of early bulking genes in the cassava improvement programme.

5. Need for a local breeding programme

Due to the failure of the IITA introductions from the 1980s to 2001, it is clearly important for Kenya to develop its own cassava breeding research capacity. For the semi-arid regions there is a need for locally developed, early bulking, disease-resistant cultivars, with acceptable storage root quality. In order to improve the bulking period of the landraces, without changing the preferred root qualities, it is crucial that the local landraces are crossed with the early material such as the IITA germplasm. Farmers' preferences need to be taken into consideration when identifying early bulking genotypes, which when planted in the October/November short rains, would produce edible roots by June - August of the following year. The period from June to November is characterised by serious food shortages and it is particularly women, children and the aged who become malnourished and vulnerable to diseases. During this period, communities are reliant on food rations from the government famine relief programme, which is often inadequate. Therefore, a functional breeding programme for cassava, that would breed early bulking varieties for the semi-arid areas, would go along way in reducing human suffering and relieving the national economy from the burden of importing relief food.

6. Research approach

Plant breeders have in the past often failed to address the needs of the farmers and consumers. This has in many cases resulted in communities not adopting varieties developed for them. Therefore a participatory rural appraisal was used in this study to identify and prioritise researchable production constraints in the semi-arid areas. Furthermore farmers' variety preferences were evaluated.

Because of the historical absence of a functional breeding programme in Kenya, there is a need to establish locally developed breeding methodologies, especially for the semi-arid areas. These include appropriate methods for: controlled hand-pollination, uniform seed germination and rapid vegetative propagation.

Traditionally cassava breeders have tended to use seed from uncontrolled polycross mating designs. The disadvantage of this method is that the breeder has no information on the paternal parent. In this study, controlled crosses between selected parents were made. The parents were crossed in a North Carolina (NC) II design mating scheme. Progenies of these crosses were evaluated in a seedling trial and two clonal trials. Gene effects on yield components were studied. Participatory selection was used to select genotypes that combined early root bulking and end-user root qualities.

7. Research objectives and structure of thesis

The research objectives were to:

1. Identify farmers' perceptions of cassava production constraints and farmers' variety preferences in the semi-arid areas of Eastern Kenya;
2. Develop appropriate breeding methodologies for cassava in these areas;
3. Study the inheritance of the root yield related traits; and
4. Identify early bulking genotypes with the desired root qualities.

This thesis is divided into the following chapters:

1. Literature review;
2. Farmers' perceptions of cassava production constraints and their preferences for varieties that require research intervention in the semi-arid areas of Eastern Kenya;
3. Combining ability among cassava genotypes for yield and secondary traits;
4. Farmers' participatory selection of early bulking cassava varieties;
5. Overview and the way forward.

Research on the development of specific breeding techniques, such as pollination method, seed germination and vegetative propagation has been included as a research note as an appendix.

This thesis is presented in a composite form, with the Chapters 2 to 4 intended for publication. For this reason, there may be overlapping of content and references.

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Chapter 1: Literature Review

1.1 Introduction

Cassava (*Manihot esculenta* Crantz) was introduced into Africa from South America in the sixteenth century by the Portuguese settlers. It has since spread throughout sub-Saharan Africa, becoming one of the dominant starchy staples in the diet of the people. Initially the crop was grown predominantly in the high rainfall lowlands. Over time, the crop has spread to the high altitude and semi-arid areas. Africa produces approximately 203 million t of cassava annually. It is a major source of calories for roughly two out of every five Africans. This translates into an average of more than 200 calories per day for more than 200 million people (FAO, 2006). In terms of calories consumed in Africa, cassava is second only to maize. It is consumed with a sauce made with ingredients rich in protein, vitamins, and minerals.

In the Congo, Kenya, Madagascar, Sierra Leone, Tanzania, Uganda, and Zambia, cassava leaves, which are rich in protein, vitamins, and minerals (Latham, 1979) are important vegetables (Fresco, 1986; Haggblade and Zulu, 2003). Cassava is the most important crop in the Democratic Republic of Congo. In the coastal region of West Africa, from Cameroon to the Ivory Coast, cassava is as important as yam (*Dioscorea alata*). Further west, cassava is second to rice. In the eastern and southern African region, maize is the dominant staple food that plays an important role as a food security crop (Nweke *et al*, 2002).

The colonial governments in these countries forced indigenous farmers to plant cassava as a famine relief measure and subsidized maize grown by settler farmers (Jones, 1959). This made cassava more expensive than maize. That policy has stigmatised cassava in the minds of many African farmers as a colonial crop (Marter, 1978). These old policies have tended to marginalize cassava in food policy debates because it is burdened with the stigma of being an inferior food when compared with other crops such as maize, rice and wheat (Nweke *et al,* 2002).

However, the role played by cassava in the diet of many people in the semi-arid areas is critical. Prices of farm inputs and implements have increased to levels that subsistence farmers can barely afford. Consequently, food production has been falling due to unaffordable inputs and increasing labour costs. The population increase in the high rainfall areas has forced people to migrate into the more marginal agricultural zones in

the semi-arid areas. Rising population densities in the marginal areas have reduced the buffering capacity of subsistence production in areas of inadequate rainfall. Food production in these marginal areas is inherently risky, as it is essentially dependent on erratic rainfall (Nweke *et al*, 1994).

Cassava has the ability to survive and give reasonable root and leaf yields on relatively marginal soils and under erratic rainfall conditions, compared to other crops (Romanoff and Lynam, 1992). In addition, the ability to store roots underground for long periods helps maintain a continuous food supply throughout the year, making cassava a basic component of the farming system in the semi-arid areas (Nweke *et al*, 1994).

Famine rarely occurs in areas where appropriate varieties of cassava are widely grown (Nweke *et al*, 1994). Unfortunately, many countries, such as Kenya, have in the past not invested in the improvement of cassava in the semi-arid areas. Farmers grow late bulking, local landraces which were introduced by the Arab traders. The landraces have good root qualities (mealy texture, taste, consistency, high dry matter and low cyanide), but are susceptible to cassava diseases and pests. Farmers rarely process cassava in the semi-arid areas of Kenya. The fresh roots are chewed raw, roasted, boiled or stewed with vegetables, meat, legumes and cereals after peeling.

1.2 Botany

Cassava (*M. esculenta* Crantz) belongs to the Fruticosae section of an unknown cultigen in the wild of the family Euphorbiaceae (Jennings, 1976a). *Manihot esculenta* Crantz is the only cultivated species of the *Manihot* genus that has 98 species already described (Rogers and Appan, 1973). It is thought to have evolved from one or more species complexes in Mexico and Central America (Rogers, 1965; Rogers and Appan, 1973). Wild forms of *M. esculenta,* which are likely to be the progenitors of cassava, have been identified in South America (Allem, 1987). However, Olsen and Schaal (1999) studied wild *Manihot* species from the southern border of the Amazonian basin and concluded that cultivated or domesticated cassava was not from several progenitor species as previously proposed. Many of the wild species have, in fact, been shown to be distantly related to cassava (Schaal *et al.*, 1994, Roa *et al.*, 1997). However, it is still speculated that the cassava may have come from hybridization of *Manihot* species (Fregene *et al.*, 1994). Olsen and Schaal (1999) recently examined the origin and found that cassava does not share haplotypes with *Manihot pruinosa*, a closely related and potentially hybridising specie. Genetic variation within the crop is a subset of that found in *M.*

flabellifolia (Olsen and Schaal, 1999) and cassava is interfertile with subspecies *M. flabellifolia* (Roa *et al.*, 1997).

Cassava is diploid with 2n=36 chromosomes (Magoon, 1969; Jos, 1978). Jennings (1963) considered the chromosome number of other genera in the Euphorbiaceae, together with the evidence from the meiotic studies, and suggested that cassava is of allopolyploid origin. If this theory of origin is true, it is likely that cassava originated from some wild *Manihot* form with 18 somatic chromosomes. Out of 27 species of *Manihot* studied by Nassar (1978), all had 2n=36 chromosomes. Occasionally, natural hybridisation results in triploids (2n=3x=54) and tetraploids (2n=4x=72). Triploids and tetraploids differ from diploid plants in vigour, leaf shape and size (Dixon *et al.*, 1994). The allopolyploid theory has not been proven yet, and lack of wild species having chromosome numbers 2n=18 does not support it.

1.2.1 The cassava plant

Cassava is a woody shrub that grows 1 to 3 m tall. It is grown between 30° north and south of the equator from sea level to an altitude of 2000 m in areas that receive from 200 to over 5000 mm of annual rainfall with mean temperatures above 18°C (Cock et al, 1985, Hahn and Keyser, 1985; El-Sharkawy and Cock, 1987). Environmental factors such as temperature, rainfall, solar radiation and soil conditions have a strong influence on the physiological processes of a cassava plant and ultimately its root yield (Cock, 1983). Cassava grows well in warm moist climates, where mean temperatures range from 25 - 34°C (Nweke *et al.*, 1994). The optimum temperature for photosynthesis in cassava is between 25° and 30°C. Cassava photosynthetic capacity is C_3-equivalent at low temperatures and C_4-equivalent at higher temperatures (El-Sharkawy, 1993).

The shoot and the extensive fibrous root system are developed in the first 3 mo (Osiru *et al.*, 1997). In many genotypes, the shoot has strong apical dominance, which suppresses development of side shoots. Subsequently, the apical dominance breaks and two auxiliary buds below the apex develop into branches. The pith of stems is large, woody and brittle. Branching in cassava is genotype specific. The timing of branching varies from one genotype to the other while some do not branch. Those genotypes that branch after 6 mo are associated with early bulking in warm humid areas (Tan and Cock, 1979). Stem colour varies from very light grey with a silvery aspect due to the granular, waxy surface to yellow, orange, or brown due to varying amounts of anthocyanins. The pigmentation on the stems provides a stable characteristic for differentiating genotypes.

The shoots are topped by palmate, dark green or purplish leaves. The fully developed vegetative leaves have five to nine lobes, but the leaves found in association with the inflorescence are almost invariably reduced in number of lobes. Cassava leaf size determines the photosynthetic surface when other necessary factors are not limiting. However, cassava leaf size depends on the fertility of the soil and the growing temperature. Under very high fertility, especially nitrogen, cassava tends to produce excessive vegetation at the expense of tuber formation (Nweke *et al.*, 1994). The leaves grow larger at temperatures above 24°C. Leaf life varies between genotypes and environmental conditions (Irikura *et al.*, 1979).

The leaf area index (LAI) gives an indication of the photosynthetic area of a genotype. The LAI in cassava increases slowly in the first 3 mo of growth if conditions are near optimum (El-Sharkawy *et al.*, 1992; Osiru *et al.*, 1997; Ekanayake, 1996). The optimum LAI for a cassava plant is between 3 and 3.5 (Irikura *et al.*, 1979). The total dry matter yield in cassava is positively correlated with the LAI over the whole growing period (Webster and Wilson, 1980).

1.2.2 Flowering

Cassava is a monoecious plant with both male and female flowers on the same inflorescence. Both flowers have five sepals and no petals (Rogers, 1965). Flowering in cassava depends on the genotype and time to flowering varies from 6 to 18 mo after planting (Jennings and Iglesias, 2002). The first flowers, which arise before 6 mo after planting, are rarely receptive (Hahn *et al.*, 1973; Kawano, 1980). Flowering is influenced by photoperiod and temperature. Genotypes that do not flower in low altitudes flower in higher and cooler grounds (IITA, 1982). North of the equator, flowering starts in July to January and January to July in the southern hemisphere (Hahn *et al.*, 1979). According to Veltkamp (1985) long days hasten early flower initiation while short days and cooler temperatures delay flowering, but enhance good flower development, pollination and seed development when soil moisture is not limiting. According to Indira *et al.* (1977), growth promoters like indoleacetic acid (IAA), naphthalene acetic acid (NAA) and ascorbic acid promote flowering when sprayed on the leaves.

The male flowers are about half the size of the female flowers and have ten stamens arranged in two rows (Ekanayake *et al.*, 1997). The female flowers are at the bottom and the males above them on the inflorescence. The pollen grains are large, sticky and natural pollination is mainly done by bees and wasps (Cock *et al*, 1985). The stigma is sticky and secretes a sugary solution on the day the female flower opens. The secretion

is used to identify the receptive flowers that will open that day if hand pollination is to be done (Hahn *et al.*, 1979).

Female flowers open 7 to 8 d earlier than the males, a natural mechanism that maintains cross pollination (Purseglove, 1968). Nevertheless, self pollination still occurs between flowers in different inflorescences (Kawano *et al.*, 1978a; Bryne, 1984; Hershey and Jennings, 1992). Controlled pollination by hand is easy and does not require emasculation. However, it is an expensive venture because approximately 30 to 40% of the pollinated flowers fail to develop (Jennings, 1972; Kawano *et al*, 1978b). The advantage of controlled pollination is that both parents are known and elaborate studies can be done, as opposed to the open pollination system where the pollen parents are not known. After fertilisation, the ovaries develop into a trilocular fruit capsule. In each locule, only one seed develops (CIAT, 2004). The numbers of seeds that develop from a fertilised ovary is genotype specific and varies from one to three. Fertilised fruits mature in 90 d and explosively dehisce releasing the seeds (Rogers and Appan, 1973). Cross-pollination allows sexual recombination and gene exchange from different backgrounds. The new recombinants are potentially broader in adaptation and agronomic characteristics than the parents (Buerno, 1987; Sambatti *et al.*, 2001).

1.2.3 Cassava seed germination

Botanical seeds of cassava have physiological dormancy that is common in *Manihot* species. They germinate with difficulty under field conditions (Nartey, 1978; Ellis and Roberts, 1979; Iglesias *et al.,* 1994; Elias *et al.,* 2000). Information concerning the environmental conditions required for fresh cassava seed to germinate is meagre. According to Nartey (1978) cassava seeds germinate in the dark and scarification at the micropyle may slightly improve the germination percentage, but it remains sporadic. Alternating cold and heat treatment or acid treatments used to break seed dormancy in other crops have no effects on cassava seeds (Evans, 1972). Research on the optimal temperature for germinating cassava seeds (Mumford and Grout, 1978; Ellis and Roberts, 1979) is confusing. Works by Ellis *et al.* (1982) recommended a mean temperature of 38°C or alternating 38°C for 16 h and 30°C for 8 h applied for a minimum of 21 d. In natural habitats cassava seeds germinate after burning. Basing his work on natural habitat conditions, Pujol *et al.* (2002) found that seeds heated at 60°C for 7 d germinated better at 36°C.

At CIAT in Colombia, fresh cassava seeds are germinated in high temperature and humidity in greenhouses. However, CIAT recommends a post harvest treatment to break

dormancy by storing the seeds at room temperature for 2 to 3 mo in a store free of pests and pathogens. At IITA, the seeds are planted directly in the field because the soil temperatures of 30-35°C and soil moisture content at Ibadan, Nigeria are optimum for cassava seed germination (CIAT, 2004).

1.2.4 Root cyanide

There are no cassava varieties that are entirely cyanide free. Farmers classify cassava as sweet when cyanide content is low and it is considered safe to use without elaborate processing, and bitter when cyanide content is high and processing is necessary (Bokanga, 1994). This classification is not scientific, although bitterness and high cyanogenic potential often go hand in hand. However, there are some sweet cassava roots that have high cyanide content and bitter ones with low cyanide (Bokanga *et al.*, 1994). Cyanide poisoning has been reported in areas where minimum processing is practiced.

1.2.5 Cassava physiology

Cassava is a short day plant with a critical photoperiod of 12 to 13 h (Hunt *et al.*, 1977). Short days promote storage root development while long days delay their development (Veltkamp, 1985). Within the cassava germplasm, there are genotypes that are not sensitive to photoperiod (Veltkamp, 1985). Initially, the storage roots of cassava are physiologically inactive. They start to enlarge when the supply of assimilates exceeds the requirements of stem and leaf sink (Tan and Cock, 1979). However, at the seedling stage, starch deposition in the cells of taproot and fibrous roots cells starts in the fourth and fifth week, respectively after planting (Tetteh *et al.*, 1997). The number of storage roots that develop are genotype specific varying from four to nine but can increase up to 20 roots under good management (Cock, 1985; IITA, 1982). The number and weight of storage roots is affected by moisture stress, low soil fertility and water logging (Ekanayake *et al.,* 1998).

Cassava root development has not been studied as much as tuber development in potato (*Solanum tuberosum*). However, tuberization and root development in each crop takes place under short day conditions (Williams, 1974; Jackson and Pratt, 1999; Viola *et al.*, 2001). High nitrogen in the soil promotes vigorous foliage growth and fewer tubers (Ewing and Struik, 1992). According to Jackson and Pratt (1999), the growth hormones that regulate tuberization in potato have not been identified. Nevertheless, high levels of gibberellin (GA) inhibit tuberization in potato (Jackson and Pratt, 1996). In the early stages of storage roots development in cassava, there are higher levels of abscisic acid

in young storage roots than in primary roots of the same plant. The abscisic acid is suspected to be responsible for the growth of storage roots by enhancing cell division and enlargement (Melis, 1984).

1.3 Agronomy and propagation of cassava

Cassava is grown on a wide range of soil types, but yields well on friable soils. Land must be well prepared before planting (IITA, 1982). Planting is done after the first well-defined rains at the beginning of the season. Depending on the production systems practiced by farmers, the plant population density varies from 6000 to 20 000 plants ha^{-1} (Enyi, 1972; Toro and Atlee, 1985; Keating *et al.*, 1988). The commercial spacing for cassava production is 1 m (within) x 1 m (between rows). Stakes (cuttings that are planted) are either planted horizontally, vertically, or inclined, on moulds, ridges or flat ground. Those planted horizontally are buried 5 to 10 cm below the soil surface. The stakes planted in vertical or inclined positions are covered half to two thirds of their length with soil (Cock *et al.*, 1985).

Cassava all over the world is commonly grown in subsistence agriculture. It is intercropped with cereals, grain legumes, and fruits (Ezumah and Lawson, 1990; Mason and Leihner, 1988). Significant production occurs in single crop systems too. Farmers rarely use fertiliser on cassava. In most cases it is planted in exhausted soils. Cassava is able to produce its potential total biomass in poor soils better than other food crops (Romanoff and Lynam, 1992). The crop forms mycorrhizai fungal associations with *Glomus mossea* in the roots, which enables it to access fixed nitrogen and increase efficiency of phosphorous uptake (CIAT, 1980; Hahn *et al.*, 1981).

Sexual cassava seeds are not used for cassava production. They are only used in the breeding programmes (Henry and Iglesias, 1993). There are cases where farmers have selected volunteer cassava plants, which germinate from true seeds. This increases genetic diversity on the farms and is one way to increase the number of landraces. The crop is mainly propagated from vegetative stakes cut from stems that are 8 to 18 mo old (Lozano *et al.*, 1977). Younger stems have less food reserves while stems older than 18 mo have lignified tissues with fewer food reserves that cannot support a young developing plant (Toro *et al.*, 1976). On average one cassava plant produces 10 planting stakes per year.

Rapid multiplication techniques developed at IITA and CIAT are well documented (Lozano *et al.*, 1977; Otoo, 1994). The techniques were developed to increase the

number of stakes cut from one stem. They are, however, highly labour intensive, expensive and require individual breeding programmes to adapt the techniques to the local condition and available resources (Cock, 1985).

1.4 Production constraints

Cassava production constraints include the long growing cycle, inadequate planting materials, lack of appropriate, improved varieties, post harvest deterioration, abiotic and biotic stresses and cyanide content. Eliminating these constraints could reduce production costs increasing productivity and profitability of cassava in the food, feed and industrial raw materials. Late bulking, associated with the long growth cycle, is a major constraint to cassava production. It has been identified as one of the important reasons for farmers in Africa abandoning varieties (Nweke *et al*, 1994). Post harvest deterioration is common in the production areas where processing machines are not available (Bokanga, 1994).

Cassava propagation material is often a limiting factor to production. It is worse in the semi-arid areas where most of the cassava is harvested during the dry months of May to December, 16 mo after planting. The stems are left in the field to dry. At the beginning of the rainy season, there is a serious shortage of planting materials. Farmers move from one neighbour to another looking for planting materials. This means that farmers generally plant any variety they come across (Lukombo *et al.*, 2002). When available, stakes are bulky and heavy to carry. To plant one hectare, a farmer would require a truck to transport one ton of planting materials while a maize farmer would need only 20 kg of seed (Porto and Asiedu, 1993).

Abiotic stresses that constrain cassava production include water stress, water logging conditions, cold temperature, rocky or hard soils. Although cassava is tolerant to water stress, growth and development are slowed during stress periods. Drought is the most limiting constraint in the semi-arid areas and the situation is worsened by lack of improved germplasm. The local landraces develop slowly, attaining reasonable height after the second rainy season. During the early growth period cassava experiences lengthy dry periods ranging from 3 to 6 mo and many plants dry out. This results in low plant populations, which affects the final root yield. Water logged soils, with poor aeration, prevent proper root development, induce root rots and can cause the plant to die. Likewise, in hard rocky soils, roots do not penetrate well and storage roots do not develop properly. Cool temperatures, below 20°C, also slow down cassava growth and development (IITA, 1982).

Biotic stresses include cassava diseases and pests. The common diseases are cassava mosaic virus disease (CMD), brown streak disease (CBS), bacteria blight disease (CBB), and root rots. Cassava mosaic virus disease occurs in all the growing areas in Africa (Legg, 1999; Otim-Nape *et al.,* 2000). According to Harrison *et al.* (1997), CMD is caused by a number of viruses that include, the East African mosaic virus, the African mosaic virus and other variants such as the Uganda variant (Dixon *et al.,* 1992). Brown streak virus disease is found along the East African coast. It causes spotted root rot and no resistant varieties have been developed (Hillocks, 2000). Bacteria blight disease (CBB) is common in the wet and humid areas stretching from western Kenya through the southern Africa countries to West Africa. The disease is also found in South America and Asia. Root rots caused by *Phytopthora* sp. and *Diplodia* sp. are minor diseases found mainly in the more humid areas (Hershey and Jennings, 1992). Depending on the time of infection by any one or more diseases, yield losses can be as high as 95% (Storey and Nichols, 1938; Brian and Johns, 1940; Legg, 1999; Hillocks, 2000).

Important pests of cassava are the green mites (CGM) (*Mononychellus tanajoa),* mealy bugs (CMB) *Phenacoccus manihoti* (Hahn and Williams, 1973) and the stem scales (CSS) *Aonidomytilus albus* (Swaine, 1950). The CGM and CMB are native to South America and were introduced into Africa at various times through importation of cassava stakes (IITA, 1992). The CGM attacks growing young cassava leaves sucking out the fluid content of individual cells on the leaves. The leaves become mottled and deformed while the shoot stops growing and eventually dies. The CMB attacks the growing shoot tip sucking nutrients and retarding further growth. The effects of the pests are reduced photosynthetic area and storage root development is affected, resulting in reduced yields (IITA, 1996). The CSS attacks the dormant buds along the stems sucking nutrients from the plant. Heavy infection causes die back of the growing shoots and the plants may even die during the dry periods.

Yield losses associated with these pests are high. For instance, CGM and CMB are estimated to be responsible for 8 - 88% yield losses, while CSS causes 4 - 19% (Bellotti *et al.*, 1985; Larbi *et al.*, 1998). Other pests found only in South America include whiteflies (*Aleurotrachelus socialis*) and thrips (*Frankliniella williamsi*). Yield losses due to these two pests are estimated at 4 - 79% and 6 - 28%, respectively, depending on the length of attack and the susceptibility of the variety (Bellotti *et al.*, 1985). The hornworms (*Erinnyis ello and E. alope*), also South American pests, are serious pests that could

cause 18% yield loss in a single attack, while losses caused by stem borers (*Chilomina clarkei*) may be as high as 56% when heavy breakage of stems and branches occurs. In Asia, mites are the most serious pests, and cause yield losses there similar to those recorded in Africa (Bellotti *et al.*, 1985).

Since the early 1990s, the CGM and CMB have been controlled by biological agents, namely *Typhlodromalus aripo* and *Epidinicarsis lopezi* introduced from South America. However, in the drier areas, *T. aripo* does not establish well and development of resistant varieties is required. The sporadic CSS and RSM have not received much attention in breeding and farmers are advised to control them with chemicals such as white oil and systemic chemicals (acaricides) (Bellotti *et al.*, 1985).

