Cassava breeding through complementary conventional and participatory approaches in western Kenya

by

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Thesis abstract

Participation of farmers in plant breeding programmes has been reported to increase breeding efficiency. Farmers' participation bridges the gap between variety development and dissemination and provides an opportunity for farmers to select varieties they prefer. The breeders on the others hand learn more about the farmers' preferences and the environment in which the new varieties will be grown. However, the advantages of participatory breeding can best be realized when farmers' indigenous technical knowledge (ITK) and experience complement the breeder's scientific knowledge and skills. Cassava (*Manihot esculenta* Crantz) is a clonally propagated crop grown in diverse environments by small scale farmers for subsistence. Information on the roles of farmers and breeders at various stages of breeding and their ability to effectively participate in breeding programmes is limited. The objectives of this study were to determine: (1) cassava farmers' preferences, production constraints and systems; (2) farmers' selection criteria of cassava varieties; (3) genetic inheritance of farmer preferred traits; (4) how farmers and breeders complement each other at all stages and activities of cassava breeding.

Participatory rural appraisal was conducted in three purposefully sampled districts of western Kenya based on ethnicity and agro-ecology. The results reveal that cassava is predominantly grown by small scale farmers with mean land size of 1.6 ha mainly under mixed cropping system for subsistence. The storage roots are eaten either after boiling or processing to flour. The majority of farmers (over 60%) are aware of the improved varieties but adoption rate is low (18% in some districts). The effects of pests and diseases, and the lack of high yielding varieties, capital, land, and disease free planting material are the most important constraints to cassava production. Farmers prefer tall, high yielding varieties that are resistant to diseases and pests, early maturing and long underground storability of harvestable storage roots. The districts surveyed significantly differed in popularity of utilization methods, traits preferences and relative ranking of the production constraints indicative of differences in ethnicity and agro-ecology.

Three farmer groups from the three districts selected in western Kenya were used to study farmers' variety selection criteria based on their own indigenous technical knowledge (ITK). The groups evaluated 15 (10 landraces and five improved) popular cassava varieties with concealed identities on their farms. The results revealed that farmers have effective methods of selecting varieties for most of their preferred traits. However, ITK alone cannot be used to evaluate all the important traits, such as cyanide content.

The genetic inheritance of farmer preferred traits was determined through a genetic study. Six landraces and four improved varieties popular in western Kenya were crossed using the North Carolina mating design II to generate 24 full-sib families. The 24 families, represented by 40 siblings each, were evaluated at two sites, Kakamega and Alupe research station farms, in a 24 x 40 α-lattice design. General combining ability (GCA) and specific combining ability (SCA) mean squares were significant ($P<0.05$) for all traits evaluated except dry matter content and cyanide content. However, non-additive gene action predominated over additive gene for cassava mosaic disease (CMD) resistance, height to first branching, total number of storage roots per plant and fresh storage root yield in all environments. The best crosses were not necessarily obtained from parents with high general combining ability confirming the presence of non-additive gene action. The best performing parents *per se* did not necessarily have high GCA effects implying that selection based on the *per se* performance of parents may not always lead to development of superior hybrids.

The clonal evaluation trial (CET) was established at Alupe research station and evaluated by the breeder and farmers from two districts independently. Three selection criteria were tested to determine the most appropriate approach to selection of varieties that meet both farmers' and breeder's preferences. The selection criteria were; farmers' independent selection index (SI) derived from farmers' selection criteria from each district, breeder's negative selection and independent SI, and a participatory SI which combines farmers' and breeder's selection criteria. There was 14% overlap among the top 100 varieties selected by farmers from all districts and the breeder when independent SI were used. However, there was 49% overlap among the top 100 varieties selected by farmers using participatory SI and the breeder's SI. The farmers and the breeder have a role to play in the variety development process. Varieties with traits preferred by both the farmers and the breeder are likely to enhance breeding efficiency and effectiveness.

Declaration

I, **Woyengo Vincent Were,** declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
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Signed ……………………………………. Date …………………………….

Woyengo Vincent Were (Student)

As the candidate's supervisors, we agree to the submission of this thesis:

Signed ……………………………………….. Date ……………………………

Prof. Rob Melis (Principal supervisor)

Signed ………………………………………Date …………………………...

Dr. Paul Shanahan (Co-supervisor)

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Dedication

I dedicate this thesis to the Woyengo family; my wife Pamela Minayo and children Ken Abwogi, the late Lynn Awinja and Cynthia Omuliebi. To my mother, Mama Agnes Omuliebi and late father Mzee Andrea Oyengo, my sisters Rosebellah Opiyo and Scholarstick Olumi and my brothers Dr. Fred Cholwa Woyengo, Dr. Tofuko Awori Woyengo and Justus Juma Onyango Woyengo.

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Introduction to thesis

1. Importance of cassava

Cassava (*Manihot esculenta* Crantz) is an important source of dietary energy to over 200 million people in the tropical Africa (Ariyo et al., 2006; Calle et al., 2005). In Africa, it is grown and used mainly for its storage roots by small scale poor farmers in marginal areas for subsistence (Ceballos et al., 2004; Fukuda and Saad, 2001). Cassava leaves are also used as green vegetable among many African communities (Lilley et al., 1988). Apart from its value as food crop, cassava is used as animal feed in Africa among farmers who practice mixed farming system (El-Sharkawy, 2004). Cassava is increasingly becoming an important raw material in starch, brewing, pharmaceuticals, animal feed, textile and paper industries (El-Sharkawy, 2004).

As a food crop, cassava storage roots can be eaten either raw, after boiling, or processing. In Africa, the most common on-farm processing involves sun drying followed by pounding or milling to flour (Were et al., 2004). The processed cassava flour is used to develop a wide range of recipes which include; porridge, either soft or hard, local brews, mixed with wheat flour to make baked products and feeding of livestock (Ceballos et al., 2004; Were et al., 2004).

Cassava is naturally tolerant to high soil acidity, low soil fertility and drought conditions which other crops cannot tolerate (El-Sharkawy, 1993; Oluwole et al., 2007). It is resistant to most common and important diseases and pests that attack other food crops (Cach et al., 2006) and offers convenience and flexibility in use to small scale, resource poor farmers in sub-Saharan Africa (Calle et al., 2005). It can be harvested over an extended period and its storage roots can be stored underground for as long as 24 months after maturity (Lilley et al., 1988). These factors make the crop suitable to small scale, poor farmers in marginal areas. They can plant and harvest cassava without any capital input on land where other crops cannot be produced, and harvest what they required for food or cash.

2. Cassava production constraints

World cassava production was 233.80 million tonnes grown on 18.57 million ha in 2009. During the same period, Kenya produced 0.82 million tonnes on 0.07 million ha (Table 1) (FAO, 2011). Average cassava production in Kenya was at 11.64 t ha^{-1} as compared to

Ghana with 13.81 t ha^{-1} and Mexico 14.30 t ha^{-1} (FAO, 2011). The low productivity can be attributed to a number of constraints.

Table 1: Cassava production trends between 2006 and 2009

Country	2006		2007		2008		2009	
	Area[b]	Prdn[a]	Area[b]	Prdn[a]	Area[b]	Prdn[a]	Area[b]	Prdn[a]
World	18.91	223.17	18.84	225.84	18.63	233.36	18.57	233.80
Kenya	0.07	0.65	0.05	0.39	0.05	0.75	0.07	0.82
Nigeria	3.81	45.72	3.88	43.41	3.78	44.58	3.12	36.80
Tanzania	0.99	6.16	0.78	5.20	0.84	5.39	1.08	5.92

[a] total production in million tonnes: [b] total area under cassava in million ha

Source: FAO statistics

In Africa, cassava production constraints can be classified as socio-economic, abiotic and biotic (Ceballos et al., 2004; DeVries and Toenniessen, 2001). Poor communication network, lack of functional technology transfer systems, lack of ready markets and marketing channels for cassava storage roots, are the most important socio-economic constraints (DeVries and Toenniessen, 2001). The most important abiotic stresses include drought, low soil fertility, and alkaline or acidic soils. Though cassava is considered to be tolerant to these stresses, it is sometimes grown in extreme conditions where its tolerance breaks down (Ceballos et al., 2004).

Pests and diseases are the major cassava biotic stresses (Ceballos et al., 2004; DeVries and Toenniessen, 2001). In Africa cassava production is still challenged by lack of suitable varieties that are adapted, high yielding and resistance to common biotic and abiotic stresses (Ceballos et al., 2004; Dixon et al., 2008; Fukuda and Saad, 2001). Major cassava pests include mites (*Mononychellus tanajoa* Bondar*, Tetranjchus urticae* Kock*,* and *Tetranjchus. cinnabarinus* Boisd), mealy bugs (*Phenacoccus manihoti* Mat.-Ferr. and *Phenacoccus herreni* Cox & Williams), thrips (*Frankliniella williamsi* Hoods and *Scirtothrips manihoti* Bondar) and white flies (*Bemisia tabaci* Gennadius). Their effect is either direct by feeding or indirect as vectors of disease causing pathogens (Ceballos et al., 2004)

Cassava mosaic disease (CMD) caused by a group of *Begomovirus* species, cassava brown streak virus disease (CBSD) caused by *Ipomovirus* species, and bacterial blight caused by *Xanthomonas campestris pv. Manihotis* Bondar in descending order of importance are the most important in Africa (Hillocks and Thresh, 2000). Others diseases are caused by fungi species such as *Cercospora*, *Cercosporidium, Phaeoramularia, Colletotrichum, Phoma* and *Phytophthora* species (Ceballos et al., 2004).

3. Cassava breeding approaches

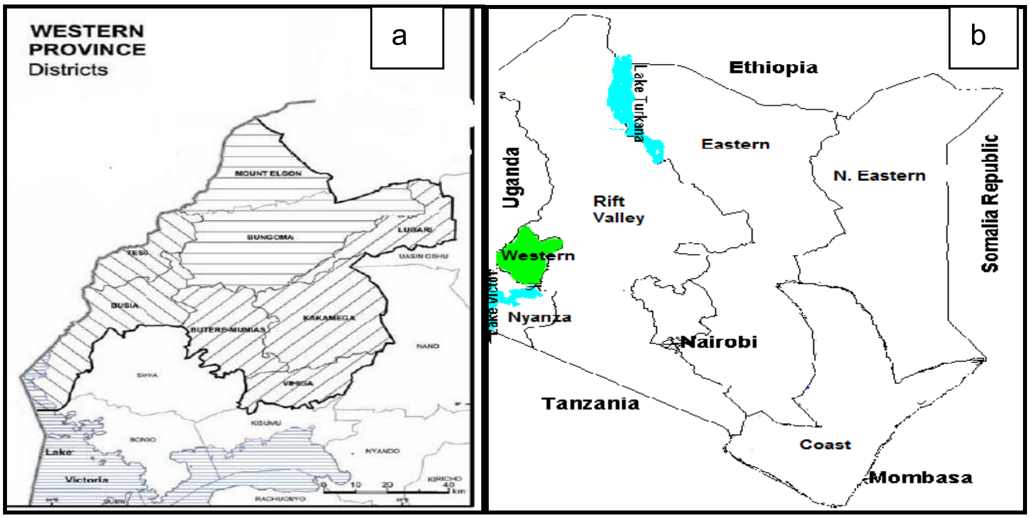
For a long time cassava breeding has been undertaken by the international research organizations such as the International Centre for Tropical Agriculture (CIAT) and the International Institute of Tropical Agriculture (IITA). National research stations being used only to test and disseminate developed varieties (DeVries and Toenniessen, 2001). In this breeding approach generally referred to as conventional plant breeding (CPB) approach, the breeder undertakes all breeding activities unilaterally (Virk and Witcombe, 2007; Witcombe et al., 1996). The breeder identifies the breeding objectives, develops and test new varieties and evaluates them on research stations. Varieties developed on-station through CPB approach fail to perform well on small scale farmers' field in marginal areas where little or no farm inputs are used (Banziger and Cooper, 2001). Without farmer participation either through collaboration or consultation, breeders fail to target farmer preferred traits (Witcombe et al., 1996)

The participatory plant breeding (PPB) approach as opposed to CPB involves farmers in all stages of breeding (Ceccarelli et al., 2001; Witcombe and Virk, 2009). The varieties developed are tested on-farm in target environments with full participation of farmers. Participatory plant breeding approach has been reported to be superior to CPB when breeding for low input crops, grown in heterogeneous environments under diverse cropping systems and utilization (Banziger and Cooper, 2001; Fukuda and Saad, 2001; Witcombe et al., 2001). Participatory plant breeding utilizes farmers’ skills in identification and selection of their preferred traits, breaks the barrier between farmers and breeders, reduces the gap between variety development and adoption and enhances availability of planting materials to farmers (Ceccarelli et al., 2001; Kanbar and Shashidhar, 2011; Smith et al., 2001).

For cassava, being a low input crop, grown in variable environments under diverse cropping system and utilization for subsistence (El-Sharkawy, 2004); the PPB approach is the most appropriate breeding approach. Cassava farmers choose the type of varieties they grow (Manu-Aduening et al., 2006; Mkumbira et al., 2003). Farmers’ preferences include traits related to plant type viz; - plant height, height to first branching, internode length, long storability of plant cuttings as seed, petiole length and colour, and stem thickness among others depending on the cropping system and utilization (Bua et al., 1994). Storage roots characteristics like cooking time, texture (friability), taste, cyanide content depend on utilization methods (Chiwona-Karltun et al., 1995; Mkumbira et al., 2003; Ngeve, 2003). Other cassava uses include using stems for firewood or construction, leaves as vegetable, and both storage roots and leaves as animal feed (El-Sharkawy, 2004). Despite the advantages of PPB over CPB in increasing breeding efficiency and effectiveness when breeding low input crops, farmer participation *per se* is not adequate (Gyawali et al., 2007). Farmers should be involved at breeding stages or in activities that complement the breeders.

4. Cassava breeding in western Kenya

Western Kenya falls within agro ecological zones (AEZ) lower midland (LM) 1-4 which has humid to sub-humid tropical climatic conditions (Jaetzold and Schmidt, 1983). Rainfall and temperature regimes are not uniform across the region due to variation in altitude. The climatic conditions in the region make it a hot spot for many cassava diseases such as CMD, CBSD, bacterial blight and pests such as green and red mites, and white flies (Legg, 1999; Legg and Fauquet, 2004; Legg et al., 2006; Were et al., 2004).



Adapted from Jaetzold and Schmidt, (1983

Figure 1.1 (a) Map of western Kenya province and (b) provinces of Kenya

Western Kenya has never had any formal cassava breeding programme and so cassava farmers in the region have never been involved in any breeding programme. A number of improved cassava varieties have been introduced in to the region over the past few decades. All these varieties were developed outside the region using CPB (EARRNET, 2004). There is a lack of information on the genetic potential of the landraces and cassava farmers' ability to participate and complement breeders in cassava breeding programme. Farmer preferred traits, methods of evaluation and whether there is heterogeneity in these factors between communities and AEZs are not known. In order to initiate an effective breeding programme that will harness the contribution of each player and available resources, a research study was conducted in the region to determine farmer preferred traits, genetic inheritance of these traits and the appropriate methods to evaluate them.

5. Research Objectives

The research objectives were to establish:

a. farmers' preferences, cassava production systems and constraints

b. farmers' selection criteria

c. genetic inheritance of farmer preferred traits and level of heterosis

d. stages and levels of complementation between farmers' and breeders' during variety development

6. Thesis structure

The chapters in this thesis are written in the form of research articles. There may therefore be some overlap of information between chapters. The thesis is divided into the following chapters:

Thesis introduction

Chapter 1: Literature review

Chapter 2: Cassava farmers' preferences, production constraints and systems in western Kenya

Chapter 3: Farmers' selection criteria of cassava varieties in western Kenya

Chapter 4: Genetic inheritance of farmer preferred cassava traits

Chapter 5: Farmer-breeder complementation in cassava varieties breeding in western Kenya

Chapter 6: Overview of the results and their implications to cassava breeding in western Kenya.

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CHAPTER 1

Literature review

1.1 Introduction

This literature review covers research work in areas related to the research objectives and the theoretical premises on which the research methodology of this thesis will be based. Literature is reviewed on the botanical, ecological and physiological aspects of cassava as a crop. This is aimed at providing fundamental principles and justifications on various methods necessary in order to meet the research objectives. Literature is reviewed on cassava breeding methods of both the conventional and participatory approach.

1.2 Cassava botanical and agronomical aspects

Cassava (*Manihot esculenta* Crantz) is a diploid plant with 2n=36 chromosomes. It belongs to the family Euphorbiacea, genus *Manihot* (Jennings, 1976). The genus *Manihot* has over 100 species already known of which only *Esculenta* Crantz is cultivated (Nassar and Ortiz, 2007). Cassava originated from South America where its progenitors have been identified (Nassar, 2006). However, studies conducted by Olsen and Schaal (1999) pointed out that there is no relationship between cassava and what were thought to be its progenitors. Fregene et al. (1997) suggested the possibility of cassava being a product of *Manihot* species hybridization.

Cassava is a perennial shrub growing to a height of between 1-3 m. Cassava stems vary in colour from light grey to yellow-orange or brown depending on amount of anthocyanins. The stems have large, woody and brittle pith. Some genotypes develop many branches while others only develop a few. Those that do not easily branch have strong apical dominance. When the apical dominance breaks, auxiliary buds develop into branches (El-Sharkawy, 1993). The size of cassava leaves depends on genotype, soil fertility and environmental conditions. Fully developed leaves have five to nine lobes. Leaves associated with the flowers, however, have a reduced number of lobes. The life span of the leaves varies between genotypes and environmental conditions (Irikura et al., 1979).

Cassava seedlings have both a taproot and fibrous roots whereas cassava cuttings develop adventitious roots only, which develop within the first three months (Osiru et al., 1999). Development of storage roots is genotypic dependant and photoperiod sensitive. Cassava is generally considered to be a short day plant (Hunt et al., 1977). However, some genotypes are photoperiod insensitive. In short day plants, day length of 12 to 13 hours promote storage roots initiation and development while long days delay the process (Tang et al., 2004). After planting, storage roots are physiologically inactive. They start enlarging at the commencement of the storage process, which starts when assimilates exceed other plant parts' requirements (Tan and Cock, 1979). The number and mass of storage roots that develop per plant depends on genotype, soil type, climatic conditions and agronomic management of the crop (Cock, 1982).

All cassava plant parts except seed contain cyanogenic glucosides. Cyanide (HCN), which is a volatile poison, is produced when the substrate linamarin and the enzyme linamarase come in contact. During harvesting or processing, the disruption of tissues allows the enzyme-substrate contact leading to the production of cyanide (Ceballos et al., 2004; CIAT, 2005). Cyanogenic glucosides are synthesized in the leaves and transported to other plant parts. However, accumulation of cyanogenic glucosides varies depending on genotype, agronomic practices, age of the plant, part of the plant and environment (Cock, 1982; Iglesias et al., 2002)

1.3 Floral biology

Cassava is a monoecious plant with both male and female flowers borne on the same inflorescence (Ceballos et al., 2004). The first female flowers are often not receptive. Flowering and duration of flowering depend on genotype and are influenced by photoperiod and environmental temperatures. Some genotypes flower as early as four to five months after planting, while others flower eight to ten months after planting (Ceballos et al., 2004; CIAT, 2005). Kawano (2003) reported that genotypes that do not flower in warm low altitude zones flower in cooler high altitudes. Generally, north of the equator, flowering takes place from July to January while south of the equator, between January and July. Hunt et al. (1977) observed that long days hasten early flower initiation while short days and cool temperatures delay flowering. It was however observed that short days and cool temperatures enhance good flower development, pollination and seed-set when soil moisture is optimal (Hunt et al., 1977). Growth promoters, indoleacetic acid (IAA) and naphthalene acetic acid (NAA), have been observed to promote flowering when sprayed on leaves (Iglesias et al., 2002).

Female flowers, which are twice as large as the male flowers, are borne at the bottom of the inflorescence. They open 10-14 days before the male flowers on the same inflorescence. This mechanism inhibits self-pollination. Self-pollination, however, still occurs between flowers borne on different inflorescences of the same plant (Ceballos et al., 2004; Jennings, 1976). Male flowers have ten stamens arranged in two rows. They produce large sticky pollen grains in the anthers. The female flowers have sticky stigmas and produce a sugary solution the day they open. Natural pollination is by insects, mainly bees and wasps (Cock, 1982). After pollination and fertilization, the ovaries develop into a tri-locular fruit capsule. In each locule, one seed develops. The number of seeds per fruit ranges from one to three. It takes about 90 days from fertilization to fruit maturity. When mature, the fruits dehisce, explosively releasing seeds (El-Sharkawy, 2004).

1.4 Cassava propagation

Cassava can be propagated both sexually via botanical seeds and asexually by stem cuttings (stakes) (Ceballos et al., 2004). Use of botanical seeds is limited to breeding programmes (Ceballos et al., 2004; El-Sharkawy, 2004). In the field, cassava stakes are planted at the onset of a rainy season. Stakes between 20 and 30 cm long are obtained from cassava stems that are 8 to 18 months old. On average, one cassava plant produces 10 stakes annually (Kawano, 1995). Commercial recommended spacing of 1 m x 1 m is used at planting giving a plant population of about 10,000 plants per hectare. On farmers' field plant population of between 6000 to 20000 plants ha^{-1} has been observed. The stakes are planted either horizontally, vertically or inclined on ridges or on flat ground. Half to two-thirds of the length of the stakes is covered with the soil at planting in cases where they are planted in vertical or inclined position (Cock, 1982). Cassava is generally intercropped with other crops and fertilizer is seldom applied (Nassar and Ortiz, 2007).

Cassava seed, like seeds from other *Manihot* species, exhibits physiological dormancy and rarely germinate under field conditions (Iglesias et al., 1994). El-Sharkawy (2004) observed that the seeds germinate in the dark and germination percentage increases after scarification at the micropyle. Other methods of breaking seed dormancy, such as alternating cold and heat treatment or acid treatment, were not effective in cassava. Cassava seedlings are raised in nurseries. The seeds are sown in seed pots or trays filled with sterile forest soil (Ceballos et al., 2004). The nursery temperature is maintained at a mean of 38^0 C or alternating temperatures of 38^0 C for 16 hours and 30^0 C for 8 hours for 21 days are recommended (El-Sharkawy, 2004). Cassava seeds germinate in 7 to 21 days. After 45-60 days, the seedlings are transplanted in the field for establishment. Cassava plants developed from seedlings can be used for vegetative multiplication after 8-12 months of growth in the field (Ceballos et al., 2004).

1.5 Cassava production and utilization

Cassava is an important calories-producing crop widely grown in the tropical and sub-tropical areas. It has diverse adaptation to agro-ecological conditions and farming systems (Hahn et al., 1980; Kawano, 2003). Since its introduction in Africa, cassava has become one of the most important crops in Africa (Were et al., 2004). It is an important source of dietary energy for over 500 million people in developing countries within the tropics and sub-tropics (Ariyo et al., 2006; CIAT, 2005; Legg et al., 2006).

In Africa, cassava is mainly produced by small scale farmers (Ariyo et al., 2006). Storage roots classified as storage roots are the most valuable parts of cassava plant. Starch forms about 80% of the storage roots' dry matter content. In some parts of Africa, cassava leaves are used as vegetable (El-Sharkawy, 2004). Cassava is grown as a subsistence crop, cash crop or as an animal feed. Cassava storage roots can be eaten either raw, after boiling, or after processing. Cassava varieties eaten raw or after boiling have low cyanide content (< 50 mg of cyanogenic glucoside per kilogram of fresh storage roots mass and are considered 'sweet' (Mkumbira et al., 2003). In Africa, the most common on-farm processing involves sun drying followed by pounding or milling to flour (El-Sharkawy, 2004; Were et al., 2004). Processed cassava flour is used to develop different recipes which include; porridge, either soft or hard 'Ugali', to make local brews, mixed with wheat flour to make baked products and as livestock feed (Ceballos et al., 2004; CIAT, 2005; El-Sharkawy, 2004; Were et al., 2004).

Apart from the traditional processing, on-farm and small scale factory processing with novel recipes are gaining popularity (EARRNET, 2004). These recipes include fried products like 'gari' or' farina' which are packaged or marketed as snacks (Ngeve, 2003). Cassava storage roots have low protein content of 2-3% of dry matter on average. Some landraces in Central America however, have been found to have higher protein content of 6-8% (Ceballos et al., 2004; CIAT, 2005). Cassava leaves have a relatively high protein content of 21% to 39% of dry matter depending on cultivar. In some parts of Africa, cassava leaves are consumed as a vegetable. They are prepared either alone or used as a constituent part of sauce recipe and then eaten alongside the main staple food as a meals (EARRNET, 2004; El-Sharkawy, 2004).

Apart from being used for subsistence, cassava storage roots and leaves are used at farm level as animal feeds. The storage roots are also used for industrial raw materials in animal feeds manufacturing companies as a major source of the carbohydrates component. The storage roots are used in starch industries. Starch from cassava is used in the manufacture of adhesives, pharmaceuticals, textile, packaging, and paper (El-Sharkawy, 2004).

Cassava, due to its specific inherent plant characteristics and qualities, is an important food security crop among the resource poor farmers (Fukuda and Saad, 2001). Cassava is a hardy crop that can grow in marginal areas where other crops cannot grow. Under harsh environmental conditions and low input farming system, cassava produces more biomass (root and leaf yield) than any other food crop (Romanoff and Lynam, 1992). The crop is tolerant to acidic or alkaline soils, drought, and low soil fertility (Edwards and Kang, 1978; Egesi et al., 2007). Cassava is resistant to most common important crop pests and diseases (CIAT, 2005).

1.6 Cassava production constraints

Despite the many inherent good qualities of cassava, its production is faced with various constraints. In Africa, these constraints fall in three broad categories; socio-economic, abiotic and biotic (Ceballos et al., 2004; DeVries and Toenniessen, 2001). Poor communication network, lack of functional technology transfer systems and lack of ready markets for cassava storage roots and products top the list of socio-economic constraints (DeVries and Toenniessen, 2001). Though cassava is considered to be tolerant to most abiotic stresses, not all genotypes are tolerant. These stresses include extreme drought, low soil fertility, alkaline or acidic soils (Ceballos et al., 2004).

Pests and diseases are the major cassava biotic stresses (Ceballos et al., 2004; DeVries and Toenniessen, 2001). In Africa cassava production is still challenged by a number of bottlenecks. This includes lack of suitable high yielding varieties adapted to specific production environments and access to planting materials resistant to both biotic and abiotic stresses with farmer preferred traits. These problems are worsened by inaccessibility of improved varieties or knowledge of such varieties by cassava farmers due to socio-economic problems. Parts of Africa that experience prolonged drought could face shortage of planting material after losing the whole crop to drought (Ceballos et al., 2004).

Cassava pests include arthropods such as thrips (*Frankliniella williamsi* Hoods and *Scirtothrips manihoti* Bondar), mites (*Tetranjchus urticae* Kock*, Tetranjchus cinnabarinus* Boisd and *Mononychellus tanajoa* Bondar), mealy bugs (*Phenacoccus manihoti* Mat.-Ferr. and *Phenacoccus herreni* Cox & Williams) and white flies (*Bemisia tabaci* Gennadius). These pests affect the cassava either direct by feeding on the plants or indirect as vectors of pathogens. There are many more arthropod pests in Africa but their effects are not of economic importance (Ceballos et al., 2004).

Cassava is vulnerable to attacks by various diseases. In Africa, cassava mosaic disease (CMD) caused by a *Begomovirus* species cassava brown streak virus disease (CBSD) caused by *Ipomovirus* species, and bacterial blight caused by *Xanthomonas campestris pv. Manihotis* Bondar are the most important (Hahn et al., 1980; Hillocks and Thresh, 2000). There are several fungal diseases that infect cassava when environmental conditions are conducive. Such environmental conditions are found in tropical lowland regions with high rainfall. Cassava grown in these environments can be attacked by *Cercospora spp*, *Cercosporidium spp, Phaeoramularia spp* and *Colletotrichum* fungi species. In tropical highlands, *Phoma* and *Phytophthora* species are common, causing leaf and stem lesions and root rot respectively (Ceballos et al., 2004). Attempts have been made to address the cassava productions constraints through breeding.

1.7 Cassava breeding

Cassava breeding involves the process of introduction, development and identification of new cassava genotypes. The genetic make-up of these new varieties confers desirable qualities and ability to resist various production constraints. Breeding therefore is considered to provide a permanent solution to most of the production constraints.

