DEVELOPING SUPERIOR CASSAVA [*MANIHOT ESCULENTA* (CRANTZ)] VARIETIES USING PARTIAL INBREDS

By

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THIS THESIS/ DISSERTATION IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY PLANT BREEDING DEGREE

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DECLARATION

I hereby declare that except for references to works of other researchers which have been duly cited, this work is my original research and that neither part nor whole has been presented elsewhere for the award of a degree.

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ABSTRACT

The research was conducted to develop cassava hybrids with superior traits. Two sets of elite S_2 lines collected from the National Root Crop Research Institute (NRCRI) Umudike and the International Institute of tropical Agriculture (IITA) were used for the the research. The experiments were conducted at (IITA). The field experiment was conducted in an alpha lattice design. A component of the research involved a Participatory Rural Appraisal which was conducted to identify farmers' preferences for cassava varieties were carried out in the three senatorial zones of Edo State. The Participatory Rural Appraisal was conducted through focus group discussion and semi-structured questionnaire administration. The survey revealed that farmers in Edo State desire varieties with high yield, high dry matter, and starch content. It also revealed that the farmers prefer their local varieties to improved varieties. Two sets of crosses were made between the S_2 lines. The first involved random matings and was done at off season in November, 2012. The other was a 6x6 diallel mating design done in September, 2013 to determine combining ability, degree of heterosis and gene action influencing the yield and yield component traits. Much of the genetic variation identified among the S_2 lines was non-additive in nature. High heritability in some of the traits indicated high breeding value in the S_2 lines. Sufficient useful genetic variation was present in the lines that could be exploited for high fresh root yield and dry matter. There was significant heterosis for yield and dry matter content. For the first group of crosses, the highest mid-parent and better parent heterosis for root number was recorded in the hybrids TMS14-001-03 with 147% increase and TMS14-091-08 with 122 % increase. For fresh root yield, the highest positive mid-parent and better parent heterosis were recorded for the same hybrid TMS14-001-07 with 350.08% for MPH and

with 276% for BPH. The best MPH for dry matter content was recorded for the hybrid TMS14-035-5 with 18.3% and the same hybrid for BPH with 13.24%. For harvest index, the best hybrids for MPH was TMS14 091-04, with 39.2% and TMS14-035-06 with 33.9% increase respectively. Eight hybrids recorded superior dry matter content and two hybrids recorded superior fresh root yield compared to the parents and checks. For the second group, ten hybrids had high fresh root yield, three hybrids had high dry matter, and seven hybrids had high total carotene content making a total of 20 superior hybrids. Significant heterosis was observed. The highest MP and BP heterosis for fresh root yield was seen in the cross IBA102888 X NRIS2109-10. The highest for BP heterosis for DM was seen in the cross IBA102923 X NRIS2109-14. MP heterosis was as high as 204.68%, 63.98% and 89.77%, and BP heterosis was as high as 176.50%, 51.31% and 75.32% for the three traits, respectively. Five hybrids had high levels of heterosis and specific combining ability better than the best parent and the best check (farmers' variety) used in the study.

DEDICATION

To my husband – Ifesinachi

To my children – Somtoochukwu and Ifesinachi

To the blessed memories of our late mothers – Mrs Anne Udu and Mrs Ucha Okoro

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LIST OF ABBREVIATIONS

ACMV	African Cassava Mosaic Virus
AFLP	Amplified Fragment Length Polymorphism
ANOVA	Analysis of Variance
BPH	Better-Parent Heterosis
CBB	Cassava Bacterial Blight
CBSD	Cassava Brown Streak Disease
CBSV	Cassava Brown Steak Virus
CIAT	International Centre for Tropical Agriculture
CMD	Cassava Mosaic Disease
CMGs	Cassava Mosaic Geminiviruses
DM	Dry Matter
DNA	Deoxyribonucleic Acid
EACMCV	East Africa Cassava Mosaic Cameroon Virus
EACMMV	East Africa Cassava Mosaic Malawi Virus
EACMV	East Africa Cassava Mosaic Virus
EACMV-Ug	East Africa Cassava Mosaic Virus-Ugandan Variant
EACMZV	East Africa Cassava Mosaic Zanzibar Virus
ESADP	Edo State Agricultural Development Programme
ESTs	Expressed Sequence Tags
FAO	Food and Agriculture Organization
GCA	General Combining Ability
GEI	Genotype and Environment Interaction
H^2	Broad Sense Heritability
h^2	Narrow Sense Heritability
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
MPH	Mid-Parent Heterosis
NGOs	Non-Governmental Organizations
NRCRI	National Root Crop Research Institute
PCA	Principal Component Analysis
PRA	Participatory Rural Appraisal
RAPD	Random Amplified Polymorphic DNA
RFLP	Restriction Fragment Length Polymorphism
SACMV	South Africa Cassava Mosaic Virus
SAS	Statistical Analysis System
SCA	Specific Combining Ability
SCARs	Sequence Characterized Amplified regions
SGD	Specific Gravity Determination
SSR	Simple Sequence Repeats

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Manihot Mill. is a genus of the spurge family *Euphorbiaceae,* sub family Crotonoidae and the tribe *Manihotae*. *Euphorbiaceae* is a dicotyledonous family with 334 genera and 8,900 species of which cassava and castor plants belong. The roots of *Manihot* cultigens are tuberous and rich in carbohydrate while the roots of the wild species are fibrous and slender. All *Manihot species* are native to the tropical regions of the America with centers of diversity in Brazil and Mexico (Nassar, 2004; Ospina and Ceballos, 2012). Of all the 98 species, *Manihot esculenta* Crantz (cassava) is the most important being the only commercially cultivated species in the tropics and subtropics.

Cassava is the fourth most important food after rice, wheat and maize and is a fundamental component in the diet of millions of people (FAO/IFAD, 2000). Cassava is one of the most accepted root crops grown in Africa, especially Nigeria (Ajani and Onwubuya, 2013) It is a starchy root crop that feeds about 800 million people in the developing countries (FAO, 2002) and it is estimated that 250 million people in Sub Saharan Africa derive half of their daily calories from cassava (FAO, 2006). Scott *et al.*, (2000) estimated that for the year 1993, annual production of cassava was about 172.4 million tons with a value of $US9.31billion.

Nigeria is currently the world's largest producer of cassava, with an estimated 45 million tons per year (IITA, 2007; FAOSTAT, 2012). Since 1980, the expansion of cassava production in Nigeria has been relatively steady, gaining momentum during the period 1988-1992 following the release of improved IITA varieties that boosted farm production (IITA, 2007). Brazil is the second largest producer (Nassar *et al.*, 2002; FAO, 2005). Africa

alone accountes for 51% of production (FAOSTAT, 2008). Approximately 57% of cassava production is used for human consumption, 32% for animal feed and industrial purposes. (Bellotti *et al.,* 1999).

One of the best methods to increase cassava production to serve as a main staple, food security and a cash crop in Nigeria is by developing of superior varieties that have fixed agronomic traits and are resistant to diseases, pest and drought (Ugorji, 1998). Like most crop breeding activities, cassava genetic improvement begins with the assembling and evaluating a broad *germplasm* base, followed by production of new recombinant genotypes derived from selected elite clones.

Genetic diversity study is a tool geared towards harnessing the genetic variability that exists in available germplasm. (Hurtado *et al*., 2008). The success of a breeding programme depends greatly on the knowledge of genetic diversity that exists in available germplasm (Meredith and Bridge, 1984). The knowledge of genetic distances of gene pools in a breeding programme is useful; it creates a better understanding of germplasm organization and efficient parental selection. Genetic diversity can be assessed by a number of methods including morphological data and DNA-based data (Mohammadi and Prasanna, 2003). DNA based molecular markers reveal polymorphisms and is extensively used in various fields of plant breeding and germplasm management. These markers can identify many genetic loci simultaneously with excellent coverage of the entire genome. They are phenotypically neutral and can be applied at any developmental stage (Jones *et al.*, 1997). Crop production effort is geared towards optimum yield. Optimizing yield can be achieved through agronomic practices and/or through breeding. To get maximum yield with best quality combinations are the aims of breeding programmes. The use of heterosis for getting

high yield with improved quality has been largely employed in cross-pollinated crops, mainly cereals. The economic importance of heterosis has been proven over the years for large increases in hybrid production for crops like maize, rice, onions, cotton, alfalfa, tobacco and Ethiopian mustard (Suwarno *et al*., 2014; Bagheri and Jelodar 2010; Pavlović *et al*., 2011; Muhammad *et al*., 2014; Tucak *et al*., 2012; Gixhari and Sulovari, 2010; Teklewold and Becker 2006) and can be gainfully explored in cassava breeding scheme.

The studies on the inheritance of quantitative and qualitative traits of cassava have been reported (Easwari *et al*., 1995; Easwari and Sheela 1998; Pérez *et al*., 2005; Chavez *et al*., 2005). Unikrishnan *et al*., (2004) assessed hybrid vigour for root yield over better-parent values and root yield performance was associated with heterosis for yield components. In chilli pepper Khadi (1983) observed high heterosis for vitamin C content and found additive gene effect was more predominant than non-additive gene effect, also Nair *et al*., (1986) reported increased heterosis for ascorbic acid content in the hybrids. Similarly, Mtunda (2009) found that 23 out of top 30 best performing cassava progenies were obtained from a cross between a local Tanzanian and exotic variety cassava *germplasm*. In addition, Friedrichs (2009) found heterosis in yield, seed size and height for *Glycine max.* Tuhina-Khatun *et al*., (2010) also reported on superior relative heterosis and heterobeltiosis in wheat.

In order to develop cassava varieties that will meet farmers' diverse preferences and fit into the different cropping systems, it is important to adopt a participatory rural approach where farmers will be involved at all stages of variety development. Morris and Bellon (2004), inferred that farmers in Participatory approach evaluate varieties developed by plant

breeders in their fields using their own management practices, provide germplasm, identify agronomic traits to be improved, suggest the selection criteria and help to set the breeding objectives, for instance, participatory rural appraisal has been used in eastern Ethiopia to identify selection criteria for beans varieties, which was based on yield and yield components (Assefa *et al*., 2005). Muhinyuza *et al*., (2012) reported about the identification of preferred traits and potato production constraint in Rwanda using PRA. Similarly, Tumuhimbise *et al*., (2012) indentified a selection criteria and farmers' perception on early bulking storage in cassava in East and Central Uganda. Kamble (2014) identified PRA as an efficient tool for participatory policymaking, planning and development process for local farmers. Manu-Aduening *et al*., (2007) used PRA to describe the characteristics needed for cassava varieties in Ghana and reported that farmers preferred cassava varieties that had early growth and vigour to suppress weeds, early maturity, high yield, good cooking quality for making fufu are suitable for intercropping. This would ensure that improved varieties meet farmers' needs and fit into their cropping systems and environments, improving prospects for adoption.

Food security is a challenging task globally and more so in the developing countries in the face of increasing population, climate change and limited resources. Conventionally this is met by more inputs from pesticides, herbicides, fertilizers, and irrigation to increase yield. Farmers who cannot afford these farm inputs always resort to acquiring more land to meet the increasing demand for food.

Cassava has limited genetic diversity and is a vegetatively propagated perennial shrub, so improving it requires innovative genetic enhancement methods. Also many cultivars do

not flower readily as a result cassava is almost exclusively cultivated clonally by stem cuttings.

The genetic improvement of cassava could benefit from introducing inbred lines to exploit heterosis, enhance back-cross scheme for fundamental trait introgression, maintained and improved successful allele combination (Ceballos *et al*., 2012).

Each time pollination is made in cassava it makes the hybrids highly heterozygous therefore, sending the breeders back to starting point. Identification of the true value of each family and progenitor is difficult in cassava breeding unlike the cereals where within family variation is absent in the first generation of crosses. (Ceballos *et al*., 2015)

The development of inbred lines in an out crossing crop like cassava with long period of maturity requires between 9-10 generations of selfing to attain the expected level of homozygosity and many cassava varieties show severe inbreeding depression upon long selfing Kawuki *et al*., (2009). Developing a hybrid that allows frequency of desirable allele, better understanding of the inheritance of key traits especially fresh root yield in cassava needs different approach in cassava breeding programme.

However, literature on exploiting heterosis in cassava with inbred lines or partial inbred is scarce. In a heterozygous clonal plant like cassava, to produce improved crop varieties that are resistant to major pests and diseases, high yielding, and can meet sufficient nutritional requirements, a more practical option is the use of available genetic diversity, through a hybrid breeding strategy that maximizes heterosis. The vegetative propagation of cassava is an advantage to exploit heterosis because once a trait or few traits are fixed it will be perpetuated clonally by small holder farmers.