1.5 Cassava breeding

1.5.1 History of cassava breeding

Cassava improvement in the world started at different dates in different continents and countries. In Asia and Africa cassava improvement was started around the same time. It was motivated by the role cassava played as a food security crop and as a raw material for feed and starch industries in Europe and to strengthen the economies of the cassava producing countries (Lynam, 1987; Hershey *et al.*, 2001). Interspecific crosses between cassava and its wild relatives were started in Java, before 1934 (Koch, 1934), and subsequently at Alatroa Agricultural Research Station in Madagascar (Cours *et al.*, 1997) and at the Amani Research Station in Tanganyika (Storey, 1936). In South America, Brazil's breeding programme had developed improved varieties such as Aipin Valenca and Macaxeira Aipin by the 1930s. The early breeding programmes aimed at improving the yield potential and disease and pest resistance in the lowland high rainfall areas (Jennings, 1957). The local landraces were crossed with introduced germplasm and wild relatives. Seeds from these wide crosses were evaluated and sent out to other national programmes within and across the continents (Jennings, 1976a).

However, research at the time was limited to what the governments of the day could do without international coordination. However, in 1970, CIAT and IITA were established in Colombia and Nigeria, respectively, with the mandate to coordinate cassava research internationally (CIAT, 1973; Hahn *et al.*, 1979). Through the efforts to characterise the core germplasm, CIAT and IITA started research into early bulking and resistance to important diseases and pests to enhance the germplasm that was to be used by national breeding programmes to improve the local landraces (CIAT, 1972; Kawano *et*

al., 1978a; Hershey and Jennings, 1992; Kawano, 2003). In an effort to breed for high yielding cassava to increase productivity, CIAT developed a model of an ideotype cassava plant based on Donald's (1968) wheat ideotype (Cock *et al.,* 1979). The ideotype cassava plant was expected to have large erect leaves, high harvest index and either branch 6 mo after planting or not at all, according to Cock *et al.* (1979). Its storage roots were supposed to be closely arranged cylindrical or cylindrical-conical shape and be attached to the stem by a short thick peduncle and be close to the soil surface for ease of harvesting (Cock *et al.*, 1979). High branching with two branches at each level is associated with high root yield and earliness in cassava (IITA, 1980; Veltkamp, 1985). At IITA, cassava breeding was started in 1971 continuing the work that had begun at Amani station in the 1930s. IITA imported large quantities of germplasm from Brazil (Hahn *et al.,* 1977; Dixon *et al.*, 1994; Otoo *et al.*, 1994).

Kenya is one of the East African countries that benefited from the early breeding work of Amani station (Jennings, 1976b). After the station was closed in 1956, the East African community took over the coordination of research for the lowland ecologies in Kenya, Tanzania and Uganda until 1977 (Bock and Guthrie, 1976). Through these efforts, a number of varieties were released that included Kibandameno and 46106/27 for the coast region and Mkezumbe, F100, 504321/6 and 50284/23 for the western region (Mailu, 1997).

Cassava research in the semi-arid areas of Kenya started with agronomic trials in the late seventies (Seif and Chogoo, 1976; KARI-Katumani, 1978). This work was followed in the 1980s, with organised local germplasm collection and introductions from IITA in the form of tissue cultures (Shakoor *et al.*, 1987). From these efforts, two varieties 820001 and 820058 from the local germplasm were released on the basis of tolerance to cassava mosaic (CMD) and preferred root qualities (KARI-Katumani, 1978). A third variety, 880061, from the IITA germplasm was released for its resistance to CMD and high root yield (Kiarie *et al.*, 1991). More introductions of open pollinated seed populations from IITA continued in the 1990s to 2001 of which early bulking, and high yielding genotypes that were resistant to CMD were identified (Kamau *et al.*, 1998b; Githunguri and Migwa, 2003).

1.5.2 Breeding for disease and pest resistance

Several diseases and pests of cassava were mentioned among the constraints that limit its production. Significant progress has been made in breeding for pest and disease resistance (IITA, 1994; 1995; Fokunang, 1995; Nukenine, 1995), but a lot more needs to

be done. Breeding for resistance to cassava mosaic virus disease (CMD) in Africa started in the 1930s at Amani station (Storey and Nichols, 1938). The resistance to this disease was identified at IITA in the 1980s from the progenies of the early interspecific crosses done at Amani station in the 1970s (Hahn, 1978; Dixon *et al.*, 1994; Dixon *et al.*, 1995). From the 1930s to the 1960s resistance to CMD was suspected to be controlled by quantitative genes (Jennings, 1970) and in the seventies it was thought to be influenced by recessive genes (Hahn, 1978). However, the resistance identified in landraces with high levels of resistance in Africa was influenced by dominant major genes (Akano *et al.,* 2002).

Bacterial blight disease (CBB) is common in the warm humid areas of S. America, Africa and Asia (Lozano *et al.*, 1984). It is caused by two pathogens *Xanthomonas manihotis* and *X. campestris,* which are spread by raindrop splashes, infected planting materials and contaminated farm equipment. Genetic sources of resistance to CBB exist within the crop germplasm, but no resistant varieties have yet been identified (Lozano *et al.*, 1984). Brown streak virus disease is important at the coast of East Africa. A lot of work has gone into breeding for resistance but no resistant variety has been identified (Hillocks, 2000). Other root rot diseases caused by *Phytophthora* sp. and *Diplodia* sp. (Hershey and Jennings, 1992) are minor diseases for humid areas. Breeding for resistance to these diseases is being conducted in the specific production areas where they are important.

Important pests in sub-Sahara Africa are cassava green mites (CGM), *Mononychellus tanajoa;* mealy bugs (CMB), *Phenacoccus manihot* (Bellotti *et al.*, 1987; Hahn and Williams, 1973); and stem scales (CSS), *Aonidomytilus albus* (Swaine, 1950). Breeding for resistance to these pests has not been very successful (Hershey and Jennings, 1992), despite their importance in limiting cassava production in the semi-arid areas. A few genotypes tolerant to mealy bugs have been identified (CIAT, 1991). Following the difficulties involved in breeding for pest resistance, entomologists, spearheaded by IITA resorted to biological control measures in the 1980s. In the late 1980s and early 1990s biological control agents *Typhlodromalus aripo* for CGM and *Epidinicarsis lopezi* for CMB identified from South America, were released in all the African countries to control these two pests (Kariuki *et al.*, 1990; Herren and Neuenschwander, 1991). However, *T. aripo* did not establish well in the semi-arid areas. Therefore, breeding for resistance to CGM should be encouraged.

1.5.3 Breeding for root yield

Much progress has been made to improve root yield, root quality and several agronomic characteristics (Dixon *et al.,* 1995; Mahungu *et al.,* 1996). Root quality characteristics considered in breeding schemes include cyanide content, starch quality, protein content, dry matter content (DMC) (Mahungu, 1987) and palatability (Cock, 1985). Root yield potential as high as 70 t ha^{-1} of fresh roots or 27 t ha^{-1} of dry matter have been recorded under experimental conditions (Cock, 1977; El-Sharkawy, 1993). However, the high root yields at research stations have not been realised at the farmers' fields. More efforts to improve root yield and early bulking including studies on yield related traits are still required, especially for the marginal areas. A few studies conducted in the humid areas suggest that the secondary traits are quantitatively inherited (Table 4) and strongly affected by the environment (Austin, 1989; Zhuang *et al.,* 1997). Little is known about the number of genes or the effects of their interactions in defining the phenotypes (Tanksley *et al.,* 1989). In qualitatively inherited traits, breeders have problems finding sources of desirable alleles in cassava. For that reason, only a few articles have been published on the inheritance of these traits (Ceballos *et al.*, 2004).

Table 4: Inheritance of secondary traits in cassava

Trait	Gene action	Reference
Root quality traits; DM, CNP and post harvest deterioration	quantitatively inherited (polygenes)	Buerno, 1985
Resistance to CMD, CBB, and CGM	quantitatively inherited (polygenes)	Buerno, 1985
Cyanide content	Minor genes	Hahn *et al.*, 1977

1.5.4 Breeding for early root bulking

The characteristic nature of drought prone environments is the high variability of crop yield, response to inputs and management (Austin, 1989). Genotype by environment interactions are always more important in the semi-arid areas than in the favourable environments (Kawano, 1990). Thus, plant characteristics that are optimal for yield in a given season may be sub-optimal in another season. Heritability estimates for yield and yield related traits tend to change with the season and this is a major concern to the breeders.

Cassava storage roots and foliage develop at the same time. It is not possible to tell when the roots are ready to harvest. Days to flowering is positively correlated with

maturity and grain crop breeders use it to estimate maturity (Rinke, 1962; Beil, 1975). In the absence of such morphological traits, Kawano (1990) recommended the use of root yield as the criterion for assessing early bulking. The roots start to develop a month after planting (CIAT, 1972) such that any difference in yield after 6 mo can only be attributed to the differences in bulking rate (Wholey and Cock, 1974). There is similarity with grain crops in that they also tend to exhibit variation in the rate of grain filling (Daynard, 1969).

Breeding cassava for early root bulking was started in Madagascar (Cours, 1951), Ghana (Doku, 1969) and in India, (Indira and Sinha, 1970). At CIAT and IITA, breeding for early bulking was started in the 1970s in the quest to develop germplasm for the semi-arid areas (Wholey and Cock, 1974; Hahn *et al.,* 1979; Hershey, 1984). The early genotypes were found to have early growth vigour and long leaf life (Lozano *et al.,* 1984), which was an added advantage to the crop's genetic potential and adaptability to stressful environments (Hershey, 1984; Hershey and Jennings, 1992). The work was later taken up in Brazil in the 1980s, where participatory breeding was used to select improved varieties for the semi-arid northeastern state (Fukuda *et al.*, 2000). The experience at CIAT and Brazil showed that the ability to bulk early and yield in the semi-arid areas was possible. The problem was to combine early bulking and acceptable root qualities (CIAT, 1994). According to Cock (1985), high yielding varieties are useless to farmers unless they also have acceptable root qualities.

Cassava is an important food security crop in the semi-arid areas of Eastern Kenya. Nevertheless, research on the crop was only started three decades ago to evaluate the local germplasm for resistance to cassava mosaic disease, early bulking and quality (Kusewa, 1983). Farmers still grow landraces that bulk in 16 to 24 mo after planting. Efforts to introduce early bulking germplasm from IITA failed because the lines did not have end user preferences. However, two varieties 880061 and 880068 that were considered early at 12 mo from IITA had waxy roots, which were not accepted by farmers (Kiarie *et al.,* 1991).

Between 1994 and 2001, thousands of open pollinated seeds from early bulking parental lines that had good root qualities were introduced from IITA, Nigeria. The new germplasm was evaluated for earliness, root quality, disease and pest resistance at the research stations. Several genotypes were identified on the basis of root yield, disease and pest resistance and advanced to on-farm testing (Githunguri and Migwa, 2003). The farmers again rejected the new germplasm on the basis of poor root quality (waxy) (Githunguri and Migwa, 2003). These early bulking genotypes were conserved at KARI-

Katumani as sources of early bulking breeding. Learning from the experience of CIAT and Brazil, participatory breeding is the only option for the semi-arid breeding programme in Kenya. This would ensure that only those genotypes that are early and have the preferred end-user qualities are selected and advanced.

1.5.5 Selection index

Breeders make observations on many traits, which they use to identify superior genotypes. Breeders often combine the different measurements into one selection index. Selection indices are very useful in combining all the information recorded for each genotype in order to compare and in ranking of genotypes according to their performance. The phenotype values of each of the agronomic traits such as root mass, root number, dry matter, and harvest index that are measured are multiplied by standard values given according to the importance of the trait by the breeder or farmers and summed together to get one overall value (Baker, 1986). The phenotype values or scores for each trait (x_{ij}) may also be standardised by subtracting from each trait its mean (m_i) and dividing by its standard deviation (SD) [$P_1 = (x_{ij}-m_i)/SD$] (Banziger *et al.*, 2000). The farmers' weights on the various traits measured were used in this research to rank and identify the best genotypes.

1.5.6 Parental selection and mating designs

A breeder has two ways of selecting parental genotypes, namely the direct method based on the performance of the genotype and the indirect method based on the performance of the progenies (Banziger and Paterson, 1992). In maize, parental genotypes are selected primarily based on the performance of test cross progenies (Fehr, 1984; Lee, 1995). Nevertheless, experienced maize breeders use direct selection of parents when breeding for simply inherited traits from their core germplasm (Lee, 1995). Cassava breeders use direct selection (Robertson, 1959) rather than through the performance of the progenies (Ceballos *et al.*, 2004). In this research, the parental genotypes were selected on the basis of their performance across the agro-ecological zones in the semi-arid areas of Kenya (Kiarie *et al.*, 1991; Kamau *et al.*, 1998b).

Mating designs are used to produce progenies for direct utilization in breeding programmes and/or for utilization in genetic studies. In order to identify the appropriate mating design, it is important for the breeder to understand the type and mode of pollination, pollen dissemination, the aim of the breeding programme, genetic information required and the size of the progeny population (Stuber, 1980). The estimates of the components of variance, covariance and parental-offspring regression coefficients are

interpreted in view of their genetic expectations. These are based on assumptions of the particular genetic model adopted. Mating designs, such as the diallel (Sprague and Tatum, 1942) and NC mating design I, II, and III (Comstock and Robinson 1948; 1952) have in many instances been used to generate genetic information on both parents and their offspring. The diallel mating scheme is useful where three or more parental genotypes are crossed in all possible combinations. Diallel analysis and interpretation of genetic information is often done using Hayman's (1954) and Griffing's (1956) procedures.

The NC II design (Comstock and Robinson, 1948; 1952,) is a factorial design, which allows the estimation of genetic variances of multi-flowered species such as cotton, safflower and cassava and in evaluating inbred lines of single flowered species such as maize for combining ability. In NC II design, each male parent (m) is crossed to all the female parents (f) to produce (fm) progenies. Reciprocal crosses in most cases are assumed similar with direct crosses and are bulked together to plant progeny trials (Stuber, 1980). The NC II design allows two independent estimates of male general combining ability (GCA) and female GCA. The interaction of the female and the male estimates the specific combining ability (SCA_m) (Hallauer and Miranda, 1988). When the number of females equals the number of males then the GCA_m equals the GCA_f, in the absence of maternal effects. Thus, if the GCA_m is not equal to GCA_f, then significant maternal effects are suggested. In the presence of maternal effects narrow sense heritability (h^2) is calculated using the GCA_m, which is free from maternal effects. Significant GCA and SCA effects are indications of additive and non-additive gene action respectively.

This design has been utilised before to study the effects of genes controlling important traits in variety crosses (Eberhart and Gardner, 1966); hybrid maize (Pixley and Bjamason, 1993); resistance to the maize grain weevil (Derera *et al.,* 2000) and field resistance of cassava varieties to cassava mosaic disease (Lokko *et al.,* 2004). To analyse and interpret from NC II design experiments, the following assumptions are taken into considerations: the individuals mated were randomly selected to produce progenies, there was random distribution of genotypes relative to variations in the environment, there were no maternal effects, there was regular diploid behaviour at meiosis, no multiple alleles, no linkage except where equilibrium between coupling and repulsion phases exists and there was no epistasis.

The main difference between a diallel and NC II is that there are two independent estimates for GCA effects in the NC II, which is an advantage of the NC II over diallel. Another advantage is that the NC II can handle more parents and produce fewer crosses than a diallel. In the NC II, dominance variance can be determined directly from the m variance. An additional advantage of the NC II is that crossing of parents in sets can increase the sample size to be tested (Hallauer and Miranda, 1988).

The NC II mating design was chosen instead of diallel because the interest was between crosses from two different sources (local and IITA varieties). Four late bulking, local varieties were crossed to six early bulking IITA varieties to produce 24 crosses. Use of a diallel design would have produced many more crosses, which would have been difficult to manage in the trials. Compared to the diallel, the NC II mating design has two independent estimates for the GCA due to male and female parent sources. Although the diallel has the advantage of incorporating reciprocal effects in the model for checking maternal effects, the NC II mating design can also estimate maternal effects by testing the differences between the male and female mean squares. As a result, h^2 can be calculated using the m variance, which is free from the maternal effects. If present, these maternal effects would lead to the upward bias of the additive variance (Hallauer and Miranda, 1988).

1.6 Summary

Cassava is a very important food security crop in Africa and it has the ability to grow under marginal conditions. Information on the botany and physiology of the species has been well documented. Of particular interest to the breeder is the knowledge on flowering and seed germination. There are a number of constraints that affect cassava production of which drought is one of the most important in semi-arid Kenya.

CIAT and IITA have played an important role in germplasm enhancement and development of improved cassava varieties. There is no cassava breeding programme in Kenya. The traditional approach in breeding cassava has been to harvest large numbers of open pollinated seed and select the best progeny. Only recently mating designs such as diallels have been used in cassava breeding. The NC II mating design is a good alternative to the diallel design for use in cassava programmes.

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Chapter 2: Farmers' perceptions of production constraints and preferences in cassava grown in semi-arid Eastern Kenya

Abstract

Cassava is an important food security crop in the semi-arid areas of Eastern Kenya. Despite its importance during the long periods of drought and famine, no breeding programme has ever been conducted to improve the crop in Eastern Kenya. Therefore, this study was initiated by engaging farmers to identify researchable constraints that limit cassava production in the semi-arid areas. Participatory rural appraisal (PRA) tools, including two focus group discussions and interviews with 72 individual farmers, were conducted in Machakos, Makueni and Mwingi districts in the eastern province of Kenya in 2004. Results from interviews revealed that farmers were growing 13 varieties, which were all late maturing (15 to 24 mo). The varieties were usually intercropped with other crops. Many farmers planted cassava after weeding the first planted grain crop, which exposed the crop to early season drought. Gender differences were apparent, as male farmers showed high preferences for varieties that produce long and thick round roots for the markets, while women preferred short and round roots that are easy to handle for domestic use, as well as for the local market. Both focus group and individual farmer interviews identified 11 production constraints that were perceived to be important. Farmers prioritised these constraints to the four most important ones, which in order of importance were drought, lack of suitable planting material, insect pests (green mites and mealy bugs) and disease (cassava mosaic). It was therefore agreed that breeding for early bulking varieties (6 to 10 mo) that escape late season drought was a priority. Breeding should also incorporate resistance to the important disease and pests. In addition, researchers should develop germplasm multiplication and dissemination methods for semi-arid areas.

2.1 Introduction

Cassava is an important food security crop in the semi-arid areas of Eastern Kenya. It provides food for a longer period in a calendar year than any other food crop grown in the region. Despite the importance of cassava in alleviating human suffering during the long periods of drought and famine, no breeding has ever been conducted to improve the crop in Eastern Kenya. For a long time farmers have depended on landraces and introduced germplasm, that often fail to meet their requirements. In order to devise a new and effective breeding programme there is a need to gather important information about farmers' perceptions of production constraints. Furthermore the breeder needs to know the local cassava preferences.

During the farming system research (FSR) approach, developed in the late 1970s and early 1980s, formal surveys were used to collect information from farmers. Surveys were laborious, time consuming and expensive to implement (Rifkin, 1992). They generated quantitative and or qualitative data, which was statistically analysed (Chambers, 1983). Nevertheless, these surveys did not easily allow for information outside the scope of the questionnaire to be collected. The researchers used the information to develop varieties without consulting target farmers in the process (Ashby *et al.*, 1996). Subsistence farmers perceived research as an activity created to address the problems and needs of resource endowed large-scale farmers, who could influence government policy. Therefore, technologies that were developed at the time of FSR, were in many cases rejected by the subsistence farmers (Rukandema, 1983; Ockwell *et al.*, 1988). In the current study a participatory approach, in which farmers are actively involved in generating information is followed as a way of accelerating adoption of new technologies.

A study conducted in the semi-arid areas of Kenya (Mavua, 1985) revealed that subsistence farmers reject new technologies for a number of reasons. The farmers complained that the new technologies required more fertilisers and agro-chemicals, which they could not afford. In semi-arid areas of Eastern Kenya, farmers rejected varieties selected from seed populations introduced from IITA on the basis of poor root qualities (Kamau *et al.*, 1998b). In Uganda, Bua *et al.* (2000) reported that cassava varieties bred between 1990 and 1999 were abandoned immediately after release because they lacked in preferred end-user root qualities. Thus, new ways of ensuring cassava variety adoption have to be found. Breeding is perceived successful when target farmers adopt released varieties.

In an effort to improve on the passive and traditional methods of gathering information, the rapid rural appraisal (RRA) was developed in the late 1980s (Grandstaff, 1988; Conway, 1990). The RRA attempted to bring farmers' perspectives, practices and indigenous knowledge into the forefront of the planning process, improving on the traditional top-down development approaches. However, it failed to effectively articulate the interests of the rural farmers and adoption rate remained low (Paris and Atlin, 2005). In the late 1980s and early 1990s, the RRA was replaced by participatory rural appraisal (PRA), which emphasised active participation of farmers in the formulation of research objectives and selection process at an early stage in the breeding process (Chambers, 1993).

PRA was developed after it was realised that there was a need to analyse location specific problems. Researchers had to rely on the farmers' knowledge to understand the needs within each agro-ecology. PRA emphasised on the participation of both the researchers and producers in identifying the constraints and in technology development. It uses tools such as semi-structured interviewing, focus group discussions, preference ranking, mapping and modeling, seasonal and historical diagramming to identify and prioritize the production constraints time, and trend lines (Theis and Grady, 1991).

PRA recognises the importance of farmers' indigenous knowledge and skills to understand the target area, identifies production constraints, and prepares the action plan together (Sperling *et al.*, 1993). Instead of the tedious questionnaire, PRA uses guiding questions to stimulate group discussion in semi-structured interviews. Open-ended questions or issues that arise during the discussion, are explored further during the interview (Theis and Grady, 1991; Chambers, 1993). The discussions are held in a friendly atmosphere, where everybody is perceived to be equal, irrespective of their status in society. It allows stakeholders to work together in identifying constraints, which are used to formulate research objectives (Sperling *et al.*, 1993). As a result, breeding has been made more participatory and opened the way for the concept of participatory plant breeding (PPB).

In PPB farmers and breeders make decisions together in the technology development. For example, if the subsistence farmers are not capable of buying inputs such as fertilizer and crop protection chemicals, varieties that are released should guarantee some acceptable yield level with minimum inputs (Okali *et al.*, 1994). Examples of crop varieties that have been bred through PPB include grain legumes in India (Gupta, 1985), maize in Western Kenya (Odendo *et al.*, 2002) and cassava in Brazil (Fukuda *et al.*, 2000). Adoption rate of varieties developed through PPB is often good. In Tanzania, Kapinga *et al.* (1997) demonstrated that PPB accelerated dissemination and adoption of cassava technologies.

Objectives

Therefore this study was initiated to work with cassava farmers in Eastern Kenya to identify researchable production constraints, prioritise them and develop cassava-breeding objectives for this semi-arid area.

2.2 Materials and methods

1.6.1 Study area

The eastern-mid altitude (800 to 1800 m) and semi-arid areas cover two major agro-ecological zones in Kenya (Figure 1). One zone receives 700-800 mm of rainfall annually, classified as lower Midland zone 4 (LM4) and the second zone receives 500 – 600 mm of rainfall annually, classified as lower Midland zone 5 (LM5) (Jaetzold and Schmidt, 1983). From these zones two villages, namely Kathekakai in LM4, and Muuni village in LM5 in Machakos and Makueni district, were selected for the study. The local leaders and the extension staff of the respective districts selected the two villages on the day researchers visited the district offices of the Ministry of Agriculture. These two villages were selected for focus group discussions. Individual interviews were conducted in several divisions such as Central and Yatta in Machakos district, Makindu and Kasikeu in Makueni district, and Central in Mwingi district.

Machakos district: In Yatta division, Matuu village was selected for individual interviews. Matuu village is along the Thika - Garisa road on the northeast side of Machakos LM5. Soils vary from red clay and loam soils to the heavy black cotton soils, which dominate the lower area. There is a canal that supplies water for irrigation and household use. Crops grown are mainly horticultural crops for export and local markets, and food crops such as tomatoes, kale, maize, beans, pigeon pea, pumpkins, cassava, sweet potatoes, bananas, mangoes and pawpaw.

Makueni district: In district, Makindu and Kasikeu divisions were selected for the interviews. In Makindu division, Muuni village was chosen for the group and individual interviews, while Kasikeu village in Kasikeu division was selected for individual interviews only. Muuni village is located along the Nairobi - Mombasa road, approximately 15 km south of KARI-Kiboko station in LM5. The soils are mainly sandy loam and red clay. Water comes from two wells, one borehole plus one line of piped water that is pumped once a week from the Kibwezi river, in the neighbouring division. The crops grown include maize, sorghum, millets, beans, and cowpeas, pigeon peas, green grams, cassava, sweet potato and cotton.