1.7.1 Cassava breeding objectives

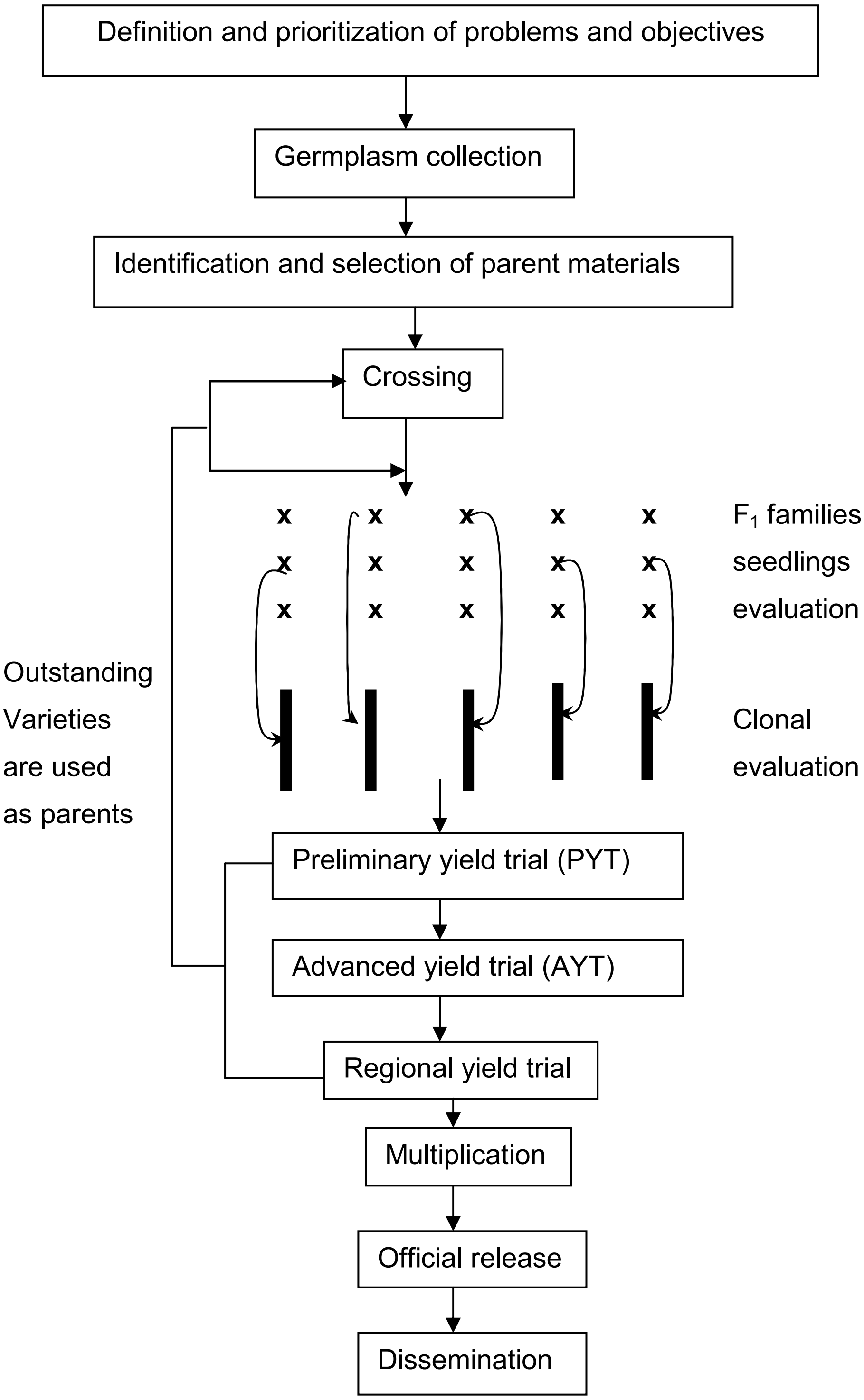
Cassava breeding objectives are set based on the crop's final intended uses such as a base product in industry, human consumption or as animal food (Ceballos et al., 2004). Starch quality, high dry matter yield, which is a function of dry matter content and storage roots yield per unit area, are the most important breeding objectives for an industrial crop production. For subsistence use, apart from high yields, production stability and good cooking or processing qualities and adaptation are important breeding objectives. Subsistence farmers associate cooking qualities to a number of characteristics like colour of the peel of the roots and petiole and stem colours (Manu-Aduening et al., 2006). Farmers reject or accept varieties based on the presence or absence of these traits irrespective of whether they are correlated to cooking quality of storage roots or not. These traits are farmer specific and important breeding objectives as they influence the adoption of the varieties (Fukuda and Saad, 2001; Manu-Aduening et al., 2006). Other storage roots qualities considered in breeding programmes are cyanogenic potential, bulking capacity, protein content, rate of post-harvest physiological deterioration, and lately high level of vitamins A precursor (Ceballos et al., 2004; DeVries and Toenniessen, 2001; Fukuda and Saad, 2001).

Apart from breeding for root quality and quantity, breeding for biotic and abiotic stress resistance or tolerance are equally important objectives, as it increases cassava productivity and production stability. The types of stresses considered as main objective in a cassava breeding programme are specific to the target environment (Ceballos et al., 2004; CIAT, 2005). Among the biotic stresses, breeding for disease and pest resistance or tolerance has remained fundamental in most cassava breeding programmes (Kawano, 2003).

1.7.2 Cassava breeding scheme

Cassava breeding programmes start with germplasm acquisition which is then evaluated to identify superior genotypes to be used as parents (Ceballos et al., 2004). Recombinant genotypes are then developed from the selected parents and evaluated through various stages starting from seedling evaluation to regional trials as shown in the Figure 1. Identified superior recombinant genotypes are vegetatively propagated and released to farmers (Ceballos et al., 2004; Fukuda and Saad, 2001; Kawano, 1995; Kawano, 2003).

Previously, selection of parental clones was purely based on their phenotypic performance. This led to little progress in cassava improvement (Ceballos et al., 2004; CIAT, 2005). A few decades ago, several researchers started selection of parental clones based on their ability to pass-on the good traits to their progeny or re-combine to give superior genotypes (combining ability) for the specific trait to be improved (Ceballos et al., 2004; Hallauer and Miranda, 1988). These abilities depend on the type of genes (gene action) controlling these traits (Fasoula and Fasoula, 1997; Hallauer and Miranda, 1988). The combining abilities are determined through progeny testing developed by controlled crossing of the potential parents (Ceballos et al., 2004; Hallauer and Miranda, 1988). The developed half- and full-sib families are evaluated to determine the breeding values of their parents. Based on these, only parents with high combining ability are deployed in the breeding programme (Ceballos et al., 2004; CIAT, 2005; Hallauer and Miranda, 1988)



(Adapted from Fukuda and Saad, 2001)

Figure 1: Cassava breeding scheme

1.7.3 Breeding for yield and farmer preferred traits

High yield is the ultimate objective of all breeding programmes (Ceballos et al., 2004; Rimoldi et al., 2002). Cassava is mainly grown for its storage roots. Cassava breeding for yield potential improvement started in 1970s at the Centro Internacional de Agricultura Tropical (CIAT) headquarters Cali, Colombia (Kawano, 2003). Generally, yield in cassava is considered to be total mass of fresh storage roots harvested per unit area of land (Rimoldi et al., 2002). However, there are other methods of assessing cassava yield. These methods depend on the end use of the cassava storage roots. For industrial use, where cassava storage roots are used for starch extraction or to manufacture animal feeds, starch and dry matter contents are important yield components. Starch and dry matter content per unit mass of cassava storage root is finally translated to starch and dry matter yield per unit area of land respectively (Ceballos et al., 2004). From a crop physiology perspective, high yielding cassava varieties are those that apportion a greater proportion of assimilates (photosynthates) to the storage organs (storage roots) (El-Sharkawy, 2004). Based on this thinking, cassava yields can also be assessed based on harvest index. Harvest index is the ratio of fresh storage root mass to total biomass [mass of the whole plant (roots and shoots)] (Ceballos et al., 2004; El-Sharkawy, 2004; Kawano, 2003).

Despite high yielding varieties being the ultimate goal for both breeders and farmers, other selection criteria come in to play. High yielding varieties without these farmer preferred traits fail to be adopted (Mkumbira et al., 2003; Ngeve, 2003). As a subsistence crop, cassava is used to make a wide range of traditional recipes and food products (Ngeve, 2003). Procedures of using cassava storage roots in making recipes and food products differ from region to region (Fukuda and Saad, 2001; Ngeve, 2003). This implies that the qualities of the storage roots required differ from region to region. Where cassava is grown for industrial use, starch quality and quantity are important whereas for subsistence use cooking qualities and taste, among others, are important storage roots qualities (Ceballos et al., 2004).

In regions where the storage roots are eaten raw or after boiling, farmers prefer early maturing sweet varieties and cooking qualities are important (Ngeve, 2003). Ngeve (2003) categorizes cassava cooking qualities into three categories namely non-boilable, glassy and mealy. Non-boilable types do not boil soft however long they are heated. Such varieties are used for processing. The glassy types cook after heating but are hard to chew. The storage roots appear 'glassy' or translucent after boiling. The mealy types boil easily and soften with floury texture easy to eat. Storage roots qualities are key farmer preferred traits which vary from region to region. Based on experiences, farmers associate certain plant characteristics like leave, petiole, peel, and stem colour and cyanide content with cooking quality of the storage roots.

Most of the important cassava agronomic traits have high genotype by environment interaction (Ceballos et al., 2004). Suitable varieties are those adapted to the target environment. This requires breeding for specific adaptation as opposed to broad adaptation. Farmers grow cassava under diverse cropping systems (Cach et al., 2006). Farmers therefore prefer varieties that suit their cropping systems. Plant height and height to first branching have been observed to be one of the criteria farmers use to select cassava varieties (Cach et al., 2006).

1.7.4 Plant breeding approaches

Plant breeding is a multi-stage process which includes objectives setting, identification of suitable germplasm, development of new genotypes and testing and selection of new superior genotypes (Sleper and Poehlman, 2006). Efficiency and effectiveness of plant breeding programmes depends on the accuracy in selection of both the parents and newly developed genotypes. The new genotypes should be adapted to the target environment and have traits preferred by farmers and other end users. A successful breeding programme is one which develops varieties that are highly accepted by the farmers and all other end users. Plant breeding programme can take either conventional or participatory approach.

Conventional plant breeding

In a conventional plant breeding (CPB) approach the breeding process is solely scientist-led and conducted on research stations (Almekinders and Elings, 2001; Atlin et al., 2001). Conventional plant breeding is highly successful in breeding high input commercial varieties with broad adaptation grown under large scale farming conditions. In such high input commercial crops, the farming environment, and the on-station environment where the crops are tested and selected, are similar (Almekinders and Elings, 2001; Atlin et al., 2001). Farmers growing these types of crops can afford the necessary farm inputs making the production environment identical to research stations. There is uniformity in production environment over a large area. This makes it possible for the breeder to identify production problems on which basis breeding objectives are set without the input of the farmers (Almekinders and Elings, 2001). Conventional plant breeding approach is however ineffective when breeding low input crops grown in marginal areas by small scale farmers

(Banziger and Cooper, 2001). The conditions in marginal areas and farmers' fields are diverse and different from on-station conditions where the varieties are tested.

Participatory plant breeding

Participatory plant breeding (PPB) was developed in order to overcome the limitations of CPB approach. Witcombe et al. (1996) described two levels of farmer participation; participatory variety selection (PVS) and participatory plant breeding (PPB). In PVS, there is collaboration and consultation between the breeder, farmers and consumers during variety selection. The selection process can take place either on-station or on-farm. However, PPB involves breeders, extension staff, farmers and consumers in all stages of variety development right from breeding objectives development to variety evaluation and seed multiplication (Atlin et al., 2001; Joshi and Witcombe, 1996; Sperling et al., 2001). Apart from increasing breeding efficiency and effectiveness due to amalgamation of efforts from breeders and end users, PPB shifts breeding activity from on-station to farmers' fields where the developed varieties will be grown. Such varieties have been shown to easily diffuse to farmers, thus increasing adoption rate (Ceccarelli and Grando, 2007; Kanbar and Shashidhar, 2011).

The initial stage of PPB involves identification of the end users and production environment. To achieve this participatory rural appraisal (PRA) can be employed (Witcombe et al., 2005). During the PRA, the breeder is able to identify and understand both the target environment and farmers. It creates a conducive environment where farmers and breeders exchange ideas and start working towards a common goal (Fukuda and Saad, 2001). In the CPB approach, breeders more often select varieties based on their own priority objectives, using their own selection techniques. In some cases, these varieties fail to be adopted, because they lack farmer preferred traits (Fukuda and Saad, 2001). Participatory plant breeding overcomes this bottleneck by giving farmers and end-users the opportunity to prioritize traits to be improved on and select genotypes that posses these traits.

In low input crops grown in marginal areas by small scale farmers, the production environments (farmers' fields) are different from research stations (Witcombe et al., 1996). The conditions in marginal areas and farmers' fields where these crops are grown are diverse (Joshi et al., 2007; Virk and Witcombe, 2007). The diversity in environmental conditions includes climatic conditions, soil types, cropping system, and agronomic management of the crop. Varieties selected in these diverse conditions have specific (narrow) adaptation as opposed to varieties developed through CPB approach which have broad adaptation (Witcombe et al., 1996; Witcombe et al., 2006). Breeding varieties with broad adaptation limits breeding gains, while prohibiting exploitation of high potential environment and genotypes (Ceccarelli et al., 2003; Ojwang et al., 2011; Witcombe et al., 2001). Breeding for specific adaptation increases genetic diversity in the crop (Witcombe et al., 2001). This is important in the management of genetic resources and biodiversity (Joshi et al., 2007). Breeders are often challenged by the effects of genotype x environment (G x E) interaction. The G x E interaction effects is minimized through breeding for specific adaptation which has been well addressed through PPB approach (Banziger and Cooper, 2001).

Information on varieties developed by breeders on research stations more often fails to reach small scale farmers in marginal areas due to poor communication channels (Banziger and Cooper, 2001). Commercial seed companies have no interest in low input crop grown by small scale farmers in marginal areas because they focus on profit. This hinders variety promotion and seed availability to farmers (Machado and Fernandes, 2001). PPB reduces the gap between breeders and farmers. Furthermore, in PPB, variety evaluation is done on farmers' fields where the farmers compared the developed varieties to commercial varieties they grow. On-farm evaluation has a double effect of selecting the best varieties within the production environment and promotion of these varieties to farmers (Ceccarelli et al., 2001). During variety selection, farmers keep seed of the varieties they prefer and multiply them on their farms. They do not wait to buy them from seed companies (Banziger and Cooper, 2001).

Though PPB has many advantages over CPB, especially when breeding low input crops grown in marginal areas by small scale farmers, opponents of PPB approach argue that breeding is too a complex science for farmers to understand, it is expensive to involve farmers in the breeding process and that farmers cannot handle a large number of genotypes in a segregating population (Atlin et al., 2001; Virk and Witcombe, 2007). To counter these arguments, client oriented breeding (COB), a new concept of PPB approach, where farmers are only involved at stages where they are required, has been developed (Virk and Witcombe, 2007; Witcombe et al., 2006). Likening the process of variety development to product development, Witcombe et al. (2006) outlined four key stages; product design, development, testing and marketing. Farmers' involvement at any of these stages may be optional depending on the crop and production environment (Gyawali et al., 2007; Witcombe et al., 2006). The guiding principle behind participatory breeding is to increase breeding efficiency and effectiveness; farmer participation therefore should complement the breeders in order to achieve these goals (Gyawali et al., 2007).

1.7.5 Gene action and breeding

The efficiency and effectiveness of any breeding programme can be enhanced by selecting parents, using an appropriate breeding design to develop new genetic recombinants and use efficient and effective methods to identify superior recombinant genotypes (Hallauer and Miranda, 1988). The objective can be met by understanding the nature of gene action in operation for the traits of interest (Fasoula and Fasoula, 1997).

Types of gene action

Gene action is defined as the way genes express themselves. Generally there are two types of gene action, additive and non-additive (Falconer and Mackay, 1996; Fasoula and Fasoula, 1997). In additive gene action, the expression of a quantitative trait is due to the sum product of all the genes controlling the trait. Under additive gene action, the performance of the F_1 offspring is intermediate to that of the two parents. Any observed deviation in the F_1 offspring from the mean phenotypic value of the two parents is due to non-additive gene action.

Non-additive gene action is as a result of an interaction effect between genes (Fasoula and Fasoula, 1997). The interaction results in the expression of the trait either above or below the mean of the two parents as in case of additive gene action (Falconer and Mackay, 1996). The gene interaction can either be intra- or inter-locus. Intra-locus gene interaction leads to expression of dominant gene action while inter-locus interaction leads to epistatic gene action. (Fasoula and Fasoula, 1997; Hallauer and Miranda, 1988).

Gene action and combining ability estimation

Resemblance between offspring and parents is due to additive gene action while their differences are due to non-additive gene action (Falconer and Mackay, 1996). The ratio of the resemblance among the offspring to the total differences observed in both the parents and their offspring give a heritability measure (Falconer and Mackay, 1996). Heritability of a given trait provides a guide to the breeder on which selection and breeding strategy to employ. For traits with high heritability value, substantial genetic improvement can be attained in the F_1 hybrids after selecting parents based on their observed performance (phenotype). However, for traits with low heritability, superior hybrids can only be developed if parents are selected based on their combining abilities (Falconer and Mackay, 1996; Robinson et al., 1949).

Parents in a breeding programme are chosen based on their gene action for the trait of interest (Falconer and Mackay, 1996; Fasoula and Fasoula, 1997). Parents with high resemblance to their progenies are considered to have high breeding value (Falconer and Mackay, 1996). Good performing progenies are likely to be produced when such complementary parents are crossed. Some parents when crossed to other parents always produce high performing progenies. Such parents are considered to have high general combining ability. On the other hand, some parents will only produce high performing progenies when crossed to some specific parents. Such parents are considered to have high specific combining ability (Falconer and Mackay, 1996; Fasoula and Fasoula, 1997).

Superior hybrids are obtained when two parents are crossed resulting in accumulation of genes in cases where the trait of interest is under additive genes action. Improvement on traits under additive gene action can therefore be achieved through a breeding design that aims at accumulating genes in one variety (Griffing, 1956). Such breeding designs may involve selecting the two parents with the trait (high general combining ability) and crossing them resulting in offspring with a higher level of gene expression than the two parents. In the absence of additive gene action, we have the non-additive gene action which is due to gene interactions. The interactions can be lead to enhanced performance above the mid-parent value (positive interaction) or to reduced performance (negative interaction) (Fasoula and Fasoula, 1997). Parents that produce hybrids with enhanced performance are considered to have high specific combining ability. In cases where non-additive gene action is dominant with positive gene interaction, the breeding programme is designed so as to maximize the interaction effects like in the development of hybrid varieties. In cases where we have significant negative gene interaction, such parents are discarded (Falconer and Mackay, 1996).

Gene action and combining ability are estimated by evaluating parents and their offspring developed using designed crossing procedures generally referred to as mating designs (Hallauer and Miranda, 1988). From this evaluation, variation observed in parents and offspring are estimated. These co-variances measure the type of gene action involved and the ability of the parents to pass on those traits. There are many different mating designs. These include the; bi-parent, topcross, line x tester, polycross, North Carolina I, II and III and diallel (Hallauer and Miranda, 1988; Singh and Chaundry, 1977). In all these designs, gene action is estimated by relating the variation among the offspring and their parents through analysis of variance.

1.8 Overview of literature review

Cassava is an important food and cash crop grown by small scale farmers in marginal areas under diverse agro-ecologies, production systems and utilization. Apart from being a low input crop, cassava is heterozygous and propagated vegetatively through cuttings which contribute to cassava's production constraints. Cassava therefore requires well designed breeding programmes. An appropriate cassava breeding programme is one that uses the breeder's scientific knowledge and farmers' experience. This increases the efficiency and effectiveness of breeding programme. Western Kenya, the most important cassava producing region in Kenya, has never had any cassava breeding programme. Understanding the cassava production environments, cassava production constraints, farmer preferred traits and how they evaluate them, generates information that can be used to design a breeding programme where the breeder and farmers can complement each other. This information can be used to develop simple techniques and procedures that can enhance the efficiency and effectiveness of the breeding programme.

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CHAPTER 2

Cassava farmers' preferences, production constraints and systems in western Kenya

Abstract

Western Kenya is the most important cassava producing region in Kenya with diverse agro-ecologies and ethnic communities. Despite its importance, there has never been any formal cassava breeding programme in the region. A research study using participatory rural appraisal (PRA) tools was conducted in the region to determine cassava production systems, utilization methods, production constraints and farmers' preferences. Three districts, Teso, Busia and Mumias, were purposefully sampled to represent different ethnic communities and agro-ecologies. Data was collected on cassava cropping system, utilization methods, adoption level, production constraints and farmer preferred traits. The results reveal that cassava in western Kenya is mainly grown by small scale farmers owning mean land size of 1.6 ha for subsistence under mixed cropping system. Maize and beans are the popular crops in the mix. Cassava storage roots are utilised after boiling or processing to flour. A majority of farmers in Mumias and Teso districts use storage roots after boiling and processed to flour, respectively. In Busia district, both utilization methods are used in approximately equal proportions. Adoption of new cassava varieties is low, less than 20% in some districts, despite awareness levels of over 60% in all districts. The effects of pests and diseases, and the lack of high yielding varieties, capital, land and disease free planting materials are the most important cassava production constraints. Farmers prefer tall varieties that are high yielding, resistant to diseases and pests, mature early and have extended underground storability of storage roots. Some traits and constraints are more important in some districts than others indicating differences in agro-ecologies, cropping systems and cultural beliefs and practices.

2.1 Introduction

Cassava (*Manihot esculenta* Crantz) is an important source of carbohydrate widely grown in the tropical and sub-tropical areas by small scale farmers (Ariyo et al., 2006; Kawano, 2003). It is grown as a food crop, cash crop or an animal feed (Ceballos et al., 2004; El-Sharkawy, 2004). As food crop, cassava storage roots can be eaten either raw, after boiling, or after processing. In Kenya, the most common on-farm processing involves sun drying followed by pounding or milling to flour. The flour is used for making a variety of recipes which include porridge, either soft or hard *'Ugali'*, local brew, or for home baking after mixing with wheat flour (Kamau, 2006; Mkumbira et al., 2003). Cassava leaves have a relatively high protein content of 21% to 39% of dry matter depending on the cultivar. In some parts of Africa, cassava leaves are consumed as a vegetable. They are prepared either alone or used in a sauce and eaten alongside the main staple food (El-Sharkawy, 2004). As a cash crop, cassava can be used as raw material for a wide range of industries. These include animal feed, and in pharmaceutical, textile and starch manufacturing industries (Ceballos et al., 2004; El-Sharkawy, 2004).

There is variability in cassava varieties that make some more preferred for specific utilization than others. High starch content is an important trait in varieties grown for industrial purpose (Carvalho et al., 2004). Organoleptic qualities (taste and texture) and ability to cook fast are important traits of cassava varieties grown for food. In Malawi, farmers associate bitter storage roots taste with high cyanide content, white flour and less elastic ‘*Ugali’* (Chiwona-Karltun et al., 1995; Mkumbira et al., 2003). Bitter varieties are grown for processing to flour because the cyanide level is reduced during the processing, while sweet types are eaten raw or after boiling.

Cassava is a hardy crop grown in diverse agro-ecological conditions (Akparobi et al., 2007; Perez et al., 2005; Rimoldi et al., 2002). The ability of cassava to grow in diverse agro-ecologies indicates differences in variety adaptability. Agro-ecologies vary in rainfall amount and pattern, temperature regime and soil types (Jaetzold and Schmidt, 1983), which have direct and indirect effects on the performance of cassava varieties. These conditions influence abiotic stresses such as soil pH, soil fertility, drought and biotic stresses such as diseases and pests. Cassava has been shown to have wide variability in resistance/tolerance to these abiotic and biotic stresses (Edwards and Kang, 1978; Egesi et al., 2007). In semi-arid areas, early maturing and drought resistant varieties are more preferred (Kamau, 2006). In ecologies where rainfall is unreliable, cassava is an important food security crop. It provides flexibility in harvesting and therefore long underground storability is an important trait (Ceballos et al., 2004).

Cassava is cultivated under different farming systems (Bua et al., 1994). The type of farming system used depends on farm size and utilization. Cassava is grown as a mono-crop in areas where farmers have large farm sizes and grow cassava for commercial purpose. However, in most areas where cassava is grown by small scale farmers for subsistence, intercropping is practiced (Kariuki et al., 2002). Cassava plant height and branching habit (plant type) have been demonstrated to be important traits when selecting varieties for specific cropping system (Bua et al., 1994). Short heavily branching types of cassava varieties are suitable for mono-cropping since their canopy cover hinders other crops to grow underneath.

Cassava variety preferences vary depending on agro-ecology, cropping system and utilization method. Development of varieties through the formal breeding method by scientists mainly focuses on yield, and disease and pest resistance, with little attention to farmers'/consumers' preferences (Ngeve, 2003; Witcombe et al., 1996). Participatory rural appraisal (PRA) tools are employed by plant breeders to gather and analyze information about target production environment (Sperling et al., 2001). A PRA also provides a conducive environment where the breeder and farmers exchange ideas (Joshi and Witcombe, 1996; Odendo et al., 2002), reducing the gap between research and adoption (Gyawali et al., 2007; Virk et al., 2003).

In Kenya, 60% of cassava is produced in the western region (Munga, 2008). The region has diverse agro-ecologies and is inhabited by various ethnic communities with different socio-cultural practices and food preparation methods. Western Kenya is a hot spot for major cassava diseases and pests (Legg et al., 2006; Otim-Nape et al., 2001: Were et al., 2004). Cassava production in the region is also affected by a myriad of abiotic stress such as low soil fertility, soil acidity or alkalinity, drought and water logging (Hahn et al., 1980; Hillocks and Thresh, 2000).

Although western Kenya is an important in cassava producing area, with many production constraints, it has no formal cassava breeding programme. New varieties grown in the region were developed elsewhere. During the development of these varieties, the focus was on high yield and CMD resistance. In the development of these new varieties, farmers from the region were bot involved, their cherished landraces were not used and local preferences were not considered. In order to understand cassava production and utilization within the diverse agro-ecologies and amongst the various ethnic groups in the western region and to develop a working relationship between farmers and the breeder, a PRA was carried out in Mumias, Busia and Teso districts in western Kenya with the objectives to determine:

a) production systems under which cassava is produced;

b) cassava utilization methods;

c) adoption levels of improved varieties;

d) cassava production constraints within the region; and

e) farmer preferred traits.

2.2 Materials and methods

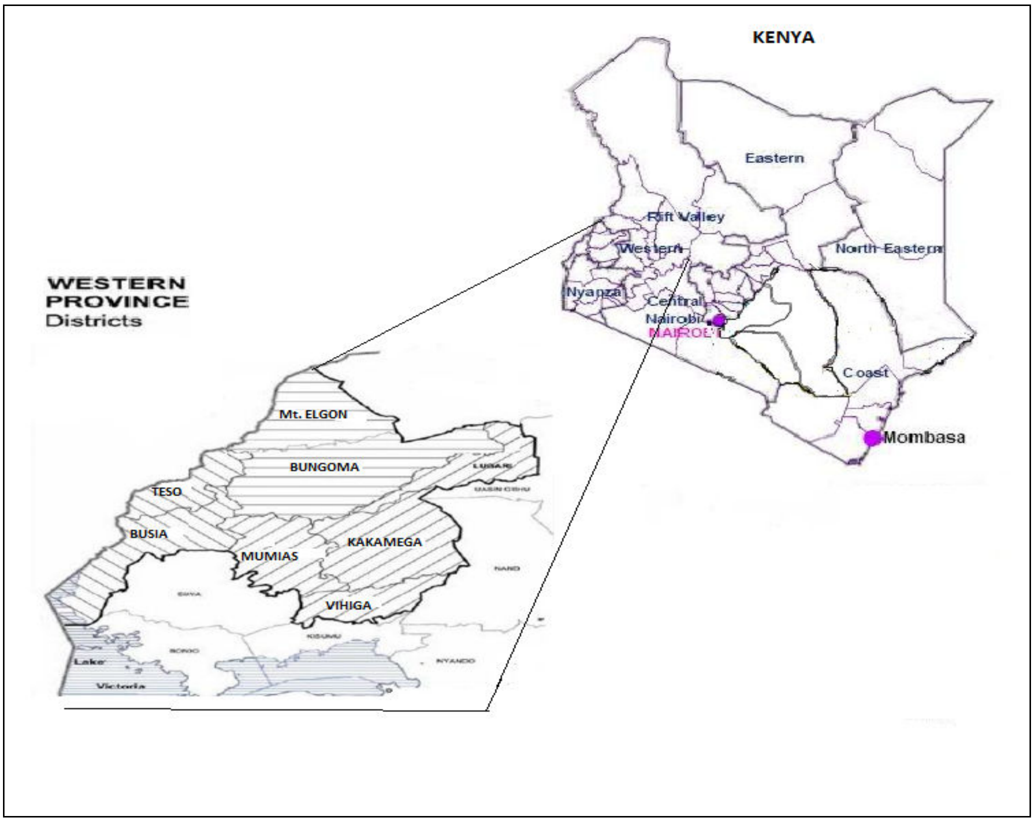
A PRA approach using both focused group discussions (FGD) and household interviews was used. The PRA was conducted in 2010.

2.2.1 Study areas

The western Kenya region was selected for its importance in cassava production in Kenya. Mumias, Busia and Teso districts were selected as the key cassava producing districts and represent different ethnic communities and agro-ecological zones (AEZ). Mumias district is inhabited by the Bantu speaking Luhyia tribe. The district falls within AEZ LM_1 which has relatively high rainfall and temperature (Jaetzold and Schmidt, 1983). It receives average annual rainfall of 1650-2000 mm and has an annual mean temperature of $21.0\text{-}22.2^0$ C. It lies within altitude range of 1200-1440 masl and has a population density of 467 persons per km^2. Farmers in this district are commercial sugarcane farmers and reserve small pieces of land for food crops.

Teso district is inhabited by the Nilote speaking Ateso tribe. The district lies in LM_3 which is sub-humid. It receives average annual rainfall of 1200-1450 mm and has an annual mean temperature of $21.0\text{-}22.7^0$ C. It lies within an altitude range of 1140-1500 masl with a population density of 325 persons per km^2. The Ateso community is more conservative in their traditions. They grow several food crops, but have no specific cash crop.

Busia district lies between Mumias and Teso districts (Figure 2.1). Due to intermarriages, the community in this district has both the Bantus' and Nilotes' cultural practices. The district lies in LM_2 with a population density of 335 persons per km^2. It receives average annual rainfall of 1400-1800 mm and has an annual mean temperature of $21.4\text{-}22^0$ C. It lies within altitude range of 1200-1450 masl. One division was purposefully sampled from each district based on inhabiting community and AEZ. Five neighbouring villages were randomly sampled from each division.



Adapted from Jaetzold, and Schmidt, (1983)

Figure 2.1: Map of Kenya showing the PRA sites.

2.2.2 Data collection and analysis

2.2.2.1 Focused group discussion

A research team comprising the breeder, research assistants, agricultural extension staff and village elders was formed. In order to establish a rapport with farmers, the research team under the guidance of the village elder visited the selected villages for a reconnaissance and farmers sensitization exercise. A date was set for focused group discussion at a central meeting point in each division where farmers from the five selected villages would conveniently meet. A member of the research team most versed with the local dialect facilitated the group discussions using a checklist. A total of 101 farmers (47 male and 54 female) participated in FGD. Discussions covered cassava utilization, production constraints and variety preferred traits. Preferred cassava traits and production constraints were listed and ranked using pairwise ranking matrix.

Figure 2.2: Methods used to gather information during PRA (A) individual interviews (B) focused group discussions

2.2.2.2 Household interview

Information gathered during FGD was used to develop a structured questionnaire for the household interview. A survey route transecting across the selected division was mapped by the research team. During the survey, all households along the survey route were interviewed. A total of 151 households (52, 50 and 49 in Mumias, Busia and Teso districts respectively) were interviewed. Information on farm size, land under cassava, improved varieties adoption, utilization and cropping system was captured. Data collected was analyzed for descriptive statistics using SPSS 15th edition (SPSS, 2010) and non-parametric methods using GENSTAT 14th edition software (Payne et al., 2011).