Despite the advances made in cassava breeding for traits such as tolerance/resistance to major diseases, the crop's yield has remained the same in the major producing areas of the tropics (Kawano, 2003). The obvious reason is the geographical limitation of germplasm diversity. Kawano (2003) stated that 0.5% of 5263 accessions held in CIAT gene bank are from Africa. Similarly, less than 1% of Latin American materials are found in IITA breeding program.

The primary goal of this research was to determine farmers' perception of different cassava varieties and preferred characteristics for cassava varieties, and develop inbred lines which will allow for specific hybrid combinations to be identified in cassava and to determine the performance of hybrids.

Specific Objectives:

- ✓ Objective 1: To determine farmers' perception of the available cassava varieties and their preffered characteristics for cassava varieties.
- ✓ Objective 2: To evaluate the performance of some S_2 parents and their derived F_1 progenies.
- ✓ Objective 3: To determine combining ability and heterosis in the hybrids of the (S_2) lines using half diallel mating design

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin, History and Botany of Cassava

The *Manihot* genus contains 98 species among which the production of latex and cyanogenic glucosides is common (Rogers and Fleming, 1973; Bailey, 1976). These species are classified into 19 taxonomic sections (Rogers and Appan, 1973) varying from trees in the section Glazioviannae to nearly acaulascent subshrubs in the section Stipularis. Other sections such as Tripatitae and Gracilis are perennial subshrubs with large woody roots whose stems frequently die back to the root crown in response to dry periods or fires (Nassar, 1980).

2.1.1 Origin and evolution of cassava

All 98 species of the Manihot genus are native to the Neotropics from where cassava was introduced to other regions of the world (Rogers and Appan, 1973). The origin of cultivated cassava is still unclear. Allem (2002) propounded that cultivated cassava originated in South America (Olsen and Schaal, 2001; Allem, 2002).

2.1.2 Taxonomy

Cassava belongs to the *Euphorbiaceae* family, which is made up of about 7200 species, characterized for their notable development of lactiferous vessels, themselves made up of secretory cells called lacticifers. These produce the milky secretion, or "latex", that characterizes the plants of this family. Plant architecture varies enormously within this family, ranging from arboreal types such as rubber (*Hevea brasiliensis*) to shrubs, also of economic importance, such as the castor-oil plant (*Ricinus communis*). Also representing

this family are numerous weeds, ornamental plants, and medicinal plants. A highly significant genus of this family is Manihot to which cassava belongs. Although all species of the genus can cross with each other, evidence suggests that, in nature, they are reproductively isolated. About 98 species have been described in this genus, of which only cassava (*Manihot esculenta* Crantz) has economic importance and is cultivated. Perhaps more than 100 common names now exist for this species, owing to its spread throughout the tropical world by early traders. In Latin America, it is usually known either as yuca (Spanish) or as mandioca (Portuguese). In Brazil, sweet cassava (*aipim*) is distinguished from bitter cassava (mandioca). Other names in different languages include manioc, manioca, tapioca, and mhogo (Cock, *et al.,* 1979).

2.1.3 Genetics and cytology of cassava

Very little is known of either cassava genetics or cassava cytogenetics. The basic chromosome number in the *Euphorbiaceae* family is usually 8, although this may vary between 6 and 11. About 50% of Euphorbia species are polyploid (Léon, 1976). Although cassava is frequently considered as a polyploid species, analyses conducted during diakinesis and metaphase I indicate the presence of 18 small and similar bivalents in cassava (Hahn *et al*., 1979). Univalents, trivalents, and late bivalent pairings have also been observed in cassava. The plant is therefore a functional diploid, that is, 2n = 2x = 36 (De Carvahlo and Guerra 2002; Nassar *et al*., 2008). Magoon *et al.,* (1969) have suggested that certain portions of the genome may be duplicated and, therefore, cassava may in fact be a segmental allotetraploid.

Cassava is a perennial shrub. It is monoecious, that is, a single plant may carry both male and female flowers, but these are separated from each other. Cassava plant has sympodial

branching and variable plant height, ranging between 1 and 5 m, although maximum height usually does not exceed 3 m.

2.1.4 The stem

Stems are particularly important in cassava, as they are the means by which the species is propagated vegetatively or asexually. Lignified parts of the stem, commonly called stakes or cangres (cuttings), serve as "seed" for the crop's commercial production. The mature stem is cylindrical, with a diameter that varies from 2 to 6 cm and coloring that may be silvery gray, purple, or yellow. Both stem diameter and color vary significantly with plant age and, obviously, with variety. Stems are formed by the alternation of nodes and internodes. The oldest parts may show protuberances, which mark, within the nodes, the position that leaves had initially occupied. The node is that place where a leaf joins the stem. Inserted into the node are the leaf petiole, an axillary bud protected by a scale, and two lateral stipules. The length of internodes in the principal stem is highly variable and depends, not only on the variety, but also on other factors such as plant age, drought, thrips attacks, and available soil fertility. The stem provides a lasting record of the history of the plant's development, enabling one to deduce the conditions and events that had influenced it.

2.1.5 The leaf

Leaves are the organs in which photosynthesis mostly occurs, transforming radiant energy into chemical energy. Leaves are caducous, that is, with age they senesce, and fall from the plant as it develops. The total number of leaves produced by the plant, their longevity, and

photosynthetic capacity are varietal characteristics, which are profoundly influenced by environmental conditions.

Leaves are simple, consisting of the leaf blade and petiole. The blade is palmate with variable number of lobes, usually, odd, ranging between 3 and 9. Lobes measure between 4 and 20 cm long and between 1 and 6 cm wide. The central lobes are larger than the lateral ones. Lobe shape can be classified in different ways, with variable number of categories. A simple classification distinguishes three types of lobes: linear or straight, obovate, and pandurate. Intermediate types also exist, encouraging the development of other classification systems to qualify such characteristics. Leaf size is a typical characteristic of each cultivar, although it varies with environmental conditions. Leaves produced in the first 3 to 4 months of the plant's life are larger than those produced after the fourth month. For example, in variety M Col 72, the average leaf area at 4 months old is about 250 cm^2 ; at 7 months, it is 130 cm^2 ; and at 10 months (harvest), only about 90 cm^2.

2.1.6 The inflorescence

Not all cassava varieties flower under the same environmental conditions. The environment greatly influences the induction of flowering. Cassava undergoes cross pollination, which makes it a highly heterozygous plant, with each individual being a hybrid. Pollination is typically carried out by insects. Self-pollination is prevented by the female flowers of a raceme opening first before the male flowers of that same raceme. This phenomenon is known as protogyny. However, occasionally, the male and female flowers of different racemes on a single plant may open simultaneously. When this happens, self-pollination may naturally occur. Cassava "flowers" are produced in inflorescences. The basic arrangement of flowers is the raceme where the female flowers occupy basal positions and

the male the distal ones. The latter are smaller and usually more numerous than the female ones. Frequently, panicles are also produced, that is, from the botanical viewpoint, a raceme of racemes develops. In such cases, a principal raceme exists, which is composed of secondary racemes.

2.1.7 The fruit

Once the female flower has been pollinated, fruit begins to form from the ovary. Fruit maturation requires about 3 months to complete. The fruit is a dehiscent capsule that is trilocular, and ovoid to globate, with a diameter of 1.0 to 1.5 cm and six longitudinal, narrow, and prominent ridges. Cross-sections of the developing fruit show a series of clearly discernible tissues: epicarp, mesocarp, and endocarp. As the seed matures, the epicarp and mesocarp dry up. The endocarp, which is ligneous, opens abruptly when the fruit is mature and dried, releasing and dispersing seeds to a certain distance. During dehiscence tissues separate both, throughout the mid-vein of each fruit loculus and between the separations themselves.

2.1.8 The seed

While cassava seed is not important in reproduction and commercial multiplication, it has immeasurable value for plant breeding, as only through sexual reproduction can new, genetically superior, cultivars be developed. The seed is ovoid-ellipsoid in form and measures about 1 cm long, 6 mm wide, and 4 mm thick. The seed coat is smooth, coffee-colored, and mottled gray. In the upper part, especially of new seed, the caruncle is found. This structure is lost once the seed falls to the ground. At the other end of the seed, opposite the caruncle, a small cavity is found. A slender suture leaves from the caruncle and finishes

in this basal cavity. The seed coat is the outermost part of the seed. Immediately inside the seed coat is the endosperm, which is formed of polyhedral parenchymatous cells that protect and nourish the embryo, itself located in the central area of the seed. Within the endosperm are found the cotyledons and embryonic axis that gives rise to the new plant after germination. The embryo is made up of the two cotyledonous leaves, plumule, hypocotyl, and radicle. The cotyledonous leaves and endosperm occupy almost the entire interior of the seed; they are white, elliptical, and carnose.

2.1.9 Storage roots, tuberous roots, thickening and bulking

The principal characteristic of cassava roots is their capacity for starch storage, which is the reason why, so far, it is the plant organ that has the greatest economic value. However, not all roots produced ultimately become storage organs. When the plant grows from sexual seed, a primary root develops and then, several secondary ones. Apparently the primary root always evolves into a tuberous root, and is the first to do so. If the plant grows from a stake, the roots are adventitious, forming at the lower end of the stake, which produces a callus, and form buds in that part of the stake that is buried in the soil. The roots initially form a fibrous system but, later, some begin thickening and become tuberous roots. The number of tuberous roots is determined, in most cases, by the plant's early growth. Although root density is low, penetration into the soil is deep. This is a highly relevant characteristic, as it contributes to the plant having the capacity to endure prolonged droughts. Fibrous cassava roots can reach depths of up to 2.5 m. The plant absorbs water and nutrients through the fibrous roots, a capacity that is lost when they become tuberous. Morphologically and anatomically no differences are found among fibrous and tuberous roots. Starch accumulation begins, the direction of root growth changes from longitudinal

to radial. As mentioned above, tuberous roots come from secondary enlargement of fibrous roots. This means that the root system first penetrates the soil while they are thin and only begin thickening after penetration.

2.2 Importance of cassava

Cassava (*Manihot esculenta* Crantz) is a tropical root crop in the tropics consumed by over 600 million people in Africa, Asia and Latin America. It is the third most important source of calories in the tropics after rice and maize (Fauquet and Tohme, 2008). The crop is crucial for both food security and income generation. In Asia and Latin America, cassava serves as livestock feed, an industrial raw material, and a source of food (Ceballos *et al*., 2012). Fauquet and Tohme (2008) described it as the second most important source of calories, an inexpensive food, and emerging cash crop. Cassava is known to have the highest carbohydrates contents among the staple crops (Coursey, 1973). In sub-Saharan Africa, cassava is mainly a subsistence crop grown by small-scale farmers and it feeds over 200 million people daily (Madeley, 1993).

World production of cassava root was estimated to be 184 million in 2002, rising to 230 million tonnes in 2008. (FAOSTAT, 2011) The majority of production in 2002 was in Africa, where 99.1 million tonnes were grown; 51.5 million tonnes in Asia; and 33.2 million tonnes in Latin America and the Caribbean. Nigeria is the world's largest producer of cassava. However, based on the statistics from the FAO of the United Nations, Thailand is the largest exporting country of dried cassava, with a total of 77% of world export in 2005 followed by Vietnam, with 13.6%, Indonesia (5.8%) and Costa Rica (2.1%). Worldwide cassava production increased by 12.5% between 1988 and 1990, in 2010, the average yield of cassava crops worldwide was 12.5 tonnes per hectare. The most productive

cassava farms in the world were in India with a nationwide average yield of 34.8 tonnes per hectare in 2010 (Adams *et al*., 2009). The cassava plant gives the highest yield of carbohydrate per cultivated area among crop plants, except for sugarcane and sugar beets (FAOSTAT, 2011) Cassava plays a particularly important role in agriculture in developing countries, especially in sub-Saharan Africa, because it does well on poor soils and with low rainfall, and because it is a perennial that can be harvested as required. Its wide harvesting window allows it to act as a famine reserve and is invaluable in managing labor schedules. It offers flexibility to resource-poor farmers because it serves as either subsistence or a cash crop. (FAOSTAT, 2011: Adjebeng-Danquah *et al.*, 2012).

Nweke *et al.,* (2002) stipulated that the bulk of cassava production is consumed as food. Cassava is described as a 'classic food security crop' (DeVries and Toenniessen, 2001), cassava offers several advantages: it provides a decent harvest under erratic rainfall conditions and degraded soils, it grows well under marginal conditions where few other crops could survive, and allows farmers to keep the roots stored in the ground until when needed (El-Sharkawy, 1993) It provides a flexible harvesting date or extended harvesting period.