Kasikeu village in Kasikeu division is about 10 km off Nairobi - Mombasa road, near Sultan Hamud. Soils are mainly sandy loam and the crops grown are maize, beans, cowpeas, pigeon pea, cassava, pumpkins and mangoes.

Mwingi district: This district is mainly in LM5. Soils are sandy to sandy loam and farmers grow maize, sorghum, finger and pearl millets, cowpeas, mung beans, cassava and pumpkins The central division is divided into two by the Thika - Garisa road and was selected for the individual farmer's interviews only.

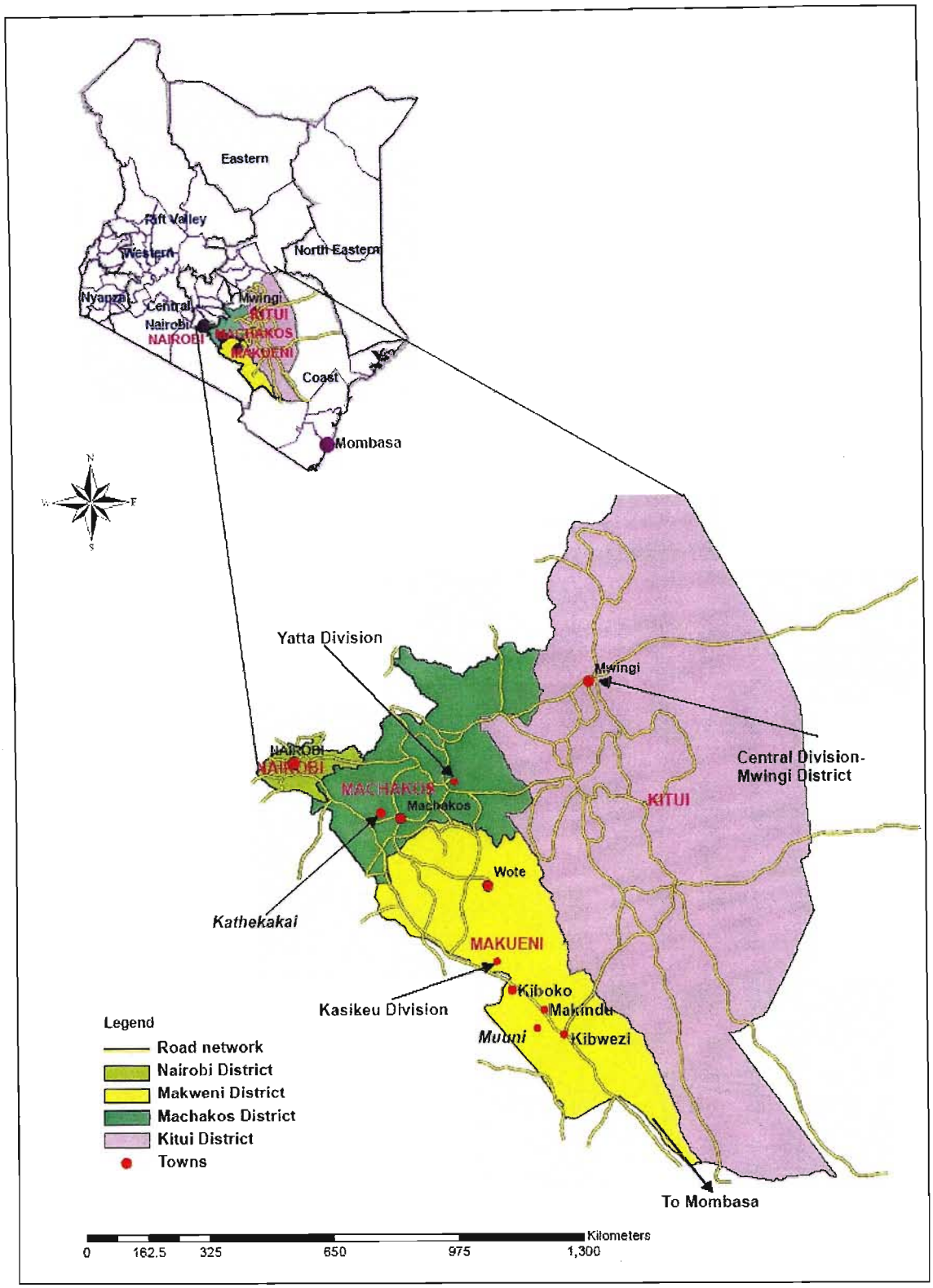

Figure 1: Kenya map showing the PRA areas

1.6.2 Data collection

The research team comprised of the principal researcher (breeder), two socio-economists, two technicians, one agricultural extension officer and a local leader. The local leader and extension staff assisted in moderating the discussions. The research

team explained purpose of the research, the need of selecting study sites, the number of farmers required and a common understanding was created during team meetings prior to the PRA. During the meetings, the guiding questions and the role within each group were discussed, and lists of farmers and traders to be invited were finalised. The research team also gathered secondary data, on cassava production and utilisation, available from the local agriculture office. In each location the local extension officer and village leaders invited all the farmers by announcements at public places such as churches.

Facilitators used a guide questionnaire, probing further into any new information that arose from group discussions. The following PRA tools were used to collect data during group interviews (Figure 2. to 7): community sketch maps, time lines, trend lines and seasonal calendar (time allocation for different activities and by gender). Farmers were also requested to list all crops grown and institutions involved. A checklist of questions was used to gather data from community members. At some point, men and women were put in different sub-groups to come up with their own list of production constraints. This was necessary because in this region men are more concerned with cassava marketing, while ladies first consider the ease of handling during food preparation.

Individual farmers' interviews were conducted to obtain additional data on crops grown, use of cassava as food and cash crop, cassava production constraints, types of cassava varieties grown, harvesting period after planting, preferred maturity period and common recipes.

Figure 2: Farmers participating in the PRA at Kathekakai

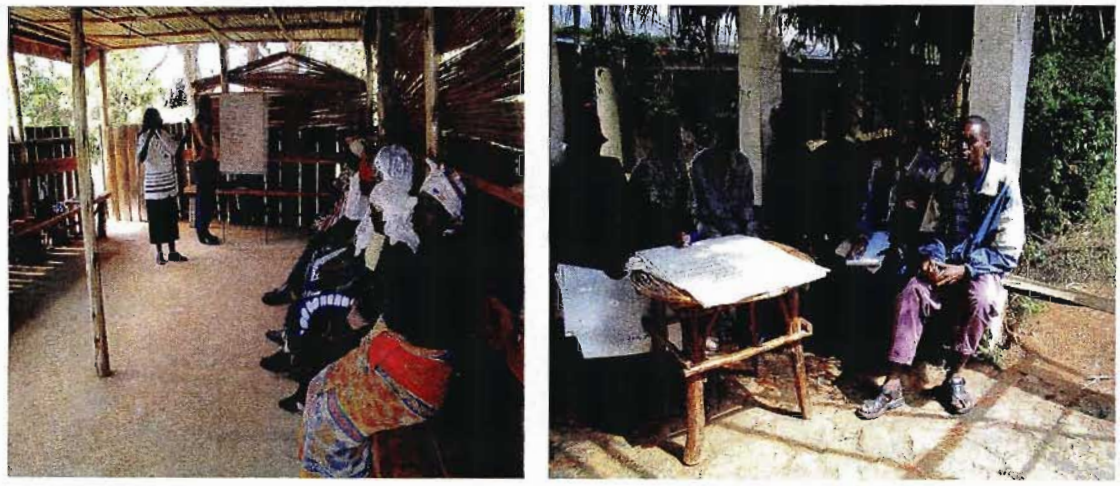

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Figure 3: Gender subgroups discussing production constraints at Kathekakai

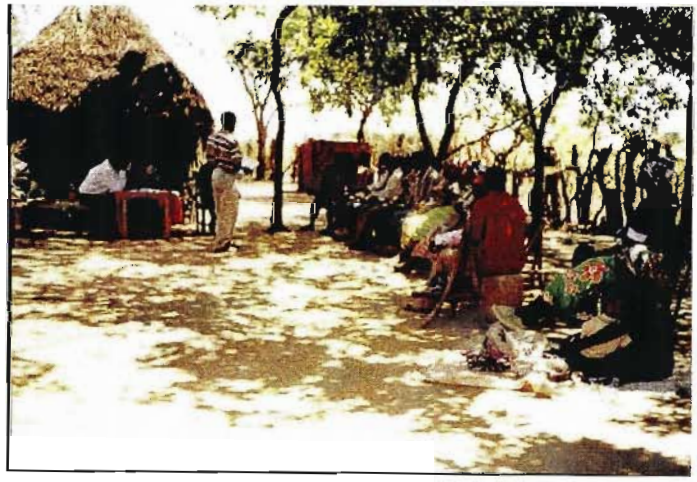

Figure 4: Social scientist explains the purpose of the PRA to farmers at Muuni

Figure 5: Farmers participating in the PRA at Muuni

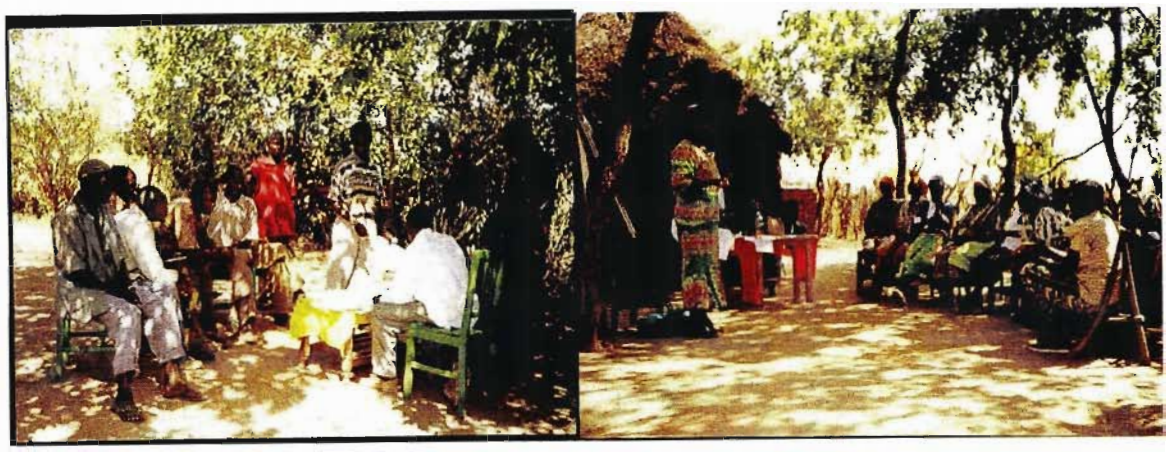

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Figure 6: Gender subgroup discussing the constraints at Muuni

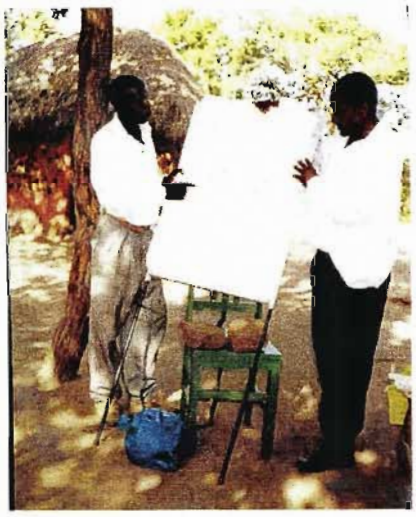

Figure 7: Farmers explaining the production constraints

2.3 Results

2.3.1 Focus group discussions

At Kathekakai, 14 farmers (58% men and 42% women) attended the meeting and 20 attended at Muuni (42% men and 58% women). At Kathekakai, 38.9% of the group members had not received formal education, while16.7% had been trained at various colleges. At Muuni, 19.4% had not received formal education, 50% attended first 8 y of primary education and 30.6% received college training.

Using time lines farmers at Kathekakai were able to describe their sub-location. Kathekakai is a former large-scale beef and coffee farm. Local people formed a

cooperative society to buy the farm in 1964. The new owners subdivided part of the land into 6 ha plots in 1965 to settle the shareholders, leaving the rest under beef and coffee. Cassava had been introduced on the farm, in the early twentieth century by the European settler to reduce food shortage among the farm workers. Two cassava varieties (Kikamba and Kiseliseli), were introduced by the Ministry of Agriculture in 1978. Farmers also grow maize, beans, pigeon pea and sweet potatoes in the village.

Before 1995, farmers replanted their own stakes or sourced them from neighbours and relatives. However, starting in 1995, 20% of the group members acknowledged buying stakes from the neighbouring, open day markets. Excess roots were sold in the local markets of Makaa, Mutituni and Machakos town. The sub-location has no stockists for fertiliser chemicals and other farm inputs. Farmers buy from the neighbouring Mutituni market or Machakos town. However, the front line extension personnel from the Ministry of Agriculture provided technical advice to the farmers on crop and animal husbandry.

Muuni sub-location is a recent settlement scheme, created by the government of Kenya in 1995 to settle the landless. In the first 5 y of settlement, cassava cultivation expanded more than any other crop. Additional planting materials came from the neighbouring villages in Makindu and Kibwezi divisions. The farmers experienced heavy cassava losses from the wild animals, in particular baboons, pigs, porcupines and elephants from Tsavo West National Park. To curb the wild animal menace the farmers subdivided their farms and sold to other people who cleared the bushes where the animals were hiding.

Important trend lines on cassava production were analysed using the farmers' perception of availability of adequate rains, occurrence of cassava diseases, pest incidences and root yields in the two sub-locations. The two focus groups agreed that the years 1974, 1984, 1989, 1994 and 1999 to 2005 were characterised by serious food shortage and famine. Cassava cultivation was affected by lack of rainfall and lack of planting materials. Heavy rains, characterised by flooding, were reported in 1966, 1997 and 1998 and cassava in the valleys was destroyed by water. Other years had near normal-rainfall (400 to 800 mm) and farmers had enough cassava for domestic use and surplus for sale. However, farmers from the two villages thought annual rainfall has been declining since 1960s for reasons they could not explain.

From 1987, farmers in Kathekakai started observing deformed leaves and some stems turning white on some cassava plants. The group at Muuni had seen such symptoms at

their original homes, but were not aware that it was a problem. Both groups reported that the plants with deformed leaves sometimes gave low yields.

Each group listed varieties they grew and the number of months it took to harvest. Varieties supplied by the Ministry of Agriculture were considered improved (Table 5). These varieties, such as Kibandameno, Binti Athumani and Kalesho, were farmers' introductions from the coast, while Mucericeri had been released from KARI-Katumani in the late 1970s.

The PRA exercise was conducted in 2004, a period when the region was experiencing severe drought conditions. All the cassava in the fields had been harvested. The few plants left on the farm had lost all their leaves and all the tubers harvested. As a result, it was not possible to differentiate improved from local varieties. Men could not clearly differentiate the varieties, but women were able to describe each variety (Table 5).

Table 5: Description of cassava varieties by women groups in Kathekakai and Muuni villages

Variety	**Kathekakai**	**Muuni**
Kitwa (local)	-2 m tall	-high branching
	-scaly roots, red outer skin	-red outer skin colour
	-cracks when mature	-high dry matter, easy to peel
	-late maturing (18 mo)	-late bulking 18 mo
Mucericeri	-white outer skin	-short roots (300mm)
(improved)	-short roots (300mm)	-white outer skin
	-early maturing (15 mo)	-early bulking (15 mo)
	-low dry matter, bitter at times	-low dry matter, bitter at times
	-2 m tall	-2m
Kisimba (local)	-white flesh, red outer skin	-
	-cracking when mature	
	-late maturing (18 mo)	
	-1 m tall	
Kiou (local)	-	-low branching
		-early bulking
		-red outer skin colour
		-easy to peel
		-high dry matter, low fibre

Both groups acknowledged that the improved varieties were introduced by the Ministry of Agriculture (MOA) and non-government organisations (NGOs). Group members at Kathekakai obtained extra planting materials from the neighbouring Mutituni location, while at Muuni farmers obtain stakes from neighbouring villages in Kibwezi division. On average most (60%) of the planting materials were exchanged with neighbours and relatives (Figure 8).

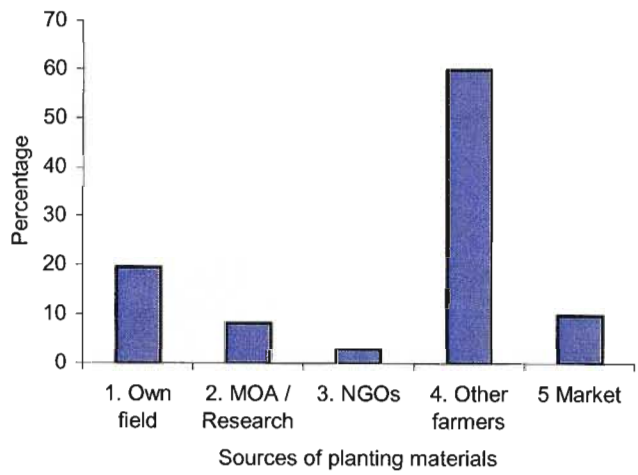

Figure 8: Organisations that have provided planting materials before

About 40% of the group members intercrop cassava with maize. The cassava is planted after the first maize weeding. However, 35% of the farmers plant cassava as a sole crop at the onset of the rains (Figure 9).

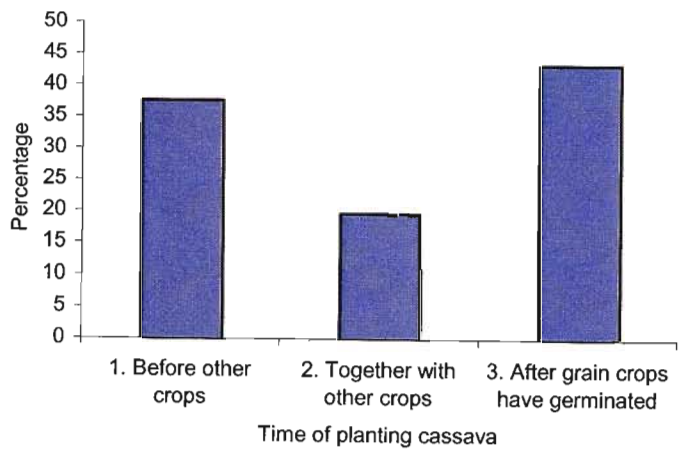

Figure 9: The time of introducing cassava in the cropping season

A list of farmers' preferences for an improved variety was made by the two focus groups (Table 6). The list was similar for both groups except that farmers from Muuni wanted a variety that can grow up to 2 m tall. At Kathekakai, plant height was important because cassava generally grows tall, but at Muuni, cassava rarely grows more than 1 m. Both men and women from the two villages agreed on most of the attributes. However, men would like a variety that produces long and thick round roots for marketing, while women preferred short and round roots that are easy to handle for domestic use (Table 6).

Table 6: Cassava variety characteristics preferred by farmers in Kathekakai and Muuni villages

Characteristics	**Kathekakai**	**Muuni**
Plant height	Tall (but not important)	Medium (1.5 to 2 m)
Root shape	Long, straight and round	Elliptic (no constrictions)
Size	Long (men) and short (women)	Long (men) and short (women)
Flesh colour	White	White
Texture	High dry matter	High dry matter
Taste (when raw)	Sweet	Sweet
Maturity period	Early (preferably <10 mo)	Early (preferably <10 mo)

Farmers valued the long period that cassava roots are available in a year (Table 7). Furthermore, they mentioned the many dishes that can be prepared from cassava and its role as a food security crop and a cash crop (Table 8).

Table 7: Period for which each crop was important for household food security in Kathekakai and Muuni villages

Crops	Kathekakai	Muuni
Cassava	August - February	April - December
Cowpea	December - January; February and June	December - January; February
Beans	January - February and June	January
Dolicos	N/A	May to June
Green gram	N/A	January
Maize	February & July	February
Sorghum	February	April
Avocado	February - December	N/A
Bananas	Throughout the year	N/A
Garden pea	April	N/A
Pigeon pea	June – August	June - August
Broad bean	May - June	N/A
Pumpkin	June	June
Sweet potato	April and August	February and August
Finger millet	N/A	March

N/A = Not applicable

Table 8: Common dishes prepared from cassava

Tubers	Dish	Preparation after peeling
Fresh roots	Snack	The sweet roots peeled and chewed raw
Cooked fresh roots	Kisili	Roots chopped, fried with, meat or legumes
	Kitau/ Mukimwa	Roots boiled with maize, bean and mashed.
	Milikyo	Cassava roots chopped and boiled alone
Processed products	Munyoloka - uvesi	Cassava flour used to prepare *ugali*[2]
	Chapati	Boiled cassava or flour mixed with wheat flour
	Mwanga	Composite cassava-maize flour to cook *ugali*
	Porridge	Composite cassava-maize/ millet/ sorghum flour
Leaves	Vegetables	Young leaves are pounded washed and fried

Each focus group listed all the crops they grew in their respective areas. The members considered the amount of food harvested per unit land and which food crop is available during the drought periods. By a show of hands the crops were ranked in the order of

[2] Ugali – is a popular paste cooked with maize or cassava-maize, cassava-sorghum/millet composite flour

their importance as food security and cash crop. Cassava took the first position as the most important food security crop (Table 9). Farmers also considered the advantage of being able to sell cassava quickly in case of need. Maize and beans were ranked higher because they store well, while cassava was placed in fourth and fifth position as a cash crop at Kathekakai and Muuni, respectively (Table 9).

Table 9: Ranking of crops grown for food security or cash crop in Kathekakai and Muuni villages

Crops	Kathekakai				Muuni			
	Food security crop		Cash crop		Food security crop		Cash crop	
	Score[+]	Rank	Score[+]	Rank	Score[+]	Rank	Score[+]	Rank
Cassava	8	1	4	4	7	1	4	5
Maize	6	3	8	1	3	6	8	1
Beans	5	4	7	2	-	9	7	2
Sweetpotato	7	2	4	5	5	5	3	6
Cowpea	4	5	4	6	6	2	1	9
Pigeon pea	3	6	6	3	-	-	-	-
Sorghum	2	7	2	7	5	3	1	8
Pearl millet	-		-		-	-	-	-
Finger millet	1	8	1	8	2	7	6	3
Dolicos	-	-	-	-	2	8	2	7
Green gram	-	-	-	-	5	4	5	4

[+]*Score 1= least and 8= most important*

The two focus groups identified and ranked the following constraints that limit cassava production in the semi-arid areas: poor soil fertility, drought, inappropriate varieties, inadequate planting materials, diseases and pests (termites, stem scales, white flies, wild animals and thieves). In addition, there were lack of well-defined markets, inadequate knowledge about cassava husbandry and processing of cassava. Ranking was done by the gender subgroups in each village. The ranking by the men and women of the constraints differed (Table 10). Women from the two sub-locations indicated that appropriate knowledge on cassava production and technologies were essential in promoting production. Drought was ranked the number one constraint at both Kathekakai and Muuni (Table 10).

Table 10: Ranking of constraints by gender at Kathekakai and Muuni villages

Constraints	Kathekakai				Muuni			
	Women		Men		Women		Men	
	Score†	Rank	Score†	Rank	Score†	Rank	Score†	Rank
Poor soil	1	8	3	3				
Drought	5	4	5	1	5	1	6	1
Planting materials					4	2	5	2
Disease	4	5	4	2			3	4
Pest	3	6	2	4	3	4	4	3
Livestock					2	5		
Market	7	2						
Wild animals	2	7						
Theft								
Appropriate varieties	6	3	1	5				
Inadequate knowledge of cassava production	8	1			4	3	1	5

†*Score 1= least important, 8= most important*

Using their own understanding of the constraints, the focus groups listed a number of solutions to each of the first four constraints they considered most important (Table 11).

Table 11: Possible solutions to constraints identified at Kathekakai and Muuni villages

Constraints	Possible solutions
Drought	-early maturing varieties or drought tolerant/ resistant varieties, - mulching, water harvesting and irrigation
Planting materials	-establish appropriate multiplication and supply channels -preservation in trenches, under shade and hanging in trees
Disease (CMD)†	-uproot affected plants and use of resistant varieties
Pests (white flies, stem scales, mites, termites, thieves and wild animals)	-training on the use of chemical control, trapping and scaring - use of repellents (burn animal dung), relocate wild animals to national parks or seek spiritual interventions for the thieves

† CMD, cassava mosaic virus disease

2.3.2 Individual farmer interview

A total of 72 households from Machakos, Makueni and Mwingi districts were visited. In each farm, the head of a household or a representative was interviewed of whom 21% respondents were women. About 55% of the household heads had attained different levels of the first 8 y of primary education, 19.4% high school (16 y of schooling) and 5% college education (Figure 10). Most of the heads of household (87.3%) lived and worked on their farms and only 12.7% had formal employment. However, 82% of them depended on their farm produce for the family food and income (Figure 11).