2.3 Results

2.3.1 Cassava production systems

Mean land ownership per household is 2.1, 1.4 and 1.3 ha in Teso, Busia and Mumias districts, respectively (Table 2.1). Mean farm size under cassava is 0.3, 0.4 and 0.2 ha in Teso, Busia and Mumias districts, respectively. Land for cassava production is prepared by hand digging, ox-plough or tractor-plough. The majority of farmers in Teso (72.5%) and Mumias (85.7%) districts prepare land by hand digging while in Busia district, 61.2% use ox-plough (Table 2.1). During group discussions, farmers indicated that they use cassava stem cuttings for planting. The majority of farmers (77.3, 71.4 and 91.7% of cassava farmers in Teso, Busia and Mumias districts, respectively) source the planting materials from neighbours (Figure 2.3). This poses a risk of disease spread, though it enhances variety diffusion and adoption.

Table 2.1: Cassava production systems in Teso, Busia and Mumias districts

Description	Type	District		
		Teso	Busia	Mumias
Mean land size in ha and SE in parenthesis	Owned	2.1(6.2)	1.4(5.6)	1.3(6.4)
	Under cassava	0.3(0.3)	0.4(0.1)	0.2(0.1)
Land preparation methods used (% of farmers)	Hand digging	72.5	28.6	85.7
	Ox-plough	27.5	61.2	10.7
	Tractor-plough	0.0	10.2	3.6
Cropping system (% of farmers)	Mixed	55.8	76.5	92.9
	Mono	44.2	23.5	7.1
Crops in mixture with cassava (% of farmers)	Maize	60.4	45.9	89.2
	Sorghum	12.5	0.0	0.0
	Beans	18.7	37.8	3.6
	Cowpeas	2.1	8.2	3.6
	Groundnuts	4.2	5.4	3.6
	Maize/beans	2.1	0.0	0.0

SE = standard error

The majority of cassava farmers, 76.5, 55.3 and 92.9% in Teso, Busia and Mumias districts, respectively practice mixed cropping (Table 2.1). The most common crop in the mixtures is maize grown by 60.4, 45.9 and 89.3% of cassava farmers in Teso, Busia and Mumias districts, respectively (Table 2.1). The commonly cultivated cassava varieties mature in 12 to 24 months.

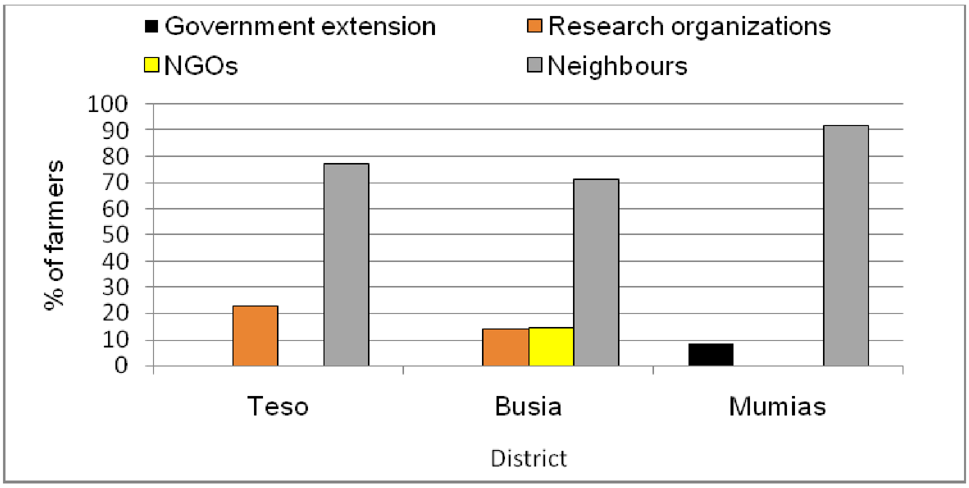


Figure 2.3: Sources of cassava planting materials and proportion of farmers utilising the sources in Teso, Busia and Mumias districts

Figure 2.4: Cassava production under mixed cropping system with maize and beans in the mix

2.3.2 Cassava utilization

Cassava is used as both food and cash crop in all the three districts. During the FGD, farmers described various methods of cassava utilization as food. Cassava storage roots can be boiled or roasted and eaten as a snack accompanied by a hot beverage (tea, coffee among others) or eaten together with green vegetable or legumes. The storage roots can also be peeled, dried and milled into flour. The flour is used for making soft or hard porridge locally called '*ugali'* or used for making local traditional brew locally known as '*Busa*'. Traditionally cassava leaves were used as vegetable. These practices stopped in early 1990s after the introduction of new cassava varieties, some of which caused death. Cassava stems are used for the construction of simple small farm structures like poultry and rabbit houses and as a source of fuel (firewood).

The majority of farmers, 67.9, 72.0 and 59.3% in Teso, Busia and Mumias districts, respectively sell surplus cassava storage roots (Table 2.2). Only 8.9 and 2.0% of farmers in Teso and Busia districts, respectively use cassava as animal feed. Eating boiled or roasted storage roots and processing to flour are the most popular forms of utilization. The flour is used for making '*Ugali'* or making local brews. The majority of farmers in Mumias district (70.3%) eat cassava after boiling or roasting the storage roots. In Teso and Busia districts, 69.4 and 43.0% of farmers, respectively use storage roots after processing to flour (Table 2.2). Eating of raw storage roots, which exposes consumers to higher risk of cyanide poisoning, is more popular in Busia district (19.3%) than in all other districts.

Farmers in Mumias district do not use cassava to feed their livestock. Teso district farmers lead in the proportion of farmers who use cassava as an animal feed (8.9%) as compared to farmers in Busia district (2.0%). In Busia district, only the storage roots are fed to livestock. In Teso district, 50.0, 12.5 and 37.5% of farmer who use cassava as an animal feed, feed their livestock on storage roots, leaves and storage roots peelings, respectively (Table 2.2). Dry storage root chips are the most popular (94.4% in Teso, 66.7% in Busia and 83.3% in Mumias districts) form in which cassava is sold (Table 2.2). The fear of cyanide poisoning limits the selling of raw storage roots, especially in Mumias district, despite the high popularity of using raw storage roots after boiling or roasting in the district.

Table 2.2: Cassava utilization methods in Teso, Busia and Mumias districts

Description	Type	Districts		
		Teso	Busia	Mumias
Utilization method (% of farmers)	Food only	23.2	26.0	40.7
	Sell surplus	67.9	72.0	59.3
	Animal feed	8.9	2.0	0.0
Form eaten (% of farmers)	Boil or roast storage roots	29.2	32.5	70.3
	Process to flour	69.4	46.5	21.6
	Eat raw storage roots	1.4	19.3	8.1
	Process other products	0.0	1.8	0.0
Part used as livestock feed (% of farmers)	Leaves	12.5	0.0	0.0
	storage roots	50.0	100.0	0.0
	Peelings	37.5	0.0	0.0
Form sold to local markets (% of farmers)	Raw storage roots	2.8	2.1	0.0
	Dried storage roots chips	94.4	66.7	83.3
	Planting materials	2.8	27.1	0.0
	Processed products	0.0	4.2	16.7

2.3.3 Cassava varieties adoption

All farmers in Busia, 71.0% in Teso and 79.3% in Mumias districts are aware of cassava improved varieties against 60.8, 84.0 and 56.5% of farmers in Teso, Busia and Mumias districts, respectively who have planted improved cassava variety at least once. Despite the high level of awareness, only 21.9, 48.1 and 18.0% of farmers in Teso, Busia and Mumias districts, respectively still grow improved cassava varieties (Figure 2.5).

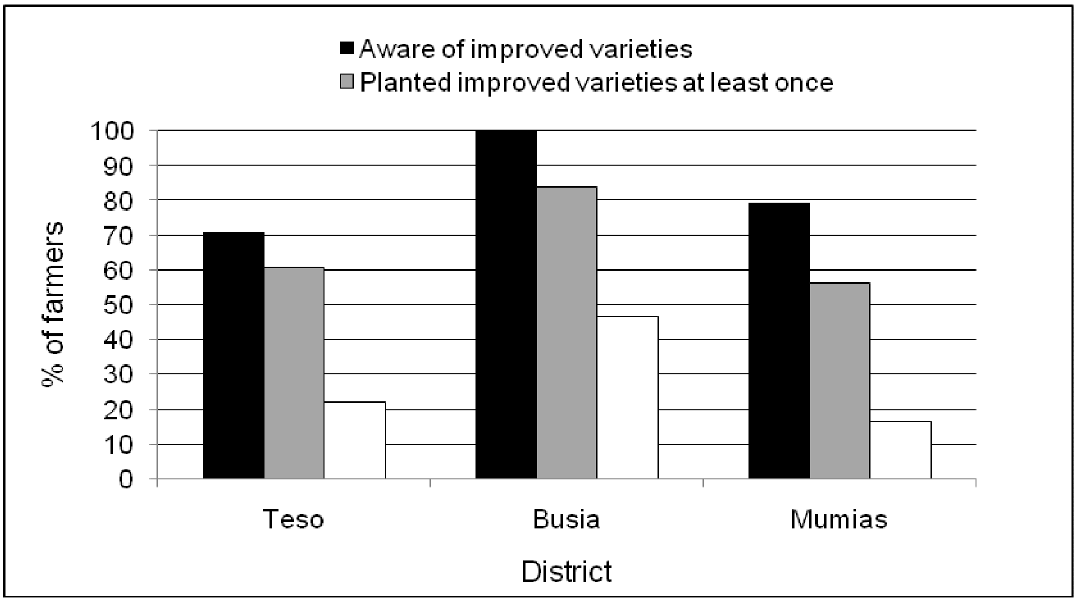


Figure 2.5: Proportion of farmers that adopted cassava varieties in Teso, Busia and Mumias districts

Farmers in all districts prefer landraces for tall plant height, long duration of underground storability and good taste and texture of boiled storage roots (Table 2.3). In addition, landraces are preferred for taste of raw storage roots in Busia and Mumias districts. Improved varieties are highly preferred (over 70% preference rate) for storage roots yield and foliar diseases and pests resistance in all districts.

Table 2.3: Percentage of farmers preferring landraces and improved cassava varieties for preferred traits in Teso, Busia and Mumias districts

Trait	Teso		Busia		Mumias	
	Improved	Landrace	Improved	Landrace	Improved	Landrace
Time to maturity	60.0	40.0	93.2	6.8	76.5	23.5
Disease/pest resistance	90.5	9.5	90.5	9.5	100.0	0.0
Internode length	68.2	31.8	51.4	48.6	66.7	33.3
Plant height	46.2	53.9	46.2	53.9	41.2	58.8
Branching of plants	58.3	41.7	92.1	7.9	69.2	30.8
Time to drying storage roots	37.5	62.5	42.9	57.1	56.3	43.8
Taste of raw storage roots	53.9	46.2	39.4	60.6	45.5	54.6
Time to boiling storage roots	60.0	40.0	42.3	57.7	50.0	50.0
Taste of boiled storage roots	44.0	56.0	18.9	81.1	41.2	58.8
No. & size of storage roots	57.7	42.3	70.7	29.3	66.7	33.3
storage roots yields	79.2	20.8	87.2	12.8	73.7	26.3
Cyanide level (poison)	54.2	45.8	70.4	29.6	52.9	47.1
Underground storage	41.7	58.3	36.0	64.0	42.9	57.1

2.3.4 Cassava production constraints

Only 25.0, 52.0 and 66.7% of farmers in Mumias, Busia and Teso districts, respectively produce cassava on their farms enough for their own consumption (Figure 2.6). Insufficient production of cassava indicates underlying production bottlenecks in the three districts.

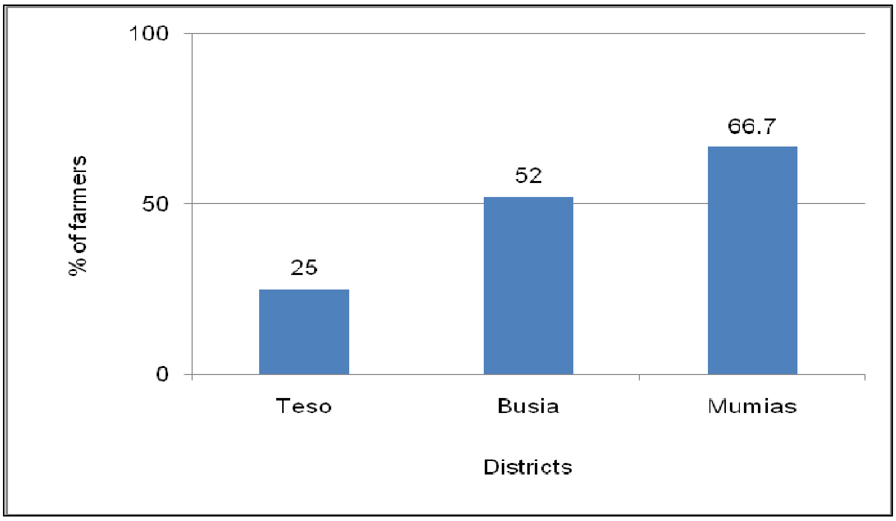


Figure 2.6: Percentage of farmers producing enough cassava for their own consumption on their farms in Teso, Busia and Mumias districts

A total of 10 cassava production constraints were identified across all the three districts and ranked during FGD. The rankings were highly correlated between the three districts (Table 2.4) implying that important cassava production constraints are rated similarly in all three districts. Foliar diseases and pests, lack of capital and land are the most pressing cassava production constraint and were ranked either first or second in all districts.

Table 2.4: Direct matrix ranking of cassava production constraints by farmers in Teso, Busia and Mumias districts

Constraint	Teso	Busia	Mumias	Mean rank
Diseases and pests	1	2	1	1.3 (1)
Lack of capital and land	2	1	2	1.7 (2)
Lack of planting materials	4	3	5	4.0 (3)
Low yields	5	4	3	4.0 (3)
Drought	5	5	6	5.3 (5)
Moles	3	6	9	6.0 (6)
Cyanide poisoning	9	9	4	7.3 (7)
Lack of production knowledge	8	9	7	8.0 (8)
Poor storability of planting materials	7	7	10	8.0 (8)
Low soil fertility	10	7	10	9.0 (10)

During FGD, farmers revealed that the most common symptoms of cassava diseases observed in most cassava fields were: yellowing, curling and dropping leaves and stunted growth of plants. Farmers associate these problems with poor soil fertility and moisture stress. These symptoms suggest the prevalence of CMD, mites/aphids and cassava bacteria blight. Though cassava is considered a low input crop and no farmer uses fertilizer or pesticide on it, cassava cultivation demands high labour input especially on weeding and processing. The number of weeding sessions per cropping season can be reduced if farmers grow varieties that have good canopy cover.

2.3.5 Preferred traits of cassava

During FGD, farmers listed a total of 13 traits they prefer in cassava varieties. These traits ranged from plant architecture, storage root yield, quality of boiled and processed storage roots, diseases and pest reaction and agronomic traits to aesthetics (in-field appeal of the crop). They described the form in which each trait was preferred (Table 2.5). Some traits were highly preferred in one district, but not in another. The most preferred traits by the farmers are high storage root yield which was ranked first in all three districts. The second most preferred trait was resistance to diseases and pests in Busia and Mumias districts and long underground storability of storage roots in Teso district. There were distinct differences in farmer preferences for short time to drying, low cyanide content, long underground storability and plant height between districts (Figure 2.7).

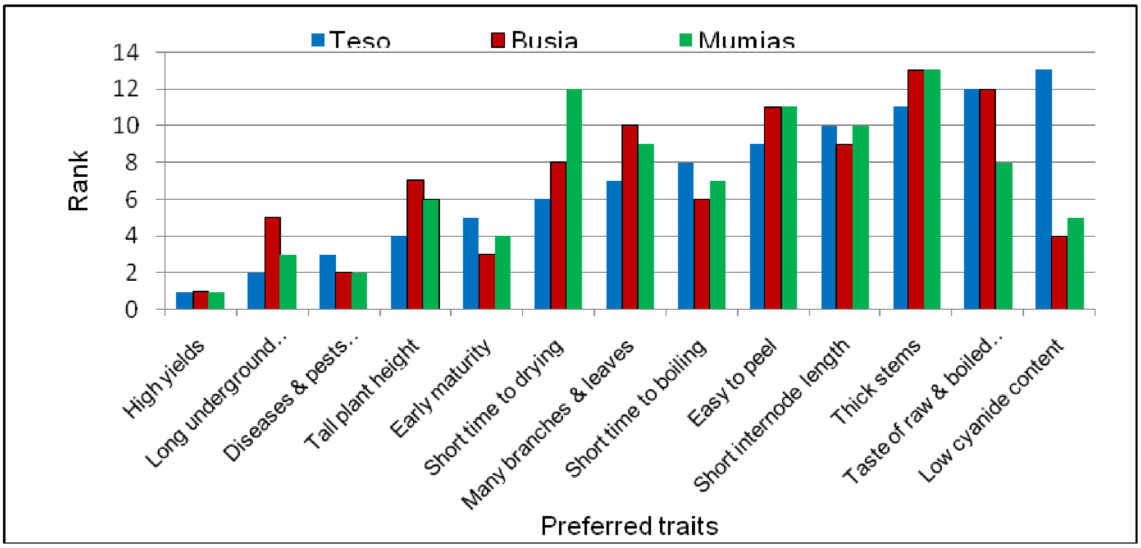


Figure 2.7: Direct pairwise matrix ranking of preferred cassava traits in Teso, Busia and Mumias districts during FGD.

Low cyanide poisoning was ranked second in Mumias district, but was ranked last in Busia district and seventh in Teso district (Figure 2.7). This is most likely due to differences in cassava utilization method between the three districts. Farmers in Mumias district predominantly eat cassava after boiling or roasting (see section 2.4.2) while farmers in Teso district predominantly use cassava after processing to flour. Cassava processing eliminates cyanide, reducing the possibility of cyanide poisoning. Short time to boiling was among the top five preferred traits in Mumias district but was ranked eighth and ninth in Teso and Busia districts, respectively. The difference in rank positions of short time to boiling can be attributed to the regional difference in cassava utilization.

Table 2.5: Farmer preferred cassava traits, forms and reasons for preference listed by farmers in Teso, Busia and Mumias districts

Trait	**Preferred form and reason**
Yield	• High yielding varieties. Yield is assessed by farmers as number and size of storage roots per plant
Diseases and pests resistance	• Dark green leaves which indicate healthy plants. No value is attached to stem petiole or leaf rib colour. Clean plants look appealing in the field.
Time to maturity	• Varieties that bulk early so that farmer can use the land for other crops.
Branching habit	• Many branches. This gives more cuttings per plant and good plant canopy that reduces the number of weeding.
Roots taste/texture	• Storage roots with soft, friable (floury) texture after boiling.
Plants height	• Tall plant. This gives more planting materials.
Low cyanide poisoning	• Low cyanide content. The farmers associate high cyanide content with bitterness of storage roots.
Underground storability	• Varieties that can stay long in the field after maturity. This is important for food security during drought and other natural calamities.
Internodes size	• Short internodes. Plants will give more cuttings.
Time to drying	• Varieties that take a short time to sun-dry. These save time and labour.
Time to boiling	• Varieties that take a short time to cook. This saves time and fuel.

2.4 Discussion and conclusions

The study aimed at collecting information on cassava production system, utilization, production constraints, preferred traits and variety adoption in western Kenya. The study area covered diverse production, agro-ecological and ethnic niches in the region. Understanding cassava production and utilization environment (target production environments), and the variation that exist between them, will provide vital information on which approach to be used in setting of breeding objectives, variety development, testing and promotion.

The results indicate that cassava is produced by small scale farmers with mean land sizes of 1.6 ha. These results concur with reports by El-Sharkway (2004) that cassava in Africa is produced by small scale farmers. Munga (2008) reported that the farm area under cassava production in coastal area of Kenya was 31%. In this study, the mean area under cassava production was 0.3 ha representing 19% of mean land owned. The majority of farmers prepare cassava field by hand digging except in Busia district where the ox-plough is popular. These results suggest that land is a limiting factor in cassava production. Cassava production can be increased by developing high yielding varieties that will increase yield per unit area and decrease the unit capital spent on labour.

Kariuki et al. (2002) reported that cassava is mainly produced under mixed cropping systems in Kenya with maize and beans being the main crops in the mixes. In this study, the majority of farmers (>55%) practice mixed cropping system. The predominant crops in the mix were cassava/maize, cassava/maize/beans or cassava/beans. Farmers practice mixed cropping system so as to minimize the risk of crop losses and maximize returns per unit land. Due to the long cropping period of cassava and limited land sizes, farmers mix the crops so that they can get some produce as they wait for cassava to mature. Production of maize and beans, the staple foods in Kenya, is faced with a myriad of challenges ranging from small land size, lack of inputs, drought, diseases and pests. Inclusion of cassava in the maize and bean mix is probably a security measure against frequent crop failure problems given that cassava is tolerant to most of these stresses (DeVries and Toenniessen, 2001). Varieties developed and tested under mono-cropping system may not perform well under mixed cropping systems. There is need to develop varieties for mixed cropping system.

Cassava is primarily used as food crop for subsistence in the study areas. Those who sell cassava do so as food in the form of dried chips which are milled to flour. They sell to neighbours and at local markets. No cassava from the area is sold to industries. Cassava utilization differed between the three districts. In Mumias district, a majority of farmers

(70.3%) eat cassava after boiling or roasting while in Teso district, a majority (69.4%) use cassava after processing to flour. In Busia district, about a half (43.0%) use cassava after processing to flour and 32.5% after boiling or roasting the storage roots. Cassava is considered and used as a traditional crop. Mkumbira et al. (2003) reported that farmers in Malawi prefer varieties with sweet tasting storage roots for boiling, and the bitter and white ones for processing. Ngeve (2003) also reported that farmers prefer varieties whose storage roots after boiling are soft with a mealy texture. Differences in utilization methods imply differences in preferences of storage roots qualities. The present cassava breeding programme should consider the differences in utilization and develop and test varieties for specific uses.

There are many different varieties, both landraces and improved, grown in western Kenya. The naming of these varieties is not consistent. Some varieties have different names in different locations. A majority of farmers in western Kenya are aware of and have at least planted improved varieties once. However, the percentage of farmers still growing these improved varieties is very low (<20% in some districts). This probably implies the varieties were not preferred or farmers lacked planting materials. A majority of farmers acquire knowledge about improved varieties from neighbours. This indicates that there are poor methods of variety promotion and dissemination. Although the acquisition of knowledge from neighbours has an advantage of enhancing technology diffusion in communities (Odendo et al., 2002), it has the disadvantage in exposing farmers to distorted information. Decentralized PPB approach has an advantage of enhancing promotion and dissemination of new variety (Ceccarelli, 1994; Fukuda and Saad, 2001; Gyawali et al., 2007), especially in low input crops such as cassava in which private seed companies have no interest (Alemu et al., 2008).

A majority of farmers obtain planting materials from neighbours. These findings concur with observations by Munga (2008). Planting cuttings from their own farm or from neighbours promote the spread of diseases. These partly explain why the CMD epidemic is severe in western Kenya. Planting infected cuttings in the presence of white flies is the main cause of the spread of CMD (Fargette et al., 1996; Were et al., 2004). Percentage of farmers producing enough cassava for their consumption on their farms is as low as 25%. Insufficient cassava production is indicative of prevailing production constraints (Odendo et al., 2002). Cassava diseases and pests, lack of capital and land, low yield, lack of planting materials, and drought are the major cassava production constraints. Development of high yielding, drought, disease and pest resistant/tolerant varieties, alongside establishment of proper channels through which farmers can access clean planting materials are the most appropriate methods of solving these production constraints. These varieties will increase productivity per unit land and capital spent, thus solving the problem of lack of capital and land.

Preferred traits of cassava varieties range from plant type, yield of storage roots and quality, diseases and pest resistance/tolerance to in-field crop aesthetics. The most preferred traits are high storage root yields, disease and pest resistance, short time to maturity, long underground storability and tall plant height. Landraces are preferred over improved varieties for plant height, time to drying, taste of boiled storage roots and long underground storability in all districts and taste of raw storage roots in Busia and Mumias districts. The lack of farmers' preferred traits in improved varieties could be a consequence of the CPB approach under which they were developed. The CPB approach mainly focuses on high yield and disease and pest resistance (Ceccarelli and Grando, 2007; Witcombe et al., 1996), overlooking other traits. The traits in which landraces are superior are plant and storage roots quality traits which are preferred by farmers. These traits are farmer specific depending on how, where and for what cassava is grown. They cannot be evaluated by the breeder on-station (Almekinders and Elings, 2001; Morris and Bellon, 2004). A PPB approach, where farmers are involved in development of breeding objectives and variety selection, provides an opportunity that ensures such traits are incorporated and improved (Witcombe et al., 2006). There is a need to develop varieties with a combination of farmer preferred traits by using both the landraces and improved varieties in a PPB programmes.

The PRA study has provided an insight into cassava production systems in different agro-ecologies, production and utilization niches of western Kenya. A majority of cassava farmers in this region are small scale farmers growing cassava under mixed cropping system for food. As a food crop, the most popular utilization methods are either eating boiled or flour processing of storage roots. Cassava production constraints and preferences are prioritised. There is need for high yielding disease and pest resistant varieties and establishment of systems that can provide clean planting materials to farmers. In addition to the above needs, farmers prefer tall cassava varieties that mature early and have long underground storability. Cassava productivity in the region can be improved by developing varieties with preferred traits under the prevailing production system that can alleviate the production and utilization bottlenecks. The approach to breeding cassava should be decentralized PPB, which takes into account differences in ethnicity, production systems, agro-ecologies and utilization methods.

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CHAPTER 3

Farmers’ selection criteria of cassava varieties in western Kenya

Abstract

The ability to select the desired parents is the basis of successful plant breeding. A research study was conducted to determine how cassava farmers evaluate varieties for preferred traits using indigenous technical knowledge (ITK) in western Kenya. Fifteen popular cassava varieties were planted by three farmer groups from Mumias, Teso and Busia districts. The districts represent three distinct production and utilization niches. Farmers evaluated and ranked the varieties using ITK for the preferred traits. The results reveal that there were significant differences between the parental varieties in mean scores of traits in all districts except for cyanide content. This implies that farmers’ evaluation elicited genotypic differences between varieties except when evaluating for cyanide content. It further implies that ITK alone cannot be used to evaluate varieties. There should be complementation between farmers’ ITK and breeder’s conventional methods of variety evaluation. The districts differed in variety scores for most of the traits evaluated indicating differences in farmers’ priorities, evaluation, environments and/or genotype x environment interaction effects and therefore the need to decentralize parental variety selection. Parental variety ranking significantly correlated with foliar disease and pest resistance, time to maturity, plant height, internode length and yield in all districts implying these traits comprise farmers’ selection criteria for ideal cassava varieties. A simple selection index was developed for each district using the correlation coefficients as weightings.

3.1 Introduction

Varieties are developed through several stages from setting objectives to the release stage (Ceccarelli and Grando, 2007; Witcombe et al., 2005). In the conventional plant breeding (CPB) approach, breeders unilaterally undertake all the activities of variety development and often select varieties using their own selection criteria on-station (Courtois et al., 2001; Sperling et al., 2001). The on-station environments are often different from the target environments where the new varieties are to be grown, especially in the case of low input crops grown by small scale farmers in marginal areas (Banziger and Cooper, 2001). By not involving the farmers, breeders miss out on information and techniques to evaluate traits deemed important by the farmers (Manu-Aduening et al., 2006; Morris and Bellon, 2004).

Participatory plant breeding (PPB) advocates for the involvement of farmers in variety development (Gyawali et al., 2007; Witcombe et al., 1996). It is believed that farmers' participation and variety evaluation in target environments enhances breeding efficiency and effectiveness (Joshi et al., 2007; Virk and Witcombe, 2007). However, involving farmers in breeding does not necessarily guarantee breeding efficiency and effectiveness. It is only when farmers' participation complements the efforts of the breeder that breeding efficiency is increased (Witcombe et al., 2005). Some stages of breeding may be carried out much better by the farmers than the breeders and vice-versa. Similarly, some traits can be evaluated better by the farmer using indigenous technical knowledge (ITK) than the breeder using conventional methods and vice-versa.

Variety testing and selection is one of the most important stages of variety development. In PPB, involvement of farmers in variety testing and selection during participatory variety selection (PVS) provides an opportunity for farmers to identify and select what they prefer (Morris and Bellon, 2004). Farmers intuitively select varieties based on a number of preferred traits using their own ITK (Odendo et al., 2002), which may be hard for breeders to mimic. Participatory variety selection increases genetic diversity of the crop since farmers from different niches select varieties suitable for their conditions and use (Joshi et al., 2007; Witcombe et al., 1996).

In order to benefit from PPB, farmers should be involved in variety selection in the early stages of breeding when the genetic variability is still large. However, selecting from large plant populations is time consuming and confusing to farmers (Joshi et al., 2007). The limitation of farmers in selecting from large populations can be alleviated by designing a simple selection index formula that aids in ranking large populations of varieties based on farmers' preferences. Selection indices have been used in plant breeding to rank and select genotypes based on a conglomeration of traits for a long time (Sleper and Poehlman, 2006). Derivation of these selection indices vary between crops, traits and purposes. The most common selection indices in plant breeding are used for indirect selection of parents based on progeny performance. Indirect selection is used for traits that cannot be directly measured, or whose method of evaluation is destructive, such as pulp quality in trees, sugar content of roots among many others. Heritability estimates are used as weighting factors for these traits in the selection index formula equation (Falconer and Mackay, 1996). In some PPB programmes, when selecting for many traits, farmer preferences are used as weightings in the development of selection indices (Odendo et al., 2002). Correlation analysis of trait scores and variety ranking provides information on important traits considered during ranking. The correlation coefficient values indicate the direction and strength of association between the two variates (Steel and Torrie, 1980). These correlation coefficient values can be used as weightings (coefficients for the trait) in the selection index formula (Witcombe personal communication). The selection index formula is used to compute a selection index which is used by the breeder to rank and select varieties.

To increase breeding effectiveness and efficiency, it is important to determine how best the developed varieties can be evaluated for preferred traits. It is also important to determine who between the farmers using ITK, and the breeders using conventional methods, can evaluate which trait(s). A research study was conducted in western Kenya, the most important cassava producing region in Kenya, with the objectives to:

a) determine local ITK used to evaluate preferred traits

b) determine farmers' variety selection criteria

c) develop selection index formula

3.2 Materials and methods

The study involved farmer groups and popular cassava varieties in three districts. The three districts represented three different production and utilization niches of western Kenya.