2.2.1 Cassava production in Nigeria

Nigeria grows more cassava than any other country in the world. The production of cassava is in the hands of numerous smallholder farmers located primarily in the south and central regions of Nigeria. A significant population of cassava growers in Nigeria has made the transition from traditional production systems to the use of high-yielding varieties and mechanization of processing activities (Nweke *et al*, 2002). According to Berry (1993), Nigeria and Zaire possess both large and small scale farms on which cassava is grown by full-time and part time farmers. In these farming areas, an average of about 45 percent of cassava field were cultivated for commercial purposes, but this varied from 0 to 100 percent (Nweke, 1989).

Table 2.1: Levels of cassava production from 1990-2003 (tons)

Year	Nigeria	Cameroon	Togo
1990	19,043,008	1,587,872	592,867
1991	26,004,000	1,622,000	510,528
1992	29,184,000	1,636,000	452,093
1993	30,128,000	1,648,000	389,448
1994	31,005,000	1,715,000	531,526
1995	31,404,000	1,780,000	607,222
1996	32,050,000	1,848,000	548,316
1997	32,695,000	1,918,000	595,792
1998	32,698,000	1,965,950	579,381
1999	32,070,000	1,889,191	693,998
2000	32,810,000	191,830	7,000,699
2001	32,586,000	1,947,266	651,530
2002	34,476,000	2,200,000	729,708
2003	33,379,000	2,619,142	724,000

Source: FAO (2004)

FAO (2004) provided statistics of cassava production of three countries, Nigeria, Cameroun and Togo, for the period 1990 to 2003 (Table 2.1). The data shows that there was increased cassava production in the three countries with Nigeria leading levels.

2.2.2 Utilization of Cassava Products in Nigeria

Cassava contains about 92.2 percent carbohydrates and 3.2 percent protein in its dry matter, and is said to have high energy content. It has a capacity of substituting up to 44 percent maize in pig feed without any reduction in the performance of pigs. Okeke (1998) also reported that in compounding feed for pigs, broilers, pullets and layers, cassava meal plays a significant role. Eagleston *et al*., (1992) provided evidence as contained in table 2 that the whole cassava plant, boiled root, cassava root meal, chips and pellets could be used in compounding livestock feed (Table 2.2). The roots could be dried, ground and fed to ruminants and it could be used as substitutes for maize in poultry feed.

Table 2.2: Animal Feed Rations using Cassava Meal

Types of feed	**Percentage cassava meal**	
	Cautius	**Maximum**
Broiler starter	5	10
Broiler finisher (4 wks)	10	20
Chick starter	5	10
Pullet starter	10	25
Layer	25	40
Piglets	5	10
Pigs (8-18 wks)	10	25

Source: Eagleston et al (1992)

Furthermore, cassava starch, cassava flour, cassava juice and fermented cassava are now used in industries (Terry *et al*., 1983; Ene, 1992; Olomu, 1995). For instance, cassava starch is used in making products such as biscuits, bread and derivatives such as sagos and sauce. Cassava starch has also been industrially modified to provide products with physical and chemical properties for specific applications, including the preparation of jelly, thickening agents, gravies, custard powders, baby food, glucose and confectioneries (Ene, 1992). Apart from being used in a variety of paste products such as spaghetti and macaroni, cassava flour has been identified to be useful in the manufacture of cassava beer in the brewery industry (Olomu, 1995). In addition, Terry *et al*., (1983) noted that since the rapid escalation of energy cost, especially liquid fuel prices, considerable attention has been given to cassava as a source of ethanol with particular example in Brazil, where enormous effort had been put into production of alcohol using sugarcane and cassava as biological resources.

2.2.3 Cassava producing states in Nigeria

Expansion of cassava production has been relatively steady since 1980 with an additional push between the years 1988 to 1992 owing to the release of improved IITA varieties The North Central zone produces over 7 million tonnes of cassava a year (1999 and 2002). South South produces over 6 million tonnes a year while the South West and South East produce less than 6 million tonnes a year. Production from the North West and North East is 2 and 0.14 million tonnes respectively (Table 2.3).

Table 2.3: Cassava Production by Region in Nigeria from 2000-2002 (tonnes)

Region	2000	2001	2002
South West	4993380	5663614	5883805
South South	6268114	6533944	6321674
South East	5384130	5542412	5846310
North West	2435211	2395543	2340000
North Central	7116920	7243970	7405640
North East	165344	414533	140620
Total	26363099	27521016	27938049

Source: (PCU, 2004)

On a per capita basis, North Central is the highest producing state at 0.72 tonnes/per person in 2002, followed by South East (0.56), South South (0.47), South West (0.34), North West (.10) and North East (0.01). National per capita production of cassava is 0.32 tonne/per person. Benue and Kogi states in the North Central Zone are the largest producers of cassava (IITA, 2004; FAOSTAT, 2012)

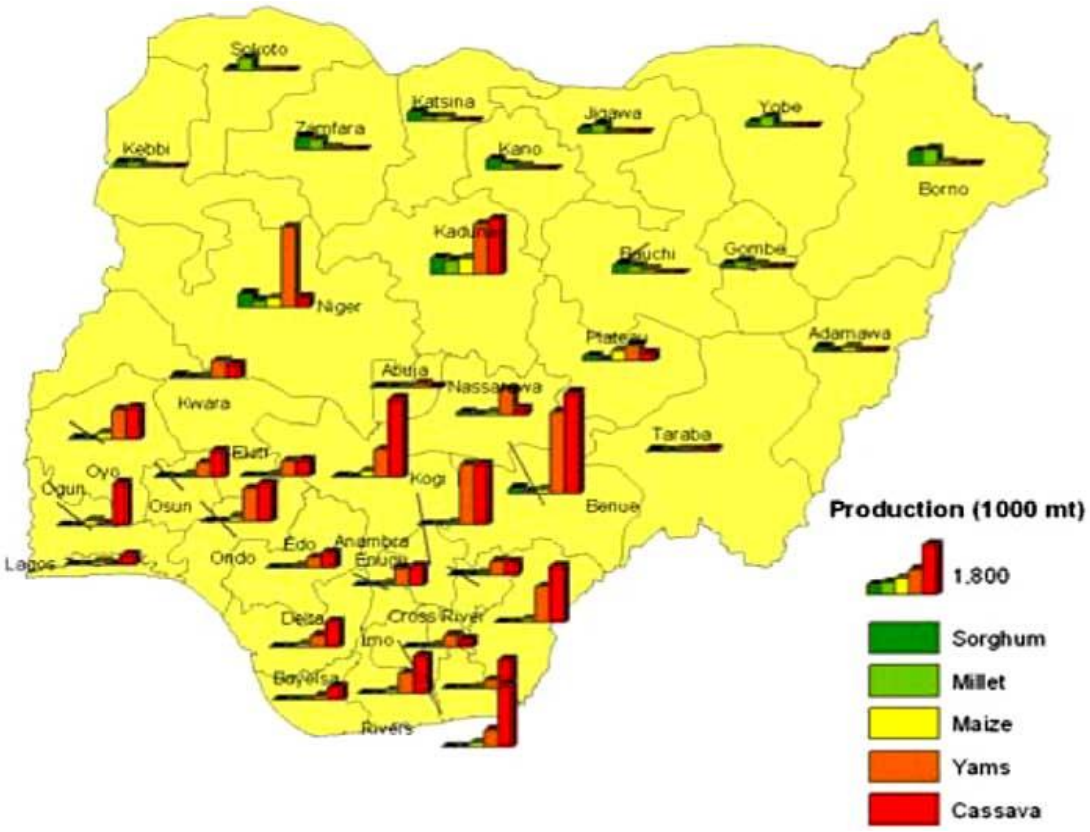

Figure 2. 1: Map of Nigeria showing 23 cassava growing areas (IITA, 2004).

2.2.4 Cassava Varieties:

In the early mid twentieth century when cassava was at the rural food staple stage in Nigeria, farmers relied on farmer- to-farmer transfer of varieties until 1940 in Nigeria. These varieties (cultivars) were originally introduced by The collaborative study on cassava in Africa (COSCA). Cassava varieties planted by the farmers were mostly the sweet type that could be eaten without processing but they gave low yields and were susceptible to pests and diseases. Farmers replaced several of the sweet cassava varieties with the bitter varieties (Nweke, *et al.*, 1994).

2.5 Cropping systems

According to Alves (2002) cassava is intercropped with short or long season staple crops. When grown particularly as a food crop it is produced under a low input and low output system (Leihner, 2002). In the Americas and Africa cassava is intercropped with maize and legumes (Mutsaers *et al*., 1993; Alves, 2002). One third of cassava grown in the world is reported to be intercropped, to minimize the risk of crop failure (Cock, 1985) (Kizito *et al*., 2007). Traditionally farmers practice mixed cropping in Nigeria. Cassava is intercropped with other food crop staples to maximize the use of the land and also to ensure food security (Francis, 1990; Okai, 2001; Dapaah *et al.*, 2003; Manu-Aduening *et al*., 2006; Baafi and Sarfo-Kantanka, 2008). Production and processing are mostly done by women, and they produce it as food and also process it into 'garri' 'tapioca' and other products (Al-Hassan, 1989; Nweke *et al*., 1994).

2.6 Genetic diversity

An understanding and clear knowledge of the distribution of genetic diversity and relationship among individuals, populations and gene pools is important for efficient management of germplasm collections and breeding programmes (Manjarrez-Sandoval *et al.*, 1997; Geleta, 2003; Yang *et al*., 2006) and the potential performance would be useful for all phases of crop improvement. Genetic variability and genetic diversity of a taxon are of great importance to plant geneticists, breeders and taxonomists (Prince *et al.,* 1995). In populations, the genetic composition and genetic diversity are derived from wild parents. This has been influenced by evolutionary processes such as mutation, recombination, genetic drift, migration, natural selection (Hartl and Clark, 1997) and adaptation to a range of environments. An understanding of the genetic diversity is the first step to harness the

genetic variability in the germplasm (Hurtado *et al.*, 2008). The success of a breeding programme depends greatly on the genetic diversity that exists in available germplasm (Meredith and Bridge, 1984). Studies on cassava based on DNA sequence and SSR marker data revealed that genetic variation found in cassava is a sub-set of that found in its putative progenitor (Olsen and Schaal, 2001).

The evaluation of genetic diversity among adapted or elite germplasm provided estimates of genetic variation among segregating progenies during pure line development (Manjarrez-Sandoval *et al.*, 1997) and also from the degree of heterosis in the progenies of parental combinations (Barbosa-Neto *et al.* 1997; Cox and Murphy 1990; Geleta, 2003). The assessment of genetic diversity within and between populations is routinely performed at the molecular level using various laboratory-based techniques such as allozyme or DNA analysis, which measure levels of variation directly. Genetic diversity may also be assessed using morphological, and biochemical maker and molecular makers.

2.6.1 Genetic diversity of cassava

The genetic distances within a population afford a better comprehension of germplasm organization and efficient parental selection during genotype sampling (Meredith and Bridge, 1984). It also has implications on the choice of parents for crosses and gene introgression from exotic germplasm. The use of DNA-based markers has contributed to cassava breeding and genetics through the understanding of the phylogenetic relationships in the genus (Fregene *et al.*, 1994; Roa *et al.*, 2000; Olsen and Schaal, 2001) and facilitates the assessment of the genetic diversity and origin (Beeching *et al.*, 1993, Second *et al.*, 1997; Okai, 2001; Elias *et al*., 2001; Mkumbira *et al.*, 2003; Kizito *et* al., 2007). It has also helped with the development of genetic maps and identification of quantitative trait loci

for traits of importance (Fregene *et a*l., 1997; Jorge *et al.*, 2000; 2001; Mba *et al.*, 2001; Okogbenin and Fregene, 2002; 2003; Lokko *et al*., 2005; Ojulong, 2006; Okogbenin *et al*., 2006). Other molecular markers used in cassava breeding include single nucleotide polymorphisms (SNPs) identified from whole genome scans, Deletion Amplified Regions Tags (DArTs) and Expressed Sequence Tags (ESTs) (Hurtado *et al*., 2008; Kawuki *et al.*, 2009). Molecular markers have been successfully used to recommend cultivars for a given region (Vieira *et al.*, 2007). It also helps breeders to concentrate their breeding efforts on the most promising combinations (Ceballos *et al*, 2004; Brennan and Martin, 2007; Betrand *et al.*, 2008). Crop plants are distinguished by classical morphological descriptors which are highly subject to environmental influences.