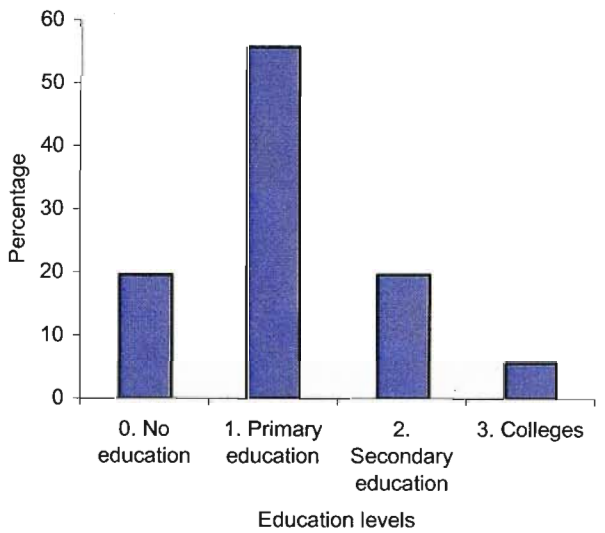

Figure 10: Education levels of heads of households

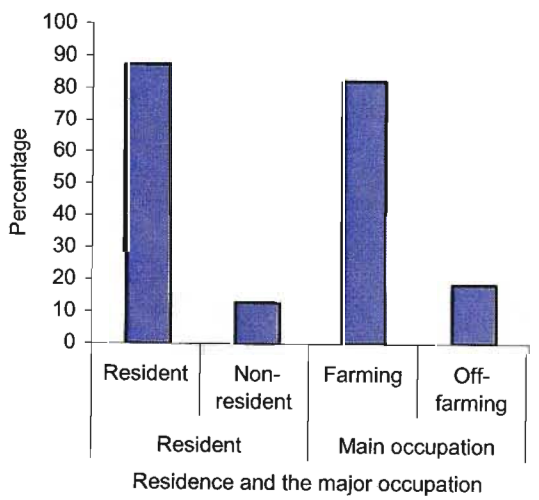

Figure 11: Characteristics of the head of the households

Out of the 72 individual farmers interviewed, 77.8% intercropped cassava with food crops such as maize, grain legumes (beans, cowpeas, pigeon peas, dolichos, mung beans), sorghum and millets, sweet potato, vegetables, sugar cane and fruits (mangoes, guavas and pawpaw). Only 8.3% planted it as sole crop (Figure 12).

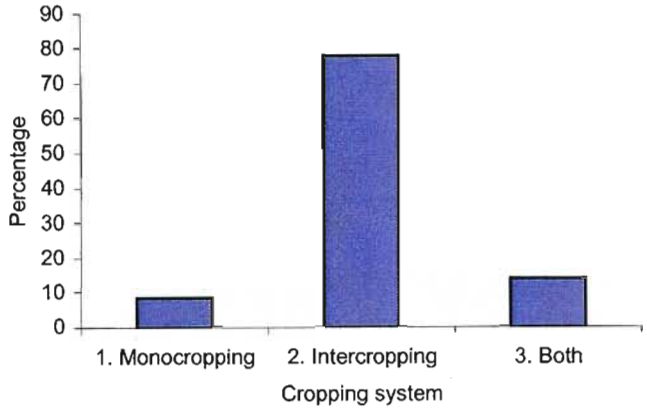

Figure 12: Cropping systems for cassava

The individual farmers listed 13 varieties, which they grew. Farmers considered varieties, brought in by the Ministry of Agriculture and non-governmental organisations, as improved. The two varieties, Mucericeri and Yanga itune were considered early (Table 12)

Table 12: List of cassava varieties grown in the semi-arid areas (I=Improved; L=Local)

Variety	**First harvesting (months after planting)**
Mucericeri (i)	15
Yanga itune (L)	15
Kitwa (L)	19
Yanga yeu (L)	20
Kibandameno (L)	19
Binti athumani (L)	20
Kaleso (L)	19
Kikamba (L)	20
KME 1 (I)	19
KME 61 (I)	24
Kisui (L)	21
Mbili (L)	24
Mpira (L)	24

A total of 65% farmers were willing to adopt early bulking varieties with preferred root qualities and abandon the traditional varieties (Figure 13). The remaining group 34.7% would adopt and keep their traditional varieties. A majority (75%) of the farmers indicated that they would like a variety that can be harvested at between 6 and 10 mo after planting (Figure 13).

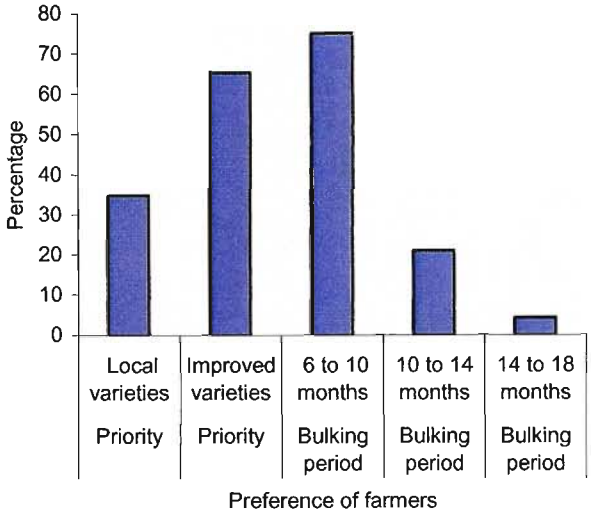

Figure 13: Farmers preferences on the period of an early bulking variety

According to the individual interviews, majority of the farmers (66.8%) planted cassava during the short rains season. It is only the few farmers in Yatta division of Machakos district, who have furrow irrigation, who planted during the long rains (Figure 14). Planting was done after the rains had started by mature women in the family, while all family members did weeding.

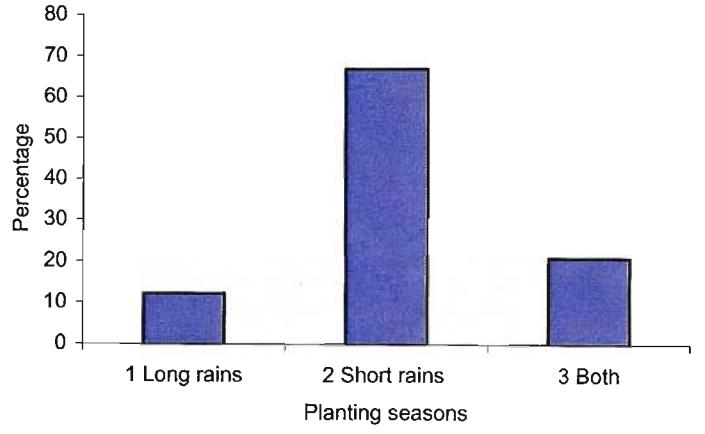

Figure 14: Season farmers prefer to plant cassava

When the individual farmers were asked about the importance of cassava, 91.7% said that it was the most important food security crop. Fifty eight percent of the respondents thought that cassava was an important cash crop (Figure 15).

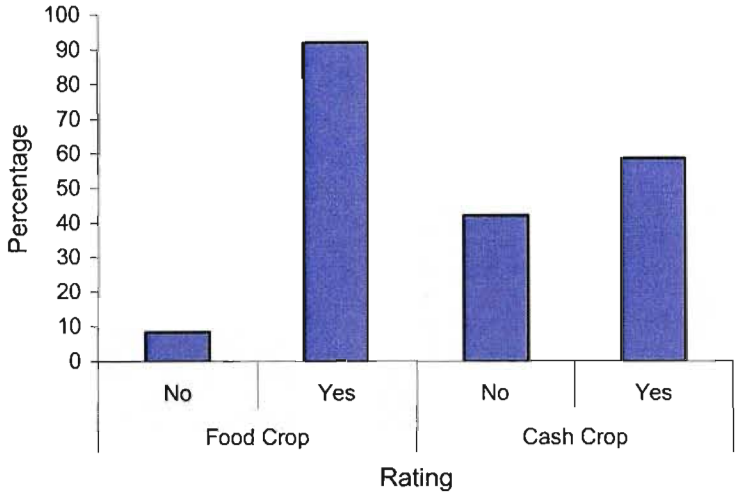

Figure 15: Percentage of farmers growing cassava as food and cash crop

The following constraints were identified; drought, planting materials, diseases and pests. Over 55% of farmers thought drought was the most serous constraint that research should address, followed by planting materials, diseases and pests (Figure 16).

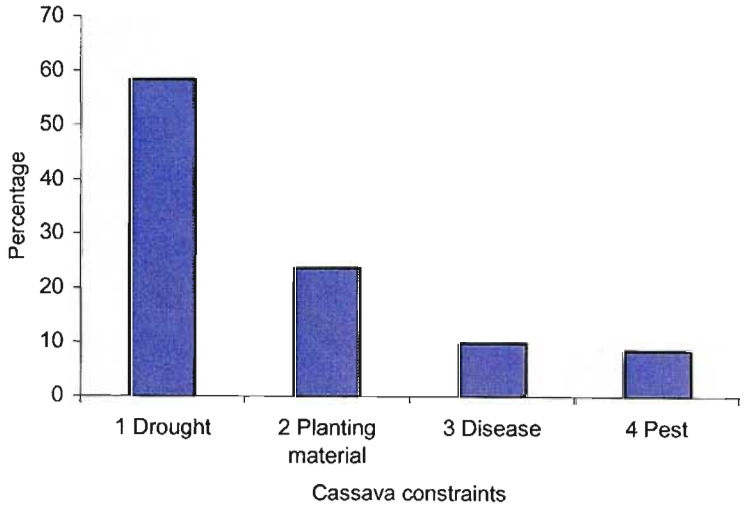

Figure 16: Cassava constraints identified by individual interviews

According to 51.4% of the farmers the solution for drought was to breed for early bulking varieties, while 5.6% of the farmers mentioned irrigation (Table 13). The interview

showed that 16% of the farmers would be willing to buy planting material, while 4% said they should be trained in methods of conserving planting material. About 9% of the individual farmers thought they could control pests by spraying with chemicals and diseases by uprooting the sick plants (Table 13).

Table 13: Solutions to the constraints identified from individual interviews

Constraints	Solutions	Percent of farmers
Drought	Early maturing varieties	51.40
Drought	Irrigation	5.60
Planting material	Train in conservation	4.20
Planting material	Be advised the place to buy	16.70
Pests	Pesticide	9.70
Disease	Uproot or resistant varieties	8.30
All above	Do not know	4.20

2.4 Discussion and conclusion

The aim of this study was to involve cassava producers in identifying cassava production constraints and preferences. Farmers proved to have detailed insights into the cassava production system and they were willing to share information freely with the research team. The combination of focus group and individual interviews resulted in a detailed picture of all the aspects of cassava production. The farmers responded particularly well to focus group discussions and the whole group openly and freely discussed ideas initiated by one person. The open-ended nature of the questions generated answers that would not have been obtained from the individual interviews. Separating males and females proved beneficial at times.

Trend lines were important tools to study how cassava production has taken its place in the local economy over time. Farmers remembered events going back to the year they settled in their villages. Members of the focus groups were able to recall easily the years the villages had received above normal rainfall, characterised by flooding, and years with below normal rainfall. In the last decade farmers have observed an increase in plants with what appear to be diseased leaves. Farmers were aware that rainfall in the region was unreliable, inadequate and has been declining over the years. The general perception was that area under cassava production has increased in recent years.

The farmers emphasised the importance of cassava as a food security crop in the semi-arid area. They knew that cassava out-yields all other crops grown and it is the only crop available during the long dry period from June to November. Therefore, cassava is a very important crop, especially to children, women and the aged who suffer malnutrition and become vulnerable to diseases during the drought and famine periods. Apart from food, the crop proved important as source of income to the families. Cassava serves as a cash crop and provides employment to many, young and old.

Gender differences were obvious when the focus groups were subdivided into men and women subgroups. It emerged that the men are more concerned with marketing of cassava and require varieties that produce long and thick roots. Women would like varieties that produce short thick roots that are easy to carry in a basket or handle when preparing meals. The ladies were more concerned with family food and only considered selling on the market when there was excess.

Over the years farmers appear to have proactively introduced cassava from other areas, mainly from the coastal region. They were aware of the differences between varieties in bulking period, and knew advantages and disadvantages of each variety. Most varieties were late bulking. Gender differences were evident, when men could not clearly describe all the varieties grown, while women were very knowledgeable about differences between varieties. The farmers were keen to adopt new improved varieties, as long as they combined preferred root qualities with early bulking.

Pairwise ranking proved an important tool to facilitate the ranking of cassava production constraints by the farmers. The women wanted to be trained on the crop's husbandry and processing while men thought diseases and pests were important. The groups agreed that research should address drought first, followed by unavailability of planting materials. Development of early bulking varieties should also include resistance breeding to pests and diseases important in the areas. The farmers emphasised the need for varieties that would escape the long drought period of June to November. Discussion of the seasonal calendar was used to find out when cassava is planted and introduced in the cropping system.

Farmers had strong views of the kind of variety they prefer. The varieties should be early, with sweet (low HCN), high dry matter and short, thick roots. Farmers in agro-ecological zone LM5 wanted tall varieties, to give them more planting material.

The PRA has highlighted the importance of cassava in the farming system of the semi-arid areas of Kenya. Constraints have been prioritised and the need for early bulking varieties, with resistance to important pests and diseases, established. Men and women had at times differing views of the ideal cassava plant. The farmers have demonstrated the willingness to work together with the researchers in solving the production constraints that affect cassava in the area. In order to develop appropriate varieties, which have the preferred end-user root and plant habit qualities, participatory plant breeding will need to be an integral part of the cassava breeding programme for the semi-arid areas of Kenya.

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Appendix 1: Chapter 2

PRA of the focus groups: Guiding questions

1. How do you access agricultural information? (Be brief)

2. What are the social structures (relationships & membership to the different institutions)?

3. What crops do farmers grow in this area?

4. When is each of the food crops important as food in a year? (calendar)

5. What are the problems you encounter in farming? (draw table)

6. Do all the farmers grow cassava (If yes what percentage grows for food or for sale or both and percentage area)? (draw a table)

7. Where do you get cassava planting materials? (Emphasise research agenda)

8. How many varieties of cassava do you grow? (Emphasise research agenda)

9. What attributes of cassava do you prefer (early/late bulking, plant habit)?

10. What kinds of storage roots do you prefer? (shape, size, colour, taste (sweet, bitter etc) texture (kitutu or uzi), etc.

11. How do you utilise cassava roots of the different varieties?

12. How many know cassava leaves are used as vegetables?

13. How many utilise the young cassava leaves as:
    a. Vegetables? [If yes] Which varieties? [If no] Why?
    b. Livestock feed? [If yes] Which varieties? [If no] Why?

14. Do you process cassava? [If yes] Which varieties and for what products?

15. In what form do you market your cassava roots, processed or cooked products?

Chapter 3: Combining ability of selected cassava genotypes for yield and secondary traits in the semi-arid areas of Eastern Kenya

Abstract

Despite the importance of cassava for food security in semi-arid areas of Kenya, there is a lack of information regarding gene action determining yield in local varieties. Therefore the objective of this study was to estimate combining ability for yield and associated secondary traits by crossing popular local varieties with some varieties from IITA using a NC II mating design. The F1 progenies were evaluated in a seedling trial laid out as a 7 x 7 simple lattice with two replicates. Results indicated significant variation among progenies for shoot weight, root number, root weight, root yield, biomass, harvest index, percentage dry matter, dry matter yield, cyanide content, and resistance to cassava mosaic disease and green mites. Average fresh root weight at 6 mo ranged from 1.1 kg to 1.4 kg plant^{-1}. To a great extent SCA effects (57 to 75%) explained variation for shoot weight, root weight, harvest index, dry matter content, root cyanide content and resistance to cassava mosaic, while GCA effects (55%) were more important for root number. Thus, our results suggested that non-additive gene action was more important than additive gene action in influencing yield and most of its associated traits in this cassava population. Overall, the results suggested that the success of cassava breeding in the semi-arid areas would depend on the ability of breeders to assemble heterotic groups of germplasm that combine well for early vigour, disease and pest resistance, root quality and high yield potential.

3.1 Introduction

Cassava is the fourth most important staple food in the tropics (De Vries *et al.*, 1967). It is commonly cultivated in areas considered marginal for most other crops. It is adaptable to low soil fertility and erratic rainfall ranging from less than 600 mm in semi-arid tropics to more than 1000 mm in the humid tropics and survives prolonged drought of 4 to 7 mo during the growing cycle in northeastern Brazil (Alves *et al.*, 2004). It requires minimum inputs, which makes it ideal for drought prone areas in tropical and sub-tropical Africa, Asia and the Americas (El-Sharkawy, 2003).

In Kenya, cassava is grown in both semi-arid and high rainfall areas for food security and as a cash crop. Surplus cassava is sold to earn income for the family. However, the varieties grown by farmers in this region are landraces that are late bulking and have low root yield potential. In order to improve the yield potential of these landraces, an

understanding of the gene effects controlling root yield and secondary traits affecting yield is important. Such knowledge would assist in devising the best breeding strategy to improve early bulking and yield potential (Kariuki *et al.*, 2002).

Improving the local landraces requires a hybridisation programme to generate hybrid progenies for selection and recombination (Fehr, 1984). Population improvement and recurrent selection in cross-pollinated crops progressively increases the frequencies of genes for specific desirable traits (Hahn *et al.,* 1980; Bryne, 1984). However, the success of population breeding depends largely on the choice of parents. Parental genotypes are usually selected on the basis of their performance or the performance of their F_1 progenies (Banziger and Paterson, 1992). In maize, selection of parental genotypes to produce F_1 hybrids is usually based on performance of their progenies (Fehr, 1984; Lee, 1995). However, experienced breeders with fully characterised core germplasm, also use direct evaluation of parents, when breeding for simply inherited traits in maize (Lee, 1995). Cassava breeders have traditionally used performance *per se* of parental genotypes (CIAT, 2004). In the current study, parental genotypes were selected based on their performance *per se* in semi-arid Eastern Kenya. The local varieties, though late bulking, have good root qualities and are popular with the farmers in the area (Kiarie *et al.,* 1991). The IITA varieties, used to cross with the local, popular varieties, were early bulking, but lacked certain attributes acceptable to farmers (Kamau *et al.*, 1998). It was assumed that crossing the two groups (local and IITA), would result in new genotypes, which combine early bulking with acceptable root qualities.

Plant breeders and geneticists frequently use diallel-mating design to obtain genetic information (Sprague and Tatum, 1942; Griffing, 1956, Eberhart and Gardner, 1966). Analyses of broad based populations are generally conducted according to Eberhart and Gardner (1966) Analyses I, II and III. Apart from diallel design, breeders also use factorial mating designs such as the North Carolina (NC) mating designs I, II, and III (Comstock and Robinson 1948; 1952) to generate genetic information on parents based on progeny performance. Genetic information generated by these mating designs is used to estimate general combing ability of the parental genotypes and specific combining ability of the progenies (Sprague and Tatum, 1942; Haulauer and Miranda, 1995).

In this study the NC II mating design, was used to generate the progenies from crosses between two groups of parents (local versus IITA varieties). Several researchers have used this design in for example, sugar cane (Hogarth *et al.,* 1981), variety crosses in maize (Eberhart and Gardner, 1966), maize (Pixley and Bjamason, 1993; Derera *et al.,*

2000) and even feed conversion in broiler rabbits (Dedkova *et al.*, 2002). In cassava, the design has been used to study resistance to cassava mosaic disease (Lokko *et al.*, 2004). Combining abilities in cassava are creatively estimated, because of the difficulties of obtaining reliable family (cross combination) mean values for traits. In most cases, data is collected on plants selected from the seedling and later selection stages. Thus, the combining ability information on cassava lines is estimated from a small group of superior progenies, which germinated or a few advanced into the clonal trials (Ceballos *et al.*, 2004). In addition, the problem with this approach is that the combining ability estimates will not be based on a random, unselected progeny population and will therefore be biased. With selection, non-additive effects tend to increase.

Objectives

The objectives of the current study were:

1. to develop F_1 populations segregating for root yield and related traits, and
2. to determine combining ability for yield and secondary traits of the selected parental genotypes

3.2 Materials and methods

3.2.1 Selection of parents

The selection of parents, to build populations for future cassava breeding work for the mid-altitude eastern semi-arid areas of Kenya, began when open pollinated derived seeds were introduced from IITA, Ibadan, Nigeria from 1994 to 2000. The seeds were mainly bulk collections from the trials. Selected genotypes were evaluated on station trials at KARI-Katumani main centre and at Kampi Ya Mawe, and Ithookwe sub-centres over several seasons. The superior genotypes were advanced by subjecting them to on-farm testing by farmers. Farmers used their experience to observe the growing habit of the various genotypes and performed a palatability test at the end of each trial (Table 15). Palatability tests of raw and boiled roots were based on appearance of fresh and boiled roots, taste (bitter or sweet) and fibre (presence or absence) (Table 15) (Kamau *et al.*, 1998; Githunguri and Migwa, 2003). The four local entries were popular local varieties with high root yield, good root quality and tolerance to cassava mosaic disease (Table 14). Their selection for this research was based on their performance *per se* and not on the performance of their progenies.

Table 14 Source, general information, agronomic traits, disease and pest resistance of parental genotypes used in the study

			Incidence		Severity		Agronomic traits					
Clone	**Source**	**General information of the origin**	**CMD**	**CGM**	**CMD**	**CGM**	**PH12**	**BH**	**RCNP**	**RTN**	**RTW**	**DM**
820001	Local	1982 collected in Makueni district	1	4	1	4	174.46	46.87	4	11	2.87	36.59
820058	Local	Local (unknown origin)	1	4	1	2	183.31	69.31	3	12	3.04	33.63
990010	Local	1995 collected in Machakos district	1	2	1	3	135.59	32.32	3	10	3.12	36.25
990014	Local	1995 collected in Kitui district	2	2	2	2	191.39	65.78	2	9	3.62	37.71
960249	IITA	OP Local germplasm (Ibadan)	1	4	1	3	184.40	45.00	3	14	2.90	34.50
990056	IITA	PPA 96	1	2	2	2	181.93	52.50	4	8	3.26	33.70
990067	IITA	OP seeds from PYT Mokwa	1	3	1	1	201.60	77.86	3	10	4.58	36.18
990072	IITA	OP seeds from PYT Mokwa	1	4	1	2	187.20	26.50	4	11	3.96	32.68
990127	IITA	Local germplasm (Ibadan)	1	3	1	2	206.32	47.47	3	21	3.35	36.44
990130	IITA	OP Local germplasm (Ibadan)	1	1	1	1	201.84	68.71	2	10	3.40	34.12
990183	IITA	89/02228	1	2	1	2	-	166.08	4	16	3.30	30.20

(Kamau, et al., 1998b; Githunguri and Migwa, 2003)

CMD- cassava mosaic disease, CGM- cassava green mites, PH12 - plant height at 12 mo, BH- branching height, LCNP- leaf cyanogenic potential, RCNP- root cyanogenic potential, RTN- root number, RTW- root weight, DM% - percentage dry matter content.

Disease and pest scores: 1= no disease, 2=10% disease, 3= 33%, 4=40% diseased, 5= 50% diseased, 6= 66% disease, 7= 75 % disease, 8= 85% disease, 9= 100% (*the percentage disease score indicate the number of plants infected per plot, which is the incidence.*); Pest score 1= not infested, 2=10% infested, 3= 33%, 4=40% infested, 5= 50% infested, 6= 66% infested, 7= 75 % infested

Table 15: Farmers' palatability scores of raw and boiled roots, and fresh root yield (RTY, in t/ha) of parental genotypes used in the study

		Raw roots				Cooked roots				
Clone	Source	Appea-rance	Taste	Texture	Fibre	Appea-rance	Taste	Texture	Fibre	RTY
820001	Local	1	1	1	1	1	1	1	1	32.8
820058	Local	2	1	1	1	2	1	1	1	33.4
990010	Local	1	1	2	1	2	1	2	1	35.0
990014	Local	2	1	1	1	2	1	1	1	35.3
960249	IITA	1	2	2	2	2	1	2	1	33.0
990056	IITA	1	2	2	2	1	1	2	1	41.0
990067	IITA	2	1	1	1	1	1	1	1	21.0
990072	IITA	2	2	2	1	1	2	1	2	35.0
990127	IITA	1	1	1	1	1	1	2	1	30.0
980130	IITA	2	1	1	1	2	2	1	2	37.0
990183	IITA	2	2	1	2	2	1	1	1	39.0

(Kamau et al., 1998; Githunguri and Migwa, 2003) Scores: 1- Good, 2 - Acceptable, 3- Poor, RTY root yield (t ha^{-1})

3.2.2 Crossing block

A crossing block was established at KARI-Kiboko farm in 2004 with four popular, but late bulking varieties and six early bulking varieties from the IITA germplasm. The varieties were crossed following the NC II mating design (Table 16). The local varieties were used as the females and the IITA as the males. The method of pollination was a modification of that employed by IITA (IITA, 1982). For further details on pollination methodology refer to Appendix 1.