3.2.1 Study sites

Three districts in western Kenya, Mumias, Busia and Teso were purposefully selected as the major cassava producing districts that represent different ethnic communities and agro-ecological zones (AEZ). From each district, with the help of the agricultural extension staff, one active farmer group with experience in cassava production was identified. Mumias district was represented by the Development Association Foundation (DAF) youth group with membership of 23 members (9 men, 14 women). The district is inhabited by the Bantu speaking Luhyia tribe. The district falls within AEZ LM_1 which is humid (Jaetzold and Schmidt, 1983). Farmers in this district are commercial sugarcane farmers and reserve small pieces of land for food crops. Naako-Aterait women group with a membership of 17 members (3 men, 14 women) was selected from Teso district. Teso district is inhabited by the Nilote speaking Ateso tribe. The district lies in LM_3 which is sub-humid. The Ateso community highly relies on cassava and sorghum as their staple food. They do not have any specific cash crop. Agro-farmers group with membership of 31 members (19 men and 12 women) represented Busia district. Busia district lies between Mumias and Teso districts. Busia district is inhabited by a hybrid community between Bantus (Luhyia) and Nilotes (Teso) and lies in LM_2 (Jaetzold and Schmidt, 1983).

3.2.2 Germplasm

A germplasm collection survey was conducted within the three districts. The germplasm collection team comprised of the breeder, technicians and agricultural extension staff. Popular cassava varieties were selected from key cassava producing areas based on secondary data from district agricultural extension office's crops production records, knowledge of extension staff and farmers.

Table 3.1: Popular cassava varieties collected in three districts of western Kenya

Variety name	District in which it is most popular	Main utilization form
Sudhe	Siaya	Flour
CK9	all districts	Raw, boiling and flour
Sifros	Busia	Raw and boiling
Ebwanatereka	Teso	Flour
Opongi	Teso	Raw, boiling and flour
Adhiambolera	Siaya	Raw and boiling
Kaleso	all districts	Raw, boiling and flour
Namambakaya	Busia	Raw, boiling and flour
Bumba	Busia	Raw, boiling and flour
Serere	all districts	Raw, boiling and flour
Migyera	Introduced high yielding CMD resistant	Raw, boiling and flour
SS4	Introduced high yielding CMD resistant	Raw, boiling and flour
MM96/3972	Introduced high yielding CMD resistant	Raw, boiling and flour
MM96/1871	Introduced high yielding CMD resistant	Raw, boiling and flour
MM96/4684	Introduced high yielding CMD resistant	Raw, boiling and flour

During germplasm collection, the local name, utilization, and any other special attribute(s) of the variety were described. Ten popular landraces and five improved varieties were selected (Table 3.1).

3.2.3 On-farm evaluation of parental varieties

Each farmer group identified a piece of land centrally located and accessible by all group members. On this land, the 15 parental varieties were planted under concealed identity using a completely randomised design (CRD) with three replications. Plots consisted of single rows of five plants each, planted at a spacing of 1 x 1 m. The trials were managed by the group members.

Farmer preferred cassava traits identified during participatory rural appraisal (PRA) (Chapter 2) were used to evaluate the 15 parental varieties. Farmers used their ITK and selection criteria to evaluate the varieties. Before evaluation, farmers listed and described the indigenous technologies they use to evaluate each of the preferred cassava traits. Using simple answer sheets (Appendix 3.1), each farmer independently evaluated each variety for each trait by scoring on a scale of 0 to 5 (0 = the variety is lacking the trait; 5 = the variety express the trait at a satisfactory level). Variety evaluation was conducted at two stages; one day before harvesting and at harvest.

One day before harvest, farmers scored for traits related to plant aspects. These included; disease and pest resistance, plant height, internode length, branching level, height to first branching, and time to maturity. Apart from scoring for preferred traits, farmers ranked the varieties based on visual assessment, without considering the scores awarded for preferred traits (ranking before harvest).

Plants were harvested 12 months after planting (MAP) by uprooting the whole plant leaving all storage roots intact on the plant. Using a simple questionnaire (Appendix 3.2), farmers evaluated all the varieties by scoring for traits related to yield and storage roots quality. These traits included; storage roots yield, taste of raw storage roots, taste and texture of boiled storage roots and cyanide content. To score for taste and texture of boiled storage roots, two storage roots were harvested from each variety, peeled and chopped into small pieces of about 4 – 5 cm long. After washing, the pieces were placed in transparent plastic bags. The pieces in plastic bags were all boiled in a large cooking pot using local method for about 45 minutes. The boiled pieces were put on plates with concealed label identity on tables. Farmers went round the table to evaluate for both taste and texture awarding scores for each variety. After the exercise, farmers were asked to give overall ranking without considering scores for the traits.

3.2.4 Breeders evaluation of agronomic and morphological traits

Data for the following agronomic and morphological traits was recorded by the breeder: cassava mosaic disease (CMD) resistance on a score scale of 1-5 [1= resistant and 5= susceptible], plant height (PH) and height to first branching(HB) (m), number of storage roots per plant (NR), fresh storage root yield (t ha^{-1}) (RY), dry matter content (DMC%) = {[Wa/(Wa - Ww)] x 158.3} – 142 where Wa =mass of roots in air and Ww = mass of roots in water and cyanide content using picrate score method (Bainbridge et al., 1996).

All data collected were subjected to analysis of variance using both parametric and non-parametric (Kruskall-Wallis) methods in GENSTAT version 14 (Payne et al., 2011) to detect differences between varieties within and between districts. Variety mean scores for all traits were computed. Using these means, cassava varieties were ranked for each trait per district. Spearman's rank correlation analysis was conducted between variety ranks and mean trait score. Correlation coefficients were used to determine the importance of each trait to farmers when selecting varieties (selection criteria) and to generate a simple selection index.

3.3 Results

3.3.1 Farmers' indigenous technical knowledge on trait evaluation

Farmers have their own way of assessing various traits they prefer. In this study, the indigenous technology used by farmers to evaluate cassava preferred trait are:

(i) **Storage roots yield:** yield is assessed at two stages; one day before harvest and at harvest stages. At harvest stage farmers assess yield by directly observing the storage roots and consider number and size of storage roots. However, before harvest, farmers use indigenous technical knowledge to assess yield by observing:

a. Cracking of soil around the plant. High level of deep, large and many cracks in the soil radiating from the crown of plant indicate high yield and vice-versa.

b. Thickness of the stem at the crown. Thick stems indicate high yields

c. Level of foliage. Heavily foliated varieties with large leaves have low storage yields.

(ii) Foliar disease and pest resistance: This evaluation is based on the health of the leaves. Varieties with deformed, few, small leaves are considered to be susceptible and undesirable. Despite the region being a hot spot for many cassava diseases and pests, most farmers could not identify any of them. They believe the poor health of plants expressed as yellowing, curling and dropping-off of leaves, stunted growth of plants and drying of stems are due to poor soils, water stress or bad varieties.

(iii) Cyanide content: cyanide content was assessed at harvest time by;

a. chewing a small piece of a cassava storage root. Farmers believe the more bitter the storage roots were, the higher the cyanide content, and the greater the potential to be poisonous.

b. based on easiness to peel. Varieties that peel easily are believed to be sweet hence with low cyanide content.

(iv) Early maturity: this trait was assessed one day before harvest by observing the extent of soil cracking around the plant and the appearance of plants in terms of vigour and hardening of stems. Varieties that cause soil cracking early in the field are assumed to mature early. Those varieties that have a high vigour (grow faster and become woody early in life) are also considered to mature early.

(v) Plant height, internode length, and branching: this trait was assessed one day before harvest. Farmers lack any ITK of indirectly evaluating these traits. The traits were evaluated by direct observation of the plants.

(vi) Taste of raw and boiled storage roots: these traits were evaluated at harvest stage. These traits lacked any indirect indigenous technique of evaluation. They were directly evaluated by farmers by tasting the raw and boiled storage roots.

3.3.2 Breeder's evaluation

All 15 parental varieties were significantly ($P<0.01$) different for the traits evaluated (Table 3.2). All the varieties performed differently ($P<0.01$) in the three districts except for resistance to CMD. There were significant ($P<0.01$) interaction effects between varieties and districts in all traits except CMD and number of storage roots per plant.

Correlation between breeder's evaluation of morphological and agronomic traits and farmer's variety traits scores were significant for most of the related traits except between breeders and farmers evaluation of cyanide content (Appendix 3.5).

Table 3.2: Significance of mean squares for morphological and agronomic traits of parental varieties evaluated by the breeder in Mumias, Teso and Busia districts

SOV	d.f.	CMD	PC	DMC	PH	HB	NR	RY
Variety	14	8.27**	5.47**	45.39**	3310.90**	9885.20**	37.61**	8.58**
District	2	0.48ns	0.99**	102.63**	100061.90**	2834.80***	44.16**	6.61**
Variety x district	28	0.40ns	3.58**	42.84**	1628.90**	819.50**	4.31ns	2.19**

ns, * and ** = non significant, significant at P<0.05 and 0.01 respectively; sov = source of variation; df = degrees of freedom; CMD = cassava mosaic disease score; PC =picrate score; DMC = dry matter content; PH = plant height; HB = height to first branching; NR = number of storage roots; RY = fresh storage roots yield

3.3.3 Farmers' evaluation

There were significant (P<0.05) differences between varieties for all traits evaluated in all districts except for cyanide content in Teso and Busia districts (Table 3.3). The varieties performed significantly (P<0.05) different between districts in cyanide content, internode length, taste of raw and boiled storage roots, yield and in mean score.

Table 3.3: Mean square and Kruskal-Wallis H-values for cassava traits scores given by farmers

Source	Mumias	Teso	Busia	Between districts
Branching level	95.1**	52.9**	36.1**	0.9ns
Cyanide content	27.7*	5.7ns	21.6ns	6.3**
Disease & pest resistance	66.8**	65.5**	33.2**	0.5ns
Internode length	30.2*	34.6**	24.4*	3.3**
Time to maturity	18.3*	25.6*	24.4*	2.1ns
Plant height	76.2**	12.9*	49.1**	1.3ns
Taste of boiled storage roots	34.7**	62.3**	29.2**	3.9**
Taste of raw storage roots	40.9**	77.8**	27.8**	4.3**
Yield at harvest	77.6**	106.0**	60.7**	1.9ns
Yield before harvest	34.9**	59.0**	33.1**	2.7*

ns, * and ** = not significant, significant at $P \leq 0.05$ and 0.01, respectively

The differences in variety performance between districts could be due to either differences in farmer's rating or variety performance between districts. Differences in variety performance between districts could be attributed to differences in environments or genotype x environment interaction effects. There were significant differences between districts in variety ranking at harvest and before harvest stages.

Figure 3.1: Evaluation of cassava at (a) plant and (b and c) at harvest stage

The varieties ranking first before harvest were the landrace Mercury (V13), in Mumias and Busia district and the improved variety Migyera (V3), in Teso district (Table 3.4). Ebwanatereka (V15), a landrace, was ranked top at harvest in all districts. The poorly ranked varieties before harvest stage were Kaleso (V14) in Mumias and Busia districts and Sudhe (V11) in Teso district. At harvest stage, Serere (V5) in Mumias and Busia district and Sifros (V10) in Teso district were ranked last. All the varieties ranked last are landraces. Among the improved varieties, MM96/1871 (V12) and MM96/3972 (V1) were the best in Mumias district before harvest and at harvest stages respectively. Miygera (V3) and MM96/3972 were ranked top in Teso district before and at harvest stages, respectively in Teso district. In Busia district, the best among the improved varieties were SS4 (V9) before harvest and Migyera (V3) at harvest. The varieties were ranked differently for the various traits in the districts. Migyera (V3) was the most resistant variety to foliar diseases, ranked first in Teso district and second in Busia and Mumias districts (Appendix 3.3). Mercury (V13) was ranked the best for storage root yield in Mumias and Teso district and second in Busia district. This implies that when breeding for foliar disease resistance, Migyera (V3) is the best parent to be used while when breeding for high storage root yield, Mercury (V13) is the best parent to be selected.

Table 3.4: Variety mean rank and overall rank (in parenthesis) before and at harvest in Mumias, Teso and Busia districts

Variety	Mumias		Teso		Busia	
	BH	AH	BH	AH	BH	AH
V1	3.3(3)	3.9(2)	3.3(2)	3.8(3)	4.0(3)	6.8(4)
V2	6.3(5)	7.8(7)	13.6(14)	10.1(10)	6.7(5)	6.2(3)
V3	7.0(6)	4.1(3)	2.4(1)	5.8(5)	7.3(7)	6.1(2)
V4	12.5(14)	11.4(13)	6.8(5)	8.8(9)	12.7(14)	9.7(13)
V5	8.1(8)	13.0(15)	7.8(8)	4.5(4)	7.6(8)	11.6(15)
V6	7.8(7)	4.6(4)	7.0(6)	10.1(10)	7.1(6)	9.5(12)
V7	10.9(11)	9.4(10)	12.9(13)	7.3(7)	10.4(11)	7.2(8)
V8	9.9(9)	10.6(12)	10.3(12)	6.3(6)	10.1(10)	7.9(9)
V9	10.1(10)	6.1(6)	5.5(4)	7.4(8)	3.9(2)	11.5(14)
V10	10.9(11)	8.4(9)	9.5(11)	14.1(15)	10.9(13)	6.8(4)
V11	4.4(4)	8.3(8)	13.9(15)	12.6(13)	10.7(12)	7.0(6)
V12	2.1(2)	10.0(11)	3.5(3)	12.3(12)	4.1(4)	8.0(10)
V13	1.0(1)	5.6(5)	8.5(10)	2.1(2)	1.0(1)	7.0(6)
V14	14.8(15)	12.4(14)	7.0(6)	14.0(14)	13.9(15)	8.9(11)
V15	11.1(13)	3.7(1)	8.3(9)	1.0(1)	9.7(9)	5.6(1)

V1 =MM96/3972; V2 = Nambukaya; V3 = Migyera; V4 = Opongi; V5 = Serere; V6 = MM96/4684; V7 = CK9; V8 = Bumba; V9 = SS4; V10 = Sifros; V11 = Sudhe; V12 = MM96/1871; V13 = Mercury; V14 = Kaleso; V15 = Ebwanatereka; BH and AH = variety ranking before and at harvest respectively.

3.3.4 Farmers' selection criteria and index

There were significant (P<0.05) correlations between farmers' overall variety ranking by visual assessment before harvest stage for disease and pest resistance, time to maturity, plant height, internode length, yield assessed before harvest in all districts and level of branching in Busia and Teso districts only (Table 3.5). Overall variety ranking at harvest stage was significantly (P<0.05) correlated to yield evaluated at harvest in all districts, taste of boiled storage roots in Busia and Teso districts, taste of raw storage roots in Teso districts and cyanide content in Mumias district only.

Significant correlations between variety trait scores and ranking imply that these traits form the basis on which farmers rank varieties. Correlations between trait scores and variety ranking provide information on traits considered by farmers during variety ranking. Correlation coefficients can be used as weighting for traits that form the selection criteria.

Using these correlation coefficients, simple linear selection indices can be developed (Witcombe personal communication). Given that variety ranking before and at harvest were not significantly correlated and that varieties scores for most of the traits differed significantly (P<0.05) between districts (Tables 3.3 and 3.5), selection indices were developed for each district separately.

Table 3.5: Spearman's rank correlation coefficients between cassava variety traits scores and ranking before and at harvest in Busia, Teso and Mumias districts

Trait	Busia		Teso		Mumias	
	BH	AH	BH	AH	BH	AH
Branching level	-0.89**	-	-0.92**	-	-0.25 ns	-
Cyanide content	-	-0.86**	-	-0.25 ns	-	-0.24 ns
Disease & pests resistant	-0.83**	-	-0.93**	-	-0.68*	-
Time to maturing	-0.80**	-	-0.95**	-	-0.56**	-
Plant height	-0.76**	-	-0.56**	-	-0.22*	-
Internodes length	-0.92**	-	-0.82**	-	-0.50*	-
Taste of boiled storage roots	-	-0.36*	-	-0.57**	-	-0.01 ns
Taste of raw storage roots	-	0.11 ns	-	-0.64**	-	-0.25 ns
Yield assessed before harvest	-0.85**	-	-0.88**	-	-0.53*	-
Yield assessed at harvest	-	-0.78**	-	-0.97**	-	-0.76**

* and ** = significant at P<0.05 and 0.01 respectively; BH = variety ranking at before harvest; AH = variety ranking at harvest; - = not assessed at that stage.

All the correlation coefficients as expected were negative since the rank of the best variety is numerically lower than the worst yet the reverse is true for scores. In the selection indices, positive correlation coefficients are used for each trait used as weighting since the scores were positively awarded. Preferred traits had high positive score, while less preferred traits had lower score. The best variety is one with the highest positive selection index.

$SI_{Mumias} = 0.25Bl + 0.24Cc + 0.65Dr + 0.50IL + 0.56Mt + 0.22Ph + 0.01Tb + 0.25Tr + 0.53Yb + 0.76Yh$

$SI_{Teso} = 0.92Bl + 0.25Cc + 0.95Dr + 0.82IL + 0.93Mt + 0.56Ph + 0.57Tb + 0.64Tr + 0.88Yb + 0.97Yh$

$SI_{Busia} = 0.89Bl + 0.86Cc + 0.83Dr + 0.78IL + 0.80Mt + 0.76Ph + 0.36Tb + 0.11Tr + 0.85Yb + 0.92Yh$

Where: Bl = branching level, Cc = cyanide content, Dr = resistance to foliar diseases and pests, IL = internode length, Mt = time to maturity, Ph = plant height, Tb = taste of boiled storage roots, Tr = taste of raw storage roots, Yb = yield assessed before harvest and Yh = yield assessed at harvest.

3.4 Discussion and conclusions

Participatory plant breeding (PPB) requires the participation of farmers in the breeding process (Sperling et al., 2001; Witcombe et al., 1996). The objective of participation is to improve the efficiency and effectiveness of the breeding programme (Joshi and Witcombe, 1996). Farmers should be involved at stages that can lead to improved efficiency and effectiveness of the breeding process. Knowledge of farmers' selection criteria, accuracy of selection and their ability to evaluate large population using limited resources and time, enormously contribute to breeding efficiency and effectiveness.

Farmers have their own way of selecting the varieties they grow. They select varieties based on their own preferred traits using informal ITK. Some of the farmer preferred traits lack any alternative formal scientific method(s) of evaluation apart from the ITK. Such traits cannot be evaluated by breeder on-station without the participation of farmers (Morris and Bellon, 2004). In this study, farmers used ITK to evaluate potential parental varieties for preferred traits. Significant differences were observed between varieties for all traits evaluated except cyanide content. This indicates that the ITK methods used were able to elicit genotypic differences and can be employed in cassava variety evaluation. These results are consistent with those observed by Mkumbira et al. (2003) who reported that farmers in Malawi are able to distinguish between cassava landraces with higher precision than scientists.

Some of the ITK listed and used in this study have been reported to be used by farmers elsewhere. Assessment of yield by soil cracking has been reported to be used in coastal Kenya (Munga, 2008) and by thickness of the stems in Ghana (Manu-Aduening et al., 2006). The use of soil cracking as an indicator for yield is logical. Level of cracking corresponds to number and size of storage roots which are important yield component parameter. In the study, cyanide content is evaluated by tasting raw storage roots. 'Bitter' taste indicates high cyanide content. Similar method of cyanide content evaluation is used by farmers in Malawi (Mkumbira et al., 2003) and Ghana (Manu-Aduening et al., 2006). However, there are contradicting reports on the efficacy of this method of cyanide content evaluation. In Malawi, Mkumbira et al. (2003) reported that farmers classification of cassava into 'cool' and 'bitter' accurately reflected actual cyanide content. In their studies Roger and Fleming (1973) reported that there is no correlation between 'bitterness' or 'sweetness' of storage roots and cyanide content. In this study a confirmation test was carried out by the breeder to determine the effectiveness of farmers in evaluation this trait. After measuring the cyanide content of all the varieties evaluated by farmers, there was no significant correlation between picrate score and farmers' score for bitterness or sweetness of the storage roots. This implies farmers' evaluation of cyanide content using ITK is not reliable. Testing for cyanide content should therefore not be left to farmers alone using ITK, but need to be tested using conventional laboratory techniques.

Significant differences observed between varieties in traits scores when evaluated in different districts reflect regional differences in farmers' scores for various traits. This indicates differences in levels of satisfaction between farmers from different districts. These differences in scoring may be due to differences in farmer preferences, environment and genotype x environment interaction effects. Environmental effects lead to differences in expression of traits when the same genotype is grown in different environments (Sleper and Poehlman, 2006). Differences in environments lead to differences in scoring and ranking of the same genotype in different environments. The evaluation by the breeder on morphological and agronomic traits revealed significant differences between environments and their interaction with genotypes. This implies the three districts need to be considered as different target environments that require decentralized participatory variety evaluation and selection.

In order to enhance variety adoption, at least one of the parents used in their development should be selected by farmers and be adapted to the production environment (Witcombe and Virk, 2009). Varieties selected by farmers have preferred traits. These varieties are normally popular within their production environments. Popularity indicates presence of farmer preferred traits and adaptation to the production environment. Ideal parental varieties are those selected through participatory variety selection (PVS) (Witcombe and Virk, 2009). In this study, Mercury among the landraces and MM96/3972 among the improved varieties were favourably selected by farmers. However, selection of varieties based on ranking may be misleading. It is more logical to select parental varieties based on breeding objectives (traits to be improved). For example in this study, if the breeding objective was to increase storage root yield, the best parents would be Mercury in Mumias and Busia districts and Ebwanatereka in Teso district. Since there were significant differences between districts in variety scoring and ranking, parental varieties should be selected per district.

Variety ranking by visual assessment is a quick assessment method based on a few observable traits. During maize variety selection in eastern Kenya, farmers selected varieties based on yield and time to maturity. Early maturing varieties with high yields were selected irrespective of whether they were resistant to blight or not, though farmers had listed resistance to blight as a preferred trait (Odendo et al., 2002). Traits that farmers highly consider during variety selection express large significant correlation between variety ranking by visual assessment and trait score. Traits that highly and significantly correlate with variety ranking form the selection criteria (a combination of traits that influence variety ranking and selection). The results of this study indicate that resistance to foliar diseases and pests, time to maturity, plant height, internode length and yield form the selection criteria in all districts. In addition, taste of boiled and raw storage roots in Teso district were part of the selection criteria.

Development of a simple selection index formula to aid in quick selection of a large number of varieties is important. Correlation coefficients indicate the direction and degree of association between traits (Steel and Torrie, 1980). Correlation coefficients of traits that significantly correlate with variety ranking are used to develop selection index formula (Witcombe personal communication). The correlation coefficients represent the contribution and direction of contribution of the trait to the ranking. In this study, foliar diseases and pests resistance, early maturity time, plant height, internode length and storage roots yields significantly negatively contributed to variety rank in all districts. Additionally, taste of boiled and raw storage roots in Teso district significantly contributed to variety rank. Based on the selection index formulae, the best variety is one with highest positive selection index.

Farmers, using their own selection criteria, have the capacity to select suitable parental varieties. The selection differs between production niches based on preferences. To increase breeding efficiency, farmers should be involved in selection of parental varieties. This should be decentralized, based on the traits to be improved on (breeding objectives) and not overall performance of the variety. Despite the ability of farmers to select suitable varieties, their ability to evaluate for certain traits is limited. There should be complementation between the breeders and farmers in parental variety selection especially for traits where ITK methods cannot elicit.

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APPENDIX 3.1

CASSAVA VARIETIES EVALUATION SHEET AT VEGETATIVE STAGE

Name of farmer: __________________________Name of Division: ___________________________ Date: ______________

Name of Village: ____________________________ Gender: ____________ Group member: YES NO

Instruction: *For each plot, award 'marks' for each trait based on the level of satisfaction (To what level of satisfaction is the trait expressed by the variety?)*

Traits		Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15
1	Resistant to foliar diseases and pests															
2	Yield at plant															
3	Time to maturing															
4	Internode length															
5	Plant height															
6	Uniform germination															
7	Branches and leaves level															
Overall rank																

Key: Score out of 5: 5 = Variety has the trait to satisfactory level 0 = Variety does not have the trait
Give overall rank based on your own judgment like best variety to be one

APPENDIX 3.2

CASSAVA VARIETIES EVALUATION SHEET AT HARVEST STAGE

Name of farmer: ___________________________Name of Division: ____________________________ Date: _______________

Name of Village: _____________________________ Gender: _____________ Group member: YES NO

Instruction: *For each plot, award 'marks' for each trait based on the level of satisfaction (To what level of satisfaction is the trait expressed by the variety?)*

Traits		Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15
1	Yield of storage roots															
2	Taste of raw storage roots															
3	Taste and texture of boiled storage roots															
4	Cyanide content															
Overall rank																

Key: Score out of 5: 5 = Variety has the trait to satisfactory level 0 = Variety does not have the trait
Give overall rank based on your own judgment ie best variety to be one

APPENDIX 3.3

Variety means score and rank (in parenthesis) for farmer preferred traits in Mumias, Teso and Busia districts

Trait	Site	Variety															H Value
		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	
Bi	M	4.2(5)	2.9(11)	4.4(1)	1.8(14)	1.4(15)	3.9(6)	3.6(9)	2.7(12)	4.4(1)	3.9(6)	3.9(6)	4.3(4)	3.6(10)	4.4(1)	2.2(13)	95.14**
	T	4.6(3)	3.0(12)	4.9(1)	4.4(4)	3.6(9)	3.9(6)	2.4(14)	3.8(7)	4.3(5)	3.3(11)	2.4(14)	4.8(2)	2.9(13)	3.8(7)	3.6(9)	52.85**
	B	3.5(5)	4.5(1)	3.1(8)	2.5(13)	2.3(4)	2.6(12)	3.2(7)	3.0(9)	2.2(15)	4.1(2)	3.5(5)	2.8(11)	3.7(14)	3.0(9)	4.1(2)	36.1**
Cc	M	2.9(7)	2.6(12)	2.8(9)	2.2(14)	2.1(15)	2.7(10)	3.4(1)	3.2(2)	2.7(10)	3.1(4)	3.0(6)	2.6(12)	3.1(3)	2.9(7)	3.1(4)	27.65*
	T	3.9(12)	4.0(10)	4.4(1)	3.9(12)	4.4(1)	4.3(3)	3.8(14)	4.3(3)	4.0(10)	4.1(7)	4.3(3)	4.1(7)	4.3(3)	3.8(14)	4.1(7)	5.74
	B	4.2(1)	3.8(4)	3.9(2)	2.4(15)	3.0(13)	3.2(8)	3.2(8)	3.2(8)	2.9(14)	3.2(8)	3.6(6)	3.3(7)	3.7(5)	3.2(8)	3.9(2)	21.56
Dr	M	4.3(1)	3.8(5)	4.1(2)	1.7(15)	2.1(14)	3.7(6)	3.5(7)	3.1(9)	4.0(4)	2.9(12)	3.1(9)	4.1(3)	3.5(7)	3.0(11)	2.9(13)	66.83**
	T	4.4(6)	1.9(14)	4.9(1)	4.5(5)	3.6(10)	4.8(3)	2.3(13)	2.8(12)	4.6(4)	3.4(11)	1.1(15)	4.9(1)	3.9(8)	4.3(7)	3.8(9)	65.51**
	B	4.5(1)	3.5(6)	4.2(2)	2.4(15)	2.5(14)	3.1(12)	3.7(4)	3.2(11)	2.7(13)	3.3(10)	3.5(7)	3.4(8)	3.7(9)	3.4(8)	4.1(3)	33.2**
Li	M	3.4(4)	2.7(10)	3.1(8)	2.6(12)	2.2(14)	3.2(7)	3.3(5)	2.9(9)	2.2(14)	2.7(10)	3.6(3)	2.5(13)	3.6(1)	3.3(5)	3.6(1)	30.23*
	T	4.6(2)	4.1(7)	4.4(3)	4.3(5)	3.5(12)	4.3(5)	2.6(15)	3.4(13)	4.4(3)	3.9(8)	3.1(14)	4.8(1)	3.6(10)	3.8(9)	3.6(10)	34.58**
	B	3.8(3)	3.9(2)	3.7(4)	2.5(13)	2.4(14)	3.2(9)	2.9(11)	3.1(10)	2.4(14)	3.5(5)	3.3(7)	2.8(12)	3.4(6)	3.3(7)	4.0(1)	24.4*
Mt	M	3.7(5)	3.7(5)	3.2(11)	3.1(14)	3.0(15)	3.4(9)	3.6(7)	3.4(9)	3.1(12)	3.8(4)	3.9(2)	3.4(8)	3.9(1)	3.1(12)	3.9(2)	18.31
	T	4.5(3)	2.8(13)	4.9(1)	4.3(4)	4.0(7)	4.1(6)	2.0(14)	3.3(12)	4.3(4)	3.6(10)	2.0(14)	4.6(2)	3.9(8)	3.6(11)	3.9(8)	25.63*
	B	4.2(2)	4.6(1)	3.7(8)	3.2(13)	2.8(15)	3.7(8)	3.9(5)	3.7(8)	3.0(14)	4.2(2)	3.8(6)	3.8(6)	3.7(8)	3.(12)	4.2(2)	24.4*
Ph	M	4.1(5)	4.5(2)	2.7(12)	3.5(8)	3.9(7)	2.6(13)	4.4(3)	3.2(9)	1.4(15)	3.1(10)	4.1(5)	2.9(11)	4.2(4)	2.1(14)	4.6(1)	76.19**
	T	4.1(4)	3.8(11)	4.1(4)	3.3(15)	4.3(2)	4.0(7)	3.4(13)	3.9(9)	4.5(1)	3.5(12)	3.9(9)	4.3(2)	4.1(4)	4.0(7)	3.5(12)	12.87
	B	4.8(1)	3.8(4)	3.5(8)	1.9(15)	2.3(13)	3.2(10)	3.6(5)	3.6(5)	2.3(13)	3.1(11)	3.6(5)	3.4(9)	4.3(2)	2.9(12)	4.3(2)	49.1**

APPENDIX 3.3 Cont.......