2.7 Genetic distance

Nei and Li (1979) defined genetic distance as that measure that accounts for the extent of the gene differences between cultivars, as measured by allele frequencies at sample loci while the genetic relationship among individuals and the populations can be measured by similarity of any number of quantitative characters (Souza and Sorrels, 1991). Genetic distance measurements are indicators of relatedness among populations or species and are useful for reconstructing the history and phylogenetic relationships among such groups. There are two basic approaches for measuring genetic distance, these are the cluster analysis and the parsimony analysis and they represent the genetic and phylogenetic relationship, respectively. The data input for this analysis involves numerical or a combination of different variables provided by a range of markers that can be used to measure genetic distance. This includes pedigree data, morphological traits, isozymes and more recently DNA-based markers such as restriction fragment length polymorphism

(RFLP), amplified fragment length polymorphism (AFLP), simple sequence repeats (SSR), random amplified polymorphic DNA (RAPD), sequence characterized amplified regions (SCARs) and several others. The molecular markers are recognized as significant tools to enhance plant resource conservation management. This provides a means to accurately estimate the genetic diversity and structure for species of interest (Hamrick and Godt, 1997).

2.8 Cassava pests and diseases

African farmers recognize pests and diseases as important production constraints (Ndunguru *et al*., 2005). Arthropod pests including the cassava green mite (*Mononychellus tanajoa* Bonder), cassava mealybug (*Phenaccocus manihoti* Matile-Ferrero), and whitefly (*Bemisia tabaci* Gennadius) and (*Bemisia afer* Priesner and Hosny) which pose serious damage to the crop, affect the final yield (IITA, 2000). The cassava green mite mainly causes direct physical damage whilst the whitefly is primarily important as a virus vector. Cassava mealybug and green mite can be controlled by effective classical biological control. Some of the major diseases of economic importance is cassava mosaic disease (CMD) caused by cassava mosaic geminiviruses (CMGs) (Geminiviridae; Begomovirus), cassava bacterial blight (CBB) caused by *Xanthomonas axonopodis* f.sp. *manihoti*) which is the most important non-virus disease (Lozano, 1975) and cassava brown streak disease (CBSD) caused by cassava brown streak virus (CBSV) (*Potyviridae; Ipomovirus*) (Hillocks and Jennings, 2003; Nichols, 1950). Yield losses of susceptible varieties due to CMD have been reported to range from 20 to 95% (Hahn *et al*., 1979). Unlike CMD, symptoms of CBSD may be found on the roots as brown/yellow, corky necrosis in the starch-bearing tissue, making severely affected roots unfit for consumption (Hillocks *et al*., 2001). Cassava brown streak disease can decrease the root weight of susceptible cultivars

by up to 70% (Hillocks *et al*., 2001). Mtunda *et al.* (2003) recorded yield losses due to CBSD of up to 64% in Muheza district, Tanzania. These diseases are the biggest threats to the crop's health and productivity. Recent studies (Ndunguru *et al.,* 2005) have shown the presence of six distinct cassava mosaic geminiviruses (CMG) species found to infect cassava in Africa: African cassava mosaic virus (ACMV), East African cassava mosaic virus (EACMV), East African cassava mosaic Cameroon virus (EACMCV), East African cassava mosaic Malawi virus (EACMMV), East African cassava mosaic Zanzibar virus (EACMZV) and South African cassava mosaic virus (SACMV). The report indicate that much variation exists in the CMGs including the evidence that certain CMGs when present in mixtures, employ pseudo-recombination or re-assortment strategies and recombination at certain hot spots such as the origin of replication resulting in the emergence of new viruses with altered virulence (Ndunguru *et al*., 2005). For instance, the severe CMD designated East African cassava mosaic virus-Ugandan variant (EACMV-Ug) which is currently devastating cassava in east and central Africa is a recombination of ACMV and EACMV. Additionally, small satellite DNA molecules (satDNA II and III), which seem to spread with CGMs and have proved to increase disease severity and break resistance in some of the CMD resistant varieties, have also been discovered (Ndunguru *et al*., 2005).

2.9 Genetic improvement in cassava

Genetic improvement begins in cassava, with the assembly and evaluation of broad based germplasm (Ceballos *et al*., 2004; Poehlman and Sleper, 1995; Hahn *et al*. 1979). The source populations with high frequencies of genes associated with desirable characters are acquired, followed by the production of new recombinant genotypes derived from selected elite clones (Ceballos *et al.*, 2004; Hahn *et al*., 1979). Selected genotypes from the initial germplasm evaluation normally enter the hybridization scheme, followed by selection of superior clones in the segregating population (Kawano, 2003; Poehlman, 1987).

2.10 Hybridization and selection in cassava

The recombination of genes occurs as a result of sexual reproduction (Poehlman, 1987). Since the cassava parent genotypes are highly heterozygous, the selection of suitable parents for hybridization is one of the most important steps in a hybridization programme. Parents are generally selected on the basis of their known performance as varieties and as parents in hybridization programmes. However, selection based on phenotypic performance alone is not a sound procedure (Hallauer and Miranda, 1988), since phenotypically superior lines may yield poor recombinants in the segregating population. Hence, it is necessary that the parents are chosen on the basis of genetic value (Singh, 2003). The performance of a genotype in hybridization programmes depends on its effectiveness in transmitting heredity characteristics to its offspring and it's combining ability (Falconer and Mackay, 1996). If general combing ability (GCA) is more important, a small number of parents with good GCA should be used in hybridization programmes. On the other hand, when specific combining ability (SCA) is important, a large number of parents should be used to produce a large number of the F_1 families (Singh, 2003;

Poehlman, 1987). Knowledge of the clones to be used as parents is very important to enhance effective hybridization. Improvement through hybridization comprises: selection of parents; production of F_1 progeny; and selection of superior clones (Singh, 2003). Crossing in cassava is relatively easy (Kawano, 1980; Kawano *et al*., 1978). Clonally propagated crops are generally improved by crossing two or more desirable clones, followed by selection in the F_1 progeny. Crossing can occur by controlled pollination, carried out manually to produce full-sib families, or in polycross nurseries where open pollination results, in half-sib families (Ceballos *et al*., 2004).

2.11 Breeding

The goal in cassava breeding is to develop varieties which combine high and stable yields with good quality characteristics relevant to the ways in which the crop is utilized in specific regions. The objectives of a cassava breeding program usually include: high yield in terms of dry matter per unit of land area per unit time, resistance to the major diseases prevalent in target areas (for example, ACMV, CBB and CAD) and resistance to the major insect pests in target areas (for example, CM and CGM). Improved quality in terms of local consumption requirements (for example, low cyanide and mealy varieties in areas where the roots are boiled and eaten without further processing). Adaptability to environmental conditions and cropping systems in target areas and improved plant characteristics in terms of canopy and roots are important to farmers.

2.12 Breeding procedures

2.12.1 Germplasm collection and evaluation

The most important tasks in any cassava breeding are the acquisition and selection of superior breeding material. In Africa, there is considerable variability among the local *germplasm* collections. There are two reasons for this. Firstly, some of the materials flower and set seed freely, and new cultivars are established from volunteer seedlings; because cassava is a cross-pollinated crop, continuing recombination and generation of variation occur from outcrosses of genetically heterozygous cultivars. Secondly, spontaneous mutation may give rise to additional genetic variation, although this has not been proven. Many of the local cultivars flower well. However, some flower only to a limited extent ('shy flowering') and others do not flower at all under normal growing conditions; this makes their exploitation in a breeding program rather limited (Ceballos *et al*., 2012).

Both the clones developed by a breeding programme and those from exotic introduction in seed form need to be evaluated in order to identify their potential as breeding materials or as varieties in terms of their agronomic characteristics. The agronomic characteristics include resistance to diseases and pests, characteristic plant architecture, yield, tuber quality, cyanide content, adaptation to agroecological zone and any additional locally important traits. The *germplasm* may be conserved as clones in field plots, as meristem tips *in vitro*, and or as seeds in low temperature and humidity conditions.

2.12.2 Source population

The source population for improvement is made up of genotypes which have genes associated with desirable characteristics. The population may be improved through cyclic recombination and selection procedures while retaining a high degree of genetic variability.

Conventional methods of creating source population can also be used by making crosses between two selected parents.

2.12.3 Seed production

The female flowers are large, and open first; the male flowers are small, and usually open about 1 week after the female flowers. Under normal conditions the stigma remains receptive for up to 24 hours after the opening of the flower and dried pollen remains viable for about 6 days under controlled conditions. Both the stigma and pollen are sticky, and pollination is easily carried out by honey bees. Structurally and functionally, therefore, cassava flower is well adapted to cross-pollination. In the northern hemisphere, cassava usually flowers from July to January, with a peak between September and November. In the southern hemisphere, it usually flowers from January to July, with a peak between March and May. The time of flowering, however, depends to a large extent on rainfall distribution, day-length and temperature. In general, there is a vegetative phase of 1 to 4 months in most cultivars that flower under natural conditions, making it important to plant cassava at least 4 months before the peak flowering period. In order to synchronize the flowering periods of different cultivars or clones, parental genotypes should be planted every 2 to 3 months because flowering of an individual plant usually lasts for more than 2 months.

For pollination by hand, pollen is collected early in the morning before 10:00 hour and pollination made before 13:00 hour. Both male and female flowers that are at the point of opening are used. When the anthers are mature, they change from green to yellow. This change in color is a useful indication of when pollen can be collected. Pollination can be done by hand using the male flower after removing the perianth or, for mass pollination,

by using an applicator. The applicator can be made from a stick with the tip covered with an adhesive piece of velvet-like material to which the pollen will readily adhere. Several flowers can be pollinated without recharging the applicator. If the applicator is to be used for other pollen parents, it should be sterilized; this is done by dipping it into alcohol before using it for new parents. The pollinated flowers are bagged with cloth to protect them against bees or other insects carrying foreign pollen and the bags are removed 5 days later. Seeds mature about 70 to 90 days after pollination. Fruits from pollinated plots are collected in cloth bags hung on cassava plants for each variety or clone and left there until they shatter, releasing hybrid seeds which are ready for germination.

2.12.4 Seed germination and transplanting

Cassava seeds have very short dormancy. Seeds germinate quickly at optimal soil temperatures between 30 to 35^{o}C and moisture regimes. Seeds may be sown in peat pellets, jiffy pots or plastic bags arranged on nursery beds during the dry season. During the first 3 weeks, the nursery beds are irrigated twice daily, in the mornings and afternoons, thereafter, they are irrigated at regular intervals until the transplanting stage. If irrigation is not possible, seeds can be planted soon after the first rain. The seeds germinate from 10 to 30 days after planting and are ready for transplanting when they are from 15 to 20cm high because cassava seedlings are weak and grow slowly, weed control is very important at the early stages of growth to offset competition.

2.12.5 Breeding scheme

Breeding in cassava takes quite a number of years to develop a superior cassava hybrid. However, the International lnstitute of Tropical Agriculture (IITA) has cassava breeding scheme which may be modified to suit local conditions (IITA, 1990).

2.13 Yellow root cassava

Most of the cassava landraces cultivated in Nigeria, have white fleshed roots, with little or no pro-vitamin A. In 2005, National Root Crops Research Institute (NRCRI), Umudike, Nigeria acquired some yellow cassava genotypes with improved agronomic traits from International Institute of Tropical Agriculture (IITA), in Nigeria. These genotypes, especially those of orange fleshed roots, were bred as a tool for the global fight against vitamin A deficiency in areas that lack vitamin A rich foods materials (NRCRI, 2008). The deficiency of vitamin A is a serious public health problem in many parts of the world, as it causes eye damage, which when severe, can result in blindness, especially in children. The consumption of carotene rich foods is the most effective intervention for vitamin A deficiency. Since cassava is a major staple food crop in Nigeria the use of yellow-fleshed cassava varieties will be nutritionally preferable. Yellow pigmented cassava root is known to be cultivated in a limited way in Colombia, Philippines, Jamaica and some African countries. Previous studies have shown that yellow root cassava varieties tend to have low dry matter content (Akinwale *et al*., 2010) which is associated with poor cooking quality (Vimala *et al*., 2008). Although some yellow landraces have been identified in Amazonia in Brazil (Ferreira *et al.*, 2008; Nassar *et al.*, 2009); most breeding populations are white fleshed root. Wide variation exists in root pigmentation within the global yellow root germplasm, with a range from pale yellow through orange to pink (Nassar *et al*., 2007).