Table 16: NC II mating design scheme for local and IITA varieties

	IITA (pollen parents)					
Local (female)	960249	990056	990067	990072	990127	990183
820001	X	X	X	X	X	X
820058	X	X	X	X	X	X
990010	X	X	X	-	X	X
990014	X	X	X	X	X	X

X represents crosses made; – crosses were not successful
Families – referred in the text in chapters 3, 4, 5 and appendix 1 are all based on the female (local) genotype.

3.2.3 Seedling nursery

Preliminary experiments were done at KARI-Katumani to establish optimum conditions for uniform germination of the cassava seeds (Appendix 1). The hybrid seeds were germinated at 36°C in the laboratory. The germinated seeds were planted in 5 x 8 cm black polythene bags and grouped according to family. The bags were filled with forest soil that had been cooked for 4 d to kill most of the microorganisms. Soil analysis was conducted to determine the mineral composition of the forest soil (Table 17).

Table 17: Mineral composition of the forest soil analysed at the Del Monte Kenya limited, Thika

SAMPLE DESCRIPTION	**pH Units**	**P PPM**	**K PPM**	**Ca PPM**	**Mg PPM**	**Na PPM**	**Zn PPM**	**Fe PPM**	**Mn PPM**	**Cu PPM**	**N %**
Forest soil	4.1	10	248	585	140	27	1.54	168	26	0.98	0.31

The seedbeds were covered with a clear polythene sheet that created a humidity chamber. The temperature inside a seedbed without the seedlings rose up to 50°C when the outside air temperature was 30°C. Therefore, to keep the seedbeds temperatures 2°C above the air temperature, the sides of the seedbeds were lifted between 9.00 am and 4.00pm every day.

After 21 d the seedlings were transported to KARI-Kiboko farm where they were, once again, arranged into family groups. They were left in the open for 4 d to harden off and were watered twice daily

3.2.4 Seedling field trial

KARI-Kiboko farm is located along the Mombasa-Nairobi road located at 2° 10'S; 37° 40' E and 975 m altitude. The KARI-Kiboko farm, at which the F_1 seedling trial was conducted, receives bimodal rainfall, although there are yearly variations, with peaks usually between March - May and from October – December. The monthly rainfall for the period of experimentation, December 2003 to August 2006, is provided in Table 18. The soil at Kiboko farm is ferric luvisols (Hornetz *et al.*, 2000).

Table 18: KARI-Kiboko farm monthly rainfall data (mm) between November 2003 and June 2006

Months	**Period of experimentation**			
	2003	**2004**	**2005**	**2006**
January		143.0	6.5	12.4
February		49.0	0.0	6.0
March		22.5	40.5	85.7
April		70.8	186.5	205.8
May		0.0	13.8	43.5
June		0.0	0.0	0.0
July		0.0	0.0	0.0
Aug		0.0	2.5	0.0
September		5.0	0.5	
October		15.0	20.5	
November		49.5	57.5	
December	31.5	113.6	9.2	
Total	31.5	468.4	337.5	353.4

The seedlings were planted at Kiboko farm in a 7 x 7 simple lattice design with two replications on 2nd December 2004, where only the families were replicated. Sixteen full-sibs from a family were planted in each plot per replication at the commercial spacing of 1 m x 1 m. The plots and blocks were separated by 1.5 m and 2.0 m wide alleys, respectively, to avoid competition from neighbouring families. Stakes were used to plant the parental genotypes in the trial. No mineral fertilizer was applied at planting and during growing period. Sprinkler irrigation was used to supplement the rains when necessary. The experiment was weeded every month once and no fertiliser was added.

The trial was harvested by hand when the plants were 6 mo old. The individual plants were assessed for their number of storage roots per plant and root yield per plant. Shoot

weight was determined by weighing the stems and leaves of each plant. Plot data on number of tuberous roots and yield was averaged over the plants harvested in each plot.

Specific gravity of root samples was measured on an individual plant basis. Dry matter content was determined indirectly based on the correlation between root specific gravity and dry matter (Kawano *et al*, 1987). Measurement of specific gravity was obtained by weighing roots in air and then in water. The weight in water was measured by submerging the roots in a net into a 200 L container with water. Dry matter content (DM %) percentage was determined using the formula:

DM % = 158.3 x weight in air / (weight in air – weight in water) – 142.

Dry matter yield (DMY) per hectare was estimated by multiplying the fresh root yield per hectare by the dry matter content (Kawano *et al.*, 1987):

DMY= (DM % /100) x fresh root yield.

Harvest index (HI %) was computed as the ratio of root weight to the total harvested biomass per genotype on fresh weight basis:

HI %= (root weight/ biomass) x 100

Cyanide content in the roots of each genotype was estimated using the semi-quantitative determination (O'Brien *et al.*, 1994). Cyanide content was determined by colour change from pale green to dark brown of the picrate on the paper strip (125 mm Whatman® filter paper). A rating of 1-9 was used to estimate the root cyanide content as follows:

Rating	**Cyanide content (ppm)**
1.	< 10 (pale green)
2.	10-15
3.	15-25
4.	25-40
5.	40-60 (intermediate colour)
6.	60-85
7.	85-115
8.	115-150
9.	>150 (dark brown)

Any root that had cyanide content of 100 ppm and higher must be processed before use (Bainbridge *et al.*, 1996).

Reaction to cassava mosaic disease and green mites were assessed on individual F_1 genotypes at 3, 4 and 5 mo after planting. A scale of 1 – no apparent symptoms, 2 – mild symptoms and 3 – severe symptoms was used to rate the genotypes for resistance to cassava mosaic disease (CMD) and green mites.

3.2.5 Data analysis

The parental varieties were considered as a fixed reference population; consequently results only pertain to this set of heterozygous genotypes. Even though the selected parents represent the superior groups for the breeding programme at KARI-Katumani, the inferences drawn from this study are not to be generalised. The REML (residual maximum likelihood) procedure in the Genstat Version 9 statistical software package was used to analyse the data. General combining ability (GCA) effects and specific combining ability (SCA) effects were estimated using the following model:

$$Y_{ij\,k} = \mu + Fg_i + Mg_j + FMs_{ij} + R_k + E_{ij\,k},$$ *where,*

Y_{ijk} is the observed value for a cross between the *i*th and *j*th parents in the *k*th replication;

μ is the general population mean;

Fg_i is the GCA value of the *i*th maternal parent;

Mg_j is the GCA value of the *j*th paternal parent;

FMs_{ij} is the SCA value for the cross between the *i*th and *j*th parent;

R_k is the replication effect;

E_{ijk} *experimental* error.

In this model, the terms Fg_i and Mg_j estimated GCA effects due to the local varieties and IITA varieties, respectively, while the interaction term, *FMsij*, estimated SCA effects. The GCA and SCA variances provide an indication of the levels of additive and non-additive variance in a population respectively (Falconer and Mackay, 1996). Pearson's phenotypic correlation coefficients were also calculated between root yield and the following: shoot weight, root number, root weight per plant, root yield, biomass yield, harvest index, dry matter content and dry matter yield.

3.3 Results

3.3.1 REML analysis of variance for agronomic traits

Among the crosses, significant differences ($p<0.05$) were identified for shoot weight (TSW) and percentage dry matter content (Table 19). Other traits that were significantly different ($p<0.01$) were root weight (RTW kg plant^{-1}), root yield (RTY t ha^{-1}), total biomass, harvest index, root dry matter yield and resistance to cassava mosaic disease. However, resistance to cassava green mites was not significantly different. The IITA varieties did not differ significantly for shoot weight, harvest index, root cyanogenic potential and reaction to cassava mosaic disease. Also, the local varieties differed significantly in shoot weight ($p<0.05$) and reaction to cassava mosaic disease ($p<0.01$). General combining ability (GCA) effects were estimated for those traits that were significant (Table 19). The SCA effects were significant ($p<0.05$) for shoot weight, root number, dry matter yield and root cyanide content, while harvest index and reaction to cassava mosaic disease were highly significant ($p<0.01$) (Table 19).

Table 19: Mean square values for yield, secondary traits, disease and pests

Source	df	Mean square value										
		TSW	RTN	RTW	RTY	Biomass	HI	DM	DMY	RCNP	CMD	CGM
Crosses	23	1.80*	2.30**	2.53**	2.53**	1.82**	2.36**	1.50*	2.32**	1.84**	2.73**	1.46
GCA (IITA)	5	2.24	5.92**	2.98*	2.98*	2.24*	1.80	2.28*	3.35**	0.19	1.04	2.43*
GCA (LOCAL)	3	1.89*	0.29	0.77	0.77	2.16	0.58	1.17	0.36	0.07	5.17**	0.38
SCA (Local x IITA)	15	0.04*	1.66*	1.74*	1.74	1.61	2.19**	1.34	1.83*	0.02*	2.83**	1.25
ERROR	23	0.30	0.66	0.02	2.21	0.36	6.31	6.25	0.44	0.05	0.01	0.01

*, ** Significant at P≤ 0.05 and P ≤ 0.01 probability, respectively

Shoot weight (TSW kg plant^{-1}), root number (RTN count), root weight (RTW kg plant^{-1}), root yield (RTY t ha^{-1}), total biomass (kg plant^{-1}), harvest index (HI %), dry matter (DM %), dry matter yield (DMY t ha^{-1}), root cyanide content (RCNP score), cassava mosaic disease (CMD score) and cassava green mite attack (CGM score)

3.3.2 Combining ability effects

The proportions of the GCA and SCA effects relative to the sum of squares for crosses between the local and IITA varieties were very variable. The local varieties contributed less GCA effects for most of the traits, except for the reaction to cassava mosaic disease, for which they contributed 24.57%. The SCA effects were more important for most of the traits except for root number, which had 53.49% GCA from the IITA lines (Table 20).

Table 20: Proportion (%) of GCA and SCA effects relative to the sum of squares for the crosses

	GCA (%)		SCA (%)
Trait	**IITA**	**Local**	**Local x IITA**
Shoot weight (kg plant^{-1})	26.38	13.33	60.30
Root number (count)	53.49	1.55	44.95
Root weight (kg plant^{-1})	34.43	5.32	60.25
Total biomass (kg plant^{-1})	26.76	15.47	57.77
Harvest index %	20.69	3.97	75.34
Dry matter content %	32.49	9.99	57.52
Dry matter yield (t ha^{-1})	37.03	2.41	60.57
Root cyanide content (score)	17.78	16.61	65.61
Cassava mosaic disease (score)	8.22	24.57	67.21
Cassava green mites (score)	37.94	3.53	58.52

GCA – general combing ability, SCA – specific combing ability

General combining ability

Among the parental genotypes, 990056 from IITA had the highest GCA effects for shoot weight and root number. Although the GCA values were low, some progenies from the crosses of the 990010 (Local) and 990056 and 990067 (both IITA) had positive and significant ($P<0.005$) GCAs for shoot weight and 990056 and 990067 had significant GCAs for root number (Table 21). The GCA effects for the mean root number were significant for the IITA varieties 990056 and 990067 (Table 21).

Table 21: GCA effects of genotypes for shoot weight (kg plant^{-1}) and root number

Genotypes	Source	Shoot weight				Root number			
		Mean	GCA		GCA SE	Mean	GCA		GCA SE
820001	Local	3.35	-0.37	*	0.16	8.63	-0.05		0.23
820058	Local	3.58	-0.14		0.16	8.35	-0.16		0.23
990010	Local	4.18	0.46	*	0.16	8.73	0.06		0.23
990014	Local	3.78	0.06		0.16	8.67	0.15		0.23
960249	IITA	3.32	-0.41	*	0.19	8.03	-0.48		0.29
990056	IITA	4.26	0.53	*	0.19	9.82	1.03	*	0.29
990067	IITA	4.11	0.39	*	0.19	9.25	0.54	*	0.29
990072	IITA	3.51	-0.21		0.19	7.51	-0.99	**	0.29
990127	IITA	3.82	0.10		0.19	8.75	0.19		0.29
990183	IITA	3.31	-0.41	*	0.19	8.21	-0.30		0.29

*, **, *** Significant at 0.05, 0.01 and 0.001
GCA – general combining ability, SE - standard error

The local parental genotypes had non-significant GCA effects for root yield (Table 19). However, among the IITA varieties, 990067 had the highest, significant (P<0.005) GCA effects for root weight per plant (Table 22).

Table 22: The genotypes GCA effect for root weight (RTW kg plant^{-1})

Genotypes	Source	Root weight per plant			
		Mean	GCA		GCA SE
820001	Local	1.06	-0.04		0.04
820058	Local	1.04	-0.05		0.04
990010	Local	1.17	0.08		0.04
990014	Local	1.11	0.01		0.04
960249	IITA	1.20	0.10		0.05
990056	IITA	1.03	-0.07		0.05
990067	IITA	1.24	0.14	*	0.05
990072	IITA	1.10	0.00		0.05
990127	IITA	1.05	-0.05		0.05
990183	IITA	0.97	-0.13	*	0.05

*, **, *** Significant at 0.05, 0.01 and 0.001
GCA – specific combining ability, SE – standard error

Total biomass GCA effects for 990056 and 990067 (IITA) were significant (p=0.05). Genotype 960249 had the highest and significant (P<0.01) GCA effects for harvest index that was significant (P<0.01) (Table 23).

Table 23: Parental varieties GCA effects and standard errors for biomass and harvest index

Genotypes	Source	Biomass (kg plant^{-1}) Mean	GCA		GCA SE	Harvest Index (%) Mean	GCA		GCA SE
820001	Local	4.41	-0.41	*	0.17	25.17	1.24		0.73
820058	Local	4.62	-0.20		0.17	23.24	-0.7		0.73
990010	Local	5.36	0.54	**	0.17	24.00	0.07		0.73
990014	Local	4.89	0.06		0.17	23.33	-0.60		0.73
960249	IITA	4.52	-0.30		0.21	26.66	2.72	**	0.89
990056	IITA	5.28	0.46	*	0.21	22.95	-0.98		0.89
990067	IITA	5.35	0.53	*	0.21	23.85	-0.09		0.89
990072	IITA	4.61	-0.21		0.21	24.30	0.36		0.89
990127	IITA	4.87	0.05		0.21	22.62	-1.32		0.89
990183	IITA	4.29	-0.53	*	0.21	23.23	-0.71		0.89

*, **, *** Significant at 0.05, 0.01 and 0.001
GCA – general combining ability, SE – standard error

The GCA effects for dry matter content were quite low except for 990127, which was significant (P<0.05) and positive. In dry matter yield, only the highest yielding genotype, 990067, had positive and significant (P<0.01) GCA effects (Table 24).

Table 24: The genotype GCA effects for dry matter content (%) and dry matter yield (t ha^{-1})

Genotypes	Source	Dry matter content Mean	GCA		GCA SE	Dry matter yield Mean	GCA		GCA SE
820001	Local	38.23	0.07		0.72	4.30	-0.13		0.20
820058	Local	38.95	0.79		0.72	4.30	-0.11		0.20
990010	Local	38.04	-0.12		0.72	4.70	0.28		0.20
990014	Local	37.43	-0.73		0.72	4.40	-0.10		0.20
960249	IITA	37.77	-0.39		0.88	5.00	0.06		0.20
990056	IITA	38.26	0.10		0.88	4.20	-0.20		0.20
990067	IITA	38.75	0.59		0.88	5.10	0.60	**	0.20
990072	IITA	35.08	-3.08	**	0.88	4.20	-0.30		0.20
990127	IITA	40.01	1.85	*	0.88	4.20	-0.20		0.20
990183	IITA	39.09	0.93		0.88	4.00	-0.50	*	0.20

*, **, *** Significant at 0.05, 0.01 and 0.001
GCA – general combining ability, SE – standard error

The local varieties, 820058 and 990010, had significant GCA effects (P<0.05) and (P<0.01), respectively, for low and high root cyanide content respectively (Table 25). The two local cultivars, 990014 and 620001 had significant (negative and positive, respectively) GCA effects for reaction to cassava mosaic disease.

Table 25: Genotype GCA for root cyanide content and reaction to cassava mosaic disease

Genotypes	Source	Root cyanide content				Cassava mosaic disease			
		Mean	GCA		GCA SE	Mean	GCA		GCA SE
820001	Local	4.26	-0.07		0.07	1.22	0.11	**	0.03
820058	Local	4.16	-0.17	*	0.07	1.09	-0.02		0.03
990010	Local	4.55	0.22	**	0.07	1.08	-0.03		0.03
990014	Local	4.36	0.03		0.07	1.05	-0.06	*	0.03
960249	IITA	4.21	-0.12		0.08	1.07	-0.04		0.03
990056	IITA	4.49	0.15		0.08	1.13	0.03		0.03
990067	IITA	4.37	0.04		0.08	1.09	-0.02		0.03
990072	IITA	4.31	-0.02		0.08	1.13	0.02		0.03
990127	IITA	4.20	-0.13		0.08	1.16	0.05		0.03
990183	IITA	4.41	0.08		0.08	1.06	-0.04		0.03

*, **, *** Significant at 0.05, 0.01 and 0.001
GCA – general combining ability, SE – standard error

Specific combining ability effects

The crosses had an average TSW of 3.72 kg plant^{-1}, with a range between 2.58 and 5.70 kg plant^{-1} (Table 26). The SCA effects of crosses were significant (P<0.05) and positive for crosses 990014 x 990127, 990010 x 990056 and 990010 x 990067. Other significantly different SCA effects were negative for example cross 990010 X 960249 (Table 26). There was significant interaction (p<0.05) between the local and IITA varieties in RTN (Table 19). The specific combining abilities (SCA) effects of RTN were significant (P<0.01) but negative for 990010 x 990056 and 820001 x 990067, while cross, 820001 x 990127 had a positive and significant SCA (P<0.05) (Table 26). Root weight per plant ranged from 0.80 to 1.46 kg/plant (Table 26). A few of the crosses, 990014 x 990127 and 820058 x 900056, had positive and significant (P<0.05 and 0.01, respectively) SCA effects, while for cross 820001 x 990067, this was negative (Table 26).

Table 26: Mean and SCA effects of crosses for shoot weight (kg plant^{-1}), root number and root weight (kg plant^{-1})

Cross	Shoot weight			Root number			Root weight		
	Mean	SCA		Mean	SCA		Mean	SCA	
820001 x 960249	3.43	0.49		8.47	0.50		1.14	-0.02	
820001 x 990056	3.33	-0.55		9.69	0.13		0.94	-0.05	
820001 x 990067	3.46	-0.28		7.96	-1.83	**	0.97	-0.23	*
820001 x 990072	3.62	0.49		7.82	0.36		1.12	0.05	
820001 x 990127	2.95	-0.50		10.38	1.53	*	1.11	0.10	
820001 x 990183	3.30	0.37		7.47	- 0.69		1.09	0.16	
820058 x 960249	3.88	0.71		7.00	-0.87		1.11	-0.03	
820058 x 900056	3.58	-0.53		10.47	1.09		1.24	0.26	**
820058 x 900067	3.96	0.00		9.41	0.52		1.17	-0.02	
820058 x 990072	3.24	-0.12		6.87	-0.49		1.02	-0.03	
820058 x 990127	3.75	0.07		7.74	- 0.81		0.80	-0.19	
820058 x 990183	3.04	-0.12		8.60	0.55		0.92	0.01	
990010 x 960249	2.58	-1.19	*	8.82	0.73		1.35	0.07	
990010 x 990056	5.70	0.99	*	8.73	-1.87	**	0.99	-0.12	
990010 x 990067	5.38	0.81	*	9.92	0.81		1.46	0.15	
990010 x 990072	4.11	0.14		8.47	0.90		1.27	0.10	
990010 x 990127	3.68	-0.60		8.11	-0.65		0.96	-0.16	
990010 x 990183	3.63	-0.14		8.33	0.07		1.01	-0.04	
990014 x 960249	3.37	-0.01		7.82	-0.36		1.20	-0.02	
990014 x 990056	4.41	0.10		10.39	0.65		0.95	-0.09	
990014 x 990067	3.65	-0.52		9.69	0.49		1.36	0.11	
990014 x 990072	3.05	-0.51		6.89	-0.78		0.99	-0.12	
990014 x 990127	4.92	1.04	*	8.78	- 0.08		1.32	0.26	*
990014 x 990183	3.26	-0.10		8.43	0.07		0.86	-0.13	
Statistics									
Mean	3.72			8.59			1.10		
SED	0.68			1.01			0.18		
SCA SE		0.39			0.57			0.11	
Correlation		0.75			0.66			0.77	

*, ** Significant at 5 and 1%, respectively,

SCA - specific combining ability

Biomass of the crosses ranged from 3.93 to 6.85 kg plant^{-1} (Table 27). The SCA effects for biomass were significant and positive ($P<0.01$) for the crosses 990014 x 990127; 990010 x 990056; and 990010 x 990067. The SCA effects of 990010 x 960249 were negative and significant (Table 27). The harvest index of all the crosses was low, ranging from 18.08 to 32.85% with an overall average of 23.93% (Table 27). The SCA effects for harvest index was significant and positive for 820001 x 990127, 820058 x 990056 and 990010 x 960249 but negative for 820058 x 990127 and 820058 x 960249.

Table 27: Mean and SCA effects of the crosses for the agronomic traits, total biomass (kg plant^{-1}) and percentage harvest index

Cross	Biomass			Harvest index		
	Mean	SCA		Mean	SCA	
820001 X 960249	4.58	0.47		25.38	-2.51	
820001 X 990056	4.27	-0.60		23.17	-1.02	
820001 X 990067	4.43	-0.52		23.54	-1.54	
820001 X 990072	4.74	0.54		24.68	-0.85	
820001 X 990127	4.06	-0.41		29.54	5.69	**
820001 X 990183	4.39	0.51		24.70	0.24	
820058 X 960249	5.03	0.70		22.43	-3.53	*
820058 X 900056	4.81	-0.28		27.65	5.40	**
820058 X 900067	5.13	-0.02		23.90	0.75	
820058 X 990072	4.26	-0.15		24.76	1.16	
820058 X 990127	4.55	-0.13		18.08	-3.84	*
820058 X 990183	3.96	-0.13		22.58	0.05	
990010 X 960249	3.93	-1.13	*	32.85	6.13	**
990010 X 990056	6.69	0.87	*	21.08	-1.94	
990010 X 990067	6.85	0.95	*	21.98	-1.94	
990010 X 990072	5.38	0.23		23.76	-0.60	
990010 X 990127	4.64	-0.77		20.27	-2.42	
990010 X 990183	4.67	-0.15		24.06	0.77	
990014 X 960249	4.54	-0.04		25.96	-0.09	
990014 X 990056	5.36	0.01		19.91	-2.44	
990014 X 990067	5.01	-0.41		25.97	2.73	*
990014 X 990072	4.04	-0.63		23.98	0.29	
990014 X 990127	6.24	1.30	**	22.58	0.57	
990014 X 990183	4.12	-0.23		21.57	-1.05	
Statistics						
Mean	4.82			23.93		
SED	0.74			3.11		
SCA SE		0.42			1.78	
Correlation		0.74			0.86	

*, ** Significant at 5 and 1% respectively SCA – specific combining ability

Dry matter content of all the crosses ranged from 32 to 42% with an overall average of 38% (Table 28). The SCA effects for dry matter among the crosses were all significant ($P<0.01$) except for 820001 x 990072 and 820058 x 9900127 (Table 28). At 6 mo, the crosses produced from 3.20 to 6.20 t ha^{-1} of root dry matter yield (Table 28). The SCA effects for dry matter yield of most crosses were not significant except for crosses 990014 x 990067 and 990014 x 990127 ($P<0.05$). The root cyanide content of 6 mo old cassava plants had a range of 4 to 5. The SCA effects for root cyanide content were

significant (P<0.05) and positive for 820001 x 990127, and 820058 x 900056; and negative for 820058 x 990127 (Table 28).