Trait	Site	Variety															H Value
		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	
Tb	M	3.5(5)	3.1(9)	3.3(7)	2.8(11)	2.8(11)	2.6(14)	3.8(4)	3.3(7)	2.6(14)	2.8(11)	3.1(9)	4.0(3)	4.9(1)	4.9(1)	3.5(5)	34.74**
	T	4.8(4)	2.6(14)	4.8(4)	4.7(7)	5.0(1)	4.8(4)	5.0(1)	5.0(1)	4.2(9)	2.9(13)	2.4(15)	3.8(10)	4.3(8)	3.4(12)	3.8(10)	62.25**
	B	2.8(8)	2.7(9)	3.3(5)	2.4(14)	2.8(8)	2.6(13)	3.6(3)	2.7(9)	2.1(15)	2.9(7)	2.8(8)	3.6(3)	4.8(1)	4.1(2)	3.3(5)	29.2**
Tr	M	2.8(10)	2.0(13)	3.0(9)	2.5(11)	3.1(8)	2.3(12)	3.8(1)	3.3(7)	2.0(13)	3.8(1)	2.0(13)	3.8(1)	3.6(4)	3.5(5)	3.4(6)	40.86**
	T	4.1(6)	4.1(6)	4.4(5)	5.0(1)	4.9(2)	3.8(9)	3.4(11)	3.7(10)	2.3(13)	1.6(15)	1.8(14)	3.1(12)	4.7(4)	4.0(8)	4.8(3)	77.75**
	B	2.3(10)	1.9(13)	2.7(9)	2.3(10)	2.9(7)	2.1(12)	3.(2)	2.9(7)	1.9(13)	3.(2)	1.9(13)	3.1(5)	3.7(1)	3.3(4)	3.1(5)	27.8**
Yh	M	3.4(4)	2.3(10)	2.6(7)	1.5(14)	3.0(5)	3.0(5)	1.9(12)	2.3(10)	3.8(3)	2.6(7)	2.4(9)	3.9(2)	4.8(1)	1.0(15)	1.9(12)	77.59**
	T	4.7(3)	2.9(9)	3.9(5)	2.7(11)	4.7(3)	2.6(12)	3.2(8)	3.9(5)	3.3(7)	1.0(14)	1.7(13)	2.9(9)	4.9(2)	1.0(14)	5.0(1)	106.00**
	B	3.3(4)	2.3(8)	2.7(5)	1.3(14)	2.7(5)	2.7(5)	1.9(13)	2.0(10)	2.0(10)	2.1(9)	3.6(3)	3.7(2)	4.9(1)	1.0(15)	2.0(10)	60.7**

ns, * and ** = not significant, significant at $p<0.05$ and 0.01 respectively; V1 =MM96/3972; V2 = Nambukaya; V3 = Migyera; V4 = Opongi; V5 = Serere; V6 = MM96/4684; V7 = CK9; V8 = Bumba; V9 = SS4; V10 = Sifros; V11 = Sudhe; V12 = MM96/1871; V13 = Mercury; V14 = Kaleso; V15 = Ebwanatereka; Dr = disease & pest resistance; Mt = time to maturity; IL = internodes length; Cc = cyanide content; Bl = branching level; Ph = plants height; Tb = taste of boiled tubers; Tr = taste of raw tubers; Yh = yield at harvest; M = Mumias district; T = Teso district; B = Busia district; ( ) = rank in parenthesis; H value = Kruskal-Wallis H-values.

APPENDIX 3.4

Morphological and agronomic performance of parental varieties in Mumias, Teso and Busia districts

Variety	CMD			PC			DMC			HB			PT			NR			RY		
	M	T	B	M	T	B	M	T	B	M	T	B	M	T	B	M	T	B	M	T	B
V1	1.0	1.0	1.0	5.0	5.2	5.8	40.3	40.5	39.0	0.4	0.3	0.5	0.9	2.4	0.9	8.0	9.5	6.3	3.0	3.6	1.7
V2	2.2	4.0	4.0	6.0	6.2	6.0	40.3	20.6	43.0	1.0	0.9	0.6	1.4	1.5	1.3	10.0	12.0	9.3	5.3	6.2	2.6
V3	1.0	1.5	1.3	5.5	6.1	6.2	48.0	43.9	47.0	0.5	0.7	0.5	1.1	2.2	1.0	13.5	16.1	10.0	5.2	6.0	2.9
V4	4.0	4.0	3.7	6.0	6.2	6.1	39.5	42.8	39.5	0.8	0.6	0.9	1.4	2.4	1.0	5.5	6.0	5.7	1.0	1.2	1.6
V5	3.0	3.0	3.0	7.0	7.3	3.0	39.5	45.0	41.7	0.0	0.0	0.0	1.1	2.1	1.0	9.5	10.9	11.0	3.3	4.1	3.1
V6	1.0	1.0	1.3	2.5	2.8	4.9	33.3	45.5	42.5	0.4	0.8	0.8	0.7	2.0	1.0	8.0	9.5	7.0	3.0	3.7	2.0
V7	3.0	4.0	3.3	3.5	3.9	6.0	39.8	39.2	41.0	1.3	1.5	1.4	1.9	2.3	1.5	8.5	10.9	3.3	3.4	4.2	0.9
V8	3.5	4.0	3.0	6.5	7.2	5.7	42.3	42.2	44.5	0.9	1.5	0.9	1.7	2.1	1.4	5.0	7.2	6.7	0.8	1.0	1.9
V9	1.5	1.0	1.3	6.0	6.2	7.0	42.5	37.0	37.7	0.5	0.7	0.6	0.9	2.3	1.0	8.0	8.4	6.0	3.0	3.7	1.3
V10	3.5	3.0	3.0	4.0	4.2	8.0	40.0	29.4	43.9	0.9	1.1	1.5	1.7	2.3	1.7	6.0	7.2	8.0	0.8	1.0	2.6
V11	3.5	4.0	3.3	6.5	7.2	7.1	46.5	36.8	46.1	0.9	1.0	0.7	1.8	2.2	1.1	10.0	12.0	10.3	3.0	3.7	2.9
V12	1.0	1.5	1.3	5.0	5.2	4.0	44.0	40.7	43.4	0.5	0.9	0.6	1.2	2.5	0.9	8.0	10.9	9.3	1.4	1.7	2.6
V13	3.5	3.0	2.7	6.5	7.2	5.2	41.3	37.2	43.4	0.8	1.7	1.3	1.7	2.0	1.5	10.0	13.3	12.7	2.8	3.5	3.6
V14	2.5	2.5	3.7	6.0	6.2	6.0	42.0	44.6	41.5	0.5	0.3	0.4	0.8	2.3	0.9	6.0	7.1	4.7	0.8	0.9	0.9
V15	3.5	4.0	3.7	5.5	6.1	3.0	39.5	37.7	39.4	1.0	1.1	0.9	1.9	2.0	1.2	6.5	7.2	5.3	1.0	1.2	1.9
Mean	2.5	2.8	2.6	5.4	5.8	5.6	41.2	38.9	42.2	0.7	0.9	0.8	1.3	2.2	1.2	8.2	9.9	7.7	2.5	3.0	2.2
LSD$_{(0.05)}$	1.1	0.7	1.3	0.8	1.0	ns	8.1	7.6	ns	25.9	39.4	23.8	20.2	49.7	19.1	2.7	1.9	2.6	0.5	0.7	0.7
CV (%)	19.5	11.7	29.3	6.7	8.1	11.2	9.2	9.1	10.2	17.7	20.8	18.6	7.0	10.6	9.9	15.6	8.9	20.4	8.8	10.8	19.1

CMD = cassava mosaic disease score on a scale of 1=resistance to 5=susceptible; PC = picrate score; DMC = dry matter content; PT = plant height (m); HB = height to first branching (m); NR = number of storage roots per plant; RY = fresh storage roots yield t ha^{-1}; V1 =MM96/3972; V2 = Nambukaya; V3 = Migyera; V4 = Opongi; V5 = Serere; V6 = MM96/4684; V7 = CK9; V8 = Bumba; V9 = SS4; V10 = Sifros; V11 = Sudhe; V12 = MM96/1871; V13 = Mercury; V14 = Kaleso; V15 = Ebwanatereka; M = Mumias district; T = Teso district; B = Busia district; LSD$_{(0.05)}$ = least significant difference at 5%; CV = coefficient of variation.

APPENDIX 3.5

Spearman's rank correlation coefficients between breeders evaluation of morphological and agronomic traits and farmers variety scores in Mumias, Teso and Busia districts

Traits evaluated by Breeder	Traits evaluated by farmers in Mumias districts											
	BI	Cc	Dr	Li	Mt	Ph	Tb	Tr	Yh	Yb	RH	RB
CMD	-	0.30	-0.82**	0.09	0.19	-0.36*	-0.04	0.14	-0.40*	-0.56**	0.51*	0.35
DMC	-	0.20	0.44*	0.14	0.13	-0.24	0.37*	-0.05	0.17	0.17	-0.20	-0.35
HB	-	0.52*	-0.29	0.19	0.48	0.46*	0.20	0.23	-0.56**	-0.03	0.22	0.24
PC	-	-0.13	-0.40*	-0.06	-0.14	0.21	0.06	-0.24	-0.02	-0.46*	0.38*	-0.12
PT	-	0.54*	-0.32	0.24	0.59**	0.62**	0.20	0.33	-0.22	-0.09	0.17	-0.04
NR	-	-0.08	0.38	0.27	0.31*	0.41*	0.13	-0.23	0.40*	0.49*	-0.46*	-0.59**
RY	-	-0.27	-0.42*	-0.09	0.00	0.33	-0.27	-0.41*	0.14	0.41*	-0.42*	-0.28
	Traits evaluated by farmers in Teso district											
CMD	-0.63**	-0.11	-0.76**	-0.72**	-0.71*	-0.75**	-0.13	0.16	0.00	-0.69**	-0.03	0.76**
DMC	0.52*	0.19	0.53*	0.13	0.44*	0.24	0.62**	0.42*	0.03	0.45*	-0.13	-0.52*
HB	-0.58*	0.07	-0.43*	-0.48*	-0.54*	-0.38*	-0.12	-0.38*	0.07	-0.45*	-0.02	0.62**
PC	-0.24	0.15	-0.34*	-0.40*	-0.22	0.23	-0.05	0.31	0.25	-0.07	-0.21	0.27
PT	0.43*	-0.44*	0.31	0.39*	0.33	0.41*	0.02	-0.36	-0.35	0.30	0.36	-0.43*
NR	-0.21	0.52*	-0.07	-0.03	0.01	0.37*	0.01	0.00	0.38*	0.17	-0.21	0.11
RY	-0.09	0.24	-0.03	0.07	0.06	0.22	0.20	0.09	0.20	0.03	-0.20	0.02
	Traits evaluated by farmers in Busia district											
CMD	0.33	-0.14	-0.49*	0.16	0.14	-0.04	0.05	0.08	-0.56**	0.50*	-0.12	0.63**
DMC	0.26	0.23	0.11	0.18	0.10	0.11	0.24	0.06	0.43*	0.24	-0.30	0.13
HB	0.44*	-0.04	0.06	0.15	0.43*	0.25	0.13	0.27	-0.12	0.55**	-0.29	0.19
PC	0.13	-0.17	-0.06	0.03	0.12	-0.17	-0.30	-0.45*	-0.25	0.15	-0.09	0.30
PT	0.52*	-0.01	0.05	0.18	0.40*	0.29*	0.10	0.15	-0.01	0.65**	-0.32	0.35*
NR	0.12	0.24	0.02	0.06	-0.05	0.11	0.08	-0.10	0.82**	-0.10	-0.09	-0.40*
RY	0.24	0.32	0.11	0.19	0.05	0.18	0.18	0.03	0.78**	0.03	-0.24	-0.32

* and ** = significant at $P \leq 0.05$ and 0.01 respectively; CMD = cassava mosaic disease score on a scale of 1=resistance to 5=susceptible; PC = picrate score; DMC = dry matter content; PT = plant height (m); HB = height to first branching (m); NR = number of storage roots per plant; RY = fresh storage roots yield t ha^{-1}; Cc = cyanide content; Dr = disease & pest resistance; IL = internodes length; Mt = time to maturity; Ph = plants height; Tb = taste of boiled tubers; Tr = taste of raw tubers; Yh = yield evaluated by farmers at harvest; Yb = yield evaluated by farmers before harvest; RH = rank at harvest; RP = ranking before harvest.

CHAPTER 4

Genetic inheritance of farmer preferred cassava traits

Abstract

Understanding the genetic inheritance of preferred traits is important in choosing parents and breeding strategy. A research study was conducted to determine hybridization and combining abilities among popular cassava varieties, heterosis and gene action governing farmer preferred traits in western Kenya. Ten popular varieties were crossed using a 6 x 4 North Carolina II mating design. Forty clones representing each of the 24 families were evaluated using a 24 x 40 α-lattice design in two environments. All the parental varieties produced viable seed with a mean seed set of 66.7% and seed germination of 46.5%. Analysis of variance revealed that general and specific combining ability (GCA and SCA) effects were significant for most of the traits evaluated. The GCA effects for the parents did not generally correlate with their performance per se implying that selection of parents based on their per se performance may not necessarily lead to the development of superior hybrids. This indicates the presence of SCA effects or transgressive segregation resulting from new combinations of additive and non-additive gene action. Most of the parents' and crosses' performance and combining ability effects varied between environments indicating significant genotype and GCA by environment interaction effects. All the traits evaluated are governed by both additive and non-additive gene effects though the predominance of one over the other differed between traits and environments. Some crosses whose parents had poor GCA effects for certain traits evaluated performed well indicating the presence of significant non-additive gene effects which can easily be fixed in cassava through vegetative propagation. The crosses expressed high best parent heterosis and genetic gain for all traits evaluated ranging from negative to positive.

4.1 Introduction

Since the early 1970s, cassava breeding has been entirely the responsibility of international organizations, such as the Centro International de Agricultura Tropical (CIAT) and the International Institute of Tropical Agriculture (IITA) (DeVries and Toenniessen, 2001). At these institutions, thousands of F_1 hybrids were developed by open pollination of varieties selected on the basis of their phenotype and released to national research programmes for further selections. The success rate of these breeding programmes has been limited. Kawano et al. (1998) reported that in 14 years, a total of 372 000 genotypes were developed and evaluated at CIAT-Rayong Field Crop Research Centre of which only three were superior and released. Ceballos et al. (2004) attributes the low success rate to inappropriate breeding strategy and choice of parents.

Cassava varieties present variability in their flowering and seed setting ability, seed germination, potential to pass on favourable traits to their progeny (breeding value) (Ceballos et al., 2004; El-Sharkawy, 2004), and hybrid vigour (heterosis) among their progenies. Varieties which are genetically diverse for preferred traits when crossed produce F_1 hybrids with high heterosis (Falconer and Mackay, 1996; Sleper and Poehlman, 2006). Varieties that have low genetic diversity when crossed generally express low heterosis and those with high genetic diversity when crossed generally express high heterosis depending on the extent of gene frequency divergence (Mungoma and Pollak, 1988). The variability in cassava are genetically controlled but also influenced by environmental factors (El-Sharkawy, 2004).

As cassava is mainly cultivated as a low input crop in diverse marginal environments by small scale farmers for subsistence (Ceballos et al., 2004; El-Sharkawy, 2004), a participatory plant breeding (PPB) approach is preferred (Banziger and Cooper, 2001). Varieties with farmer preferred traits and adapted to their target environments are adopted more readily by farmers (Ceccarelli, 1994). Cassava landraces have farmer preferred traits, are adapted to local environments and have contributed immensely to crop improvement (Banziger and Cooper, 2001; Manu-Aduening et al., 2006). However, information on farmer preferred traits in landraces is very limited (Ceballos et al., 2004) which hinders their use in breeding programmes.

Understanding the crossability ability and level of heterosis (genetic diversity) among potential parents and inheritance of the farmer preferred traits are important in designing breeding strategies and in the choice of parents (Falconer and Mackay, 1996; Fasoula and

Fasoula, 1997). Parents can be selected based on their *per se* performance or progeny performance (Banziger and Paterson, 1992). Selection of parents based on *per se* performance contributes to gain in breeding for traits controlled by additive gene action with high heritability (Falconer and Mackay, 1996; Ojwang et al., 2011; Williams et al., 2008) since it is only additive gene action that is passed on from parents to progeny. The non-additive genes segregate during gametogenesis and new combinations are developed during fertilization (Falconer and Mackay, 1996; Fasoula and Fasoula, 1997).

The type of gene action governing the preferred traits determines the breeding strategy to be employed (Cach et al., 2006). Mass phenotypic recurrent selection breeding strategy is suitable when breeding for traits under additive gene action. However, for traits controlled by by both additive and non-additive genes action, recurrent selection combined with cyclical inbreeding has proven to be more efficient (Hallauer and Miranda, 1988). In PPB farmers select parental varieties based on their *per se* performance (Witcombe et al., 2006) and consequently genetic gain is faster for traits under additive gene action and high heritability. The effectiveness and efficiency of PPB is compromised if the size of the evaluated population is large (Joshi et al., 2007; Witcombe et al., 2006). In PPB, it is desirable to have the segregating population to be evaluated derived from a few crosses of precisely selected parents (Witcombe et al., 2001) that produce hybrid progeny expressing high heterosis.

Western Kenya has never had a formal local cassava breeding programme based on adapted genotypes. The potential of using the landraces grown in this region as parents and inheritance of farmer preferred traits are not known. In order to initiate an efficient and effective cassava breeding programme in the region, a research study was conducted with the following objectives to establish:

a) the hybridization ability of popular cassava varieties in western Kenya.

b) combining ability of popular cassava varieties for farmer preferred traits.

c) gene action governing farmer preferred traits.

d) the identity of cassava parental varieties and F_1 hybrids with high heterosis for farmer preferred traits

4.2 Materials and methods

4.2.1 Study sites

The research was conducted at two sites, namely the Kakamega and Alupe research stations. The crossing block was established at Alupe while the seedling trial was planted at Kakamega. Clonal evaluation trials were laid-out at both sites (Table 4.1).

Table 4.1 Characteristics of clonal evaluation sites

Station	Altitude (masl)	Latitude	Longitude	Mean Annual		Soil type
				Temp (^{0}C)	Rainfall (mm)	
Kakamega	1554	00^0 17'N	34^0 47'E	18.5 - 21.0	1600 - >2000	Well drained, deep dark red friable NITOSOLS
Alupe	1173	00^0 29"N	34^0 07"E	21.0 - 22.7	1200 – 1450	Shallow, dark clay loam ACRISOLS

Source: Jaetzold, and Schmidt, (1983).

4.2.2 Germplasm

The main criteria used in selection of parental varieties in this study was the popularity of the landraces, and high storage root yield and cassava mosaic disease (CMD) resistance of the improved varieties. The popularity of cultivated landraces indicate the presence of farmer preferred traits and adaptation to local environments. Improved varieties were used as source of CMD resistance. The six most popular landraces and four improved cassava varieties introduced in western Kenya from IITA-Nigeria were used (Table 4.2).

Table 4.2: Description of the parents used in the study

Variety	Type	Special attribute
Sifros	Landrace	Used mainly after boiling the storage roots, medium height
Ebwanatereka	Landrace	Used mainly after processing the storage roots to flour, tall
Opongi	Landrace	Used after either boiling or processing the storage roots to flour, tall
Kaleso	Landrace	Used after either boiling, short and higly branched
Nambukaya	Landrace	Used after either boiling or processing the storage roots to flour
Bumba	Landrace	Used after either boiling or processing the storage roots to flour
Migyera	Improved	High yielding, CMD resistant, short and higly branched
SS4	Improved	High yielding, CMD resistant, short and higly branched
MM96/3972	Improved	High yielding, CMD resistant, short and higly branched
MM96/1871	Improved	High yielding, CMD resistant, short and higly branched

4.2.2.1 Production of F_1 families

Ten parent genotypes were planted in a crossing block at Alupe research station farm in July 2008. The parents were planted at a wider spacing of 1.5 x 1.5 m to allow for vigorous growth. Foliar feed was also applied after every two weeks starting from the third month after planting. A 6 x 4 North Carolina Design II mating design was employed to develop 24 F_1 families (Hallauer and Miranda, 1988). The landraces (male) were manually crossed to the improved varieties (female) under controlled pollination following the procedure described by Kawano (1980) with few modifications. The pollinated flowers were labeled and left to develop into fruits. The fruits were later covered with bags made of mosquito net material to aid in seed collection when the mature dry fruits dehisce, releasing seed. Seed from each cross was harvested separately. Seed from the same cross was bulked, cleaned and sun dried before being put in labeled paper bags for storage.

4.2.2.2 Seedlings development

The clean, dry seed was sown in a nursery at Kakamega research station farm in 5 x 8 cm black polythene bags filled with sterilized forest soil. In order to increase the temperature and promote germination, the nursery was covered with clear polythene plastic. After germination, the polythene plastic was removed. The young seedlings were then protected from harsh environmental conditions by placing the seedlings under a frame covered with 90% shade-cloth. Forty-five days after planting 1440 seedlings (24 families each with 60 full-sibs) were transplanted to an unreplicated field trial at Kakamega research station farm. The seedlings from each full-sib family were planted in a single row plot at 1 x 1 m intra- and inter-row spacing, respectively. No fertilizers or pesticides were applied. Six months after planting (MAP), the seedlings were damaged by a severe hail storm that led to 100% loss of leaves and peeling of stem. Due to this damage, plants were cut back at a height of 10 to 15 cm above the ground level to allow for side-shoots to develop. This increased the number of cuttings per seedling. A maximum of three side shoots per stem were allowed to fully develop to minimize overcrowding and interplant competition. Six months after cutting-back (10 MAP), 40 siblings per family that produced at least 12 mature quality stakes (25 cm long) were selected and harvested. This was the only selection criteria used to determine the 40 plants (genotypes) that represented each F_1 family evaluated in the CET.

4.2.3 Clonal evaluation trial

A total of 970 clones, (40 siblings from each of the 24 families plus their 10 parents) were evaluated in the CET. The trial was established at two sites using a randomised 25 x 40 α-lattice design with two replications. Each plot consisted of three plants spaced at 1 x 1 m. The trial was hand weeded and no fertilizer or pesticide was applied.

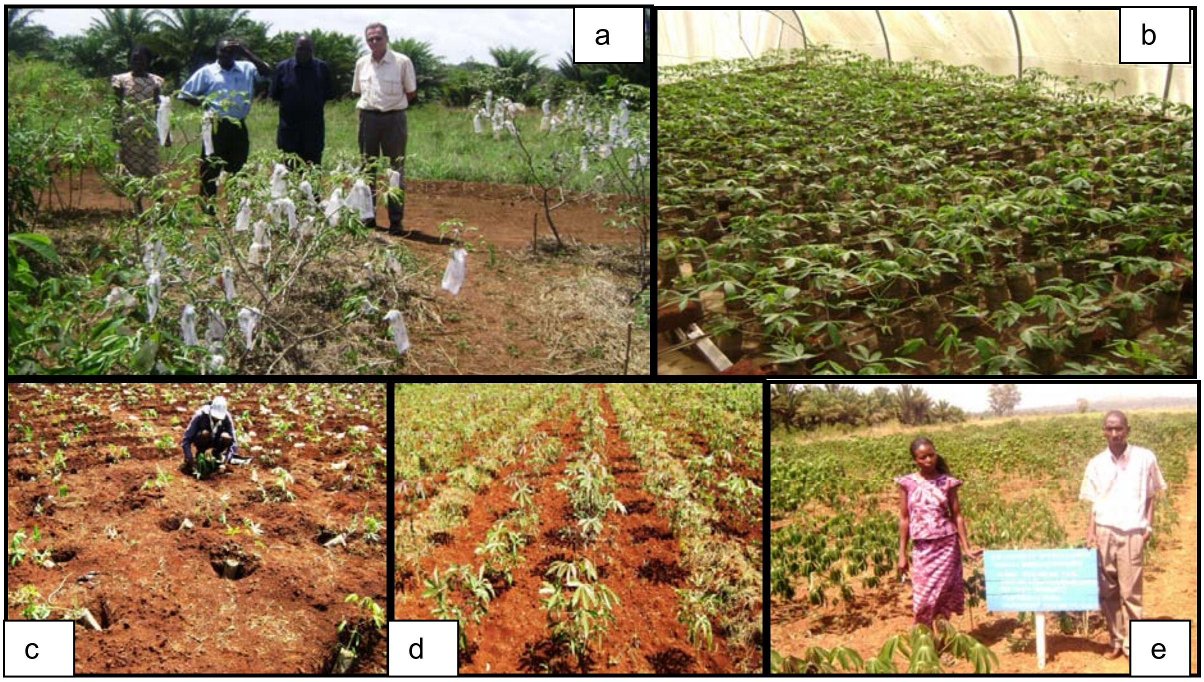

Figure 4.1: Cassava breeding cycle (a) seed production in crossing block, (b) seedlings development in a screen house, (c) seedlings transplanted in the field, (d) seedlings trial one month after transplanting and (e) clonal evaluation trial.

4.2.4 Data collection

In the crossing block, data was collected on the number of crosses made per plant and seeds harvested per cross. In the seed nursery, the number of seeds sown and those that germinated 21 days after sowing were recoreded per cross. From the CET, data was collected on the following farmer preferred traits: from 3 MAP, scored for resistance to CMD on a bimonthly basis where 1 = resistant and 5 = susceptible; and at harvest (10 MAP) plant height (PH) (m), height to first branch (HB) (m), level of branching (BL), internode length (IL) (cm), total number of storage roots per plant (NR), fresh storage roots yield (RY) (t ha^{-1}), and dry mass composition (DMC)(%) determined using the specific gravity method (Kawano et al., 1987).

$$\text{DMC (\%)} = [Wa/(Wa - Ww)] \times 158.3 - 142$$

Where: Wa =Mass of roots in air and Ww = Mass of roots in water.

Picrate score (PC) for cyanide content determined by colour change of the picrate on a 125 mm Whatman® filter paper strip as described by O'Brien et al. (1994). Colour change from pale green to dark brown was scored on a scale of 1 to 9 corresponding to a cyanide content of between < 10ppm to > 150ppm

4.2.5 Data analysis

The number of crosses made per plant and the seeds harvested per cross were used to compute seed set using the following formulae:

$$\text{Seed set (ST)} = \frac{\text{Number of crossess}}{\text{Number of seed harvested}}$$

The number of seeds sown in the nursey and those that germintaed 21 days after sowing were used to compute seed germination percentage (SG%) using the following formulae:

$$\text{Seed germination (\%)} = \frac{\text{Number of germinated seeds 21 days after sowing x 100}}{\text{Number of seeds sown}}$$

Data collected from CET was analysed using Residual Maximum likelihood (REML) in GENSTAT 14th Edition (Payne et al., 2011) at progeny and family level in each site for all traits. Family and progeny were considered to be fixed while replications were considered random effects. Bartlett's test for homogeneity of variances between sites revealed the presence of heterogeneity for error variance preventing a simple combined analysis. The data was then arranged according to family means for analysis of variance (ANOVA) per site for all traits for combining ability effects in SAS version 9.3 (SAS, Inc. 2002) for the NC II mating design per environment with parents considered as fixed effects (Model 1; Hallauer and Miranda, 1988):

$$Y_{ijk} = \mu + g_i + g_j + h_{ij} + r_k + (\Sigma_k\ \Sigma_l\ \epsilon_{ijkl})/r$$

Where: i = 1, 2, 3, 4; j = 1, 2, 3, 4, 5, 6; k = 1, 2;

Y_{ijkl} = performance of the genotype developed after crossing i^{th} female genotype with j_{th} male genotype grown in k^{th} replication, μ = overall mean performance; g_i = the general combining ability (GCA) effect common to all hybrids of the i^{th} female plant; g_j = the GCA effect common to all hybrids of the j^{th} male plant; h_{ij} = the sepecific combining ability (SCA) effect specific to a hybrid of the ith female and j^{th} male plant; r = replicates; ϵijk = experimental error term.

As the parents were considered fixed, inferences drawn from this study can not generalised. The relative importance of GCA over SCA in influencing the performance of the crosses was determined by computing the ratio of GCA to SCA sum of squares (SS).

The best parent heterosis (%) was computed using the following fomula;

$H_{(BP)}(\%) = (F_1 – BP)100/BP$

Where: $H_{(BP)}(\%)$ = percentage best parent heterosis, F_1 = mean of cross, BP = mean of best parent.

The mean performance of the best cross and parents from landraces and improved varieties were used to compute genetic gain (GG) percentage using the following formula:

$GG(\%) = (F_1 – BP)100/BP$

Where: GG(%) = percentage genetic gain F_1 = mean of best cross, BP = mean of best parent. The best parent was not necessarily one of the parents of best cross as the case with best parent heterosis but the best parent from the landrace and improved varieties. Similarly the best cross was the best performing cross among all crosses evaluated in the CET.

4.3 Results

4.3.1 Seed production of popular cassava varieties in western Kenya

The overall mean seed set was 2.0 seeds per cross (Table 4.3). Kaleso recorded the highest mean seed set of 2.6 out of the maximum of 3 seeds per cross. SS4 and Ebwanatereka had the lowest mean seed set of 1.6. Among the crosses, Kaleso when crossed to MM96/1871, Migyera and SS4; and Nambukaya when crossed to Migyera recorded the highest mean seed set rate of 2.9. SS4 when crossed to Ebwanatereka recorded the lowest mean seed set of 1.1 seeds per cross.

Table 4.3: Seed set and germination percentages of F_1 seed for six landraces crossed to four improved varieties in western Kenya

Parents	1871		3972		Migyera		SS4		Mean		SE	
	ST	SG	ST	SG	ST	SG	ST	SG	ST	SG	ST	SG
Bumba	1.8	70.8	2.3	53.4	1.7	51.6	1.2	36.5	1.7	53.1	0.2	7.0
Ebwana	2.0	57.5	1.5	54.1	1.9	61.6	1.1	30.0	1.6	50.8	0.2	7.1
Kaleso	2.9	49.1	1.6	35.8	2.9	35.0	2.9	23.6	2.6	35.9	0.3	5.2
Mercury	1.8	78.3	2.6	46.6	1.8	36.6	1.2	37.5	1.8	49.8	0.3	9.8
Nambu	2.0	35.0	1.8	46.2	2.9	35.0	1.6	34.1	2.1	37.6	0.3	2.9
Sifros	2.1	52.1	1.6	60.0	2.2	57.5	1.8	38.3	1.9	52.0	0.1	4.8
Mean	2.1	57.1	1.9	49.4	2.2	46.2	1.6	33.3	2.0	46.5	0.1	2.8
SE	0.2	6.4	0.2	3.4	0.2	5.0	0.3	2.3	-	-	-	-

ST = seed set; SG = seed germination (%); SE = standard error; 1871 = MM96/1871; 3972 = MM96/3972; Ebwana = Ebwanatereka; Nambu = Naambukaya.