This variation in root pigmentation is associated with wide variation in carotenoid contents within the germplasm (Sanchez *et al*., 2006).

The availability of yellow root cassava (Sanchez *et al*., 2006; Nassar, 2007) offers a different perception on nutritional benefits associated with the crop. Enhanced content of β-carotene (provitamin A) in yellow root cassava (Chavez *et al*., 2007; Sanchez *et al*., 2006) provides great opportunity to sustainably address vitamin A malnutrition through deployment of provitamin A cassava varieties where the crop is a major staple (Makokha and Tunze, 2005; Nassar and Ortiz, 2010). However, the global efforts towards breeding cassava for high β-carotene content are only recent with low progress registered towards deployment of carotene rich varieties to farmers (Ross Welch and Robin Graham, 2004), is attributable to the negative association between β–carotene and dry matter (Vimala *et al*., 2008; Akinwale *et al*., 2010).

2.14 Environmental variation

The field is often heterogeneous with respect to plant growth factors such as moisture, light, nutrients, and temperature (Ceccarelli and Grando, 1991). Environmental variation is normally difficult to control because it is nonheritable. Environmental variation is usually associated with environmental conditions prevailing on the site where the crops are grown (Ceccarelli and Grando, 1991; Annicchiarico and Perenzin, 1994). Some of these conditions, such as population density, plant to plant competition can be controlled by use of agronomic practices, others like rainfall, wind, and temperature cannot be controlled.

2.14.1 Genetic variation

Genetic or heritable variation is the differences attributed to genes that encode specific traits, and can be transmitted from one generation to the other Acquaah (2009). Since genes are expressed in an environment, the degree of expression of a heritable trait is impacted by its environment, some more so than others. A phenotype (P), defined as the characteristic that is observed, is as a result of a combination of its genetic constitution, called the genotype (G), and the environment (E) and a component attributed to the interaction between the genetic and environmental components (G x E). This is usually expressed as: Phenotype = Genotype + Environment + G x E (Falconer and Mackay, 1996; Sleper and Poehlman, 2006; Brown and Caligari, 2009). From this equation for phenotypic expression, it follows that any variation seen in the phenotype is due to variation in the factors resulting in the phenotype.

The relationship can then be presented as: $V_P = V_G + V_E + V_G \times V_{GE}$.

Where: VP = Phenotypic variation, VG = Genotypic variation, VE = Variation as a result of the environment, VGxE = variation due to genotype x environment interaction effects Genotypic variation is generally divided into two components, which are additive and nonadditive components (Falconer and Mackay, 1996; Sleper and Poehlman, 2006; Brown and Caligari, 2009). Additive variation is due to the cumulative effect of alleles on all gene loci influencing a trait, and is usually of most value in a crop improvement programme (Falconer and Mackay, 1996). Non-additive variation is divided into dominance variation, caused by the interaction of specific alleles at a gene locus, and epistatic variation, caused by the interaction among gene loci (Falconer and Mackay, 1996). The non-additive variation is normally given little attention since only the additive component of genetic

variation is heritable (Falconer and Mackay, 1996; Sleper and Poehlman, 2006; Brown and Caligari, 2009). Genetic or heritable variation in nature originates from gene recombination, modifications in chromosome number, and mutations (Falconer and Mackay, 1996).

2.14.2 Genotype by environment (G x E) interactions

A genotype x environment interaction may be defined as a change in the relative performance of a character of two or more genotypes measured in two or more environments (Bowman, 1972). Interactions may therefore involve changes in rank order for genotypes between environments and changes in the absolute and relative magnitude of the genetic, environmental and phenotypic variances between environments. These changes in rank order and in variances have important implications for the breeder in designing selection programmes. The selection of locations for the evaluation of quantitative character is important for the plant breeder, and involves a number of considerations. Given the complexity of quantitative traits, many different lines or crosses must be carefully analyzed over different years and environments to unravel important components of gene interaction (Baiyeri et al., 2008). Theoretically, lack of a significant interaction of genotypes with locations, years, or location x year indicates that a test at one location during one year would be sufficient to identify genotypes with superior genetic potential. The similarity in relative performance of genotypes can be determined by the magnitude of the genotype x location interaction computed by a standard analysis of variance (Frey and Horner, 1957). Wide fluctuations in the rank performance of genotypes at test locations suggest that it may be desirable to develop genotypes for different locations through independent selection and testing programmes.

Cassava is prone to significant genotype by environment interaction (GEI) (Kvitschal *et al*., 2006; Ssemakula and Dixon, 2007; Lebot, 2009). Ssemakula and Dixon, (2007) and Aina *et al*., (2009) have reported that cassava genotypes tested in contrasting environment revealed strong (GEI) on fresh root yield (FRY). Tan and Mak (1995) reported that genotype by environment interaction (GEI) effects were significant for commercial storage root number, harvest index (HI), (FRY), starch and cyanide content. Although significant, their effects were smaller than the genotype effects, except for commercial storage root number and fresh root yield. They found only cyanide content exhibited a linear G x E relationship with the environment.

2.14.3 Heritability

Heritability is the degree of resemblance between progenies and their parents. It is the most important genetic parameter on which various breeding strategies are hinged. The information on heritability of agronomic characters is considered as a prerequisite for the execution of breeding plan. There are two main measures of heritability broad-sense (H^2) and narrow-sense (h^2) heritabilities. Narrow-sense heritability estimation does not involve dominance and epistasis variances and it is more useful in breeding programmes. There are many approaches for estimating heritability. It may be estimated by the parent-offspring regression approach, or by comparing full-sibs. Analysis of variance is commonly used in estimating heritabilities, as well as correlation and regression. (Holland *et al*., 2003) Higher heritability for a trait is important for the prediction of its breeding value and genetic gain. Harvest index and resistance to diseases are important and highly heritable traits in cassava breeding programmes (Kawano, 1978) indicating that they are transmitted relatively easily to progenies.

2.15 Dry matter content

Dry matter content of cassava varies from one accession to another and ranged between 17% and 47% with the majority lying between 20% and 40% (Teye *et al*., 2011); values above 30% are considered high. The dry matter of the tuberous roots has become an important character for the acceptance of cassava by researchers and consumers. Heritability for DM in cassava is relatively high; 0.87 broad sense heritability and 0.51 – 0.67 narrow sense heritability (Kawano *et al.*, 1987). Estimation of DM and starch content in cassava is based on the principle of a linear relationship between specific gravity with DM and or starch content. Percentage DM = 158.3x – 142.

2.15.1 Accumulation and partitioning of dry matter

Dry matter production and partitioning is an important determinant of storage root yield in cassava and could be an important selection criterion in breeding programmes for enhanced yield. Total dry matter production is a good estimator of the degree of adaptation of a genotype to the environment in which it is grown (Kamara e*t al*., 2003). Differences in total dry matter accumulation in genotypes reflect differences in photosynthetic rates (Kamprath *et al*., 1982). Cassava genotypes that produce high dry matter also produce high leaf area index and root yield.

Partitioning of dry matter is particularly important in cassava because the crop has simultaneous development of leaves, stems and storage roots and supply of assimilate is partitioned between these parts (Cock, 1985; Ekanayake *et al*., 1996). This results in a delicate balance between shoot and storage root growth for maximum yield (Ramanujam, 1985). Generally, genotypes that allocate higher proportion of dry matter to storage roots

than the stems and leaves give higher yields (Osiru and Hahn, 1998). However, Manrique (1990) reported that dry matter partitioning to storage roots had little seasonal variation and increased with plant age, but allocation to branches was more sensitive to the environment, indicating that differences in root yield between seasons were largely due to differences in dry matter partitioning to branches. Thus, relationship between cassava storage root and shoot weight is very important in cassava production, a high cassava root: cassava shoot ratio being desirable for storage root production (Enyi, 1972; Lahai *et al*., 1999).

2.15.2 Estimation of dry matter content

There are two main methods for determining the dry matter content in cassava. Specific gravity method is a quick method for determining root dry matter content. The other method is the forced oven dry method (Jennings and Iglesias, 2002; Kawano *et al.*, 1987; Wholey and Booth, 1979).

The oven dry method is the conventional approach for determining dry matter (DM) of cassava tubers (is by the use of the oven dry method). With this method, a fresh tuber is shredded with hand driven machine and a standard weight of (100 g weight), is taken and dried in an oven for at least 72 hours between 65^{o}C to 70^{o}C and reweighed to determine the percentage dry matter content (IITA, 1990).

Specific gravity determination (SG): The freshly harvested tubers are peeled and thoroughly washed with water to get rid of all soil particles on the tubers. The end portions (the head and the tail) of the tubers are nicely trimmed to get a uniform shape (Teye *et al.*, 2011) the weight of the sample is first weighed in air, then weighed in water and then computed with a standard formula as follows:

$$\frac{Ww}{Wa - Ww}$$

Where Ww= weight in water

Wa =weight in air

Percentage DM=158.3x – 142, (Kawano *et al.*, 1987; (Fukuda *et al.*, 2010)

Where x= specific gravity

2.16 Mating design.

Mating design is a procedure used by breeders and geneticists in various ways and arrangement to generate improved plants or varieties (Nduwumuremyi *et al.*, 2013).

The choice of good mating designs and suitable parents are vital to the success of plant breeding programmes. Acquaah, (2012) had reported that the type of crossing to be used (artificial or natural) means of pollen dissemination (wind or insect); the presence of a male-sterility system of pollination (self- or cross-pollinated); the purpose of the project (for breeding or genetic studies); and the size of the population required are factors that influence the choice of mating design.

A number of well-known mating designs are used; so far six types of mating designs have been described: Bi-parental (BIP), Polycross, Topcross, North Carolina (I, II, III), Diallel (I, II, III, and IV) and Line x tester design. (Griffing, 1956b; Kearsey and Pooni, 1996; Hallauer *et al.*, 2010; Acquaah, 2012)

However, three out of the six methods described are used in cassava breeding scheme, they are diallel, line x tester, and North Carolina mating design. In all mating designs, the individuals are taken randomly and crossed to produce progenies which are related to each

other as half-sibs or full-sibs. A form of multivariate analysis or the analysis of variance can be adopted to estimate the components of variances.

2.16.1 North Carolina Design I

North Carolina design 1 is a versatile and very popular design for both theoretical and practical plant breeding applications (Acquaah, 2012). It is applicable to both self- and cross-pollinated species that have sufficient seeds that can be replicated in a large trial.

It is universally used to estimate additive and dominance variances as well as for the evaluation of full and half sib recurrent selection. It requires adequate seed for replicated evaluation trials, and thus is not for breeding species that are not able to produce large amounts of seeds (Nduwumuremyi *et al.*, 2013).

2.16.2 North Carolina Design II

In this design, the male parents are different from the female parents and they are mated to each other in a factorial mating design. It is used to assess inbred lines for combining ability and it also allows the breeder to measure not only GCA but also SCA (Acquaah, 2012). The design is mostly tailored to plants that have multiple flowers so that each plant can be used repeatedly as both male and female. Blocking is used in this design to allow all mating involving a single group of males to a single group of females to be kept intact as a unit (Acquaah, 2012). The design is essentially a two-way ANOVA in which the variation may be partitioned into difference between males (m) and females (f) and their interaction. However, the NCII does not provide test of epistasis or G X E interaction (Kearsey and Pooni, 1996).

2.16.3 North Carolina Design III

In this design, a random sample of F_2 plants is backcrossed to the two inbred lines from which the F_2 was descended. It is considered the most powerful of all the three NC designs. This design was made more powerful by the fine-tuning made by a third tester not just the two inbreds (Acquaah, 2012). The adjustment is called the triple testcross and is capable of testing non-allelic (epistatic) interactions, which the other designs cannot, and also capable of estimating additive and dominance variance (Acquaah, 2012; Hill *et al*., 1998) it is also called triple test cross because of the inclusion of the third tester.

2.16.4 Diallel Design

A diallel cross is a mating scheme used by plant and animal breeders, as well as geneticists, to investigate the genetic underpinnings of quantitative character (Hallauer and Miranda, 1988; Crusio *et al.*, 1984). For the design parents are crossed to each other in all possible combinations including, selfs and reciprocals. (Schlegel, 2010). This type of mating scheme seems to satisfy Hardy–Weinberg equilibrium in a population (Acquaah, 2012). *Diallel* mating design comprises two models fixed and random, both models are useful for estimating GCA and SCA effects for each pair of parents. Johnson and King (1998) reported that diallel mating designs are deployed to provide the maximum opportunity to handle co-ancestry in breeding population and maximize selection differential. There are three commonly used designs in the forestry;-

Half diallel-each parent is mated with every other parent, excluding selfs and reciprocals Diallel-parents are sorted for their breeding values from the best to the poorest and most crosses are made among the best.