Table 28: Mean and SCA effects of the crosses for the agronomic traits, dry matter content (%), dry matter yield (t ha^{-1}) and root cyanide content SCA - specific combining ability

Cross	Dry matter content			Dry matter yield			Root cyanide content		
	Mean	SCA		Mean	SCA		Mean	SCA	
820001 X 960249	39.44	1.61	**	4.80	-0.10		4.19	0.05	
820001 X 990056	40.74	2.41	**	4.00	-0.10		4.33	-0.08	
820001 X 990067	39.79	0.97	**	4.00	-0.90		4.10	-0.19	
820001 X 990072	35.25	0.10		4.50	0.40		3.94	-0.30	
820001 X 990127	37.12	-2.96	**	4.30	0.20		4.53	0.40	*
820001 X 990183	37.02	-2.13	**	4.50	0.60		4.48	0.13	
820058 X 960249	36.80	-1.76	**	4.90	0.00		4.15	0.11	
820058 X 900056	37.74	-1.31	**	4.60	0.50		4.71	0.40	*
820058 X 900067	40.99	1.45	**	5.10	0.10		3.98	-0.22	
820058 X 990072	35.09	-0.78	**	3.90	-0.20		4.38	0.24	
820058 X 990127	40.85	0.05		3.50	-0.70		3.51	-0.51	*
820058 X 990183	42.22	2.35	**	4.10	0.20		4.22	-0.02	
990010 X 960249	39.53	1.88	**	5.90	0.60		4.47	0.05	
990010 X 990056	35.35	-2.79	**	4.50	0.00		4.55	-0.15	
990010 X 990067	33.99	-4.64	**	5.00	-0.30		4.83	0.25	
990010 X 990072	38.28	3.32	**	5.10	0.60		4.37	-0.16	
990010 X 990127	40.53	0.64	*	3.80	-0.70		4.64	0.23	
990010 X 990183	40.56	1.60	**	4.10	-0.20		4.43	-0.21	
990014 X 960249	35.30	-1.73	**	4.60	-0.40		4.03	-0.20	
990014 X 990056	39.22	1.69	**	3.80	-0.30		4.35	-0.16	
990014 X 990067	40.23	2.22	**	6.20	1.10	*	4.56	0.16	
990014 X 990072	31.72	-2.63	**	3.30	-0.80		4.55	0.21	
990014 X 990127	41.54	2.27	**	5.30	1.20	*	4.12	-0.11	
990014 X 990183	36.54	-1.81	**	3.20	-0.70		4.54	0.10	
Statistics									
Mean	38.16			4.50			4.33		
SED	1.61			0.85			0.29		
SCA SE		0.11			0.50			0.17	
Correlation		0.79			0.78			0.79	

*, ** Significant at 5 and 1%, respectively

3.3.3 Phenotypic correlations

The phenotypic correlations among the family averages for shoot weight, root yield, root weight and number, dry matter and biomass evaluated in this study are presented in Table 29 below. Most of the traits were positively and significantly correlated, except dry matter content with harvest index, and cyanide content, harvest index with biomass and shoot weight, which were negatively correlated. Biomass was highly correlated with shoot weight (0.969). However, root weight was highly correlated with dry matter yield and harvest index.

Table 29: Phenotypic correlations between yield and secondary traits

	DMY	**%DM**	**%HI**	**Biomass**	**RTW**	**RTN**	**TSW**
RCNP (score)	0.102**	-0.015**	0.034ns	0.069*	0.104**	-0.044ns	0.043ns
DMY (t ha^{-1})		0.44***	0.501***	0.378***	0.873***	0.361ns	0.186***
DM (%)			-0.026***	0.042ns	0.04ns	0.102**	0.039ns
HI (%)				-0.186***	0.602***	0.089*	-0.353***
Biomass					0.429***	0.29***	0.969***
RTY(t ha^{-1})					1.00***	0.382***	0.206***
RTW (kg)						0.382***	0.206***
RTN (count)							0.22***

RCNP – root cyanide content, DMY - dry matter yield, DM -dry matter content, HI- harvest index, RWT – root weight (kg $plant^{-1}$), RTN –root number per plant, TSW – shoot weight (kg $plant^{-1}$)
*, ** - Significantly different from zero at the 0.05 and 0.01 probability levels, respectively (two-tailed test)

3.4 Discussion and conclusion

The aim of the study was to generate a segregating population from crosses between the late bulking local and the early IITA varieties to study gene action for root yield and related traits. Crosses were segregating for shoot weight, root number, root weight, root yield, biomass, harvest index, dry matter content, cyanide content and reaction to cassava mosaic disease that provided sufficient genetic variation required for selection in breeding for early bulking cassava (see Chapter 4). Although GCA variance was significant, variance in crosses was predominantly accounted for by SCA variance, which ranged from 57% to 75% of the crosses sum of squares for most traits. This finding is consistent with previous studies at CIAT (Jaramillo *et al.*, 2005; Perez *et al.*, 2005). Overall, these results indicate that the future success of the breeding programme in semi-arid Kenya would depend on the ability of the breeders to separate cassava germplasm into different heterotic pools that combine well for these traits. In addition, inbred lines could be developed within groups and then crossed between complementary groups.

The results indicated that SCA determined 60% of the variations for shoot weight, indicative of the importance of non-additive gene action. Therefore, in order to have early shoot vigour, the breeder should select and identify lines that combine well. Families 990010 and 990014 had the highest shoot weight and their crosses, 990010 X 990056; 990014 X 990072; 990014 X 990056; and 990014 X 990127 had the highest positive SCA effects, suggesting that these two parents could belong to two separate heterotic groups that can be used for future breeding for early shoot vigour.

GCA effects (53%) were mainly responsible for determining the root numbers; but a breeder should also consider SCA effects, which accounted for 45% of the variation. The small difference between GCA and SCA effects suggested that it is possible to breed for increased root yield by selecting parents with high GCA for root number. Alternatively, the breeder can use germplasm that combines well for increased root numbers. Our results were in agreement with previous studies. Whyte (1985) reported that both additive and non-additive gene action influenced root number. Root number was found to be positively correlated ($r = 0.33$) with root yield, indicating that selection for large number of roots would increase root yield. Kawano *et al.* (1987) obtained similar results.

Predominantly, SCA (at 60% of crosses variance) controlled root yield, indicating importance of non-additive gene action in influencing yield. The GCA, due to IITA varieties, accounted for 34% of crosses variance, indicating that these genotypes made a significant ($p<0.05$) contribution to early root bulking in the crosses. The proportionally higher SCA effects indicated that the individual genotypes of the two groups of parents, IITA and local, combined specifically well for root yield. Perez *et al.* (2005) also reported predominance of SCA, while GCA was not significant for yield in a diallel analysis. Jaramillo *et al.* (2005) reported 59% and 41% for SCA and GCA, respectively, for root yield, which is highly consistent with these findings.

For dry matter yield, 37% of the crosses sum of squares were accounted for by GCA effects mainly due to the IITA varieties, and which were significant ($P<0.05$) (Table 19), while SCA was responsible for 61% of the crosses sum of squares, again suggesting the predominance of non-additive gene action. A similar trend was observed with cyanide content with SCA effects accounting for 66% of crosses' Sums of Squares. Jaramillo *et al.* (2005) did not measure cyanide content, but reported that SCA accounted for 37%, while GCA explained 63% of the crosses variation in a diallel analysis. However, Perez *et al.* (2005) reported that GCA was not significant for dry matter content, which supports the predominance of SCA, and thus non-additive effects in determining dry matter content in cassava.

The local varieties had more GCA effects for reaction to cassava mosaic compared to the IITA varieties. In particular, the local genotype 990014 had negative GCA effects which reflect the involvement of additive genes in the resistance it expresses. Resistance was, however, mostly explained by SCA, 67% of crosses sum of squares, suggesting predominance of non-additive gene action for disease resistance. There is a need for continuous improvement of genotypes for resistance, because the disease is prevalent in all cassava-growing areas in Africa.

Significantly, high correlations between SCA and mean values for all traits of the F_1 progeny indicated that performance of crosses *per se* could be used to predict their SCA values (Tables 26, 27, 28 and 29). Jaramillo *et al.* (2005) reported similar results.

Harvest index was positively associated with root yield, indicating that selecting for high harvest index will not compromise yield. There will be declining returns on selecting harvest index in order to increase root yield until a fall off occurs. Redesigning the crop morphology and physiology then becomes necessary. Harvest index is an important trait as it measures the efficiency of a genotype in partitioning dry matter to the storage roots.

Positive correlation between root yield and harvest index confirmed previous results (Kawano *et al*, 1978). There were positive associations among shoot weight, root yield, root weight, root number, dry matter content and biomass, suggesting that breeding for any of these traits will not reduce the desired level of the other.

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Chapter 4: Farmers' participatory selection for early bulking cassava genotypes in semi-arid Eastern Kenya

Abstract

Cassava is an important food security crop in semi-arid, Eastern Kenya, but production is constrained by planting late bulking landraces. Therefore, farmer participatory variety selection was initiated with the aim of identifying early bulking varieties with preferred root qualities. Four popular local varieties were crossed with six early-bulking varieties selected from IITA germplasm in a North Carolina II mating scheme. The resultant 225 cloned F_1 progenies were evaluated for early bulking in a 15 x 15 simple lattice design with two replications at KARI-Kiboko farm in Eastern Kenya. Sixty-five farmers participated in the selection of early bulking genotypes with preferred root qualities during the second and third harvests at 7 and 8 mo after planting. At 7 mo, there was a significant variation among genotypes for root bulking, cyanide content, dry matter content, harvest index and root number. Farmers subjected all the genotypes to a preference test and selected 30 genotypes (13%), which combined early-bulking and high root quality. A selection index based on farmers' ranking of agronomic traits was then imposed on the selected 30 genotypes to identify those that were superior in both agronomic and end-user traits for possible release and advancement. The selected genotypes were all significantly superior to the parents. The top 10 genotypes displayed above average performance for all agronomic traits. Involving farmers in selection helped to identify early bulking genotypes with end-user root qualities that could/should ultimately accelerate their adoption.

4.1 Introduction

One of the major limiting factors for cassava production in the semi-arid areas is lack of appropriate varieties. PRA studies that preceded this trial, revealed that drought was the most limiting production constraint followed, in the order of importance, by lack of planting materials, pests and diseases (Chapter 2). Early bulking varieties with end-user root qualities could enhance cassava production in the semi-arid areas if they could be harvested between 6 to 8 mo after planting. During the PRA exercise, the farmers requested that the breeder involve them during the selection process to ensure that genotypes with the required root qualities were identified at an early stage.

Early studies on root bulking in cassava were started by physiologists wanting to know when storage root development started in different genotypes (Doku, 1969). In the early 1970s, when CIAT and IITA were established, root bulking was used in germplasm

characterisation to group accessions into early and late bulking. The different groups were to be used in the breeding programme to develop germplasm adapted to different agro-ecological zones (Wholey and Cock, 1974). This germplasm was used later to develop early bulking germplasm at the two institutions for the semi-arid areas (Hershey, 1984). Among the national programmes to benefit from this early work was Brazil, which used the early bulking germplasm from CIAT to develop early bulking varieties for their semi-arid areas (Fukuda *et al.*, 2002).

There is no above ground morphological trait that can be associated with root bulking. In the absence of such traits, Kawano *et al.* (1978) recommended the use of root yield at harvest to assess for early bulking. However, IITA (1993) reported that performance of genotypes at the early stage of the growth cycle might not necessarily predict their performance in later stages. CIAT demonstrated that harvest index (HI), observed at the F_1 seedling and first clonal trials, remained constant in subsequent advanced field trials in a wide range of environmental conditions (Kawano, 1990). Therefore, harvest index is a better trait to select for than root yield.

Storage root development starts when the plants are 1 mo old. Differences in the rate of bulking account for differences in root yield after 6 mo (CIAT 1972). In grain crops, variability in rate of grain filling accounted for 70 to 80% of the differences in yield potential of hybrids (Daynard, 1969). Wholey and Cock (1974) observed differences in the rate of bulking in three cassava varieties which was attributed to the differences in root yield. However, different genotypes have different spacing requirements, for example low densities may favour vigorous genotypes (Kawano *et al.*, 1982). To ensure that all genotypes are given equal chances of expressing their differences in root bulking, a plant density of 10000 plants ha^{-1} (1 m x 1 m) is recommended in experimental plots (IITA, 1982).

Early bulking is important in the semi-arid areas to allow harvesting after only one cycle of rain or immediately after the second rain season. Studies at CIAT and in Brazil found that it was not difficult to identify early bulking genotypes for the semi-arid environments. The major difficulties were in achieving acceptable dry matter content and the end-user root quality requirements (CIAT, 1994). Acceptable root qualities can only be defined by the end-users. In order to identify the genotypes with the preferred root qualities, breeders should involve the end-users in the selection process at the early stage of breeding, so that selection is applied on a broad range of genotypes. This is termed participatory plant breeding (PPB), which ensures that only the genotypes with the right

root qualities for the target agro-ecological zone are released as commercial varieties (Fukuda *et al.*, 2000).

Breeding programmes are established to address production constraints by developing appropriate varieties. The PPB approach utilises and builds on local experience and knowledge of the farmers and gives farmers an opportunity to participate in the development process. Farmers and breeders make decisions together relying on an adaptive, flexible and result-oriented approach (Nielsen *et al.*, 1997). It recognises that farmers have indigenous technical knowledge (ITK), which they use to assess new technologies introduced in their area (Richards, 1985; Abedin and Haque, 1989). However, ITK is locally developed and relevant and can hence not be widely applied as scientific knowledge. For instance, in Uganda, a PRA on agro-forestry conducted in the lake region identified 12 agro-forestry systems used by farmers with 43 tree species (Nielsen *et al.*, 1997). The Ugandan farmers used indigenous trees and crop combinations that increase productivity, although they did not understand the tree, crop and soil interaction.

In the semi-arid areas, subsistence farmers are generally resource-poor and must deal with poor and erratic rainfall. They plant a range of crops and varieties suited to different land, soil and moisture conditions that guarantees some harvest, even when rains are late or end early. The wide range of crops and varieties counter the uncertainty of the weather. In such environments, PPB has proved useful. In Mexico for instance, PPB was used to improve maize productivity with small-scale farmers (Fijisaka *et al.*, 1997). It has been found to increase adoption rate of new varieties, which farmers have participated in selecting (Mikkelson, 1995). Thus, in the current study, a participatory variety selection was applied in breeding early bulking and adoptable cassava genotypes in Eastern Kenya. Good breeding progress will be realised by applying high selection intensity, which depends on the proportion selected. A large population with high genetic variance should be used as the source for the selection (Falconer and Mackay, 1996). Breeding progress is realised by applying high selection pressure on diverse germplasm with new and valuable alleles (Banziger *et al.*, 2000). In the current study, farmers selected cassava genotypes from a large population created by crossing popular local varieties with early-bulking and elite genotypes from IITA.

Objective

The specific objectives of the study were to:

(i) To identify early bulking genotypes using yield as the criterion, and

(ii) To identify early bulking genotypes with acceptable end-user root qualities.

4.2 Materials and methods

4.2.1 Parental genotypes

Four popular local varieties (820001, 820058, 990010 and 990014) and six IITA varieties 960249, 990056, 9900676, 990072, 990127 and 990183 (Table 1, Chapter 4) were crossed in a North Carolina II design mating scheme to produce F_1 genotypes (Appendix 1). F_1 seedlings were planted in a trial at KARI-Kiboko in December 2004. The best genotypes were selected, primarily on the basis of resistance to cassava mosaic, and planted in the first clonal trial. This trial was planted at Kiboko in June 2005. The trial experienced a high incidence of red and green spider mites. The best performing clones were selected for evaluation in the second clonal trial that is discussed in this Chapter.

4.2.2 Field trials

The second clonal performance trial was planted on 20th December 2005 at Kiboko farm with 225 F_1 genotypes selected from the earlier clonal trial. The 10 parents were planted in plots of two rows of 12 plants, repeated twice, adjacent to the trial. The trial was planted in a 15 x 15 lattice design with two replications. Each clone was planted in two rows of 12 plants each at the commercial spacing for cassava (1 m x 1 m). The stakes planted were cut from stems that were 6 mo old, not the recommended age of 8 to 18 mo (Lozano *et al.*, 1977). At planting, three plants were intended to be harvested on each plot at 6, 7 and 8 mo after planting. However, because of the immature cuttings, establishment was poor and only one plant per plot was harvested instead. Harvesting was done by pulling plants out by hand and digging out any roots left in the ground with a hoe.

Shoot weight was determined by weighing the aerial parts (stems and leaves) and the rootstock. The number of tuberous roots per plant were counted and weighed. The root cyanide content was determined by the alkaline picrate method (Williams and Edward, 1980) and scored on a scale from 1 (<10 mg kg^{-1}) to 9 (>150 mg kg^{-1}). Root dry matter

content was estimated from the specific gravity method (Kawano, 1987) using the formula:

DM % = 158.3 x (weight in air / weight in air – weight in water) – 142

Dry matter yield = root yield x dry matter content

Biomass, harvest index, and root yield per hectare were estimated using the above data as follows:

(i) Root yield (t ha^{-1}) = root weight (kg m^{-2}) x 10000 / 1000 kg

(ii) Biomass (kg $plant^{-1}$) = shoot weight + root weight

(iii) Harvest index = (root weight / biomass) x 100%

4.2.3 Farmer-participatory selection

Using the Ministry of Agriculture extension officers, 65 cassava farmers were invited from Kiboko, Mulala, Nguu and Makindu divisions to participate in the selection of early bulking genotypes at the second and third harvesting (at 7 and 8 mo after planting) (Table 2). Sixty-five of the farmers were over 30 years, 92% had primary and secondary education and 52% were women. Farmers were selected from different villages in the divisions on the basis of being cassava growers and members of the local farmer groups. The role of the farmers was to ensure identification of genotypes that combine early bulking and preferred root qualities. They were accompanied by their local extension officers. Farmers assembled at the trial and were briefed on the importance of their invitation. Together with the breeder and the social economist, the group, led by one of the farmers, brainstormed on the important qualities they would use to select the genotypes with preferred qualities. To be consistent, they agreed to use root size, appearance, taste and fibre content of both raw and cooked roots as selection criteria. Genotypes, that had marketable roots at 7 mo, were considered early (Figure 17 to 19). Assessment was based on a 'Yes' or 'No' vote by the majority of the farmers. Size was used to select only those genotypes that had roots big enough to be cooked. All the roots harvested from each plant were presented to the farmers to make their decision based on root size.

A

B

Figure 17: Cassava roots in polythene bags and farmers assessing the size of roots

A

B

Figure 18: Farmers demonstrating long, unsuitable roots of some of the late bulking genotypes

A

B

Figure 19: Roots of some early bulking genotypes at 7 mo

Farmers, in groups of 13, chewed small pieces of the roots and rated each genotype as follows:

(i) Appearance (1= very acceptable; 2= acceptable; 3= not acceptable);

(ii) Taste/ texture (1= sweet/mealy, 2=medium, 3= bitter/waxy);

(iii) Fibre (1= few fibres; 2=medium fibrous; 3= very fibrous); and

(iv) Size (1= large/marketable; 2= medium; 3= not marketable) (rated for raw roots only)

Overall acceptability of each genotype was based on the aggregate sum of raw and cooked tubers, scores as indicated below:

(i) Aggregate score of 7 = very acceptable;

(ii) Aggregate score of 8 to 15 = fairly acceptable;

(iii) Aggregate score of 16 to 21 = not acceptable).

This rating procedure was adopted with modification from Kiarie *et al.* (1991). Preference data from the five groups of 13 farmers was pooled (summed) and the average score tabulated (Table 30). Texture was combined with taste of the cooked root to give a single score. Roots of genotypes that had acceptable size were peeled and chopped into small cubes and placed on labelled plates. Any genotype that had an aggregate score of more than 4 for raw roots or 3 for cooked root was excluded (Table 30 and Figures 18).

Table 30:The grouping of scores that were used by farmers to select the best genotypes

Raw roots		**Cooked roots**		**Aggregate score (raw + cooked)**	
Total score across groups	Preference	Total score across groups	Preference	Total score across groups	Preference
4	Very acceptable	3	Very acceptable	7	Very acceptable
5 –8	Fairly acceptable	4 - 6	Fairly acceptable	8-15	Fairly acceptable
12	Not acceptable	9	Not acceptable	16 -21	Not acceptable

A

B

Figure 20: Farmers tasting raw roots

The roots were peeled and washed with clean water. Roots of each genotype were put in separate polythene bags with a manila label indicating the genotype. They were placed in pots with water. The pots were placed over a fire, covered and allowed to boil for 10 minutes until the roots were cooked (Fig. 21 and 22).

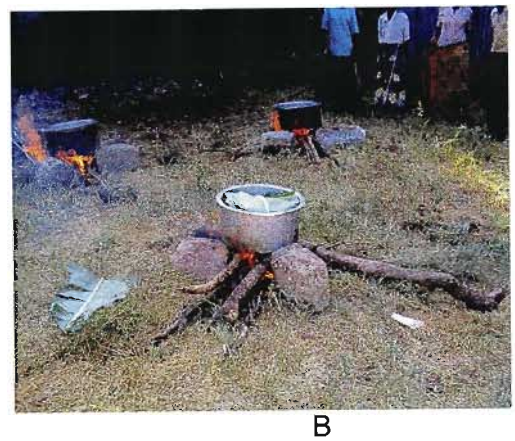
Once cooked, the pots were removed from the fire, the water drained and they were left to cool. The roots were removed and placed on labelled plates arranged on tables. Using the small groups of 13 farmers, all the cooked roots were evaluated for palatability, one genotype at a time (Figure 23 and 24).

A

B

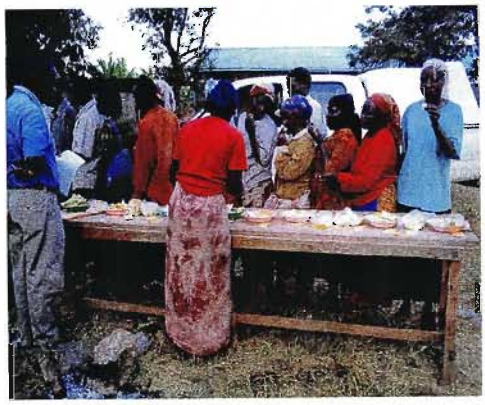
Figure 21: Farmers peeling cassava and in washing the peeled cassava

A

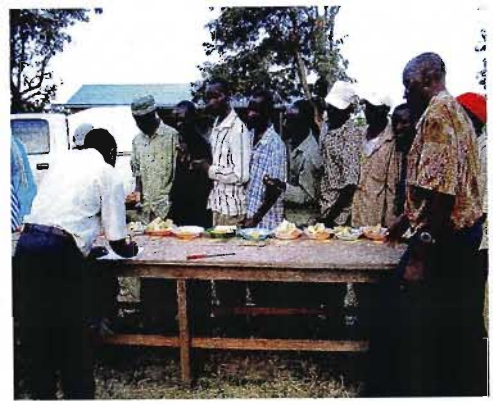


B

Figure 22: Farmers putting cassava in pots and boiling cassava in pots



A



B

Figure 23: Farmers testing the palatability of cassava roots

A

B

Figure 24: More groups of farmers testing the palatability of cassava

The selection index was applied to discriminate between the genotypes that were selected on the basis of the aggregate score of farmers' preferences. The criteria used in calculating the selection index was based on the importance farmers put on the various agronomic traits. Farmers were requested, as a group, to give the importance of each of

the following traits: root yield, dry matter yield, ratio of roots to the other plant parts (harvest index %), root cyanide, root number and aerial parts (shoot weight). Farmers agreed on a scale (1 = least important and 5 = most important) that the breeder was to impose on selected genotypes, to identify those that combined high farmers' preferences with high agronomic performance. The weight for each trait used in calculating selection index was as follows: (the letter is the code of each trait u,v,w,x,y and z are used in the model below)

Root yield	(u)	5
Dry matter yield	(v)	4
Harvest index %	(w)	3
Root cyanide	(x)	-3
Root number	(y)	2
Shoot weight	(z)	1

Negative number indicates that the trait was not desired. Standardisation of the phenotype means (P_i) measured in the separate trials was incorporated into the selection index to enable comparisons to be made as follows:

$$P_i = (x_{ij} - m_i)/s_i$$

Where, x_{ij} is the value of the trait *i* measured on genotype *j*, while m_i and s_i are the mean and standard deviation, respectively, of trait *i* in a population.