Mean seed germination was 46.5%. Seed from crosses using MM96/1871 and SS4 as one of the parents had the highest and lowest viability with seed germination of 57.1% and 33.3%, respectively. The crosses MM96/1871 x Mercury, and SS4 x Ebwanatereka expressed the highest and lowest seed germination of 78.3 and 30.0%, respectively. Noteworthy is that SS4 x Ebwanatereka recorded the lowest crossing success rate and seed germination making it difficult to develop new hybrids arising from crosses between these two parents. This obviously limits the utility of this parental combination in a breeding programme even if they are found to have good combining abilities.

4.3.2 Estimates of genotype, GCA and SCA mean squares

The crosses mean square (MS) were significantly different ($P<0.05$) for all traits except DMC and PC in both site, HB and NR when grown at Alupe (Table 4.4). The crosses MS was further partitioned into components of MS due to main effects of parents (general combining ability) and interaction effects between parents (specific combining ability). The lack of statistical significance of crosses MS for DMC and PC in both locations obviates further partitioning into GCA and SCA MS. The ratio of sum of squares (SS) due to GCA to SS due to SCA provides an estimate of the relative importance of additive to non-additive gene action in determining the expression of the trait. The ratio of GCA to SCA SS for PT and IL in both environments, DMC at Kakamega, and BL at Alupe were greater than one. The rest of the triats evaluated had GCA to SCA SS ratio less than one (Table 4.4).

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Table 4.4: Crosses and combining ability mean square for nine cassava traits when grown at Kakamega and Alupe

Sources of variation	df	Kakamega								
		CMD	BL	DMC	PH	HB	IL	NR	PC	RY
Crosses	23	0.03**	0.14**	25.46 ns	0.02**	0.02*	2.44**	2.02**	1.39 ns	250.35**
GCA (I)	3	0.02*	0.03 ns	26.49 ns	0.01 ns	0.03**	0.92**	1.10 ns	1.47 ns	212.17**
GCA (L)	5	0.06**	0.32**	2.41 ns	0.05**	0.04*	2.83**	1.05 ns	2.74 ns	60.09**
SCA (I x L)	15	0.03**	0.14**	32.94 ns	0.02**	0.01 ns	2.86**	2.52*	1.09 ns	301.13**
GCA/SCA SS ratio		0.21	0.54	1.22	1.19	0.22	4.43	0.23	0.95	0.27
		Alupe								
Crosses	23	0.02*	0.10**	8.50 ns	0.02**	0.01 ns	0.04**	1.93 ns	1.50 ns	0.06*
GCA (I)	3	0.02*	0.06 ns	9.12 ns	0.03**	0.01 ns	0.02 ns	0.70 ns	0.77 ns	0.07 ns
GCA (L)	5	0.02*	0.46**	4.85 ns	0.03**	0.01 ns	0.10**	0.09 ns	0.60 ns	0.16**
SCA (I x L)	15	0.02*	0.04*	9.03 ns	0.01**	0.01 ns	0.02 ns	2.71 ns	1.92 ns	0.04 ns
GCA/SCA SS ratio		0.63	2.76	0.44	1.22	0.53	1.66	0.09	0.20	0.82

*, ** = significant at P<0.05 and 0.01 respectively; d.f. = degrees of freedom; CMD = cassava mosaic diseases score on a 1-5 scale; IL = internode length; BL = number of branching levels; HB= height to first branching; PH = plant height; DMC = dry matter content; PC = picrate score on 1-9 scale; NR = total number of storage roots per plant; RY= fresh storage roots yields; GCA and SCA = general and specific combining ability; I = improved varieties; L = landraces; SS = sum of squares.

4.3.3 General combining ability effects

The GCA MS of the parents was partitioned into those due to female (improved varieties) and those due to male (landraces) (Table 4.4). The GCA MS due to female were significant ($P<0.05$) for CMD resistance in both locations, RY, HB and IL at Kakamega and PH at Alupe. The GCA MS due male were significant ($P<0.05$) for all traits evaluated except DMC, PC, NR in both locations and HB at Alupe only (Table 4.4).

Mercury among the landraces and MM96/1871, MM96/3972 and Migyera among the improved varieties were the most resistant parents to CMD in both locations (Tables 4.5 and 4.6). Noteworthy is that they had negative GCA effects for CMD resistance except Mercury. Bumba and Ebwanatereka among the landraces, though they were highly susceptible to CMD with mean scores above 3.0 when grown at Alupe, had negative GCA effects for CMD resistance. When breeding for CMD resistance, parents with negative GCA effects are preferred since they reduced susceptibility to CMD. MM96/3972 among improved varieties realised the highest RY of 18.5 and 21.3 t ha^{-1} when grown at Kakamega and Alupe, respectively. Mercury among landraces realised the highest RY of 12.1 and 11.0 t ha^{-1} when grown at Kakamega and Alupe, respectively. Noteworthy is that these two parents had the highest positive GCA effects for RY when grown at Kakamega which is a high performing environment, but negative GCA effects when grown at Alupe.

Migyera among improved varieties with BL of 3.6 and 3.4 when grown at Kakamega and Alupe, Ebwanatereka at Alupe with BL of 2.3 and Bumba at Kakamega with BL of 2.8 among the landraces had the highest number of branching levels. Mercury among the landraces with PH of 2.1 and 1.9 m when grown at Kakamega and Alupe, respectively, Migyera at Kakamega and MM96/1871 at Alupe among the improved varieties with PH of 1.6 and 1.2 m, respectively were the tallest parents. Migyera among improved varieties with NR of 8.6 and 10.6 when grown at Kakamega and Alupe, respectively, Sifros when grown at Kakamega and Nambukaya when grown at Alupe with NR of 9.6 and 11.7 respectively had the highest number of storage roots per plant. Migyera and Kaleso with IL of 1.9 and 3.2 cm respectively when grown at Kakamega and 2.1 cm when grown at Alupe had the shortest internode length. There was no correlation between *per se* performance of the parents and their GCA effects. Some parents had high GCA effects, either positive or negative but recorded a poor *per se* performance.

Table 4.5: Means and GCA effects of parental varieties for important agronomic and farmer preferred traits at Kakamega

Parents	CMD		BL		PH (m)		HB (m)		IL (cm)		NR		RY (t ha^{-1})	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
	Improved varieties													
MM96/1871	-0.02	1.10	0.08	2.60	0.03	1.40	-0.01	0.44	-0.39	2.08	0.03	7.79	-2.41	11.64
SS4	0.00	1.12	0.09	2.61	0.00	1.48	0.04	0.47	0.71	2.58	0.33	4.21	-1.32	16.11
MM96/3972	-0.02	1.10	0.07	2.28	0.01	1.21	0.04	1.03	-0.18	2.32	-0.39	6.5	2.40	18.48
Migyera	0.05	1.17	-0.24	3.59	-0.03	1.60	-0.07	0.29	-0.14	1.91	0.03	8.56	1.33	15.51
Mean	-	1.12	-	2.52	-	1.42	-	0.56	-	2.22	-	6.77	-	15.44
SE	0.02	0.03	0.06	0.08	0.02	0.03	0.03	0.04	0.06	0.08	0.22	0.68	0.60	0.85
	Landraces													
Nambukaya	-0.12	2.00	-0.03	2.49	0.02	1.66	0.02	0.74	-0.06	3.40	-0.11	7.08	1.00	10.08
Sifros	0.07	2.20	-0.05	2.47	-0.01	1.63	-0.01	0.76	0.10	3.56	0.50	9.64	-2.09	6.99
Ebwanatereka	-0.07	3.06	0.07	1.59	-0.03	1.91	-0.06	0.62	-0.26	3.23	-0.51	6.94	-3.00	6.08
Mercury	0.06	1.18	0.07	2.59	0.13	2.07	0.13	0.93	0.64	4.09	0.06	5.19	8.02	12.10
Bumba	-0.04	1.09	-0.08	2.84	-0.11	1.53	-0.08	1.39	-0.20	3.26	0.32	7.01	2.83	10.92
Kaleso	0.08	2.21	0.03	2.45	-0.01	1.03	-0.01	0.51	-0.22	3.20	-0.26	2.50	-6.77	7.31
Mean	-	1.95	-	2.41	-	1.64	-	0.82	-	3.46	-	6.39	-	8.91
SE	0.02	0.03	0.07	0.10	0.02	0.03	0.03	0.04	0.07	0.10	0.28	0.39	0.73	1.04

GCA = general combining ability; SE = standard error; CMD = cassava mosaic diseases score on a scale of 1 to 5; IL = internode length; BL = branching levels; HB = height to first branching; PH = plant height; NR = total number of storage roots per plant; RY = fresh storage roots yields.

Table 4.6: Means and GCA effects of parental varieties for important agronomic and farmer preferred traits at Alupe

Parents	CMD		BL		PH (m)		HB (m)		IL (cm)		NR		RY (t ha^{-1})	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
							Improved varieties							
MM96/1871	0.02	1.19	0.24	2.97	0.07	1.19	0.01	0.42	0.06	2.23	0.07	8.71	0.17	7.40
SS4	0.05	1.23	-0.09	2.59	0.01	1.13	0.01	0.42	-0.01	2.17	-0.04	6.71	-0.02	13.41
MM96/3972	-0.02	1.15	0.06	2.74	-0.02	1.10	0.00	0.41	-0.03	2.15	-0.11	8.53	-0.07	21.34
Migyera	-0.05	1.13	-0.21	3.42	-0.06	1.06	-0.03	0.38	-0.03	2.14	0.07	10.60	-0.07	19.43
Mean	-	1.17	-	2.93	-	1.12	-	0.41	-	2.17	-	8.63	-	15.4
SE	0.04	0.05	0.04	0.07	0.03	0.03	0.02	0.07	0.03	0.04	0.33	0.47	0.05	
							Landraces							
Nambukaya	0.01	2.18	0.02	2.20	0.09	1.61	0.04	0.95	0.15	2.36	0.10	11.74	0.01	6.12
Sifros	0.07	2.25	-0.04	2.14	0.03	1.15	-0.01	0.40	0.02	2.19	-0.41	8.23	0.14	6.25
Ebwanatereka	-0.06	3.11	0.15	2.32	-0.01	1.11	-0.01	0.52	-0.07	2.16	0.45	9.09	0.04	6.15
Mercury	0.04	1.21	-0.09	2.09	-0.01	1.91	0.00	0.94	0.08	3.25	-0.11	8.52	-0.08	11.03
Bumba	-0.06	3.12	-0.06	2.12	-0.09	1.73	-0.03	0.70	-0.17	3.00	-0.16	8.48	-0.12	6.99
Kaleso	0.00	4.17	0.03	2.21	-0.02	1.11	0.00	0.38	-0.01	2.10	0.13	5.77	0.00	1.11
Mean	-	2.67	-	2.18	-	1.42	-	0.65	-	2.23	-	8.64	-	6.28
SE	0.04	0.06	0.05	0.08	0.02	0.04	0.02	0.08	0.04	0.05	0.41	0.57	0.06	1.15

GCA = general combining ability; SE = standard error; CMD = cassava mosaic diseases score on a scale of 1 to 5; IL = internode length; BL = branching levels; HB = height to first branching; PT = plant height; NR = total number of storage roots per plant; RY = fresh storage roots yields.

Generally, among the two sets of parents, the landraces were more susceptible to CMD; had fewer branches; were taller; higher branching; shorter internode length; produced many storage roots per plant and had lower storage root yields than improved varieties when grown in the two locations, Kakamega and Alupe. The mean *per se* performance of the parents differed when grown in the two environments. The plants were more susceptible to CMD; short in height; lower branching; short IL and recorded lower RY when grown at Alupe than at Kakamega. The GCA effects of the parents were not consistent in all locations. Some parents recorded high, positive GCA effects in one environment but low, negative GCA effects in another environment for the same trait. For example MM96/1871 had highest positive GCA effect of 0.17 when grown at Alupe, but it had the lowest, negative GCA effects of -2.41 when grown at Kakamega for RY.

4.3.4 Specific combining ability effects

The SCA MS were significant ($P<0.05$) for all the traits evaluated except DMC, HB, and PC, when the crosses were grown at Kakamega. However, when the crosses were grown at Alupe, SCA MS were significant ($P<0.05$) for CMD resistance, BL and PH only (Table 4.4). Nambukaya x M96/3972 and Kaleso x Migyera with -0.14 and -0.11 SCA effects, respectively were the most resistant crosses to CMD with a mean score of 1.02 when grown at Alupe (Table 4.7). At Kakamega, a total of five crosses recorded a mean score of 1.0 for CMD resistance. Notably; all five crosses had either Nambukaya or Ebwanatereka as a parent from the landraces and MM96/1871, SS4 or MM96/3972 as another parent from the improved varieties. All these parents except SS4 had negative GCA effects for CMD resistance when grown at Kakamega. Mercury x SS4 with highest positive SCA effects of 2.49 and 24.50 for RY when grown at Alupe and Kakamega, respectively recorded the highest fresh storage roots yield of 17.2 and 19.3 t ha^{-1}, respectively.

Ebwanatereka x SS4 with BL of 2.9 at Kakamega and Nambukaya x MM96/1871 with BL of 2.6 at Alupe were the highly branced crosses. Crosses developed from Mercury and either SS4 or Migyera were the tallest with PH of 1.8 m at Kakamega while Nambukaya x MM96/1871 with PH of 1.4 m was the tallest at Alupe. Sifros x Migyera at Alupe and Bumba x SS4 at Kakamega branched lowest with BH of 0.3 and 0.6 m, respectively. Nambukaya x SS4 at Kakamega and Ebwanatereka x MM96/3972 at Alupe recorded the shortest internode length of 2.3 and 1.9 cm, respectively.

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Table 4.7: Mean and SCA effects of F_1 hybrids evaluated for important agronomic and farmer preferred traits at Kakamega

Crosses	CMD		BL		PH (m)		HB (m)		IL (cm)		NR		RY (t ha-^{1})	
	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean
F1 x M1	0.02	1.00	-0.16	2.41	-0.03	1.65	0.04	0.78	-0.52	2.49	1.20	5.32	4.81	12.48
F2 x M1	-0.14	1.04	0.03	2.58	0.02	1.68	-0.02	0.70	-0.53	2.64	-1.77	2.96	1.57	9.15
F3 x M1	-0.03	1.00	0.03	2.70	0.08	1.71	0.02	0.68	-0.44	2.38	0.12	3.85	4.87	8.55
F4 x M1	-0.11	1.04	0.18	2.85	-0.11	1.68	-0.05	0.80	1.42	5.12	-0.71	3.58	-16.36	3.34
F5 x M1	0.05	1.11	-0.09	2.42	0.07	1.63	0.06	0.70	-0.05	2.82	0.52	5.07	-0.87	8.64
F6 x M1	0.22	1.40	0.01	2.65	-0.02	1.64	-0.06	0.65	0.11	2.95	0.65	4.63	5.99	4.89
F1 x M2	-0.00	1.00	-0.36	2.22	0.01	1.66	-0.04	0.74	-1.77	2.34	-0.56	3.87	-0.52	7.25
F2 x M2	-0.05	1.14	-0.09	2.48	-0.01	1.62	0.01	0.77	1.07	5.34	-0.43	4.60	-5.70	2.17
F3 x M2	0.17	1.22	0.25	2.93	0.03	1.64	0.04	0.75	-0.04	3.87	-1.00	3.02	-6.51	2.26
F4 x M2	-0.06	1.12	-0.07	2.61	0.04	1.81	0.03	0.93	0.64	5.44	0.30	4.89	24.50	19.29
F5 x M2	-0.02	1.06	0.01	2.54	-0.11	1.42	-0.14	0.55	-0.46	3.51	1.50	6.36	-9.69	3.91
F6 x M2	-0.04	1.16	0.26	2.90	0.04	1.67	0.10	0.85	0.55	4.49	0.20	4.48	-2.08	1.92
F1 x M3	0.02	1.00	0.01	2.56	0.02	1.68	-0.08	0.70	-0.36	2.86	0.21	3.92	-4.92	8.56
F2 x M3	0.05	1.22	0.36	2.90	0.09	1.73	0.01	0.77	-0.84	2.54	1.84	6.16	14.18	18.57
F3 x M3	-0.03	1.00	-0.17	2.49	-0.19	1.42	-0.10	0.60	1.14	4.17	-0.54	2.77	-9.21	4.27
F4 x M3	0.05	1.21	-0.20	2.46	0.01	1.79	0.08	0.97	-0.91	3.01	-0.02	3.85	-13.76	2.24
F5 x M3	0.03	1.09	0.21	2.72	0.03	1.57	0.06	0.75	1.03	4.11	-0.90	3.24	17.72	17.03
F6 x M3	-0.11	1.07	-0.21	2.41	0.05	1.69	0.03	0.78	-0.06	2.99	-0.60	2.96	-4.01	1.70
F1 x M4	-0.04	1.02	0.52	2.76	0.01	1.64	0.09	0.77	2.65	5.90	-0.84	3.28	0.63	10.04
F2 x M4	0.14	1.39	-0.30	1.93	-0.09	1.51	-0.01	0.65	0.30	3.72	0.36	5.08	-10.04	3.28
F3 x M4	-0.11	1.00	-0.11	2.23	0.08	1.66	0.04	0.65	-0.67	2.39	1.42	5.14	10.84	13.25
F4 x M4	0.12	1.36	0.09	2.43	0.07	1.81	-0.06	0.73	-1.15	2.80	0.43	4.72	5.62	14.05
F5 x M4	-0.05	1.09	-0.13	2.07	0.00	1.50	0.02	0.60	-0.53	2.59	-1.12	3.43	-7.15	6.09
F6 x M4	-0.06	1.19	-0.07	2.24	-0.07	1.53	-0.07	0.58	-0.60	2.50	-0.25	3.73	0.10	3.74
Mean	-	1.12	-	2.52	-	1.64	-	0.73	-	3.46	-	4.20	-	7.78
SE	0.14	0.19	0.05	0.06	0.05	0.07	0.06	0.09	0.14	0.19	0.55	0.78	1.47	2.07
CV(%)	-	7.60	-	11.2	-	4.1	-	12.2	-	5.5	-	18.5	-	14.7

SCA = specific combining ability; SE = standard error of SCA; CMD = cassava mosaic disease score on a score scale of 1 - 5 scale; IL = internode length; BL = branching levels; HB = height to first branching; PH = plant height; NR = total number of storage roots per plant; RY = fresh storage roots yields; M1 = MM96/1871: M2 = SS4; M3 = MM96/3972; M4 = Migyera; F1 = Nambukaya; F2 = Sifros; F3 = Ebwanatereka; F4 = Mercury; F5 = Bumba; F6 = Kaleso and CV = coefficient of variation.

Table 4.8: Mean and SCA effects of F_1 hybrids evaluated for important agronomic and farmer preferred traits at Alupe

Crosses	CMD		BT		PH		HB (m)		IL (cm)		NR		RY (t ha-^{1})	
	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean	SCA	Mean
F1 x M1	0.11	1.31	0.14	2.58	0.09	1.36	0.03	0.50	0.13	2.51	-0.75	8.06	0.06	6.29
F2 x M1	-0.14	1.12	0.07	2.45	0.02	1.24	0.02	0.43	0.08	2.33	0.43	8.73	-1.04	4.41
F3 x M1	-0.09	1.04	-0.04	2.53	0.01	1.19	0.02	0.45	-0.01	2.16	0.14	9.30	1.49	6.47
F4 x M1	0.01	1.24	-0.07	2.26	-0.16	1.02	-0.02	0.40	-0.06	2.26	0.13	8.73	-1.52	6.05
F5 x M1	-0.04	1.09	0.04	2.41	0.08	1.17	-0.04	0.35	-0.07	1.99	-0.76	7.78	0.36	6.19
F6 x M1	0.14	1.33	-0.14	2.31	-0.04	1.13	-0.02	0.40	-0.07	2.15	0.81	9.65	-0.35	7.24
F1 x M2	-0.03	1.21	0.12	2.23	0.02	1.24	0.02	0.48	0.07	2.39	1.30	10.00	-0.12	7.09
F2 x M2	-0.02	1.28	0.11	2.16	0.00	1.17	-0.04	0.37	0.03	2.22	-0.46	7.73	0.38	4.11
F3 x M2	0.05	1.22	-0.06	2.18	0.00	1.12	-0.03	0.40	0.02	2.12	-2.32	6.73	-2.58	1.88
F4 x M2	-0.04	1.23	-0.04	1.96	0.01	1.13	0.04	0.45	-0.10	2.15	0.76	9.25	2.49	17.16
F5 x M2	0.01	1.17	-0.05	1.98	-0.07	0.97	0.00	0.39	-0.01	1.99	1.17	9.61	0.74	3.05
F6 x M2	0.02	1.25	-0.08	2.04	0.04	1.15	0.01	0.42	-0.01	2.14	-0.46	8.27	0.09	3.10
F1 x M3	-0.14	1.02	0.01	2.26	-0.09	1.11	-0.01	0.44	-0.07	2.23	0.18	8.81	0.54	4.10
F2 x M3	0.15	1.37	0.01	2.21	0.11	1.24	0.09	0.49	0.06	2.23	0.19	8.31	1.04	10.28
F3 x M3	0.00	1.09	0.07	2.45	-0.05	1.05	0.00	0.42	-0.12	1.95	0.43	9.41	-1.29	5.95
F4 x M3	0.09	1.28	0.06	2.20	0.07	1.16	-0.09	0.32	0.04	2.27	-0.01	8.41	0.17	8.18
F5 x M3	-0.04	1.06	-0.15	2.03	-0.01	1.00	0.03	0.41	-0.03	1.95	0.58	8.95	0.73	15.99
F6 x M3	-0.06	1.09	0.00	2.26	-0.04	1.05	-0.02	0.39	0.11	2.25	-1.36	7.30	-1.2	5.22
F1 x M4	0.06	1.19	-0.27	1.74	-0.02	1.14	-0.03	0.39	-0.13	2.17	-0.73	8.08	-0.48	8.20
F2 x M4	0.01	1.21	-0.19	1.72	-0.13	0.96	-0.08	0.29	-0.17	1.99	-0.16	8.13	-1.38	2.04
F3 x M4	0.03	1.10	0.03	2.14	0.04	1.09	0.02	0.40	0.10	2.18	1.75	10.91	2.38	12.32
F4 x M4	-0.06	1.11	0.05	1.92	0.08	1.13	0.07	0.44	0.12	2.34	-0.89	7.71	-0.14	15.94
F5 x M4	0.07	1.14	0.16	2.06	0.00	0.97	0.00	0.35	0.11	2.08	-0.98	7.56	-1.83	5.73
F6 x M4	-0.11	1.02	0.23	2.22	0.04	1.08	0.03	0.40	-0.03	2.11	1.01	8.23	1.46	6.18
Mean	-	1.17	-	2.18	-	1.12	-	0.41	-	2.17	-	8.58	-	7.22
SE	0.06	0.11	0.09	0.13	0.05	0.07	0.04	0.06	0.08	0.11	0.81	1.15	0.11	0.16
CV(%)		1.5		9.7		9.5		14.4		8.4	-	6.00	-	17.4

SCA = specific combining ability; SE = standard error of SCA; CMD = cassava mosaic disease score on a score scale of 1-5; IL = internode length; BL = branching levels; HB = height to first branching; PH = plant height; NR = total number of storage roots per plant; RY = fresh storage roots yields; M1 = MM96/1871: M2 = SS4; M3 = MM96/3972; M4 = Migyera; F1 = Nambukaya; F2 = Sifros; F3 = Ebwanatereka; F4 = Mercury; F5 = Bumba; F6 = Kaleso and CV = coefficient of variation.

Sifros x MM96/3972 with NR of 6.4 at Kakamega and Ebwanatereka x Migyera with NR of 10.9 at Alupe recorded the highest number of storage roots per plant.

The best performing crosses were not always developed from parents with highest GCA effects. Similarly, the performance of the crosses did not always correspond to their SCA effects. The performance of the crosses and their SCA effects varied between the two environments. For example Nambukaya x MM96/1871 when grown at Alupe recorded a mean number of storage roots of 8.1 per plant and SCA effect of -0.75. However, when grown at Kakamega, it recorded a mean number of storage roots of 5.3 per plant and SCA effect of 1.20.

4.3.5 Estimates of heterosis and genetic gain among the crosses

When breeding for CMD resistance, short internode length and lower height to first branching, the best crosses are those with the most negative heterosis. Best parent heterosis for CMD resistance ranged from -15.3 to 257.1% with an overall mean of -1.7% but in specific crosses the progress was much higher (Table 4.9). Though the worst cross was over 2.5 times more susceptible to CMD than the best parent, overall mean heterosis of -1.7% indicates a positive progress in breeding for CMD resistance. The most resistant cross recorded a mean score of 1.0 as compared to the most resistant parents with mean scores of 1.1 and 1.2 among the improved varieties and landraces, respectively. These represented a genetic gain of 10.7 and 16.7% over parents from improved varieties and landraces, respectively (Table 4.9). Best parent heterosis for IL ranged between -79.6 to 225.2% with a mean of 13.2%. The genetic gain over parents from landraces and improved varieties was 43.4 and 30.9%, respectively. The lowest branching height among the landraces and the improved varieties was 0.5 m while among the crosses was 0.3 m representing a genetic gain of 53.7 and 51.9% over the parents from landraces and improved varieties, respectively. Best parent heterosis for HB ranged between -106.8 and 240.1% with a mean of 19.2% indicating a general increase in HB.

The best parent heterosis for RY ranged from -102.7 to 246.6% with a mean of -47.0% for all the F_1 hybrids. The negative mean heterosis indicates that the crosses on average produced less RY than the mean of the best parents. However, the highest yielding parent among landraces and improved varieties recorded 11.6 and 19.9 t ha^{-1} respectively while the best cross recorded 38.1 t ha^{-1} of fresh storage roots. These represented a genetic gain of 229.5 and 91.3% over parents from landraces and improved varieties, respectively. All parents developed branches while some of the crosses did not have branches. Best parent heterosis for BL ranged between -102.5 to 256.1% with a mean of -32.2. The highly branched parent among the landraces and the improved varieties recorded BL of 3.5 and 4.4, respectively. The highly branched cross recorded BL of 5.4 representing a genetic gain of 52.7 and 22.4% over parents from landraces and improved variety, respectively. Best parent heterosis for NR ranged between -108.9 to 353.9% with mean of -47.0%. The parent with highest NR among landraces and improved varieties was 8.4 and 8.5 storage roots per plants, respectively. The best cross recorded 28.0 storage roots per plant representing a bout 230% genetic gain.

Table 4.9: Top twenty clones with the highest positive and negative best parent heterosis for fresh storage roots yield and cassava mosaic disease resistance respectively

Clone	Pedigree	CMD	IL	BL	HB	PT	NR	NY
F8-C25	Nambu x Migyera	-13.0	92.3	-19.9	169.3	28.8	-36.2	214.8
F9-C1	Mercury x SS4	-14.5	119.4	5.7	32.2	-0.1	-10.5	141.4
F9-C5	Mercury x SS4	-14.5	69.9	-16.9	-6.7	-19.1	25.2	213.9
F9-C19	Mercury x SS4	-14.8	127.4	-50.5	-4.7	-20.8	-26.7	150.1
F9-C30	Mercury x SS4	-14.8	106.2	-10.2	42.2	-1.9	61	227.4
F9-C32	Mercury x SS4	-14.5	79.7	-69.8	29.7	-34	-28.4	139.9
F9-C35	Mercury x SS4	-13.8	104.7	-6.9	114.4	6.9	-9.7	240.5
F9-C39	Mercury x SS4	-14.8	24.4	-20.3	-5.9	-36.4	25.2	239.6
F10-C15	Bumba x 3972	-11.0	45.2	-51.9	32	-2.5	-32.8	153.6
F10-C34	Bumba x 3972	-10.4	-15.2	-30.8	2.6	7.9	-15.8	219
F11-C13	Sifros x 3972	-10.7	10.7	2.6	-15.2	36.7	54.9	176
F12-C12	Mercury x Migyera	-13.3	3.2	5.9	26.0	-6.1	-82.5	157.2
F12-C21	Mercury x Migyera	-12.3	-0.5	-17.2	-15.4	-31.1	13.1	190.4
F17-C3	Bumba x 1871	-12.3	14.0	-28.8	40.4	1.4	-7.2	136.3
F17-C16	Bumba x 1871	-12.3	23.5	-43	57.9	22.4	31.5	162.6
F20-C1	Sifros x 1871	-12.5	-14.4	-5.8	18.5	29.0	5.3	146.8
F21-C2	Ebwana x 1871	-12.3	-15.1	-0.3	85.2	36.4	0.6	162.6
F21-C10	Ebwana x 1871	-12.3	-24.6	-28.8	57.4	29.4	54.7	136.3
F22-C9	Ebwana x Migyera	-12.3	-26.7	-97.6	-106.8	37.3	-10.6	244.9
F24-C23	Nambu x SS4	-15.3	63.9	-11.9	24.7	30.9	0.2	237.0
Mean		-1.7	13.2	-32.3	19.2	-0.2	-13.0	-47.0
SE		1.0	1.4	0.9	1.6	0.7	1.8	2.1
Minimum % heterosis		-15.3	-79.6	-102.5	-106.8	-96.4	-108.9	-102.7
Maximum % heterosis		257.1	225.2	256.1	240.1	73.9	353.9	246.6
BP (Improved)		1.1	2.2	4.4	0.5	1.4	8.5	19.9
BP (Landraces)		1.2	2.7	3.5	0.5	1.8	8.4	11.6
BC (F1)		1.0	1.5	5.4	0.3	2.4	28.0	38.1
GG over Improved (%)		10.7	30.9	22.4	51.9	67.8	230.7	91.3
GG over landraces (%)		16.7	43.4	52.7	53.7	30.4	233.8	229.5

SE =standard error, CMD = cassava mosaic diseases score on a score scale of 1-5; IL = internode length; BL = branching levels; HB = height to first branching; PT = plant height; NR = total number of storage roots per plant, RY = fresh storage root yields; BP = performance of the best parent; BC = performance of best cross; GG = genetic gain.