Disconnected half diallel- The half- diallel mating is repeated for the second diallel group, sometimes crosses are made between parents from two diallels to have connection between the two.

2.16.5 Half-diallel mating design

Half-diallel mating designs are widely used in genetic improvement programmes of many plant species (Yeh and Heaman, 1987; Snyder and Namkoong, 1978). In this mating scheme all possible crosses among the selected parents are made in one direction only, each parent is used either as male or female. The number of single cross required is equal to the P (P-1)/2 where P is the number of parents involved. It is used when reciprocal differences are not significant, and can be used when parents have male sterility or self-incompatibility. It also can be evaluated with or without parents.

2.16.6 Analysis of half-diallel mating design with missing crosses

Half diallel mating design has been widely adopted as a mating design for estimating genetic parameters and for future selection in many commercially important tree species. Standard commercial statistical packages do not allow direct specification of the linear model associated with the half-diallel design and therefore are not capable of analyzing diallel mating designs, even for balanced diallel mating (no missing crosses). Special computer programs for diallel analyses do not provide an adequate solution for GCA and SCA fixed effects in diallel with missing crosses. A theory of least squares for analyzing half-diallel mating designs with missing crosses, hence a SAS computer program (DIAFIXED.SAS), has been developed to test the significance of GCA and SCA effects and estimate the GCA and SCA fixed effects. The program is flexible enough to

accommodate different number of parents, multiple environments and missing individual as well as missing whole plots. The DIAFIXED.SAS output includes (1) hypothesis testing for GCA and SCA fixed effects and environmental effects, (2) estimates of GCA and SCA fixed effects, (3) estimates of standard errors of GCA and SCA fixed effects.

2.16.7 Half-diallel analysis with missing crosses using mixed model procedure in SAS programme.

In diallel, the same parents are used as females and males. Thus, each parent contributes to the general combining ability variance (GCA) as females and males. SAS does not have a simple procedure to take into account the 'double' effects of parents. Instead, various SAS codes were developed to estimate a single GCA variance by aggregating the effects of the parents. Zang and Kang, 1997; Johnson and King, 1998; Wu and Matheson 2001, 2001 Xiang and Li, 2001). It uses the following linear mixed model to estimate the variance components:

$Y_{ijkl} = \mu+B_i+G_j+G_k+S_{jk}+E_{ijkl}$

Where

Y_{ijkl} is the i-th observation of the i-th block for the k-th cross;

μ is the overall mean

Bi is the fixed effect of the i-th block, i=1 to b;

G_j or G_k is the random general combining ability effect of the j-th female or the k-th male- normally distributed and independently distributed (NID) $(0,\sigma^2G)$, j, k,=1 to p and j<k;

S_{jk} is the random specific combining ability effect of the j-th and the k-th parents ($j\neq k$) – NID $(0,\sigma^2S)$; E_{ijkl} is the random within plot error term- NID $(0,\sigma^2E)$. The general combining

(parent) effects, specific combining ability (crosses) effects and the error term are considered random. (Isik, 2009).

2.16.8 Combining ability

The concept of combining ability is a measure of gene action and helps in the evaluation of inbreds in terms of their genetic value and in the selection of suitable parents for hybridization. Superior cross combinations can be identified by this technique. There are two types of combining abilities general combining ability (GCA) and specific combining ability (SCA).

2.16.8.1 General combining ability

General combining ability of an inbred line is the average performance of the hybrids that this line produces with other lines chosen from a random mating population. It is estimated from half-sib families.

2.16.8.2 Specific combining ability

Refers to a pair of inbreds involved in a cross. It indicates cases in which certain combinations do relatively better or worse than would be expected on the basis of GCA effects of the two lines involved in it. It is the deviation of a particular cross from the expected GCA effects of the two lines.

2.17 Inbreeding

The broad scientific definition of inbreeding is that it is the mating of individuals more closely related to each other than the average relationship within the population concerned. Keller and Waller (2002); Glémin (2003) defined inbreeding as the increasing probability

of relatedness among mating individuals that occurs in small populations. This is sometimes referred to as panmictic inbreeding or inbreeding by drift. Inbreeding can also be referred to systematic inbreeding, cases where the relatedness of mates is higher than the average relatedness between random members of a population (Glémin, 2003).

2.17.1 Inbreeding depression

Inbreeding depression is the reduction in survival and fertility of offspring of related individuals that occur in plant, wild animal populations, as well as in humans. This indicates that genetic variation in fitness traits exists in natural populations. It is an important tool in crop breeding, and in the evolution of outcrossing mating systems because it improves yield.

2.17.2 The genetic basis of inbreeding depression

Little or nothing is known about the genetic foundation of inbreeding depression in most normal populations; The general postulation is that inbreeding depression is due to some combination of recessive alleles with a range of mild to lethal effects, and over-dominance, where heterozygote genotypes have the highest fitness (Keller and Waller, 2002). Gene interactions are hardly ever discussed in inbreeding depression, while epistasis is thought to influence the efficiency of purging (Templeton & Read 1984; Wang *et al*., 1999). The genetic source for inbreeding depression is of critical importance in determining whether abolition will occur in small populations (Wang *et al*., 1999).

However, there appears to be a general consensus that deleterious recessives are more important than over-dominance (Crnokrak and Barrett, 2002; Keller and Waller, 2002; Kristensen and Sørensen 2005).

2.18 Heterosis

Heterosis is an extremely important biological phenomenon in both animal and plant species. It has been reported to occur more frequently in a number of cross-pollinated crop species as compared with self-pollinated species. Heterosis typically is when there is increase in vigour, seed producing capabilities, size, better resistance to insect pests and diseases, enhanced metabolic activities. It is a genetically governed phenomenon, it is limited to first hybrid generation and declines in F_2 and subsequent generations.

Heterosis usually occur more in hybrids obtained from genetically unrelated lines, in addition the expression of heterosis in a crop species shows that some degree of genetic diversity, heterozygosity and or dominance exists in parents with respect to characters in which this heterosis has been expressed. Heterosis is dependent on specific combining ability of a cross. For most desired characters, heterosis is positive. But, for some characters like earliness, height in cereals and toxic substances may show negative heterosis. Heterosis has been extensively reported in legumes, vegetables, predominantly maize and to a lesser extent in cassava (Duvick, 1999; Stupar *et al*., 2008; Friedrichs, 2009).

2.18.1 Types of heterosis

Heterosis can be grouped into two: Euheterosis (true heterosis), and Pseudoheterosis (luxuriance) depending on the nature of the origin and reproducibility and adaptability. Euheterosis is further divided into two mutational and balanced depending upon the nature and the origin of the genes, causing heterosis in a biological system (Dobzhansky, 1952).

2.18.2 Methods for Estimation of Heterosis

Heterosis can be estimated in three various ways, mid-parent heterosis, better parent heterosis and standard heterosis. When heterosis is estimated over the mid parent it is known as mid parent, average, or relative heterosis and calculated by using this formula.

$$\frac{F_1 - MP}{MP} X100$$

Where F_1 is the mean of the F_1 and MP is the mean of the two parents.

When the heterosis is estimated over the better parent it is known as better parent heterosis or also known as heterobeltiosis and calculated by using this formula:

$$\text{Heterobeltiosis} = \frac{F_1 - BP}{BP} X100$$

Where BP is mean of better parents. The term heterobeltiosis was used by Bitzer & *Fu* (1972) to describe the improvement of heterozygote over the better parent of the cross. Standard Heterosis refers to the superiority of F_1 over the standard commercial check variety. It is also called economic heterosis or useful heterosis and calculated by using the formula:

$$\text{Standard} = \frac{F_1 - Check}{Check} X100$$

2.19 Participatory Rural Appraisal (PRA)

Participatory Rural Appraisal (PRA) is a collective approach for sharing ideas. It is a learning process that transforms researchers into learners and listeners who respect local intellectual and analytical capabilities. Farmers possess the potential and awareness for selecting crop varieties appropriate for their environments, resources, quality and other

consumer requirements (Pandit *et al*., 2007). In participatory evaluation, farmers assess varieties developed by plant breeders in farmers' fields using their own management practices, identifying agronomic character to be improved, propose the selection criteria and help to set the breeding objectives (Morris and Bellon, 2004). Participatory research seeks to empower local people to develop their own solutions to problems and also help researchers to improve the service and delivery of crop development research to the poorest, most marginalized people and areas. Dessie and Ogle (2001) reported that PRA is a widely used technique to critic the opinion and perception of the audience group. Moreover, it does not only efficiently collect information but also ensures farmers' participation in decision making (Watson and Cullis, 1994). It is as reliable as the sample survey (Temu and Due, 2000). The use of participatory rural appraisal (PRA) methods ensures that farmers participate in identifying opportunities for future development, identify constraints and suggests possible solutions. This participation makes them continue to the end of the project.

CHAPTER THREE

3.0 EVALUATION OF FARMERS' PERCEPTION OF DIFFERENT CASSAVA VARIETIES AND DESIRED CHARACTERISTICS FOR PREFERRED VARIETIES

3.1 INTRODUCTION

Participatory Rural Appraisal (PRA) should be integrated into the plant breeding programmes for efficient evaluation of farmers' preferences. A substantial number of plant breeding programmes have failed due to the fact that farmers' preferences were not considered from the onset of goal initiation, resulting in low adoption rate of released varieties (Ceccarelli *et al*., 2007; Efisue *et al.*, 2008). Duguma *et al*., 2010 also stressed the need to consider farmers' preferences to enable an active participation of target clientele in breeding programmes.

In participatory agricultural research, farmers are active participants who lead the process and whose ideas and views influence its outcome, rather than passive bystanders (Thro and Spillane, 2000). Research costs can be reduced and adoption rates increased if farmers are allowed to participate in the variety testing and selection processes (Joshi *et al*., 1995). Participatory research also increases farmers' knowledge and enables them to retain seeds effectively from year to year (Grisley and Shamambo, 1993). This eliminates the need for poor farmers to purchase seeds each year (Spearling and Loevinsohn, 1993). Manu-Aduening *et al*. (2007) used participatory rural appraisal (PRA) to describe the characteristics needed for cassava varieties in Ghana and reported that farmers preferred cassava varieties that have early growth and vigour to suppress weeds, early maturity, high yield, good cooking quality for making fufu and suitability for intercropping.

Previous studies (Sperling *et al*., 2001; Ceccarelli and Grando, 2007 and Muhinyuza *et al.*, 2012) have revealed that conventional breeding has not been useful to poor farmers since it does not solve theirt immediate needs, especially for those in marginal areas. Since plant breeders did not consider the specific preferences of the farmers, only a few improved varieties have been adopted despite the numerous available improved varieties (Muhinyuza *et al.,* 2012). Farmers still grow unimproved local varieties because officially recommended and released varieties lack the traits they prefer (Witcombe, 2009).

In order to develop cassava varieties that will meet farmers' diverse preferences and fit into the different cropping systems, it is essential to adopt a participatory rural appraisal approach in which farmers will be involved at several stages of variety development. Hence this research is demand driven with an aim at to conduct a diagnostic survey to determine farmers' perception of different cassava varieties and characteristics for preferred varieties in Edo State. The specific objectives include:

1. To determine the socio-economic characteristics/benefits of farmers involved in cassava production in the study area
2. To identify farmer preferences in cassava varieties
3. To identify the cropping systems of farmers in the study location
4. To identify the major constraints to cassava production in the study location

3.2 MATERIALS AND METHODS

3.2.1 Description of the study areas

This survey was carried out in Edo State in Nigeria one of the largest producers of cassava in the country as shown in (Figure 3. 1). Edo State is made up of eighteen local government areas and divided into three senatorial zones of Edo North, Edo Central and Edo South. Edo lies in the tropical zone between $5^0$4` and 6º57` East and 5º45`–7º38` North. It is bounded on the West by Ondo State, on the North by Kogi State, and on the East/South by Delta State (ESDSR, 2009). The State has adequate rainfall ranging from 800-1600 mm annually with diverse vegetation ranging from Sudan Savanna to Mangrove swamp and large flood plains of Fadama sites (Ministry of Agriculture and Natural Resources, 2009). Edo State is one of the largest producers of cassava in the South–South region of the country (FAO, 2004). Details of the coordinates of the various zones studied are presented in Table 3.1.