The selection index of each genotype was calculated as follows using the weights of the agronomic traits:

$$\text{Selection index} = [((u_{ij} - m_i)/s_i)*5 + ((v_{ij} - m_i)/s_i)*4 + ((w_{ij} - m_i)/s_i)*3 + ((x_{ij} - m_i)/s_i)*-3 + ((y_{ij} - m_i)/s_i)*2 + ((z_{ij} - m_i)/s_i)*1]$$ (Banziger et al., 2000)

Where the numbers (5,4,3,-3,2,1) represent the weights of importance to each agronomic trait as indicated above.

Analysis of data for agronomic traits:

Agronomic data were analysed using the GenStat Version 9 statistical software package. Time of harvesting, families and the crosses nested within families were considered fixed effects, while replications, blocks within replications and error were considered random effects in the model, as follows:

$$Y_{ijklm} = U + r_i + r(b)_{ij} + f_k + f(c)_{kl} + t_m + (t.f)_{km} + f(c).t_{kml} + e_{ijklm},$$ (Ott, 1993)

Where;

Y_{ijkm} = trait measured in the j^{th} block in the i^{th} replication corresponding to the l^{th} cross of the k^{th} family measured ant the m^{th} time

U = overall mean

r_i = i^{th} *replication effects*

$r(b)_{ij}$ = j^{th} block within i^{th} replication effects

f_k = k^{th} family effects

$f_k(c_l)$ = l^{th} cross within k^{th} family effects

t_m = m^{th} time effects

$(f.t)_{km}$ = km^{th} family by time interaction effects

$f(c).t_{kml}$= interaction between families f_k and crosses within a family $f(c)_k$ and time t_m

e_{ijklm} = random error effects

4.3 Results

4.3.1 Agronomic traits

Families were significantly different for root weight per plant, root number per plant, biomass per plant, percentage harvest index and dry matter (Table 31). The new genotypes were significantly different for all traits except root cyanide content (Table 31).

The crosses also exhibited wide variation for the various traits with root weight ranging from 0.8 to more than 6 kg/plant (Table 32).

The second harvest at 7 mo was used as the primary selection date for early bulking genotypes which combined end-user preferences by farmers. At 7 mo the parents were significantly different for all traits except harvest index and shoot weight. The new genotypes were significantly different for all traits except root cyanide content and shoot weight (Table 33).

Root weight of the parents ranged from 0.7 to 1.9 kg/plant, while that of the new genotypes varied from 0.6 to 5.6 kg/plant, indicative of the progress made in developing early bulking varieties (Table 34). The new genotypes had significantly improved harvest indices (max. 58.5%), compared to that of the parents (max. 37.8%) (Table 34).

Table 31: REML Analysis of various agronomic traits measured per plant across the families, and crosses within the families at 3, 6, 7 and 8 mo after planting

Source	d.f.	Mean Square Values													
		SHWT	sign	RTN	sign	RTW	sign	Biomass	sign	HI%	sign	DM%	sign	RCNP	sign
Time	2	119.20	***	21.62	***	262.10	***	190.55	***	45.76	***	146.95	***	33.31	***
Family	3	1.78	ns	4.13	**	14.46	***	3.65	*	3.34	*	3.12	*	0.77	ns
Time x Family	6	1.95	ns	0.11	ns	0.34	ns	1.35	ns	1.44	ns	0.16	ns	1.80	ns
Family/Cross	219	1.27	**	1.43	***	3.91	***	1.79	***	1.99	***	1.58	***	1.04	ns
Time x Family/ cross	438	0.99	*	0.97	*	1.00	ns	0.97	ns	0.95	*	1.15	*	0.79	ns

*, ** and *** is significant at 5%, 1% and 0.1% ; SHWT – shoot weight (kg plant^{-1}), RTN – root numbers per plant, RWT – root weight (kg plant^{-1}), HI% – harvest index, DM% - dry matter content, RCNP – root cyanide content

Table 32: Mean values, standard error (S.E) of the new genotypes and the average range of each trait over the three harvests (6, 7 and 8 mo after planting)

Trait	Mean	S.E.	Minimum	Maximum
Root weight (kg plant^{-1})	2.50	0.24	0.78	6.03
Dry matter content (%)	34.50	0.37	17.85	45.00
Harvest index (%)	45.00	0.01	10.00	69.00
Root cyanide content (score)	4.00	0.13	2.00	5.00
Root number per plant	9.00	0.27	3.00	15.00
Shoot weight (kg plant^{-1})	3.98	0.52	0.68	9.91
Total biomass (kg plant^{-1})	6.42	0.77	1.49	13.45

Table 33: REML analysis of variance of parents and new genotypes at 7 mo after planting

	Parents			New genotypes		
Source	df	ms		df	ms	
Root weight (kg plant^{-1})	9	4.46	***	222	2.46	***
Harvest index (%)	9	1.77	ns	222	1.87	***
Dry matter content (%)	9	2.10	*	222	1.24	**
Root cyanide content (score)	9	18.23	***	222	0.99	Ns
Root number (count)	9	2.43	**	222	1.42	***
Shoot weight (kg plant^{-1})	9	0.25	ns	222	1.01	Ns

*, ** and *** is significant at 5%, 1% and 0.1%, ns - not significant

Table 34: Mean values, standard error (S.E) and the range of each trait at 7 mo after planting

Trait	Parents				New genotypes			
	Mean	S.E.	Minimum	Maximum	Mean	S.E.	Minimum	Maximum
Root weight (kg plant^{-1})	1.25	0.18	0.68	1.87	2.42	0.23	0.59	5.59
Dry matter content (%)	35.39	0.30	31.66	37.68	34.41	0.35	21.74	44.94
Harvest index (%)	24.65	1.20	14.07	37.83	40.55	0.01	18.05	58.53
Root cyanide content (score)	5.00	0.10	3.00	8.00	4.00	0.13	2.00	6.00
Root number per plant	9.00	0.02	9.00	12.00	9.00	0.15	1.00	15.00
Shoot weight (kg plant^{-1})	3.91	0.16	2.93	4.50	3.84	0.48	0.53	9.90
Total biomass (kg plant^{-1})	5.17	0.35	4.30	5.70	6.26	0.71	1.03	12.53

4.3.2 Participatory selection

At 7 and 8 mo after planting, farmers identified three classes of genotypes based on their aggregate scores (Figure 25). At 7 mo after planting, farmers selected 30 genotypes that were early bulking with what they considered to be very acceptable attributes. At 8 mo after planting an additional 21 genotypes were selected, which were considered medium in bulking.

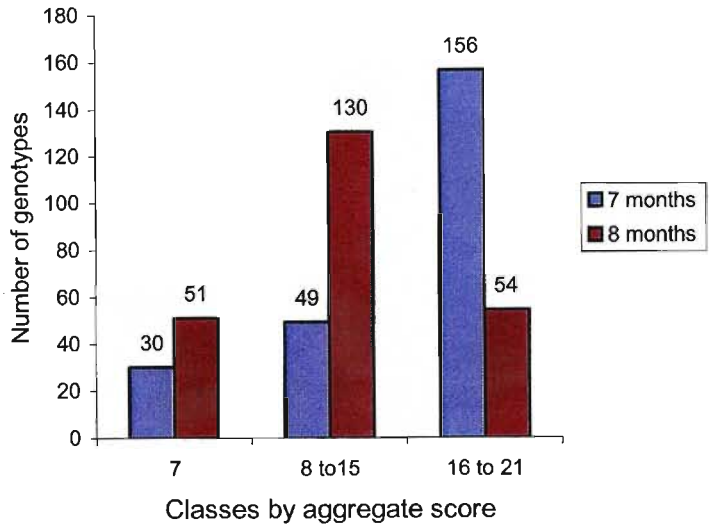


Figure 25: Classification of genotypes according to farmers' preference scores

The grouping according to the farmers' preference aggregate score of the parents and the new genotypes at 7 and 8 mo are presented below (Figure 26). Using aggregate preference scores at 7 mo after planting, the farmers selected 30 crosses out of a total of 225 new genotypes, which amounted to a selection pressure of 13%. At 8 mo after planting (Figure 27), there were additional genotypes that had edible roots, resulting in the selection of a total of 51 of the best early to medium bulking genotypes from a total of 225, equalling a final selection pressure of 22%.

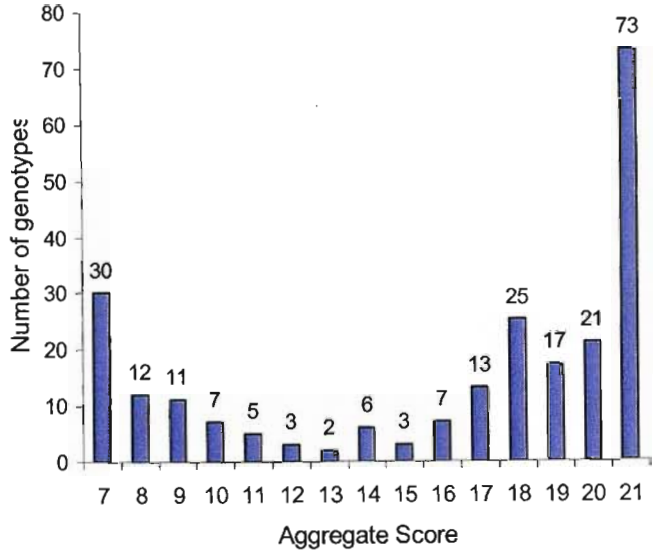


Figure 26: Frequency distribution of the 235 genotypes including 10 parents for preference score at 7 mo after planting

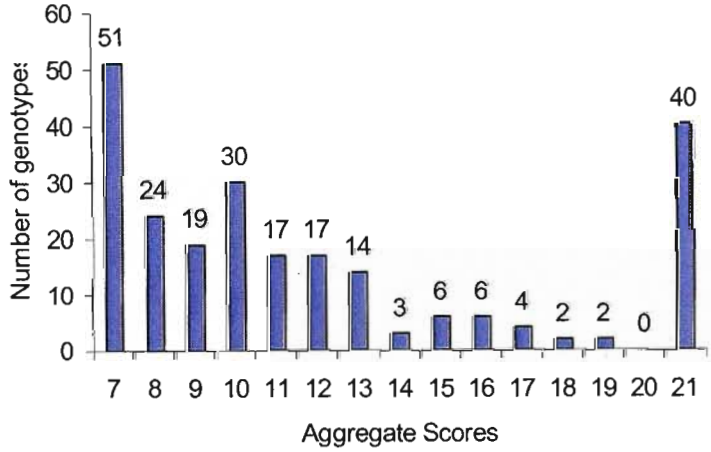


Figure 27: Frequency distribution of 225 genotypes for preference at 8 mo after planting

4.3.3 Selection index

The selection index was used to rank the 30 new genotypes, selected by the farmers, in order to identify the best ten. A comparison of the 10 best genotypes with the original parents clearly shows the progress achieved in the breeding (Table 35). The average root weight of the 10 best new genotypes was more than three times higher than the mean root yield of the parents. The harvest index of the new genotypes was 1.95 times higher than the index of the parents, while the dry matter content was 7.4% higher than that of the parents. These data are indicative of considerable genetic gain.

It appears that involvement of farmers increased the selection intensity compared to selection based on root yield alone at 7 mo after planting. Farmers' selection of 30 out of 225 genotypes (13%) is equivalent to a high selection intensity of 1.76 assuming normal distribution as described by Falconer and Mackay (1996). However, if the breeder could have used root yield, as the sole criterion to select early bulking genotypes, more than 100 genotypes or 42% would have been selected, which results in a low selection intensity of 0.97.

Comparison of root weight of each of the 10 best new genotypes with the root weight of each of their parents demonstrates the possible response to selection in root weight (Figure 28).

Table 35: Mean of agronomic data, preference aggregate score and selection index of 10 best new genotypes and 10 parents.

Crosses	Family	Pedigree	Means from REML analysis SHWT	RTN	RTW	HI%	DM	RCNP	Preference Aggregate score	Selection index
Cross 139	990010	990010 x 990183 P4R1B1	6.49	14	5.56	48.19	39.57	5	7	26.04
Cross 53	990014	990067 x 990014 P1R1B1	3.65	11	4.39	53.09	38.97	3	7	22.8
Cross 146	820001	990056 x 820001 P4R2B6	5.56	11	4.35	46.49	38.55	4	7	19.06
Cross 214	820001	990067 x 820001 P8R2B3	2.99	10	3.84	54.54	39.25	4	7	16.47
Cross 168	820001	820001 x 960249 P1R1B7	5.83	12	3.93	43.49	37.07	3	7	15.69
Cross 92	820001	820001 x 990183 P1R1B5	5.9	11	4.4	45.37	34.3	4	7	15.55
Cross 188	990014	990067 x 990014 P8R2B5	5.87	11	3.57	42.33	36.92	3	7	14.47
Cross 104	990010	990010 x 990127 P9R1B6	4.31	11	3.79	46.8	40.28	4	7	14.06
Cross 98	820058	990067 x 820058 P1R1B5	3.53	10	3.5	48.89	36.45	3	7	13.44
Cross 14	990010	990010 x 990127 P8R1B6	2.38	8	2.65	53.46	39.01	3	7	11.06
Mean			**4.651**	**11**	**3.998**	**48.265**	**38.037**	**3.6**		
Parents										
990127	IITA		3.75	12	1.75	37.83	35.6	5	18	18.68
990072	IITA		3.75	10	1.87	32.78	35.01	4	17	15.86
990183	IITA		4.05	11	1.65	29.87	35.75	5	18	10.87
990067	IITA		3.85	9	1.51	27.76	34.83	4	17	6.3
990056	IITA		2.92	11	1.38	31.98	37.68	4	18	2.82
990014	Local		4.5	10	0.73	14.07	36.24	5	18	-17.35
990010	Local		3.85	9	0.68	15.09	36.76	8	19	-19.68
960249	IITA		4.02	10	1.51	27.37	31.66	5	17	13.59
820058	Local		4.1	9	0.75	15.48	34.68	5	19	-14.31
820001	Local		4.38	9	0.73	14.3	35.68	3	19	-16.73
Mean			**3.917**	**10**	**1.256**	**24.653**	**35.389**	**4.8**		

SHWT – shoot weight (kg plant^{-1}), RTN – root number, RTW – root weight (kg plant^{-1}), HI – harvest index, DM% - percentage dry matter content, RCNP – root cyanide content. Preference score - genotypes with an aggregate score of seven were the best, 8 to15 acceptable and 16 to 21 not acceptable. Farmers weights on the different traits shoot weight – 1, root yield – 5, dry matter yield – 4, harvest index – 3 and root cyanide - (-3)

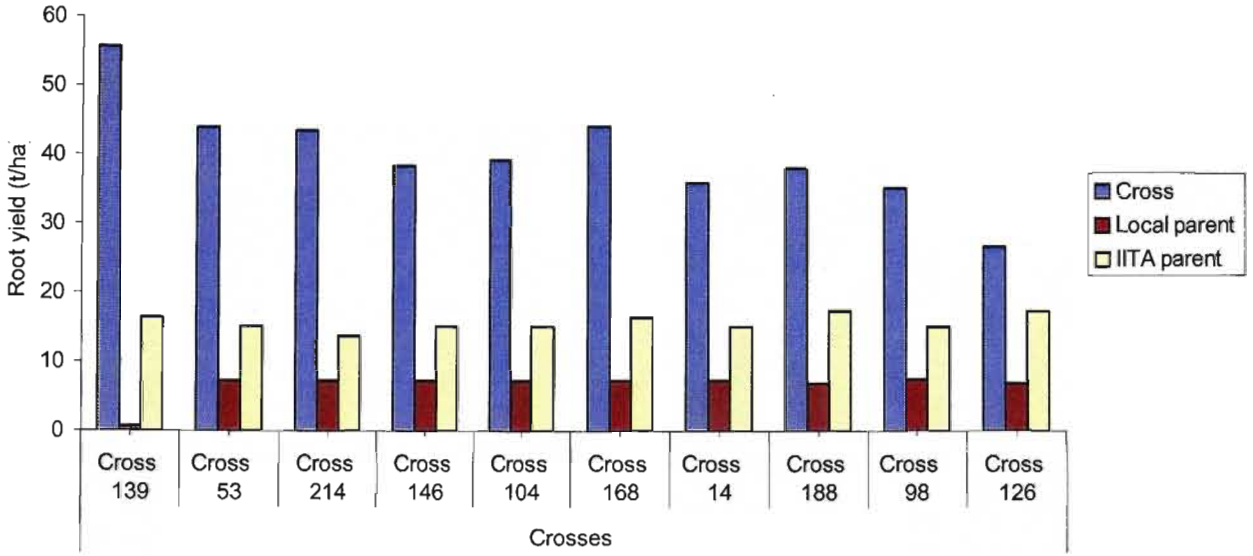


Figure 28: Comparison of the best 10 crosses from the 30 selected by farmers identified through selection index with their parents

4.4 Discussion and conclusion

The aim of this study was to identify genotypes that combined early bulking and end-user preferences from the progenies of crosses between six early bulking IITA cassava varieties and four local landraces. The progenies were initially evaluated in a seedling trial (Chapter 3). The seedlings were cloned and advanced to the first clonal trial, and the best 225 genotypes advanced to the second clonal trial discussed in this Chapter. The second clonal trial was harvested at 6, 7 and 8 mo after planting and agronomic data and farmers' aggregate scores recorded. The agronomic data was used to assess the genetic variation among the traits measured. In addition it was used to estimate the selection indices that were used to rank the farmers' selected genotypes. Finally, after using the selection index, the ten best genotypes, with superior end-user preferences and yield, were identified

Large variation in shoot weight, root weight, root yield, and dry matter content was an indication of the wide genetic variation for these traits present in the population of 225 crosses. Kawano *et al.* (1978) reported that root yield was the best criteria for selecting early bulking cassava genotypes. However, in this study, farmers' criteria for selecting early bulking genotypes was used in combination with measured, agronomic data. From the yield data at 7 mo, several new genotypes yielded more than 4.1 kg/plant, with one new genotype, number 139 yielding 5.5 kg/plant. These high root yields, observed in the crosses at 7 mo, were comparable with those observed by Williams (1974) at 8 mo after planting. In future studies it would be advisable to start selecting as early as 5 and 6 mo after planting in order to be able to identify the very early bulking genotypes.

Harvest index in cassava is little affected by the environment and is a good indicator of the potential performance of a genotype across agro-ecological zones (Kawano, 1990). The 10 new genotypes all had harvest indices over 40% and some were even over 50%, which is very high according to the CIAT classification (Kawano, 1990). A few genotypes, which were not part of the genotypes selected by the farmers, had harvest indices ranging from 57% to 64%, which is very high according to the optimum 50 to 60% for cassava (Williams, 1974; Iglesias *et al.*, 1994).

Average dry matter content for the 10 best genotypes was 34%, which compared well with 30 to 35% of the popular local parents. A number of new genotypes had dry matter contents between 41 and 45%, but these roots were often fibrous and therefore rejected by the farmers. The high dry matter content exhibited by the new genotypes was clearly

superior to all the parents, indicating that some significant improvement was achieved and contradicted previous reports from CIAT (1994) that it is very difficult to attain high dry matter content and the preferred root qualities.

The PPB selection by the farmers proved to be a fast and simple method to identify superior genotypes. The farmers in most cases appeared to use the same criteria as a breeder would. The farmers' selection process was holistic, combining several agronomic and storage root quality traits at the same time. The selection was based on consensus building process, where farmers discussed until the majority voted for or against.

Using preference scores, a total of 30 early bulking and 21 medium bulking genotypes were selected by the farmers. The 30 early bulking genotypes selected, represented a 13% selection pressure, resulting in a high selection intensity of 1.76 (Falconer and Mackay, 1996). If root yield was the sole criterion for selection, over 100 genotypes that had more than 3.0 kg/plant would have been selected i.e. 42%, equivalent to a lower selection intensity of 0.97. The PPB enabled incorporation of a preference aggregate score, thereby ensuring a higher selection intensity (i), and together with a large population (n = 225) of the new genotypes would increase response to selection. The study has shown that farmers clearly do not select varieties on the basis of root yield alone, but consider other quality traits, which breeders often ignore. Similar sentiments have been reported from Colombia (CIAT, 1994), where it was found to be essential that farmers participate in selection, and which may assist in the future adoption of the varieties selected. In Tanzania, Kapinga *et al.* (1997) reported better adoption when farmers were involved in selection.

Farmers' selection helped to bring down the final number of superior genotypes, based primarily on root yield and root qualities (taste, appearance, fibre content etc).

Several selected genotypes, such as numbers 53,139, and 146, were highly superior to the best parental genotype (990127), in root yield as well as dry matter content, showing strong progress in breeding and an indication of transgressive segregation and hybrid vigour. Merging the farmers' preference aggregate score and the selection index based on the agronomic data, assisted in the final identification of the best genotypes developed in the breeding programme.

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Chapter 5: Overview and the way forward

5.1 Introduction

The research presented in this thesis was conducted in preparation for the establishment of the first functional cassava breeding programme in Kenya targeting the semi-arid areas. The overall goal of this research was to develop new cassava genotypes with shorter bulking period compared to the local landraces for the semi-arid areas of eastern Kenya, through hybridisation with the early bulking IITA genotypes. This was achieved by accomplishing the following main objectives:

- Identifying farmers' perceptions of cassava production constraints and farmers' varietal preferences in the semi-arid areas of Eastern Kenya through participatory rural appraisal; Developing cassava breeding methodologies for the semi-arid areas that would form the baseline of future breeding and improvement;
- Identifying the gene action that influences root yield and secondary traits in order to devise an efficient strategy for improving cassava in the semi-arid areas; and
- Involving the farmers in identifying genotypes that combine early bulking with end-user preferences.

5.2 Cassava production constraints and end-user preferences

Involving cassava producers through a participatory rural appraisal (PRA) proved to be an essential part of the breeding process. Consulting farmers in the early stages help to design a focused research approach, taking into account the farmers' needs. The PRA was conducted in two phases during April and August 2004 in Eastern Kenya. Focus group discussions were conducted in two villages, Kathekakai and Muuni which are approximately 180 km apart and located in LM4 and LM5 agro-ecological zones, in April 2004. Care was taken to include both genders during the focus group interviews, because in this part of the country, the men are primarily interested in marketing cassava products, while the women are more interested in cooking quality, and the handling of the cassava during food preparation. The village groups discussed the views of each gender and a consensus list of constraints was drawn up. The second part of the PRA involved interviewing individual farmers in different agro-ecological zones in Machakos, Makueni and Mwingi districts in order to confirm the findings of the focus group discussions.

The focus groups and the individual farmers identified similar researchable production constraints, and the four most important ones were ranked as follows: drought, lack of adequate planting materials, pests and diseases. According to the farmers, drought could be addressed by developing drought escaping, or early bulking varieties, which would mature in 6 to 10 mo. These early varieties were expected to posses the end-user qualities that could only be defined by the farmers. Therefore, it was necessary that farmers be invited at appropriate times to participate in the selection of the improved varieties from the clonal populations. Pest and disease resistance was to be incorporated in the development process of early bulking genotypes as well.

5.3 Development of protocols for pollination and seed germination

Since there was no established cassava breeding programme in Kenya, it was important to develop local breeding techniques. Especially, in the areas of pollination, seed germination and vegetative propagation. Hybridisation was initially done at KARI-Katumani, but seed set was generally poor. The process was repeated at KARI-Kiboko farm. The availability of irrigation at Kiboko, as well as the higher average temperatures, resulted in a successful crossing block. The IITA pollination method was adapted to the local conditions.

Preliminary studies were done to develop procedures that would guarantee rapid and uniform germination of the hybrid seed. A uniform F1 seedling population is essential in order to identify the right gene combination and to select the most promising lines. The optimum condition for germination was at 36°C in petri-dishes, followed by transplanting into pots containing forest soil.

5.4 Gene action controlling root yield and secondary traits

Understanding the gene effects controlling the various yield related traits is essential in order to formulate an effective cassava breeding programme. In this programme, parents were selected based on their performances across the different agro-ecological zones in Kenya over several seasons. Full-sib F_1 populations were developed using a NC II mating design. The seedling trial was used to estimate GCA and SCA effects of the various agronomic traits.

Root weight (kg/plant) was 60% controlled by the SCA effects, suggesting the predominance of non-additive gene action over additive gene action. Specific combining ability (SCA) effects were also predominant in influencing the secondary traits such as

biomass, dry matter content, shoot weight, harvest index, root cyanide content, resistance to cassava mosaic disease (CMD) and green mites. GCA contribution for most traits came from the IITA genotypes, while local landraces were important in contributing three times more of the GCA effects for CMD resistance.