4.4 Discussion and conclusions

The objectives of the study were to determine the mode of gene action controlling the farmer preferred traits in cassava and to identify parents and crosses that enable genetic gain for the desired traits. A small population size with a high proportion of genotypes with farmer preferred traits is easier for farmers to evaluate during participatory plant breeding (PPB). An understanding of the gene action controlling these traits and the levels of heterosis expressed forms the basis on which the parents and the breeding strategy are selected. Precise selection of a few parents from different heterotic groups and the subsequent development of a few specific crosses are fundamental to effective and efficient participatory plant breeding. The relatively small size of the F_1 population developed from a few elite parents also reduces the cost of crossing and evaluation. The selected parents should be genetically divergent for the preferred traits and at least one of them in a given cross should be adapted to the production environment (Witcombe et al., 2001).

In this study, the seed set ranged from 1.1 to 2.9 seeds per cross. The cassava flower develops into a tri-locular fruit which develops a maximum of three seeds (El-Sharkawy, 2004), therefore out of the possible maximum of three seeds per cross, the seed set in this study ranged from 36.7 to 96.7%. Low success rate of crossing is an impediment to efficient improvement through breeding. Since cassava varieties are genetically heterozygous, many seeds are required from a single parent to increase the chances of obtaining a superior genotype (Ceballos et al., 2004; Kawano, 2003). Flowering and seed set in cassava are highly influenced by environmental conditions (Ceballos et al., 2004; El-Sharkawy, 2004). Mean seed germination ranged from 30.0 to 70.8% with a mean of 46.5%. Cassava seed exhibit dormancy for a few weeks after maturity and also require temperatures of between 30 to 35^0C to germinate. These are the probable reasons for the low germination observed in this study.

The significant differences between crosses in all the traits evaluated except DMC and PC when they are grown in both locations, and NR and HB when they are grown at Alupe imply significant genotypic differences between the crosses. The presence of significant differences between crosses in one environment and not the other, coupled with the observed differences in performance of the parents and their crosses between the two locations, indicate the presence of G x E interaction. Strong G x E effects have been reported in many important agronomic and morphological traits of cassava (Cach et al., 2006; Calle et al., 2005; Jaramillo et al., 2005). Genotype x environment in cassava has been singled out as a major challenge in cassava breeding due to its low multiplication rate of planting materials that limit the number of replicated multi-location trials (Jennings and Iglesias, 2002). There is a need to develop technologies that will enhance the multiplication rate of cassava such as the rapid multiplication technique reported by Kamau (2006) or the cutting-back method reported in this study (Chapter 4).

The ratio of GCA to SCA SS greater than one indicates the relative importance of additive over non-additive gene action (Griffing, 1956). The results of this study indicate that PH and IL when the crosses are grown in both locations; DMC when grown at Kakamega; and BL when grown at Alupe were predominantly governed by additive gene action while the rest of the traits evaluated were predominantly governed by non-additive gene action. Similar results were obtained by Cach et al. (2006) and Jaramillo et al. (2005) in their studies. They reported that RY was predominantly determined by non-additive gene action while PH was predominantly under the influence of additive gene action. Information on the type of gene action controlling preferred traits is important in selecting both the parents and the breeding strategy. For a crop such as cassava, the best breeding strategy for traits predominantly under additive gene action, is phenotypic recurrent mass selection where parents with good GCA are deployed (Cach et al., 2006; Hallauer and Miranda, 1988; Mullin and Park, 1992). However, non-additive gene action can be fixed through vegetative propagation. Any variety exhibiting superior performance due to non-additive gene action can be maintained vegetatively. A reciprocal recurrent selection breeding strategy should be employed when breeding for traits under both additive and non-additive gene action. This breeding strategy can be enhanced by introduction of inbreeding (pure-lines). Inbreeding facilitates increasing the frequency of favourable genes by unmasking important non-deleterious recessive genes (Cach et al., 2006; Sleper and Poehlman, 2006).

There was inconsistent significance of GCA MS for some traits across environments. Most parents also expressed varying GCA effects across environments for most of the traits evaluated. This indicated the presence of GCA x environment interaction effects. The presence of G x E and GCA x environment interaction poses considerable challenges to the development of widely adapted genotypes (Kimani and Derera, 2008). The implicalication is that parents and crosses should be evaluated in more than two or more distinct environments before conclusions are made on their genetic potential (Owolade et al., 2008).

It was apparent in this study that the best parents to be used in breeding for resistance to CMD, low height to first branching and short internode length are those with negative GCA effects for these traits. Such parents contribute towards the reduction of values of these traits which would satisfy the preferences of farmers. Only Ebwanatereka and Bumba had negative GCA effects for all the three traits in both locations indicating their stability in contributing towards these traits and their suitability as parents when breeding for these traits. In this study, improved varieties were used as sources of resistance to CMD. Only MM96/3972 had negative GCA effects in all environments for CMD resistance. The magnitude and sign of the GCA effect of a parent did not necessarily correlate with their *per* *se* performance, indicating the presence of non-heritable gene action and epigenetic action. This implies that selection of parents for hybridization should not be based on *per se* performance (Griffing, 1956).

A number of crosses developed outperformed their best parent expressing high heterosis percentages. The expression of heterosis indicates the presence of genetic divergence between the parents (Mungoma and Pollak, 1988; Tang et al., 2004; Tang et al., 1993) and confirms the significance of gene interaction in the crosses. The crosses developed from Mercury x SS4 dominated the list of the top 20 crosses with high positive best parent heterosis for RY and most negative best parent heterosis for CMD resistance. This implies the two parents are genetically divergent in genes governing the two traits. Genetic gain in this study ranged between 10 and 230% over the best parents from either the landraces or improved varieties. Resistance to CMD realised a genetic gain of 16.7 and 10.7% over the best parent from the landraces and improved varieties, respectively. There was also a genetic gain in fresh storage root yields of 229.5 and 91.3% over the best parents from the landfaces and improved varieties, respectively. These imply that there is a potentail of deploying these parental varieties in development of superior crosses and general progress in breeding.

Both additive and non-additive gene action play a role in expression of farmer preferred traits. Because farmers have the experience in selecting what they prefer, both farmers and breeders should be involved in selection of parents. The parental varieties selected by farmers should be evaluated and selected by breeders based on progeny testing for combining ability of the traits of interest. Though cassava exhibits severe inbreeding depression, attempts should be made to develop inbred lines for traits predominantly under non-additive gene action. This will reduce the deleterious gene load and expose useful recessive genes in cassava varieties.

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CHAPTER 5

Farmer-breeder complementation in cassava breeding in western Kenya

Abstract

Cassava is a low input crop grown in diverse environments by small scale farmers. Its breeding requires close collaboration between farmers and breeders to meet the diverse needs. Through collaboration, farmers' experience and indigenous technical knowledge, and breeders' contemporary scientific knowledge and expertise, are merged. A study was carried out in western Kenya to determine the ability of breeders and farmers to perform various activities at each stage cassava breeding. The breeder and farmers from three distinct cassava production niches were involved in all stages of cassava breeding. Farmers' most preferred traits were high storage roots yields, resistance to pests and diseases and low cyanide content and these were also the breeder's top selection criteria. However, plant height, short time to boiling and drying, high branching level and short internode length were important to the farmers, but were not on the breeder's objectives list. This implies selections made by the breeder alone, based on his objectives, cannot meet farmers' requirements. Farmers' select parental varieties based on per se performance while the breeder use combining ability studies. Two parents were commonly selected by the farmers from the three districts and the breeder. When using independent selection criteria and indices to evaluate clonal trials there was a 14% overlap of varieties among the top 100 varieties selected by farmers and the breeder. However, the overlap increased to 49% when participatory selection indices that combined farmers' and breeder's selection criteria were used.

5.1 Introduction

Cassava (*Manihot esculenta* Crantz) is grown by small scale, resource poor farmers in diverse production environments (Ceballos et al., 2004). It can yield on infertile acidic soils (Edwards and Kang, 1978), is tolerant to drought and grows under diverse cultural practices (El-Sharkawy, 1993; Kawano, 2003). Due to these inherent traits, cassava can be grown both as a cash and food crop (El-Sharkawy, 2004). In Kenya, cassava is mainly grown as a food crop for subsistence. The storage roots can be eaten raw, after boiling or processed to flour, which is used to make *ugali* (Kamau, 2006). Each of the production and utilization niches requires specific types of cassava varieties that can meet their challenges and requirements. Breeders often target yield, low cyanide content and resistance to pests and disease, overlooking other, farmer preferred traits (Manu-Aduening et al., 2006). It is through farmer participation that their preferred traits can be identified and selected in cassava breeding programme (Sperling et al., 2001; Witcombe et al., 1996).

Farmer participation in plant breeding can either be collaborative or consultative (Ceccarelli et al., 2003). In consultative participatory plant breeding, consultations are held between the breeder and the farmers. In collaborative participatory breeding, the farmers and the breeders work together complementing each other. Collaborative participatory breeding can either be farmer-led or breeder-led (Atlin et al., 2001). The collaborative approach has been shown to meet the limitations of conventional plant breeding approach more than the consultative approach (Banziger and Cooper, 2001). Though collaboration between farmers and breeders in variety development has been proven to enhance breeding efficiency (Witcombe et al., 1996), it has also been shown that farmers' participation increases breeding efficiency only if they participate at stages and in activities that complement the efforts of the breeders, and this is referred to as highly client oriented breeding (Gyawali et al., 2007; Joshi et al., 2007). The roles of each player, farmer and breeder, are specific to the crop, situation and breeding objectives (Joshi et al., 2007; Witcombe et al., 2006). In order to understand the roles of the farmers and the breeder at various stages of cassava breeding, a research study was conducted with the following objectives:

a) evaluate the roles and activities of the breeder and farmers at each stage of cassava breeding in western Kenya

b) determine an appropriate method that increases variety selection efficiency that takes in account breeders and farmers selection criteria

c) select preferred cassava hybrid varieties

5.2 Materials and methods

In order to understand how the final clonal evaluation was conducted by the breeder and farmers, this chapter presents activities described and discussed in other chapters providing a chronology of activities carried out at all stages of cassava breeding.

5.2.1 Study sites

The study was conducted in western Kenya, the most important cassava producing region in the country. Under the guidance of the agricultural extension staff and provincial administration staff, one division of Mumias, Busia and Teso districts were purposefully sampled based on cassava production, local ethnic community and agro-ecological zones (AEZ). Mumias district is inhabited by the Bantu speaking Luhyia tribe and the study site in this district lies within AEZ LM_1, which is humid (Jaetzold and Schmidt, 1983). Farmers in this district are commercial sugarcane farmers and reserve small pieces of land for food crops. Teso district is inhabited by the Nilote speaking Ateso tribe and the study site in this district lies in LM_3 which is sub-humid. The Ateso community is more conservative in their traditions and highly dependent on cassava and sorghum as their staple food. They have no specific cash crop. Busia district lies between Mumias and Teso districts. It is inhabited by both Bantu (Luhyia) and Nilote (Teso) communities and the study site in this district lies in $LM_{2.}$ From each division, one active farmer group with a history of working on cassava was identified. The selected groups were; Naako-Aterait women group from Chakol division of Teso district, Agro-Farmers group from Nambale division of Busia district and Development Association Foundation (DAF) youth group from Matungu division of Mumias district.

5.2.2 Situation analysis

A participatory rural appraisal (PRA) tool was used to gather information from the selected communities through focused group discussions (FGD). During FGD, neighbouring farmers, who were not members of the groups, were invited. Group discussions were led by one of the research team member who was versed with the local dialect. A check list was used to guide the discussions. Information was gathered on farming systems, cassava utilization, production constraints and preferred cassava variety traits, which were analysed using descriptive statistics and pairwise ranking matrix. A total of 101 farmers (47 male and 54 female) participated in FGD.

5.2.3 Parental varieties selection

In collaboration with Ministry of Agriculture extension staff, a cassava varieties survey and collection was conducted in western Kenya. A total of 15 (10 landraces and five improved) varieties also used in Chapter 3 were selected based on popularity. Popularity was assumed to indicates the presence of farmer preferred traits and adaptation to western Kenya environment.The improved varieties are also resistant to cassava mosaic disease (CMD), a major disease in the region, and have high storage roots yields.

Each farmer group identified a 25 x 25 m centrally placed and accessible piece of land for planting the 15 cassava parental varieties. The land was prepared by the group members. The varieties were planted under concealed identity in complete randomized design (CRD) with three replications. Each plot consisted of five plants spaced at 1 x 1 m. The trials were farmer-managed by the group members. No fertilizer was applied. Group member were asked to make regular visits to the trial and make observations on the cassava varieties.

At harvest time, 12 months after planting (MAP), the farmers were asked to evaluate the 15 varieties using the preferred traits listed and ranked during FGD. The traits were scored on a scale of 0 (trait absent from the variety) to 5 (variety has the trait to farmers' satisfactory level). The traits were assessed using farmers' indigenous technical knowledge (ITK). The farmers were asked to award marks based on how satisfied they were with performance of the variety. Evaluation was conducted at two stages, at plant stage and after harvesting for yield and storage root quality traits. The farmers were asked to rank the varieties by visual assessment without considering the trait scores. Mean scores for each variety and trait evaluated were computed and standardized using the following formula;

$P_i = (X_{ij} – M_i)/S_i$

Where; P_i = Standardized variety mean value for i^{th} trait, X_{ij} = Observed value of the i^{th} trait measured on j^{th} variety, M_i = Overall mean of the i^{th} trait and S_i = Standard deviation of the i^{th} trait in the population.

GENSTAT 14th Edition was used to conduct correlation analysis between mean scores and variety ranks based on visual assesment. The correlation coefficients were used to develop a simple selection index.

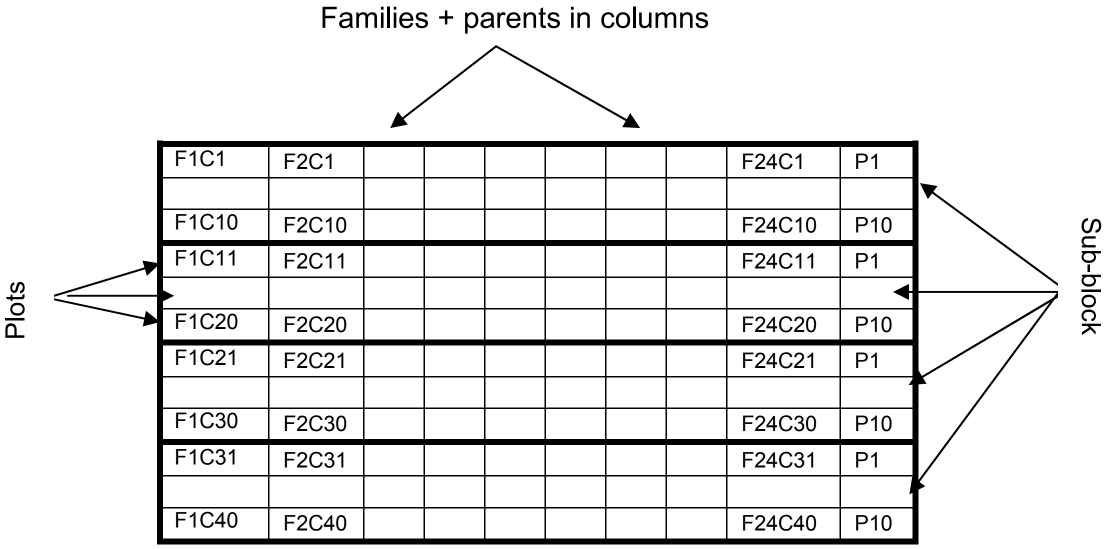
5.2.4 Cassava clonal evaluation trial (CET)

A total of 1440 F_1 hybrid seedlings from 24 full-sib families were raised and planted at Kakamega research station farm. The seedlings were developed from six landraces and four improved varieties and planted in single rows of full-sib families at spacing of 1 m between and within rows. The hybrids were developed in a crossing block at Alupe research station farm using a 6 x 4 North Carolina II mating design. Six months after transplanting (MAT), the seedlings had to be cut back to a height of 10-15 cm above the ground after a devastating hailstorm. However, this increased the number of cutting per seedling (genotype). A maximum of three side shoots per stem were allowed to re-grow which resulted in over 12 cuttings per seedling for most genotypes. Six months after cutting-back, 40 plants (genotypes) per family that produced at least 12 mature quality stakes (25 cm long) were selected and harvested for the clonal evaluation trial (CET). A total of 970 clones (40 genotype per family from 24 families plus their 10 parents) were planted in two sites, Kakamega and Alupe research station farms, in a 24 x 40 α-lattice design with two replications. Plots consisted of three plants spaced at 1 x 1 m. The trial was maintained by hand weeding. No fertilizer or pesticide were applied.

Farmers' evaluation of clonal trial

The CET was evaluated by farmers from two districts, Busia and Mumias districts and the breeder. The farmer group from Teso district did not participate in the clonal evaluation due to lack of cohesiveness in the group. Farmers evaluated the CET established in Alupe research station, which was near the farmers' districts, with almost the same climatic and soil conditions. Alupe is a hot spot for cassava diseases, especially CMD.

Farmers evaluated the CET at two stages, one day before harvest (for above the ground plant characteristics) and at harvest stage (for storage root characteristics and yield), using traits listed and ranked as important during FGD. The evaluation was 10 months after palnting (MAP). Prior to the evaluation day, farmers were invited to the trial site to acquaint themselves with the trial layout and evaluation procedure. The trial field was demarcated into four sub-blocks. Each sub-block consisted of ten plots (genotypes) from each of the 24 families and parents (Figure 5.1). Each plot within the rows was clearly labelled. Farmers from each group were divided into two groups each of approximately five members to make four sub-groups. Each sub-group was assigned a scientist to assist them during evaluation. One sub-group evaluated one sub-block of the trial at a time. Using score sheets, farmers evaluated each plot by scoring for each traits on a scale of 0 (trait is absent) to 5 (the variety expressed the trait at a satisfactory level).



F1C1	F2C1							F24C1	P1
F1C10	F2C10							F24C10	P10
F1C11	F2C11							F24C11	P1
F1C20	F2C20							F24C20	P10
F1C21	F2C21							F24C21	P1
F1C30	F2C30							F24C30	P10
F1C31	F2C31							F24C31	P1
F1C40	F2C40							F24C40	P10

Figure 5.1: Field layout and sub-division of the clonal evaluation trial during participatory variety selection

In order to ensure that the farmers completed and did the correct evaluation, they were asked to score as if they were ‘teachers’ awarding marks on the performance of a ‘student’, in this case out of five. Those varieties lacking the traits received a zero mark while those that fully satisfied the farmer received all five marks for each trait being evaluated. Each sub-group member evaluated all plots within the sub-blocks of the trial before rotating to the next sub-section. All sub-groups rotated and evaluated all four sub-blocks of the field. During the first stage, farmers evaluated the varieties for health of the plant and leaves, plant height, branching level, internode length and stem thickness.

Before the second stage of evaluation, cassava varieties were uprooted carefully, ensuring that the storage roots were left intact and attached to the plant. The uprooted plants were placed back in their original position within the plots and labelled for ease of identification and evaluation. Using the same evaluation procedure as in stage one, farmers evaluated the varieties for number, size and shape of storage roots. The evaluation of the taste of raw and boiled storage roots could not be done due to the large number of genotypes involved and the risk of cyanide poisoning.

Data collected by farmers was used to compute variety mean scores for each trait separately before being combined per group. The mean values for each trait were standardized using the formula presented above (Section 5.2.3). Standardized variety mean values were used to compute selection index (SI) formulas for each district.

Breeder’s evaluation of segregating population

The breeder evaluated the CET trials in both sites, Kakamega and Alupe. At Alupe site, the scientist evaluated the clones for traits related to plant aspects two days prior to farmers’ evaluation, while traits related to storage roots and yield were evaluated immediately after the farmers’ evaluation.

The breeder collected data on reaction to cassava mosaic disease bi-monthly, starting 3 MAP by scoring on a scale of 1-5 where 1= low incidence (resistant) and 5= high incidence (susceptible). At harvest (10 MAP) on; Total number of storage roots per plant (NR), Fresh storage root yield (t ha^{-1}) (RY),

Dry matter content [DMC(%)] = {[Wa/(Wa - Ww)] x 158.3} – 142

Where Wa =mass of roots in air and Ww = mass of roots in water. Plant height (m), height to first branching (m), branching level (stages of branching on the plant), internode length (cm) and cyanide content. Cyanide content was determined by colour change of the picrate on a 125 mm Whatman® filter paper strip as described by O'Brien et al. (1994). Colour change from pale green (< 10 ppm of cyanide) to dark brown (> 150 ppm of cyanide).

The data collected by the breeder was analysed using Residual Maximum Likelihood (REML) method of GENSTAT version 14 (Payne et al., 2011) to detect genotypic differences. The varieties were evaluated using negative selection and selection index. The negative selection criterion was based on the objectives of the breeding programme which were high yields, CMD resistance and low cyanide content. The Kenya variety release committee releases varieties that out-yield the commercial varieties. In this study, varieties with fresh storage roots yield less than the mean of parents, mean CMD score > 2 and picrate score > 6 were rejected. The selected varieties were then ranked using SI in order to include other preferred traits. The SI formula was derived from one developed by Ceballos et al. (2004), which incorporated traits perceived the breeder to be important and generally preferred by farmers. These traits included foliage level (plant height and branching level) which determine the shoot to root ratio and shown to be an important selection criteria in early selection stages. Dry matter content is an important yield component trait not considered by farmers.

$BSI = 10 (RY + NR) – 8 (CMD+PC) +8(DMC) +3(PT+BI) - 3(IL+HB)$

Where: BSI = breeder's selection index, RY = fresh storage roots yield, NR = number of storage roots per plant, CMD = cassava mosaic disease reaction score, PC = cyanide content based on picrate score, DMC = dry matter content (%), PH = plant height, BL = branching type, IL = internode length and HB = height to first branching. Traits whose breeding objective is to reduce their level (preferred form by farmers) have negative coefficients in the BSI formula. The best variety is one with the highest BSI value.

A selection pressure of 15% was used. Only the top 100 varieties were selected. The selected varieties were compared between farmers from different districts and between farmers and breeder using Spearman's rank correlation analysis and diagram mapping.

5.3 Results

5.3.1 Situation analysis

Cassava is grown by small scale farmers with mean land per household of 1.6 ha. Over 55% of the cassava farmers practice mixed cropping. The common crops in the mixtures are maize, beans and maize/beans. Cassava is used as both food and cash crop in all the three districts. Cassava storage roots are either eaten after boiling or processed to flour, which is used to make *'Ugali'*. Over 70% of farmers in Mumias district, 57% in Busia district and 30% in Teso district eat cassava after boiling while in Teso and Busia districts, over 69 and 43% of farmers, respectively use cassava storage roots after processing to flour. Over 65% of the cassava sold is marketed as dried storage roots for flour processing. Due to cassava production constraints, only 47.9% of farmers produce enough cassava on their farms for their own use. Foliar diseases and pests followed by lack of capital (mainly labour) and land are the most important cassava production constraint.

Cassava preferred traits, in order of preference, are high storage roots yields, resistance to pests and diseases, earliness, plant height, low cyanide content, short time to boiling and drying, high branching level and short internode length high branching level and short internode length (presented in Chapter 2, Table 2.7).. Only the first two traits were consistently ranked in all the three districts. Preferences for the other traits varied between districts. The farmer preferred traits were used to develop the breeding objectives

5.3.2 Selection of parental varieties

The ranking between districts were significantly (P<0.05) correlated peaking at 90% between Mumias and Busia (Table 5.1). This indicates similarities in parental variety preferences between these districts. SS4 is the most preferred parental variety by farmers from Busia and Mumias districts, while Migyera is the most preferred by farmers from Teso district. Among the landraces, Kaleso was the most preferred overall and by farmers from Mumias and Teso districts. The most preferred landrace by Busia farmers is Ebwanatereka ranked fourth.

Table 5.1: Farmers' evaluation of 15 parental varieties in Busia, Mumias and Teso districts

Variety	Variety type	Busia		Mumias		Teso		Overall Mean	
		Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Migyera	I	5.4	2	3.6	2	3.6	1	4.2	1
SS4	I	4.0	1	3.3	1	5.3	4	4.2	2
Kaleso	L	6.7	5	5.6	3	4.1	2	5.5	3
CK9	L	7.7	6	7.4	8	4.7	3	6.6	4
MM96/4684	I	6.1	3	6.1	4	7.9	8	6.7	5
Sudhe	L	7.7	7	8.1	9	6.5	6	7.4	6
Opongi	L	8.3	8	6.2	5	8.6	10	7.7	7
Ebwanatereka	L	6.5	4	7.1	7	11.9	14	8.5	8
Nambukaya	L	9.6	13	10.6	13	6.2	5	8.8	9
Sifros	L	9.0	12	10.3	12	8.3	9	9.2	10
MM96/3972	I	8.9	11	6.4	6	13.3	15	9.5	11
Serere	L	8.8	9	10.2	11	10.1	11	9.7	12
MM96/1871	I	8.9	10	9.7	10	11.8	13	10.1	13
Mercury	L	11.2	14	11.9	14	7.8	7	10.3	14
Bumba	L	11.4	15	13.6	15	10.5	12	11.8	15

I=improved variety, L = landraces

5.3.3 Selection index

There were significant correlations between ranking by visual assessment and traits scores for most traits evaluated (Table 5.2) by the farmers. The correlation coefficients were used to generate selection index formulae that can be used to rank a large segregating population where ranking by visual assessment is not feasible.

The selection indices are generated for each district separately, because there were differences in ranking of preferred traits by farmers from different districts. All the coefficients were changed to positive, because selection was based on awarding scores positively. The best variety is one with highest farmers selection index (FSI) value.

$FSI_{Mumias} = 0.25Bl + 0.24Cc + 0.65Dr + 0.50IL + 0.56Mt + 0.22Ph + 0.01Tb + 0.25Tr + 0.76Yd$

$FSI_{Teso} = 0.92Bl + 0.25Cc + 0.95Dr + 0.82IL + 0.93Mt + 0.56Ph + 0.57Tb + 0.64Tr + 0.97Yd$

$FSI_{Busia} = 0.89Bl + 0.86Cc + 0.83Dr + 0. 78IL + 0.80Mt + 0.76Ph + 0.36Tb + 0.11Tr + 0.92Yd$

Where: FSI = farmers' selection index, Bl = branching level, Cc = cyanide content, Dr = resistance to foliar diseases and pests, IL = internode length, Mt = time to maturity, Ph = plant height, Tb taste of boiled storage roots, Tr = taste of raw storage roots and Yd = yield of storage roots.

Table 5.2: Spearman's rank correlation coefficients between mean scores of farmer preferred traits and ranking of cassava varieties by visual assessment in Busia, Mumias and Teso districts

Traits	Busia	Mumias	Teso
Branching and leaf type	-0.89**	-0.25ns	-0.92*
Cyanide content	-0.86**	-0.24ns	-0.25ns
Disease & pests resistance	-0.83**	-0.65*	-0.93**
Internode length	-0.92**	-0.50*	-0.82**
Time to maturity	-0.80**	-0.56**	-0.95**
Plant height	-0.76**	-0.22*	-0.56**
Taste of boiled storage roots	-0.36*	-0.01ns	-0.57**
Taste of raw storage roots	-0.11ns	-0.25ns	-0.64**
Storage roots yields	-0.78**	-0.76**	-0.97**

* and ** = significant at $p<0.05$ and 0.01 respectively; ns = non-significant

A positive sign was used for all traits evaluated in the FSI formulae because farmers scored positively for the traits based on level of satisfaction. The best performing varieties (preferred) had the highest scores hence SI value. Using FSI values, the varieties were ranked per district.

5.3.4 Farmers' evaluation of the clonal trial

The age of the farmers who participated in the evaluation exercise ranged between 24 and 61 years. They were born in the districts and have cultivated and used cassava for almost their entire lives. They all had a minimum of seven years of education and therefore were able to read and write. Those who could not understand the plot labels or write well were assisted by the technicians in answering and filling in the score sheets.

Farmers from Busia districts gave higher scores than those from Mumias districts (Table 5.3). The overall means scores for Mumias and Busia districts were 2.26 and 3.17, respectively. Mean FSI were 72.25 and 104.64 for Mumias and Busia districts, respectively. In both districts, there were significant ($P<0.05$) genotypic differences between varieties in overall mean score and SI (standard errors of 0.02 and 0.73 for Mumias and 0.02 and 0.89 for Busia districts) indicating the ability of farmers to identify differences between the varieties. It was observed that farmers' evaluation rate depended on experience. At the onset of evaluation, farmers took relatively longer time to evaluate a single row of plots than towards the end.

Table 5.3: Variety evaluation by farmers from Busia and Mumias districts of five best and worst performing varieties

Mumias				Busia			
Variety	MS	FSI	Rank	Variety	MS	FSI	Rank
406	4.22	145.00	1	195	4.70	161.66	1
475	4.05	138.28	2	382	4.66	159.40	2
775	3.84	134.14	3	557	4.57	157.00	3
801	3.87	133.73	4	806	4.56	154.44	4
143	3.62	132.46	5	301	4.53	153.71	5
-	-	-	-	-	-	-	-
751	1.12	38.84	734	705	1.49	40.83	734
679	1.12	38.72	735	025	1.63	40.62	735
245	1.13	38.70	736	118	1.47	40.51	736
025	1.11	38.39	737	045	1.25	38.34	737
140	1.08	37.87	738	716	1.12	36.69	738
Mean	2.26	72.25	-	-	3.17	104.64	-
SE	0.02	0.73	-	-	0.02	0.89	-
Minimum	1.08	37.87	-	-	1.12	36.69	-
Maximum	4.22	145.00	-	-	4.70	161.66	-

SI = selection index; MS = mean score; SE = standard error.

5.3.5 Breeder's evaluation of clonal trial

The breeder used both negative selection and breeder's selection index (BSI). Varieties with CMD and PC greater than 2 and 6 respectively and fresh storage roots yield less than the mean of the parents were rejected. BSI was used to allow other important traits to be included in the selection criteria based on the weightings of preference. Using these selection criteria, only 172 varieties were selected. Variety 913 was the best performer while the best performing parent was P3 (MM96/3972), an improved variety (Table 5.4). All landraces were rejected due to high reaction to CMD and poor yield except Mercury which had a CMD score of 1.12.

Table 5.4: Mean performance of best and worst five clones and best parents selected by the breeder.