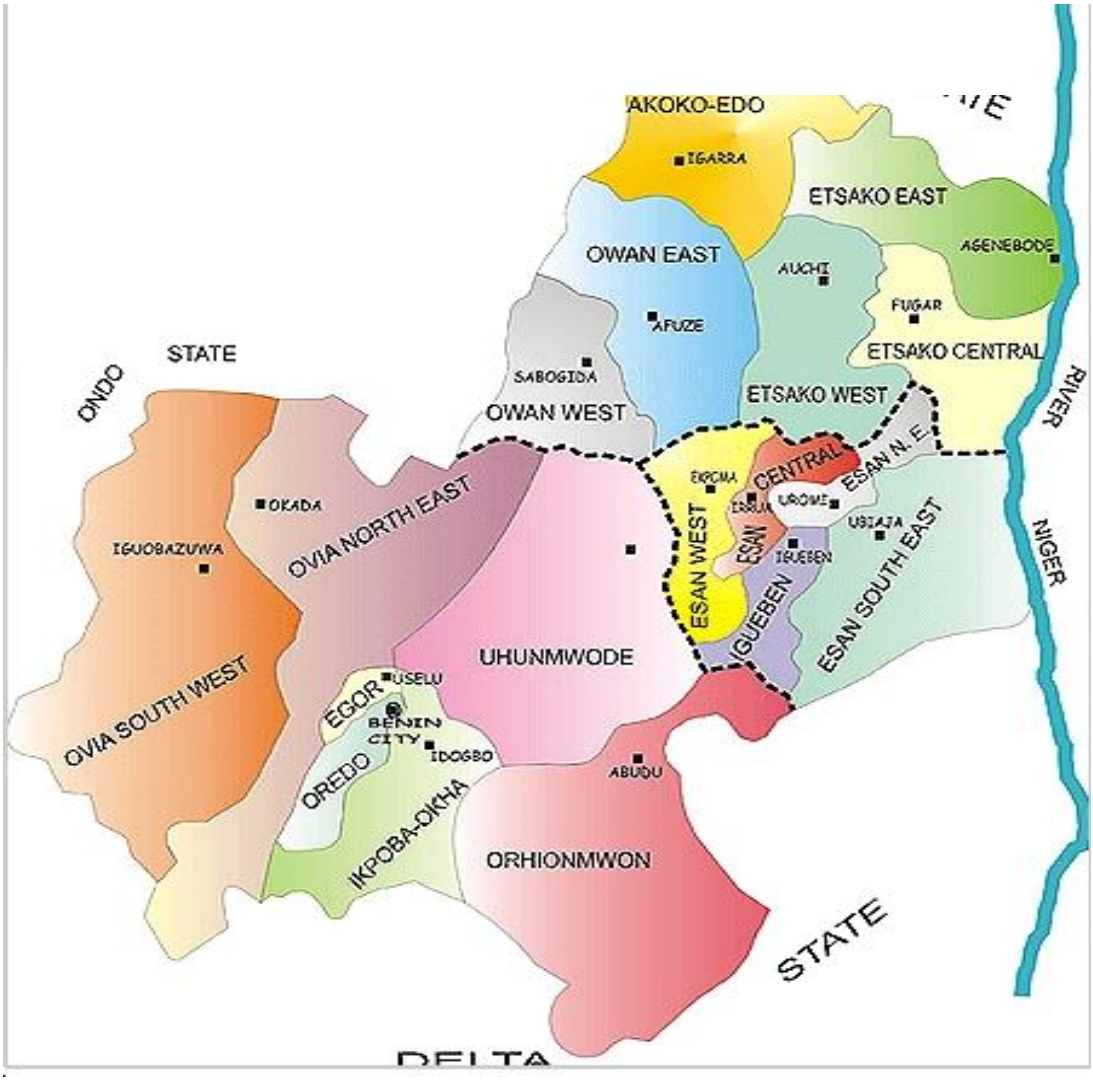

Figure 3. 1: Map of Edo State showing the survey areas
Source: http://www.hourofrenewaloutreach.org.za/images/MAP

Table 3.1: Location and elevations of the study areas

Community	Village	Local Government Area	Zone	Goegraphic position of the village	*Elevation (masl)
Evhokhia	Ayogwiri	Etsako West	Edo North	006023.410'E;07006.627'N	213
Oyomon	Ubiaja	Essan South-East	Edo North	006022.240'E;06039.512'N	106
Atani	Uromi	Essan North-East	Edo Central	006021.067'E;06040.933'N	353
Irrua	Usugbenu	Essan Central	Edo Central	006014.407'E;06041.995'N	377
Ugbekun Quarters	Iguomokhoa	Orhionmwo	Edo South	005039.300'E;06017.994'N	74
Igbogiri	Igbogiri	Uhunminode	Edo South	005055.366'E;06017.553'N	106

Source: 2013 PRA Survey. *masl =metres above sea level

3.2.2 SAMPLING PROCEDURES AND DATA COLLECTION

3.2.3 Structured Survey

A pre-survey visit was conducted in which farms and farmers were visited. Information obtained was used to design the questionnaire for the main survey. The questionnaire was used to collect information on farmers' bio and socio-economic data, farm size, average yield of cassava, farming practices, varietal preferences, source of varieties and constraints to production. Different administrative levels were considered including community, village and Local Government Area from the three Senatorial Zones of Edo State (Edo North, Edo Central, and Edo South). Random sampling was employed to select two Local Governments from each senatorial zone involved in cassava production. Two villages were selected from each of the Local Governments. A community from each of the villages was selected and 50 respondents per village that are actively involved in cassava production

were selected. This resulted in a total of 6 Communities, 6 Villages, 6 Local Government Areas and 300 respondents from the 3 Senatorial zones of Edo State.

3.2.4 Participatory Rural Appraisal (PRA)

Visits were made to village leaders, IITA contact farmers and extension workers from the Edo State Agricultural Development Programme (EDADP), Federal Ministry of Agriculture and State Agricultural Ministry. With the help of information gathered from these visits, random sampling was employed to select farmers in each village for the study. Six focus groups for group discussions were constituted across the study areas to collect data. In each village, a focus group of 6 to 10 representative farmers who had adequate knowledge on the villages, the farms, cassava crop, varieties planted/preferred, farming practices, problems encountered in the production of cassava specific to their location, available technologies adopted by farmers as well as the role of NGOs and research institutes in the area of agriculture in the state were selected. Gender balance was taken into account. Visits were also made to some farms (Plate 1 and 2).

3.2.5 Data collection and analysis

The questionnaires were administered and the following data were collected:

- Desirable traits to be incorporated into cassava breeding programmes.
- Cassava varieties most preferred
- Major constraints to cassava production.

The trait with the highest frequency (high score or occurrence) was the most important trait to be incorporated into cassava breeding programmes. Cassava varieties that were most preferred and major constraints to cassava production were also derived from the rankings. Data collected were analyzed using SPSS, (2006) 16.0 computer software. Data were subjected to descriptive statistics (frequency and percentage).

3.3 Results

3.3.1 Bio-data and Socio-economic characteristics of Respondents

Table 3.2 presents the following information on the socio-economic characteristics of respondents:

- **Gender**

The gender distribution of farmers interviewed indicated that 55.3% of the farmers were males while 44.7% females.

- **Age distribution of respondents**

Most farmers 47% were 45-64 years old while famers less than 25years (3.7%) were the fewest.

- **Marital Status**

A higher proportion of the respondents were married (89.7%) followed by singles (7.0%), and widow/widowers (3.3%).

- **Household size**

Majority (51.3%) of the respondents had household size of 6-10 followed by 1-5, 11-15, 15 and above which accounted for 30.3%, 16.3% and 2.0%, respectively.

- **Educational level**

Fifty one percent of the respondents had at least primary education. Only 16.7% had no formal education while 30.3% and 2.0% had secondary and tertiary education, respectively.

- **Size of farm land**

Land area allocated to cassava production was higher than other food crops in the study area. In the three senatorial zones, average farm size per household was 0.01 ha. The majority of the farmers (59.3%) had farm size within 0.01-0.03 ha while those with farm size less than 0.01ha were the least in the population.

- **Average yield of cassava**

Average yield of cassava in the study location was less than 1ton/ha (35.3%), followed by 1-3 tons/ha (25.0%), 4-6 tons/ha (16.3%), 7-9 tons/ha (5.0%) 10–12 tons/ha (8.7%) and 13 tons/ha (9.7).

Annual income

The majority of the farmers earn annual income of ₦146,000 and above (30.7%), followed by farmers who earn between ₦1,000 - ₦45,000, ₦46,000 - ₦90,000, ₦91,000 - ₦145,000 for 27.7%, 21.3% and 20.3%, respectively.

- **Profit from the production of cassava**

Most (75.7%) of the farmers made a profit from their cassava production but 24.3% of them did not make profit.

- **Farmer groups**

Only 25.0% of the farmers belonged to a farmer group. Most (75.0%) did not.

Table 3.2: Bio-data and Socio-economic characteristics of respondents

	Location			Total	
Variable	**Edo North**	**Edo Central**	**Edo South**	**Frequency**	**Percentage**
Gender (Sex)					
Female	43	53	38	134	44.7
Male	57	47	62	166	55.3
Total	**100**	**100**	**100**	**300**	**100**
Age					
< 25 years	7	1	3	11	3.7
25-44 years	53	41	29	123	4.1
45-64 years	32	49	60	141	4.7
65 years and above	8	9	8	25	8.3
Total	**100**	**100**	**100**	**300**	**100**
Marital Status					
Married	82	97	90	269	89.7
Single	12	2	7	21	7
Widow/Widower	6	1	3	10	3.3
Total	**100**	**100**	**100**	**300**	**100**
Household Size					
1-5	23	29	39	91	30.3
6-10	56	52	46	154	51.3
11-15	20	14	15	49	16.3
15 and above	1	5	-	6	2
Total	**100**	**100**	**100**	**300**	**100**
Educational Level					
No formal education	20	17	13	50	16.7
Primary education	54	46	53	153	51.0
Secondary education	24	37	30	91	30.3
Tertiary education	2	-	4	6	2.0
Total	**100**	**100**	**100**	**300**	**100**

Table 3.3: continued

Size of Farm Land					
< 1 acre	5	0	3	8	2.7
1-3 acres	56	67	55	178	59.3
3.5-5.5 acres	26	19	19	64	21.3
6-7 acres	-	-	1	1	0.3
7.5-9.5 acres	9	14	7	30	10.0
10-12 acres	2	-	8	10	3.3
12.5 a cre and above	2	-	7	9	3.0
Total	**100**	**100**	**100**	**300**	**100**
Average Yield of Cassava					
< 1 ton/ha	28	50	28	106	35.3
1-3 tons/ha	19	40	16	75	25.0
4-6 tons/ha	20	5	24	49	16.3
7-9 tons/ha	11	1	3	15	5.0
10 to 12 tons/ha	15	3	8	26	8.7
13 tons/ha and above	7	1	21	29	9.7
Total	**100**	**100**	**100**	**300**	**100**
Annual income					
₦1,000 to ₦45,000	26	28	29	83	27.7
₦46,000 to ₦90,000	20	24	20	64	21.3
₦91,000 to ₦145,000	21	24	16	61	20.3
₦146,000 and above	33	24	35	92	30.7
Total	**100**	**100**	**100**	**300**	**100**
Profit from Cassava Production					
Yes	94	89	94	277	75.7
No	6	11	6	23	24.3
Total	**100**	**100**	**100**	**300**	**100**
Member of Farmers Group					
Yes	6	12	57	75	25.0
No	94	88	43	225	75.0
Total	**100**	**100**	**100**	**300**	**100**

Source: Field Survey, 2013

3.3.2 Farmers' major objective for cassava production and customer patronage

1. Farmers' major objective for cassava production and customer patronage are presented in Table 3.3.

- **Major Objective for Cassava production**

Across the three senatorial zones, most (94.7%) of the farmers produced cassava for both home consumption and income, 5.0% for home consumption alone and 0.3% produce for income alone.

- **Customers**

The major customers of most of the farmers (60.7%) were market women, 34.3% of the farmers sold to consumers within the neighbourhood while 5.0% did not sell at all (for home consumption only).

Table 3.4: Farmers' major objective for cassava production and Customer patronage

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Farmers' major objective for cassava production					
For income	-	-	1	1	0.3
For home consumption	10	2	3	15	5.0
For both home consumption and income	90	98	96	284	94.7
Total	**100**	**100**	**100**	**300**	**100**
Customer patronage					
Do not sell (for home consumption)	9	2	3	15	5.0
Market women	63	59	60	182	60.7
Consumers within the neighbourhood	26	39	38	103	34.3
Total	**100**	**100**	**100**	**300**	**100**

3.3.3 Percentage of cassava harvest sold and difficulties experienced in the sale of cassava.

Percentage of cassava sold in a cropping season

In a given cropping season, (45%) farmers sell between 61-80% of their cassava produced while 5% of the farmers do not sell their cassava. (Table 3.4) The least amount sold in a cropping season is between 20-40%.