From these results it appears that SCA effects are important in the improvement of root yield in cassava and the related secondary traits. Cassava is heterozygous and there are no inbred lines that have been developed. To be able to utilise the SCA effects to improve cassava for all the traits mentioned above, it is necessary that inbred lines are developed to maximise on the benefits accruing from the SCA effects. They may be developed through the use of anther culture, to produce dihaploids which would avoid the problems associated with inbreeding depression, or by self pollinating the plants of varieties, that are not as sensitive to inbreeding depression for several cycles until there is no further segregation. These inbred lines should be developed in such a way that the breeding programme would have separate, heterotic groups for improving various traits. This should be investigated in future research.

5.5 Identifying early bulking genotypes with end-user preferences

Involving farmers to identify genotypes that combine early bulking and end-user preference is of primary importance in the semi-arid areas of Kenya. Cassava is mainly utilised when raw or cooked, without elaborate processing. As a result of this mode of utilisation, the end-users have attached some qualities, which must be in a variety if it is to be adopted.

The genotypes in the seedling trial were cloned and planted in two successive trials. Red spider mites and the green mites affected the first clonal trial and the tolerant genotypes were selected and then advanced to the second clonal trial in which different plants were harvested at 6, 7 and 8 mo after planting. At the second and third harvests, farmers were involved in selecting early bulking genotypes with acceptable end-user qualities, using palatability tests. Thirty genotypes were identified as early bulking with preferred end-user qualities. A selection index was imposed on the farmers' selections and the 10 best genotypes were found to be high yielding, early bulking and superior to their parents. The parental genotypes were late and had not developed tuberous roots at 7 mo. At 8 mo after planting, 51 genotypes, which included the 30 genotypes selected at 7 mo after planting, had developed tuberous roots that could be subjected to palatability tests.

These results demonstrate that it is possible to breed for early bulking cassava genotypes for the semi-arid areas, and combine high root yield and end end-user qualities. Importantly, early bulking genotypes could be identified at 7 mo. Nonetheless, it could be suggested that selection could even be conducted at 6 mo after planting to identify the very early genotypes. Future research should investigate the optimum time for selection of early bulking genotypes.

5.6 Breeding progress achieved

Through participatory selection, farmers identified 30 genotypes that combined early bulking and end-user qualities at 7 mo after planting. The genotypes were among the superior genotypes in high dry matter, harvest index and root yield. Among them were genotypes that were within the optimum range of 50 – 60% harvest index for cassava. In comparison, some of the best 10 genotypes had root yields of over 300% that of parents. The new genotype number 139 had a root weight of 5.6 kg/plant after 7 mo compared with 0.75 kg/plant of the best local parent (820058). Harvest index was more than doubled and dry matter content increased by 7%. This is a significant breeding progress obtained for cassava in 3 y. Since harvest index in cassava is not affected by environment, these genotypes are expected to remain high yielding across the agro-ecological zones. Selection of improved genotypes was done under high CMD pressure and progress in resistance to this disease will have been made.

5.7 The way forward

The best 10 genotypes should be multiplied to increase planting materials for replicated trials in different agro-ecological zones. At each trial site farmers in the areas should be involved in selecting the variety of their choice. The best of the 30 genotypes should also be included in the next crossing block to generate new gene combinations for future selection for earliness, end-user traits, and disease and pest resistance. Particular attention will need to be given to an evaluation of the resistance to CMD in the improved genotypes. Following the successful breeding in such a short time, it will be necessary to establish and strengthen the multiplication and dissemination of planting materials system. Such a system will be used in future to disseminate new varieties released from the breeding programme.

Appendix 1: Research notes

Appraisal of techniques for use in breeding cassava in the semi-arid areas of Eastern Kenya

Abstract

In Kenya, access to a diversity of clones and quantities of disease free planting materials are a major limiting factor for cassava production. In part, this is because previously Kenya relied on cassava varieties bred in other countries. And consequently, there are no established breeding techniques for cassava in Kenya. The main objective of this study was to develop techniques that would facilitate cassava breeding in the semi-arid areas. Controlled pollinations were conducted between six IITA and four local varieties, using the NC II mating design. Germination tests were conducted in a range of temperatures, with preheated seeds and non-treated (control). Rapid propagation techniques were tested using branch shoot tips from locally available clones. The first pollinations, at Katumani, failed because of water and low temperature stress. The second pollinations, at Kiboko, were successful because of higher temperatures and the use of irrigation. The best temperature for seed germination was 36°C, without any pre-heating treatment. In the vegetative propagation trials of green stem cuttings, the portion of the stem below the tip, planted in a mixture of topsoil and sand, sprouted best.

1. Introduction

Because of the absence of a functional breeding programme in the semi-arid area of Kenya, there are no local protocols that can be used to efficiently produce hybrids, successfully germinate the seed, and rapidly propagate cloned genotypes for replicated trials. In addition, a mechanism for rapid multiplication and dissemination of the improved varieties to the farmers is needed.

Cassava breeders in the past have relied on open pollination to generate populations for selection. This procedure has the inconvenience of allowing a considerable number of undesirable pollen parents to be involved in the improvement of cassava. Reports from CIAT indicate that uncontrolled open pollinated progenies of two varieties include large numbers of selfs (Kawano *et al.*, 1978a). Therefore, controlled pollination is essential if the breeding programme is to make rapid progress. However, controlled pollination is not common in cassava breeding and local pollination procedures, based on available skill and resources, need to be developed.

Cassava seeds germinate with difficulty under field conditions. Germination percentage is often low and seedling emergence uneven (Nartey, 1978). The long period needed for germination makes the seeds vulnerable to infection by soil pathogens. Uniform germination is important in a breeding programme to identifying genetic differences between genotypes in a breeding programme. Common seed treatment methods, used to break the physiological dormancy in seeds, does not seem to work in cassava (Myer and Poljakoff-Mayber, 1963). A number of experiments on seed germination have not led to the development of a effective procedure (Ellis and Roberts, 1979; Ellis *et al.*, 1982). Fresh seeds at CIAT are germinated in heated greenhouses. Storing cassava seeds at room temperature and high relative humidity for 3 mo improved germination (CIAT, 2004). At IITA, the soil temperature and moisture content at planting are generally favourable for seed germination, and seeds are planted directly into the field.

Vegetative propagation has many physical and biological constraints (Lozano *et al.*, 1984). In sites with moderate to high stress conditions, sprouting may be low and plant development slow, resulting in delayed storage root development (Porto and Asiedu, 1993). Stakes from younger stems are susceptible to attack by pathogens and pests (Lozano *et al.*, 1984; Toro and Atlee, 1985). Developing an efficient propagation and delivery system for planting materials will enable rapid dissemination of improved varieties. Therefore this research proposes to conduct preliminary investigations on the propagation of the young green shoots.

Objectives

The specific objectives of this study were:

1. To develop a hand pollination protocol for the semi-arid areas of Kenya;
2. To establish the best condition for uniform germination of cassava seeds;
3. To develop a local method to propagate cassava from young green shoots.

2. Materials and methods

Cassava pollination

Crossing blocks were established at KARI-Katumani Research Centre in Machakos district of Kenya (1°35' S; 37° 14' E; 1600 m altitude) in agro-ecological zone LM4 (Jaetzold and Schmidt, 1983) with bimodal rainfall. Average temperature is 25°C dropping to 13°C in June, July and August. Each season receives 250 to 400 mm of rainfall in approximately 60 d (Mavua and Kusewa, 1989). April and November are the

only months which receive rainfall in excess of potential evaporation. The soils are deep, broadly similar in texture and range from friable clays to loamy sand, which caps under the raindrop impact, becoming brick hard when dry.

At KARI-Katumani, pollination was conducted on varieties in an advanced yield trial planted in October-November 2001. Each variety was planted in a plot of 40 plants, replicated three times. Crossing was done according to the NC design II mating scheme (Comstock and Robinson, 1948 and 1952). Four local varieties (820001, 820058, 990010 and 990014) were designated females and the six varieties (990056, 990067, 990072, 990127, 990183 and 960249) from IITA were used as the males.

Pollen was collected before 10.00 am using sterile ear bud cleaners obtained from the African Cotton Industries Ltd, in Mombasa, Kenya. The bud cleaners were used instead of the velvet cloth recommended by IITA, which was not locally available. Use of the local resources was important in this study (see introduction). Pollen collected from each IITA genotype was placed in labelled 250 ml glass beakers in a cooler box. Each beaker was covered with aluminium foil to prevent contamination of pollen. All the beakers had been sterilised with ethanol and allowed to dry before use. At harvest seeds for each cross were bulked.

A second site for crossing was established at KARI-Kiboko farm, located along the Mombasa Nairobi road (2° 10'S; 37° 40' E; 975 m altitude). Rainfall is bimodal with peaks in April (113 mm) and November (145 mm), and annual mean of ± 561 mm. The short rainy season (October to December) has a seasonal mean of 328 mm and the rains are more reliable than the long rains. Long rains occur during March to May with a mean of 233 mm. Average temperatures are highest in February and October (KMD, 1984). Soils on the farm are mainly rhodic ferralsols to ferric luvisols (Hornetz *et al.*, 2000).

At Kiboko the same varieties were planted as at Katumani, with the exception of the IITA varieties 990072 and 990130. All local varieties, and the remaining five IITA varieties, were planted at a spacing of 1 m x 1m in plots of 15 plants each. For ease of pollination, varieties were established in paired rows. Pollination started at 9.00 am and continued to 3.00 pm. Male flowers were used to carry pollen and pollinate the female flowers (Figure 29 A and B). Female flower buds were opened with a pair of forceps, pollinated and a tag, indicating the date and the parents (female x male), was attached. The pollinated flowers were immediately covered with a polythene bag until the following day, to prevent

contamination with unknown pollen (Figure 29). The polythene bags were replaced with net-bags that remained tied on until seeds were harvested.

A B

Figure 29: A and B: Pollination and developing seed

Seed germination

The aim was to establish the best constant temperature for germinating cassava seeds, using the local facilities. Preliminary seed germination trials were conducted with open pollinated seeds of a popular local variety 820001. Seeds were collected from the crossing block at Kiboko in June and July 2004. Germination tests were conducted under controlled temperature in four different incubators, set at 36°C, 38°C, 40°C and 45°C. Seeds were disinfected by washing with a weak solution of *sodium hypochlorite* (3.5% m/v) and subsequently rinsed with distilled water to remove the bleach. Ten seeds were placed on a 125 mm Whatman® filter paper in a petri-dish.

Seeds were either pre-heated at 60°C for 7 d (treated) or left untreated (control). For each treatment 10 seeds were placed in a petri-dish and each petri-dish was considered a replicate. Distilled water was added in each petri-dish until the 125 mm Whatman® filter paper was soaked. The two sets of petri-dishes with seeds were arranged in the incubators. Each temperature (incubator) was considered as a separate experiment. Germination was monitored every day for 25 d and water was added to prevent dehydration. Seeds were considered to have germinated when the radicle had emerged from the hard seed coat.

Propagation

Propagation experiments were conducted to compare sprouting of green cuttings in different media. Each nursery bed was 90 cm wide, 3 m long and 10 cm deep (Figures 30 and 31). At KARI-Katumani, three media consisted of the topsoil (normal); the topsoil mixed with equal amount of sand; and a commercial cocopit medium with no mineral or nutrition qualities. The chemical analysis of the soil and sand is presented in Table 36. Planting was done in plastic trays (*TEKU Seedling trays JP 3050/160),* which had 160 segments. Three plastic trays of each medium were randomly allocated to three replications and placed in the nursery bed, such that each replication had all three media represented.

Table 36: Mineral analysis of the different media used in propagation of cuttings

Soil sample	**pH**	**P** (ppm)	**K** (ppm)	**Ca** (ppm)	**Mg** (ppm)	**Na** (ppm)	**Zn** (ppm)	**Fe** (ppm)	**Mn** (ppm)	**Cu** (ppm)	**N** %
Normal soil	5.8	56	767	1303	288	34	2.65	31	101	1.57	0.140
Sand	6.2	1	59	445	127	4	0.21	16	18	0.07	0.028
Norman soil and sand	6.1	31	416	835	183	6	1.35	18	59	0.83	0.112

Note - cocopit was not tested because the company, which sells it, had information that it is lignified fibre with no minerals. Soil test was done at the Del Monte Kenya Ltd, Thika, Kenya

Shoot tip cuttings (with three nodes) were obtained from branches of cassava plants. In addition, three node sections, taken immediately below the shoot tip cutting were obtained from the branches. Cuttings were stored in buckets with sterilised water under the shade. All the cuttings were washed in a solution of a systemic fungicide (Ridomil) and insecticide (Karate) to prevent fungal infection and pest attack. Each nursery was covered with clear polythene that created a humidity chamber (Figure 31). The sides of the sheet were lifted from 10.00 am to 3.00 pm to allow cooling. A 1.5 m alley separated the nurseries. Watering was done every day to avoid dehydration. The number of sprouted cuttings was counted.

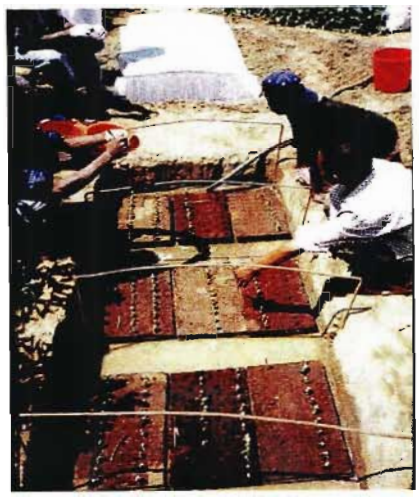

Figure 30: Planting the cuttings

Figure 31: Covering the nursery with a clear polythene sheet

Data analysis

Data for seed germination and propagation were analysed using REML (residual maximum likelihood) procedure in the Genstat Version 9 statistical software package. Pooled error was used to test for significance.

In propagation trials, the shoot tip cutting and cutting below shoot tip were conducted in different experiments, but they were combined during the analysis.

3. Results

Appraisal of pollination procedures

At KARI-Katumani, pollination started in May and continued up to the end of June, i.e. pollination was conducted over 2 mo. Pollen was collected from 8.30 am to 10.00 am every morning. Pollination started at 10.30 am every morning. Immediately after

pollination, the flowers were covered with a transparent polythene bag for 7 d to prevent contamination with unknown pollen. This crossing block failed to yield enough hybrid seeds for a breeding trial due to water stress and low temperatures. During this period, the average minimum and maximum temperature were 11.3°C and 23.6°C, respectively, and only 26.3 mm of rainfall was received in August.

The crossing block was repeated the following year at Kiboko, where irrigation facilities were available and day and night temperatures are higher than at Katumani. Flowering started in March and continued to November, while pollination was done from March to the end of June. Flowers opened much earlier in the day than at Katumani, starting at 8.30 am in Kiboko. The seeds took 90 d to reach physiological maturity. The mature fruits were dried in the sun until the capsule dehisced open releasing hybrid seeds. For unknown reasons there were some flowers that aborted. Another problem encountered at Kiboko was the plants grew taller than the pollinators (Figure 32)

Figure 32: Height of the plants after 6 mo

Seed germination

Seed germination tests at four different temperatures (36, 38, 40 and 45°C) were significantly different (P<0.001). Differences between the treatments were also significantly different (P<0.01) (Table 37). There was no seed treatment x temperature interaction effects. The highest germination (77%) was from untreated seeds at 36°C (Figure 33). The control seeds germinated better than the pre-heated seeds at all temperatures, except at 45°C, where both the heated and control seeds failed to germinate (Figure 33).

Table 37: Cassava seed germination at different temperatures (36, 38, 40 & 45°C)

Source	d.f.	ms.	Significance
Reps within experiments	8		
Temperature	3	176.71	<0.001
Treatment	1	9.85	0.002
Experiment x temperature	3	1.74	0.156

Treatment – Heated seeds and not heated (control)

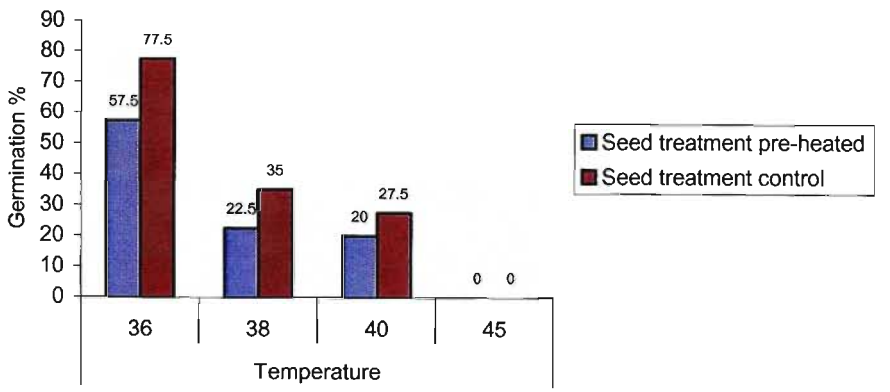

Figure 33: Germination percentage of heated and control seeds (Temperature °C)

Propagation techniques

Preliminary investigation of the vegetative propagation of the green shoots of branches using the topsoil, cocopit medium and normal soil mixed with sand, indicated better sprouting of the cuttings from normal soil mixed with sand (Figure 34). There was a significant interaction ($P<0.05$) between cutting type and media (Table 38). The cutting below the shoot tip sprouted better (9.9) than the cutting of the shoot tip (4.8). The cutting below the shoot tip sprouted better in all three of the media (Figure 34). Figure 35 shows three nursery beds with plantlets grown from cuttings below the shoot tips.

Table 38: REML analysis for sprouting of shoot tips cuttings and below shoot tip in three different media

Source	d.f.	ms	Significance
Reps within experiments	4		
Experiment	1	6.42	0.011
Media	2	0.58	0.557
Media x Cutting	2	3.26	0.039

Experiment - comparison of the shoot tip and section below tip conducted in separate experiments
Cutting - Sections within experiments

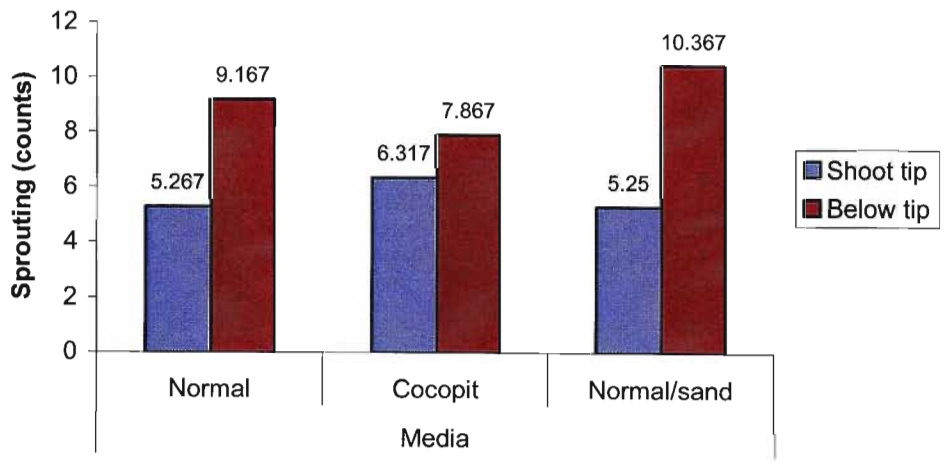

Figure 34: Average sprouting of each treatment in different media

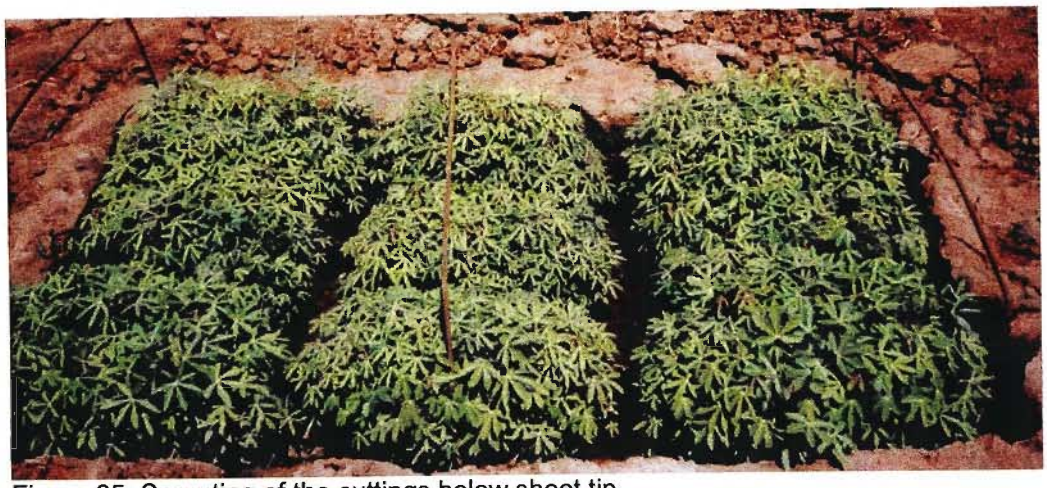

Figure 35: Sprouting of the cuttings below shoot tip

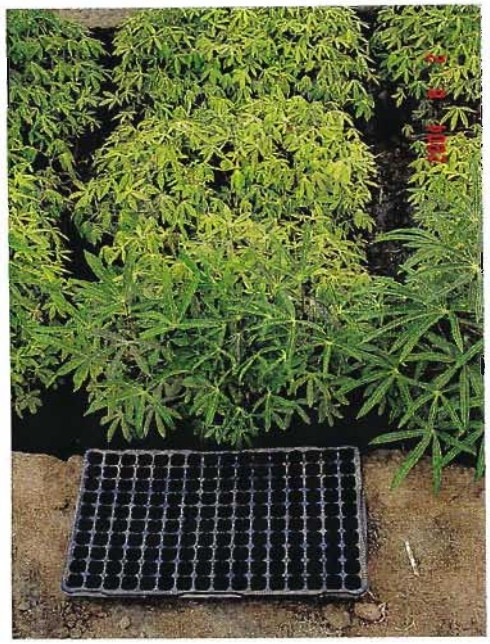

Figure 36: Propagation nursery showing the propagation trays

4. Discussion

Research on cassava in the semi-arid areas of Kenya has been mainly agronomic, collecting local landraces and introducing germplasm from outside the country. At no time had this germplasm been hybridised in a breeding programme. As a result, techniques for controlled hand pollination, seed germination and accelerated rapid multiplication of planting materials have not been developed and local expertise is lacking. This study aimed at appraising the methods developed at international institutes localise them and develop local expertise that will be necessary in the new breeding programme for the semi-arid Kenya.

The success of pollination of cassava at Kiboko demonstrated that cassava pollination in the semi-arid areas is possible, when adequate water and warm temperature are available, to avoid water stress and low temperature stress. The first pollination failed at Katumani because of water and low temperature stress during the cold season which was suspected to have impacted negatively on the proper development of fertilised ovaries. Kiboko clearly has the best conditions best suited to successful pollination and seed set.

Reports from CIAT indicate that pollinated ovaries require constant supply of minerals and water. Plant abort immature ovaries when they experience some stress (Kawano, 1978b). However, for reasons that we could not explain abortion of pollinated flowers was still observed at Kiboko, thus for each cross, many pollinations should be done to obtain adequate seeds. The experience gained from these two crossing blocks will be used in future hybridisation of cassava to develop appropriate varieties for the semi-arid areas of Kenya.

In order to utilise the new genetic recombinants, it is essential that most of the seeds harvested are germinated and planted in a seedling trial. This however, is not possible in the semi-arid areas where rainfall is erratic and takes at most 60 d (Mavua and Kusewa 1989). Our germination results showed that seeds germinated best at 36°C constant temperature in 7 to 21 d. The success of these experiments was an indication that many seedlings with new gene combinations would be available for selection by the breeders. Although temperature was found to be important for germination, above 36°C, it had negative effects on germination. It is likely that higher temperature has negative effects on the enzymatic activity or denatures the proteins involved in the biochemical processes necessary for seed germination. More investigation to identify optimum temperature, which is likely to be below 36°C, is recommended.

Preliminary experiments on vegetative propagation using immature sections of the stems showed promising results. The green shoot can be raised in nurseries using locally available topsoil mixed with sand. Such plants would escape the early season drought that affects plants planted late from mature cuttings. The plantlets would also help to avoid waiting for the recommended period of 8 to 18 mo of growing mother plants for planting stakes (Toro *et al.*, 1976; Otoo, 1996). Cassava breeders would also cut short the selection period from 12 mo to 5 or 6 mo. In addition the problem of poor stand

establishment as encountered in this research (Chapters 3 and 4) when planting materials, were obtained from 6 mo old plants, need to be addresses. Further investigations are required to improve on the sprouting of the three node sections.

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