Variety	CMD	IL (cm)	BL	HB (m)	PT (m)	DMC (%)	PC	NR	RY (ha^{-1})	SI	Rank
913	0.99	2.56	1.92	1.94	2.03	43.00	4.00	11.44	59.74	1014.20	1
445	1.00	2.50	4.99	0.35	2.36	46.00	3.00	13.51	47.99	964.56	2
350	0.99	4.47	2.97	0.84	1.81	44.30	3.00	13.51	48.32	939.33	3
359	0.99	2.7	2.64	0.56	1.17	42.30	4.00	10.51	50.13	906.68	4
394	1.00	2.23	2.36	0.61	1.49	43.00	3.00	5.20	53.59	902.82	5
-	-	-	-	-	-	-	-	-	-	-	-
288	1.00	4.56	2.03	0.98	1.61	35.02	6.00	5.86	12.11	397.92	168
301	1.00	5.31	5.00	1.20	1.91	36.30	6.00	4.20	11.13	386.42	169
300	1.00	4.92	1.75	0.98	1.81	33.50	5.00	3.51	13.65	380.51	170
579	2.00	3.75	2.50	1.30	2.00	30.00	3.00	5.51	12.49	378.39	171
743	1.00	2.99	1.50	0.55	1.35	34.04	3.00	2.01	10.99	367.94	172
-	-	-	-	-	-	-	-	-	-	-	-
P3	1.12	2.71	3.41	0.59	1.38	38.01	2.00	6.17	19.93	544.51	82
P10	1.14	2.65	3.51	0.57	1.43	38.00	5.00	6.47	9.52	419.94	169
P1	1.15	2.73	3.12	0.52	1.34	46.05	4.00	8.47	17.47	589.83	56
P4	1.17	2.17	3.31	0.59	1.38	47.12	4.00	4.57	14.76	533.73	91
P6	1.20	3.17	1.34	1.13	1.84	45.15	3.00	6.36	11.57	502.34	117
Mean	1.08	3.04	2.66	0.71	1.63	39.59	4.15	7.25	21.46	563.65	-
SE	0.01	0.08	0.07	0.02	0.02	0.39	0.09	0.21	0.85	9.64	-

P1= Migyera; P3 = MM96/3972; P4 = SS4; P6 = Mercury; 10 = MM96/1871; SI = selection index; CMD = cassava mosaic disease scored on a score scale of 1-5 (1 = susceptible, 5= resistant);, IL = internode length; BL = branching level; HB = height to first branching; PT = plant height; DMC = dry matter content; PC = picrate score on a scale of 1-9; NR = total number of storage roots; RY = fresh storage roots yield.

5.3.6 Comparison between Busia and Mumias farmers' evaluations

Farmers' variety ranking were significantly ($P<0.05$) correlated between districts at 30% only. Among the top 100 varieties selected by farmers from both districts, there was only 16% overlap (16 varieties were commonly selected among the top 100 varieties both districts) (Table 5.5). Parent P7 (Bumba), a landrace, was one of 16 varieties selected among the top 100 varieties in both districts. Those varieties with low mean rank number like 195, Bumba and 004 are preferred by farmers from the two districts. They are therefore stable and can be adopted by farmers from the two production environments. They can be released and promoted in both districts.

Table 5.5: Varieties commonly selected among the top 100 by farmers from Busia and Mumias districts.

Variety	Mumias Rank	Busia Rank	Mean rank	Overall rank
195	9	1	5.0	1
P7	16	17	16.5	2
004	13	36	24.5	3
487	33	21	27.0	4
256	19	42	30.5	5
650	37	24	30.5	6
557	73	3	38.0	7
843	28	48	38.0	7
468	6	81	43.5	9
252	79	19	49.0	10
755	80	26	53.0	11
215	58	51	54.5	12
834	81	39	60.0	13
892	71	58	64.5	14
328	70	62	66.0	15
031	75	86	80.5	16

5.3.7 Comparison between breeder's and farmers' selection

It is important to know how closely breeders' and farmers' evaluations are in order to predict adoption of varieties and design appropriate variety evaluation processes in future that can enhance variety adoption. Correlations in variety ranking between the breeder and Busia and Mumias farmers were only 0.16 and 0.70 respectively (Table 5.7). Having varieties commonly rated high by both the breeders, using their contemporary techniques, and farmers using their own indigenous technical knowledge (ITK), is an assured way to achieving a high level of adoption. In this study, 23 varieties were commonly selected among the top 100 (approximately 15% selection pressure) by the breeder and farmers from Busia district while 25 varieties were commonly selected among the top 100 by the breeder and Mumias farmers. A total of 14 varieties were commonly selected among the top 100 by the breeder and farmers from both Busia and Mumias districts. Varieties 423 and 468 were ranked favourably by the breeder and farmers from both Mumias and Busia districts.

Table 5.6: Commonly selected varieties among the top 100 by the breeder and farmers from Busia and Mumias districts

Variety	Mumias farmers	Breeder	Mean rank	Overall Rank	Variety	Busia farmers	Breeder	Mean rank	Overall rank	Variety	Mumias farmers	Busia farmers	Breeder	Mean rank	Overall rank
468	9	48	9.0	1	284	37	23	30.0	1	468	9	39	48	32.0	1
410	19	18	18.5	2	478	22	43	32.5	2	355	38	62	4	34.7	2
355	38	4	21.0	3	355	62	4	33.0	3	487	40	20	65	41.7	3
849	61	2	31.5	4	461	60	9	34.5	4	284	68	37	23	42.7	4
559	24	55	39.5	5	386	12	66	39.0	5	848	37	51	59	49.0	5
139	80	41	41.0	6	749	59	20	39.5	6	423	42	56	58	52.0	6
660	43	39	41.0	6	413	70	13	41.5	7	556	91	3	80	58.0	7
284	68	23	45.5	8	556	3	80	41.5	7	139	80	64	41	61.7	8
411	22	74	48.0	9	468	39	48	43.5	9	594	90	81	29	66.7	9
848	37	59	48.0	9	325	84	4	44.0	10	755	81	28	92	67.0	10
423	42	58	50.0	11	139	64	41	52.5	11	327	84	69	57	70.0	11
487	40	68	54.0	12	594	81	29	55.0	12	892	73	57	82	70.7	12
242	35	76	55.5	13	848	51	59	55.0	12	369	57	98	60	71.7	13
369	57	60	58.5	14	423	56	58	57.0	14						
594	90	29	59.5	15	487	20	68	59.5	15	r_s	0.16*	0.07 ns	1.00	-	-
451	100	22	61.0	16	755	27	92	59.5	15	-	-	-	-	-	-
656	99	31	65.0	17	348	22	100	61.0	17	-	-	-	-	-	-
756	39	98	68.5	18	327	69	57	63.0	18	-	-	-	-	-	-
892	73	82	77.5	19	892	57	82	69.5	19	-	-	-	-	-	-
386	98	64	81.0	20	383	74	78	76.0	20	-	-	-	-	-	-
561	84	79	81.5	21	369	98	60	79.0	21	-	-	-	-	-	-
327	84	57	84.0	22	470	32	81	81.0	22	-	-	-	-	-	-
556	91	80	85.5	23	261	83	96	89.5	23	-	-	-	-	-	-
755	83	92	87.5	24	-	-	-	-	-	-	-	-	-	-	-
645	99	84	91.5	25	-	-	-	-	-	-	-	-	-	-	-

rs = Spearman’s rank correlation coefficient between breeder’s and farmers variety ranking

5.3.8 Participatory selection index

The objective of participatory variety selection (PVS) is to select varieties that satisfy both the farmers and the breeder. In this study farmers from each district and the breeder had their own selection criteria and index. In order to select varieties that satisfy selection criteria used by both the farmers and the breeder, a new selection index for each district was developed. The new selection index [Participatory SI (PSI)] combined selection criteria by farmers and the breeder. Some traits are well evaluated by either the farmers or the breeder. For example shape and taste of raw and boiled storage roots are well evaluated by farmers. Dry matter and cyanide content are scientifically quantified by the breeder. Such traits were incorporated in the PSI using their weightings in farmers or breeders independent SI formulas. However, some traits are effectively evaluated by both the farmers and the breeder. Because of the poor correlation between breeder's and farmers' evaluation for these traits, they were incorporated in the PSI using the average of their weightings in farmers' and breeder's independent SI. For these traits, both farmers' and breeder's data sets are used. The PSIs were;

$\mathrm{PSI}_{\mathrm{Mumias}}$ = 1.63(BBI + FBI) + 0.65FDr + 0.25FIL + 0.56FMt + 1.61(FPh + BPh) + 0.01FTb + 0.25FTr + 5.38(FYd + BYd + FNSR + BNSR) + 0.76FSZ + 8BDMC – 1.5BIL - 8(BCMD + BPC)

$\mathrm{PSI}_{\mathrm{Teso}}$ = 1.96(BBI +FBI) + 0.95FDr + 0.41FIL + 0.93FMt + 1.78(FPh +BPh) + 0.57Tb + 0.64Tr + 5.49(FYd + BYd + FNSR +BNSR) +0.97FSZ + + 8BDMC – 1.5BIL - 8(BCMD + BPC)

$\mathrm{PSI}_{\mathrm{Busia}}$ = 1.95(BBI + FBI) +0.83FDr + 0.39FIL + 0.80FMt + 1.88(FPh + BPh) + 0.36Tb + 0.11Tr + 5.46(FYd + BYd + FNSR +BNSR) + 0.92FSZ + + 8BDMC – 1.5(BIL - 8(BCMD + BPC)

Where: BBI and FBI = breeder and farmers' evaluation for branching level; FDr = disease and pests by farmers; FIL and BIL = internode length by farmers and breeder; FMt = time to maturity by farmers; FPh and BPh = plant height by farmers and breeder; FTb and FTr = taste of boiled and raw storage roots by farmers; FYd and BYd = yield by farmers and breeder; FNSR and BNSR = number of storage roots per plant by farmers and breeder; FSZ = size and shape of storage roots by farmers; BDMC = dry matter content by breeder; BCMD = cassava mosaic disease rating by breeder and BPC cyanide content by breeder.

Table 5.7: Forty-nine varieties commonly selected among the top 100 by the breeder using his own selection criteria and farmers from Busia and Mumias districts using participatory selection indices

Variety	Busia farmers	Mumias Farmers	Breeder	Mean rank	Overall final rank
350	1	1	1	1.0	1
461	9	9	7	8.3	2
351	7	7	12	8.7	3
328	10	10	8	9.3	4
446	11	11	10	10.7	5
378	13	13	14	13.3	6
368	15	14	17	15.3	7
452	16	16	15	15.7	8
859	18	17	18	17.7	9
324	17	18	20	18.3	10
749	20	26	21	22.3	11
424	22	19	26	22.3	12
652	21	22	31	24.7	13
005	24	23	35	27.3	14
403	32	29	30	30.3	15
353	29	28	37	31.3	16
473	30	32	39	33.7	17
455	43	42	19	34.7	18
451	44	40	22	35.3	19
334	34	25	50	36.3	20
656	49	35	34	39.3	21
406	40	30	51	40.3	22
392	31	45	48	41.3	23
326	52	51	24	42.3	24
139	46	37	46	43.0	25
569	37	39	54	43.3	26
810	45	48	40	44.3	27
696	41	49	45	45.0	28
731	38	43	65	48.7	29
733	33	36	77	48.7	30
594	73	53	29	51.7	31
333	65	54	36	51.7	32
734	58	66	33	52.3	33
468	61	46	53	53.3	34
432	63	59	47	56.3	35
647	55	56	59	56.7	36
466	59	67	52	59.3	37
619	53	41	84	59.3	38
423	71	55	62	62.7	39
725	60	61	70	63.7	40
160	48	50	93	63.7	41
559	78	62	57	65.7	42
283	66	58	85	69.7	43
327	74	92	58	74.7	44
367	72	84	76	77.3	45
407	91	75	75	80.3	46
287	87	89	71	82.3	47
470	77	96	95	89.3	48
242	98	91	88	92.3	49
r_s	0.53**	0.50**	1.00		

rs = Spearman's rank correlation coefficient between breeder's and farmers variety ranking

The PSI includes all the major cassava preferred traits. These traits are evaluated at different stages of variety development. Traits not evaluated at a given stage are dropped and only those evaluated used to compute PSI at that time. For example in the clonal trial, the taste of raw and boiled storage roots was not evaluated due to the large number of clones evaluated and lack of information on cyanide level that posed risk of cyanide poisoning. These traits were dropped from the PSI formula. They will however be included and determined in the next stage of evaluation.

Using PSI, correlation between breeders and farmers' variety selection increased to 53% between Busia farmers and 50% between Mumias farmers (Table 5.7). A total of 49 varieties were selected in common among the top 100 by the breeder and farmers from both districts (Table 5.7).

5.4 Discussion and conclusions

The aim of this study was to provide an insight in to the evaluation of cassava varieties by farmers and breeders and to investigate how their selections may complement each other. Farmers being the clients of plant breeding products, have wide experience and ITK. Breeders on the other hand have a wealth of contemporary scientific knowledge and expertise and the means to do accurate measurements of a range of traits. Collaboration between farmers and breeder in variety development has been observed to be important (Almekinders and Elings, 2001; Gyawali et al., 2007). This collaboration can be more effective if the role of the farmers and breeders are established at the different stages of the plant breeding process. The role of each should match their knowledge, experiences and expertise, which again depends on the crop and purpose of breeding (Witcombe et al., 2006).

Farmer preferred cassava traits, which determine the breeding objectives, were in accord with the breeder's objectives for high yield, low cyanide content and foliar diseases and pests resistance. Cassava mosaic disease (CMD) is the major disease in western Kenya since the mid in 1990s (Were et al., 2004) and reference to foliar disease by farmers generally refers to CMD. Of the 10 farmer preferred traits, plant height, branching type and internode length were not among the breeder's objectives. Preference for these traits differed between districts implying centralized evaluation cannot produce varieties that will be adopted across all districts. To maximize the effectiveness of farmer-breeder collaboration in cassava breeding, the breeder should identify different zones in his target area. This could be based on agro-ecology, cassava utilization, and cropping systems, among others. Information from each zone should be analyzed and breeding objectives set, based on farmers' and breeder's preferences.

Selection of parents to be used in a breeding programme can be based on the performance of the parent *per se* or on the performance of its progenies (Banziger and Paterson, 1992). Farmers select parents based on *per se* performance (Witcombe et al., 2001). In decentralized participatory breeding, farmers should be involved in parental varieties selection. At least one of the parents in a cross should be selected by farmers and adapted to the production environment. Ideal parental varieties are those selected through participatory variety selection (PVS) (Witcombe and Virk, 2009). Selection based on *per se* performance is suitable for traits under additive gene action with high heritability. Selection of parents for improving traits with low heritability should be based on progeny performance in order to obtain higher response to selection (Falconer and Mackay, 1996). This study has demonstrated that farmer preferred traits in cassava are under both additive and non-additive gene action (Chapter 4). This means that both the farmers and the breeder should be involved in the selection of parents. The ranking of parental varieties by farmers from the three districts was similar. This implied a parent preferred in one district will likely be preferred in others. Farmers preferred SS4 and Migyera among the improved varieties and Kaleso and Ebwanatereka among landraces. The breeder, based on combining ability analysis, preferred MM96/3972 among the improved varieties and Ebwanatereka and Bumba among the landraces for CMD resistance breeding. MM96/3972 and Migyera among the improved varieties and Mercury and Bumba among the landraces were preferred by the breeder for storage roots yield improvement.

Farmers evaluate varieties intuitively based on many factors (Sunwar et al., 2006), which are assessed using ITK. Farmers' evaluation of parental varieties for preferred traits, using their own ITK, elicited significant genotypic differences. Mean scores for these traits significantly correlated with breeder's evaluation except for PC. This implies the ITK methods used to evaluate varieties are effective except when evaluating cyanide content. Farmers did not have an ITK method to evaluate DMC or even consider it in their evaluation process. Dry matter content is an important yield component parameter especially in early selection stages (Ceballos et al., 2004). The breeder on the other hand lacks the skills to evaluate for taste of storage roots (both raw and boiled). This requires close collaboration between the breeders and farmers in the evaluation of cassava varieties.

Development of new genetic combinations through crossing of potential parents from which new superior genotype are selected is an important stage of breeding (Allard, 1999; Sleper and Poehlman, 2006). Breeders have considered this stage of breeding to be too technical and it cannot be handled by farmers, even though in Nepal, farmers were successfully involved in crossing elite germplasm from CIMMYT to local landraces of maize (Sunwar et al., 2006). In the present study, farmers in the participating farmer groups were trained and practiced cassava hybridization techniques. However, most of them were unable to perform pollination because of the cassava flower biology, which requires specific timing for pollen grain harvesting, pollination and covering of the female flowers (El-Sharkawy, 2004; Kawano, 2003). Most farmers lacked the patience and time to concentrate on pollination. Cassava crossing should therefore be conducted by trained personnel/breeders, who should commit their time to crossing in order to achieve the required timing.

Involving farmers in early selection stage when variability is still high is better than in later stages when variability is low (Gibson et al., 2008). Cassava is a clonally propagated crop which is genetically heterogeneous; selection in the early stage of breeding is hindered by the crop's poor multiplication rate and the need to have many genotypes to evaluate per cross (Manu-Aduening et al., 2006). Involving farmers in early stages of selection in sweet potato breeding process has been seen to increase efficiency, while minimizing the risk of selecting undesirable varieties or discarding good genotypes (Gibson et al., 2008; Gruneberg et al., 2009). In this study, farmers evaluated over 800 F_1 hybrids of cassava in early stage of breeding. Significant differences in mean scores between the varieties imply farmers were able to elicit genotypic differences between the varieties in the segregating population. These results are consistent with those from potato breeding (Gibson et al., 2008) and cassava breeding (Manu-Aduening et al., 2006).

The ability of farmers to evaluate a large segregating population in this study was made possible due to the procedure employed. The demarcation of the trial field into small units made it easier to manage and supervise the exercise. The use of score sheet and the scoring procedure of 0 – 5, awarded as score marks was well understood and implemented by farmers. Other methods used by breeders such as scoring on a scale of 1-2 (1=like the variety 2= dislike the variety) (Odendo et al., 2002) may not work on large population.

One important aspect of PPB is its ability to take in account genotype x environment interaction effects (Joshi and Witcombe, 1996). This is achieved by decentralized on-farm PVS where varieties are evaluated in target environments (Banziger and Cooper, 2001). Cassava has a low multiplication rate which limits multi-location replicated trials (Ceballos et al., 2004). From a seedling, each cassava plant (genotype) can produce on average 10 cuttings per year (Kawano, 2003) making it impossible to conduct on-farm trials at this stage. The size of land and labour required are enormous at early selection stages, which cannot be managed by cassava farmers who are small scale farmers (El-Sharkawy, 2004).

Though the correlation in evaluation between farmers from Mumias and Busia districts was significant, it was only 0.3. The low correlation is shown by the relatively few varieties (16 varieties) commonly selected by farmers from the two districts and ranked among the top 100 varieties with only 16% overlap. The number of varieties selected in common (overlap) represents the level of correlation in variety preferences (Odendo et al., 2002). The low percentage overlap between varieties selected by Busia and Mumias farmers observed in this study imply either little commonality in variety preferences between farmers from the two districts, G x E and/or human x variety interaction effects. Breeding programmes should therefore consider these two districts as different target environments. The 16 varieties selected in common can be considered stable since they are preferred by farmers from both districts.

Collaboration between farmers and breeders provides a platform for merging breeder’s scientific knowledge and expertise and farmers’ ITK and experience in variety development. This enhances breeding efficiency and effectiveness (Gyawali et al., 2007; Witcombe et al., 2006). Farmers have their own selection criteria and use their own ITK to evaluate varieties. Breeders on the other hand have skills to test for some traits with higher precision than farmers. They can interlink different fields of science to unravel complex problems that farmers may have and predict trends. Collaboration and concordance between farmers and breeders in variety selection is important. The best varieties are those that have both the breeder’s and farmers’ preferences. The use of PSI that brings together traits preferred and evaluated by both the breeder and farmers is better than selection done using independent selection indices. The results of this study demonstrate that use of PSI increased the number of varieties commonly selected by the breeder and farmers. The varieties selected by both the breeder and farmers from both Busia and Mumias districts increased from 14 to 49. Increased number of varieties selected increases biodiversity of the crop and provide a wider genetic base on which further selection can be conducted.

As in any product development, plant breeding must meet the requirements of the clientele. It is only through a well designed PPB that the requirements of farmers as clients can be achieved. The results of this study clearly indicate that farmer participation should not be passive but active in all breeding stages right from the establishment of breeding objectives, parental varieties selection, through progeny evaluation, selection and release. For example during variety evaluation, there should be complementation between breeders and farmers. In the case of cassava for example, farmers can evaluate varieties for taste, preferred internode length among other traits while the breeder can evaluate cyanide, yield and dry matter content. The evaluation and selection results should be used to select the best varieties.

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CHAPTER 6

General overview of the thesis

Introduction

Western Kenya is one of the most important cassava producing regions of Kenya (EARRNET, 2004) and is characterized by diversity in ethnicity, agro-ecologies and cropping systems (Jaetzold and Schmidt, 1983). Cassava farmers from western Kenya have never been engaged in any formal cassava breeding programme. An efficient cassava breeding programme requires cooperation between farmers and breeders (Gyawali et al., 2007). The ability of cassava farmers from western Kenya to effectively contribute to cassava breeding is not known. Information is lacking on the strength and weaknesses of both the farmers and breeders to handle activities at all breeding stages. This information will ensure effective complementation between farmers and breeders thus ensuring that the varieties developed have the preferred traits and will be adopted. In order to address this knowledge gap, a research study was conducted in western Kenya. The results and their implications to an effective and efficient cassava breeding programme are discussed.

Participatory rural appraisal (PRA) tools were used to gather information on cassava production systems in western Kenya. Three districts Teso, Busia and Mumias, were purposefully sampled based on cassava production level, agro-ecology and inhabiting ethnic community. The results of this study reveal that a majority of cassava farmers in western Kenya are small scale farmers with a mean land size of 1.6 ha growing cassava mainly under mixed cropping systems. Cassava is grown as a food crop for subsistence where the storage roots are eaten after boiling or processing to flour. The districts differed significantly in popular methods of utilization, indicating ethnic differences since cassava is used to make traditional recipes. Over 60% of farmers in the region are aware of the improved varieties which have been introduced in the region over the past few decades. However, adoption rate was as low as 18% in some districts. Lack of high yielding varieties, effects of diseases and pests and lack of capital, land and clean planting materials are the most important constraints to cassava production. The results of this study also reveal that western Kenya cassava farmers prefer tall varieties which are high yielding, resistant to diseases and pests, mature early and have long underground storability of storage roots. Districts significantly differed in traits preferences and importance of constraints.

For example low cyanide content is less important in Teso district as compared to Mumias and Busia districts. Short time to drying of storage roots is less important in Mumias district while long underground storability of storage roots is less importance in Busia districts than the other districts.

These results imply that there is a need for breeders to stratify the target areas in order to capture differences in farmers' needs. The differences between districts in cassava utilization methods, production constraints and traits preferences indicate ethno-ecological differences. These means that cassava breeding should be directed towards decentralized participatory approaches taking into account differences in ethnicity and agro-ecologies of western Kenya.

In order to understand the ability of farmers to select cassava parental varieties for preferred traits using their own ITK, three farmer groups were identified in the three study districts, Busia, Teso and Mumias. Each group established an on-farm trial where a collection of 15 (10 landraces and five improved) popular cassava varieties were planted with concealed identities. Farmers evaluated these varieties for preferred traits identified during PRA (Section 2.3.5) using their own ITK. The results from this study reveal that farmers have effective ITK methods of selecting varieties for most of their preferred traits. However, some of the ITK methods failed to identify phenotypic differences between the varieties for example cyanide content. The study also reveals that farmers are able to select good parental varieties. Overall, farmers have effective methods to evaluate varieties for their preferred traits. The ITK of farmers should be exploited in cassava breeding programmes because some traits like taste of raw or boiled storage roots have no alternative conventional methods of evaluation. However, farmers' evaluation should not be the only selection method relied on because they failed to effectively evaluate varieties for cyanide content necessitating complementation by the breeders.

A genetic study on the farmer preferred traits identified during PRA was conducted. Six popular landraces and four popular improved varieties collected in western Kenya were crossed using a 6 x 4 North Carolina II mating design to generate 24 full-sib families. The 24 families each represented by 40 genotypes were evaluated at two sites, Kakamega and Alupe research station farms, using a 24 x 40 α-lattice designs with two replications. The results of this study revealed that all the traits evaluated were under both additive and non-additive gene action effects. However, there was a preponderance of non-additive over additive gene action effects for reaction to CMD, IL, DMC, NR and RY. Best crosses were not necessarily developed from parents with high general combining ability indicating the presence of non-additive gene action

(Falconer and Mackay, 1996; Fasoula and Fasoula, 1997). There was no correlation between *per se* performance of the parents and GCA effects implying selection of parents based on *per se* performance may not necessarily lead to development of superior hybrids. The presence of both additive and non-additive gene action indicates the need to have a harmonized breeding strategy that takes advantage of both gene actions (Cach et al., 2006; Calle et al., 2005).

Farmers' evaluation of the clonal trial was conducted on-station at Alupe research station which is within the vicinity of the target farmers/districts. Farmers evaluated the clones based on their ITK for preferred traits. The varieties were selected using a selection index derived from farmers' selection criteria from each district. The clonal trial was also evaluated by the breeder by measuring agronomic traits using conventional methods. The breeder selected clones using negative selection followed by a selection index as proposed by Ceballos et al. (2004), with a few modifications to meet the breeder's objectives. There was a 14% overlap between the top 100 varieties selected by farmers from all districts and those selected by the breeder. The 14 common varieties have traits preferred by the farmers from all the districts and the breeder which implies that they are stable in terms of preference (Tan and Mak, 1995).

Varieties that stand a high chance of adoption and contribute towards increasing cassava productivity are those with both the farmers' and the breeder's preferred traits. Such varieties can be selected by using farmers' and breeders selection criteria for preferred traits. To achieve this, a combined selection criteria used by farmers from each niche and the breeder was developed. Under these new criteria, the breeder's selection index (BSI) was combined with farmers' selection index from each district (FSI) to come-up with a participatory selection index (PSI). Using PSI, 49 varieties were commonly selected among the top 100 varieties selected by the farmers and the breeder.

Conclusions and the way forward

Based on the results of this study, the following participatory breeding model for cassava is recommended:

1. **Situation analysis:** before initiation of a cassava breeding programme, the breeder should undertake a situation analysis study to assess the needs of the target farmers and the conditions under which cassava is grown. The breeder should stratify the target area as much as possible to capture all the diversity present. In this study, the targeted cassava producing

area was stratified according to ethnicity and agro-ecological zones. Differences between strata were observed in cassava utilization, traits preferences and production constraints depicting ethnic and agro-ecological differences.

2. **Setting of breeding objectives:** setting of breeding objectives influences the success of breeding programmes (Sleper and Poehlman, 2006). Correctly set objectives take in to account the needs of the target farmers (Ceccarelli et al., 2003) and require a participatory approach. In this study, three traits; high storage roots yield, resistance to pests and diseases and low cyanide content which were preferred by farmers from all the three districts were also among the breeder's objectives. However, a number of farmers' preferred traits such as plant height, branching, internode length, taste of raw and boiled storage roots among others were not included in the breeder's objectives. On the farmers' list of preferred traits, high dry matter content was missing which was on the breeder's objectives. It is therefore essential to harmonize the breeding objectives to meet the breeder's and farmers' preferences.

3. **Engagement of farmers:** after the identification of various strata in the target area, farmers should be engaged in the breeding process. They should practice on-farm some of the key activities they are expected to conduct such as identification of preferred traits and evaluation of varieties for these traits. The results from this study indicate that experience increased the efficiency and rate of evaluation. The rate of farmers' evaluation increased with time as they practiced and gained experience. Involving farmers in the important activities of cassava breeding early on increases the efficiency and effectiveness at the participatory variety selection stage, one of the most important stages of breeding.

4. **Selection of parents:** good choice of parents increases breeding efficiency by increasing the chances of developing superior genetic combinations with preferred traits (Witcombe and Virk, 2009) and reducing wastage of resources. It is recommend at least one of the two parents should be selected by farmers (have farmer preferred traits) and adapted to the target environment. Farmers' select parental varieties based on *per se* performance. The outcomes of breeding programmes, where parents are selected on *per se* performance, are poor unless the trait is under additive gene action with high heritability (Falconer and Mackay, 1996). This study revealed that the preferred traits were under both additive and non-additive gene action with varying preponderance of one over the other for each trait. It is therefore recommend that farmers should be involved in the selection of parents within the farmers' production environment. A combining ability study should then be conducted at the selected

parents to identify superior parents on a statistical basis. Any superior progeny with good specific combining ability effects identified during combining ability studies should be advanced and vegetatively propagated.

5. **Development of segregating population:** cassava flowering is sensitive to environmental condition (El-Sharkawy, 2004). The floral biology makes it hard to make specific crosses by hand (Irikura et al., 1979). Due to the specific timing of the reproductive process and sensitivity to environmental conditions, farmers cannot conduct manual pollination. Cassava seed express dormancy and therefore have poor germination (Kawano, 2003). It is economically not feasible for farmers to grow seedlings on their farms because the yields are poor at this stage (Ceballos et al., 2004). Crossing should be carried out by technically trained personnel and seedlings should be raised on-station.

6. **Evaluation of clones:** farmers should be involved in variety evaluation right from the early stages of breeding when variability is still high (Gibson et al., 2008). Ideally, the process of variety evaluation should be conducted in the target environments where the varieties will be grown (Banziger and Cooper, 2001). However, due to the poor multiplication rate of cassava (Ceballos et al., 2004), this is not feasible. In such a situation, it is prudent to establish the clonal evaluation trial in an environment similar and near the farmers (Odendo et al., 2002).

7. **Variety selection:** farmers select varieties instinctively based on many traits using ITK (De Groote et al., 2004). Breeders on the other hand use contemporary scientific techniques to evaluate varieties. They can also inter-relate different fields of science to predict or determine preferred traits and varieties which farmers may not be able to do. Some traits can be more effectively evaluated by the farmers using ITK than the breeder using scientific approaches while the reverse is true for other traits. Varieties selected for preferred traits using the most appropriate approach stand a high chance of adoption. A good variety should have traits considered important by both the breeders and the farmers. In this study, the correlations between breeder's and farmers' evaluation for the traits considered was very low indicating disagreement in variety selection. To overcome this, a new selection index which takes in account farmers' and breeder's evaluation and preferences was employed and is recommended for other PPB programmes.

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