Most (81.7%) of the farmers experience no difficulties in the sales of their cassava roots, but 13.3% experience difficulties.

Bad roads and high cost of transportation were the major difficulties experienced by the farmers. Poor storage and the activities of middle men were also problems experienced by farmers in the study area while glut was not much of a problem.

Table 3.5: Percentage of Cassava sold in a Cropping season, difficulties experienced in the sales of cassava and Reasons for difficulties experienced in sales

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Percentage of cassava sold in a cropping season					
Do not sell (for home consumption)	10	3	2	15	5.0
20% to 40%	16	9	4	29	9.7
41% to 60%	13	38	24	72	24.0
61% to 80%	43	39	50	135	45.0
81% to 100%	18	11	20	49	16.3
Total	**100**	**100**	**100**	**300**	**100**
Difficulties in sales of cassava					
Do not sell (for home consumption)	9	2	3	15	5.0
Yes	15	15	10	40	13.3
No	72	83	90	245	81.7
Total	**100**	**100**	**100**	**300**	**100**
Reasons for difficulties experienced in sales of cassava					
Do not sell (for home consumption)	9	2	3	15	5.0
do not experience difficulties	79	73	86	238	79.3
Bad road and high cost of transportation	14	12	3	29	9.7
Glut	-	-	1	1	0.3
Poor storage	1	7	1	9	3.0
Activities of middllemen	1	3	4	8	2.7
Total	**100**	**100**	**100**	**300**	**100**

3.3.4 Farming Practices of Cassava Farmers in Edo State

The majority (60.3%) of the farmers rent the land they use for cassava production. A few (6.7%) of the farmers own the land while 13.7% cultivate cassava on inherited land and 19.3% of the farmers cultivate on communal land. The majority (36.7%) of the farmers have 11-20 years of experience in the cultivation of cassava.

The majority (68%) cultivate cassava twice in a year, by planting in the main season April and off season August while 32% cultivate once in a year. In the three senatorial zones, the majority (61.7%) of the respondents does nothing to control insects, pests and diseases while 26.3%, 9.3% and 2.7% use chemicals, weeding and plant resistant/tolerant varieties, respectively (Table 3.5).

Table 3. 6: Farming Practices of Cassava Farmers in Edo State

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Cropping system					
Mono Cropping	63	58	35	156	52.0
Mixed Cropping	37	42	65	144	48.0
Total	**100**	**100**	**100**	**300**	**100**
Land ownership					
Rent	22	67	92	181	60.3
Own	7	6	7	20	6.7
Inherited	24	17	-	41	13.7
Communnal cropping	47	10	1	58	19.3
Total	**100**	**100**	**100**	**300**	**100**
Years of experince in cassava production					
1-10	34	41	27	102	34.0
11-20	43	33	34	110	36.7
21-30	15	18	27	60	20.0
31-41	6	4	12	22	7.3
41 and above	2	4	-	6	2.0
Total	**100**	**100**	**100**	**300**	**100**
Cultivation of cassava in a year					
Once	22	7	67	96	32
twice	78	93	33	204	68
Total	**100**	**100**	**100**	**300**	**100**
Kind of labour used for cassava farming					
Family	17	6	13	36	12.0
Hired	48	64	73	185	61.7
Communal	3	1	-	4	1.3
Family and Hired	32	29	14	75	25.0
Total	**100**	**100**	**100**	**300**	**100**
Control of insect, pest and diseases					
Use of chemical	26	23	30	79	26.3
Planting of resistant/tolerant varieties	1	7	-	8	2.7
No cotrol	68	60	57	185	61.7
Weeding	5	10	13	28	9.3
Total	**100**	**100**	**100**	**300**	**100**

3.3.5 The most preferred cassava varieties

The cassava varieties grown per household differed across the zones (Figure 3.2). A minimum of two and a maximum of four varieties per household were recorded. A total of 14 varieties of cassava were preferred across all locations. 'Give me chance' and 'Queen' were specific to Edo South. The preference of 'Give me chance' in Edo South was the highest among all the varieties listed in all the three zones.

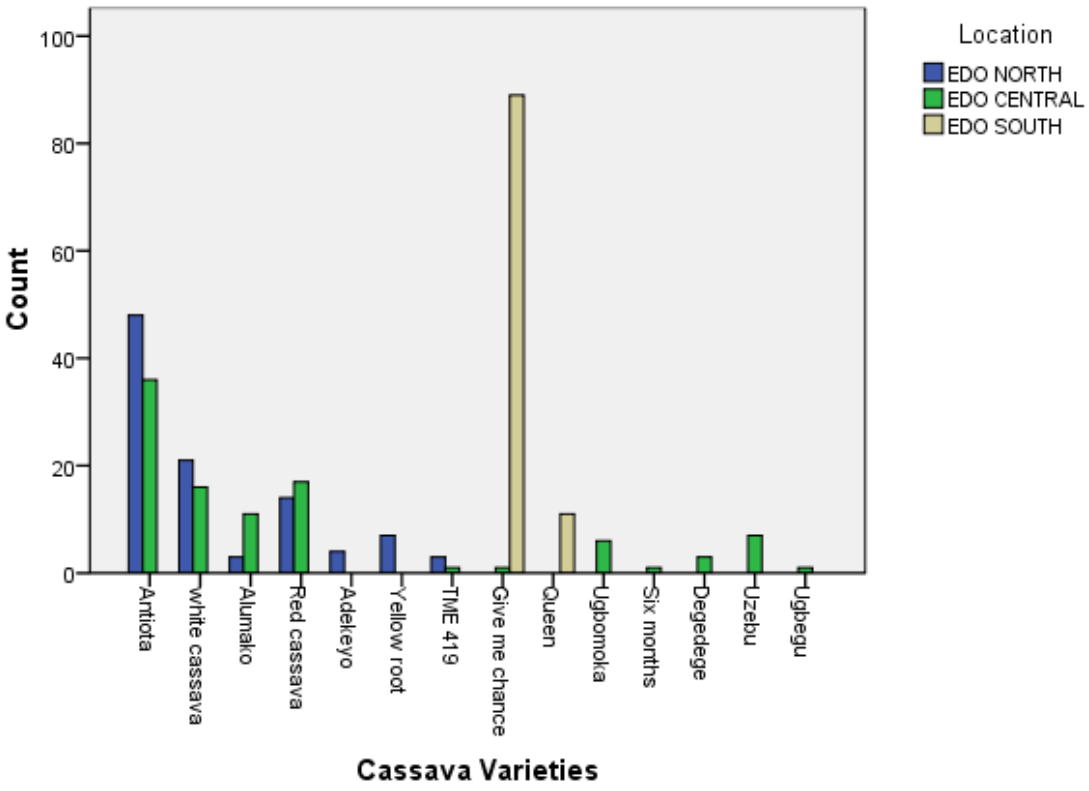

Figure 3.2: Distribution of Cassava Varieties most preferred and specific to location

3.3.6 Farmers' Desirable traits to be incorporated into cassava breeding programmes

Traits such as high yield, dry matter content, early maturity, starch content, and disease tolerance are important agronomic qualities in cassava production. High yield is the most desirable trait farmers want to be incorporated into cassava breeding programmes followed by disease resistant varieties and high starch content (Figure 3.3) However, in each zone, the ranking of desirable traits to be incorporated in cassava breeding programme varied:

In Edo North: High yield (1st), Disease resistance (2nd), High starch content (3rd) were the most important.

In Edo Central: Disease resistance (4th), Baking and Confectioneries (3rd), High starch content (2nd) and High yield (1st), as most desired.

In Edo South: Early maturity (4th) High yield (3rd), as most desired (1st), (2nd), High starch content Disease resistance.

3.3.6.1 Cassava Varieties most preferred for Dry Matter Content

The results indicated that about 45% of farmers in Edo Central cultivate Antiota, white cassava, Alumako, Red cassava, Ugbomoka, Sixmonths, Degedege, Uzebu and Ugbegu for their root dry matter content (RDMC), while about 40% of farmers in Edo North cultivate Antiota, white cassava, Alumako, Red cassava, Adekeyo, Yellow root and TME 419 for root dry matter content. About 10-90 % of farmers cultivate;- 'Give me chance' and 'Queen' in Edo South for their root dry matter characteristics (Figure 3.4).

3.3.6.2 Cassava Varieties most preferred for Starch Content

Results showed that about 5-38% farmers in Edo Central and Edo North cultivate Antiota, white cassava, Alumako, Red cassava and TME 419 for starch content characteristics. In Edo North, a few farmers (2-8 %) cultivate Adekeyo, Yellow root and ogudugu for their starch content. Ugbomoka, Degedege, Uzebu and Ugbegu were cultivated by (5-10%) of farmers in Edo central, while 8-80% of farmers cultivate Give me chance, Queen and shiny in Edo South Senatorial Zone for starch content characteristics as shown in (Figure 3. 5).

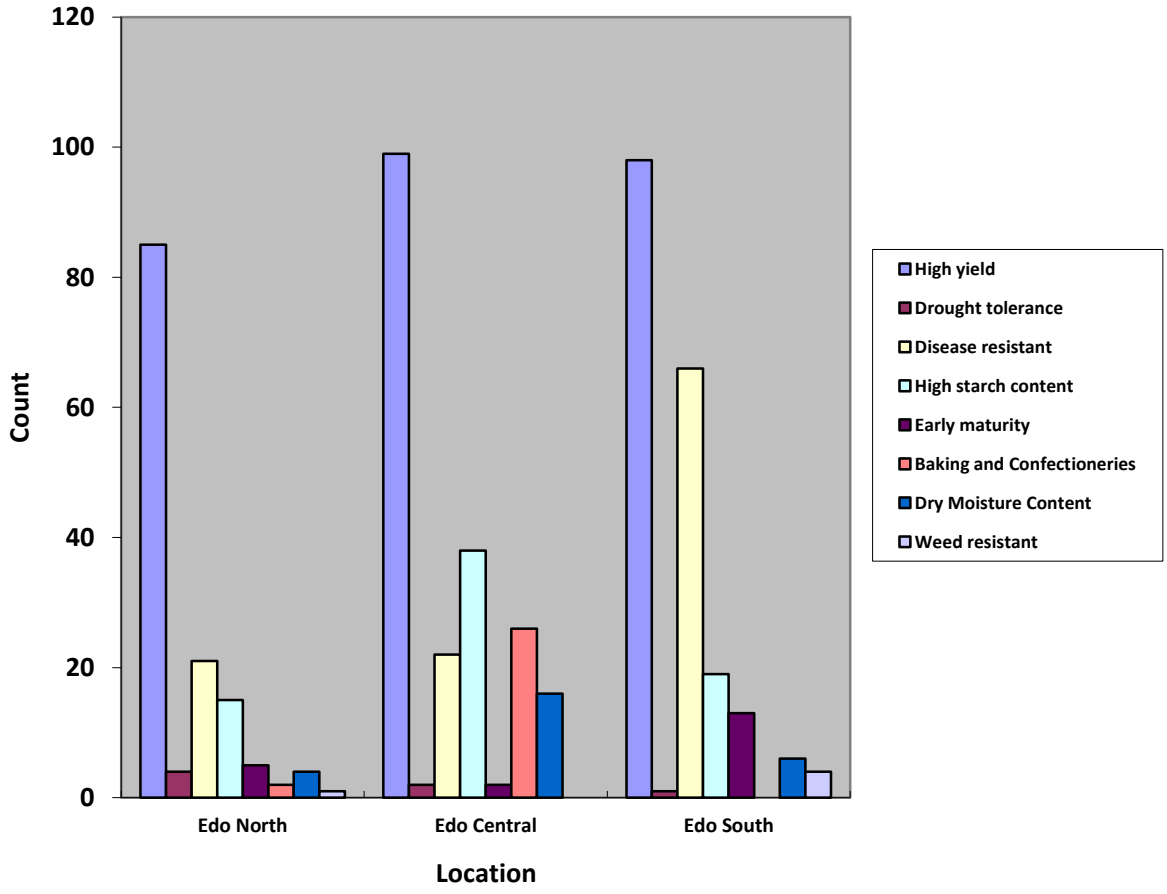

Figure 3.3: Ranking of farmers desired cassava traits to be incorporated into cassava breeding programme

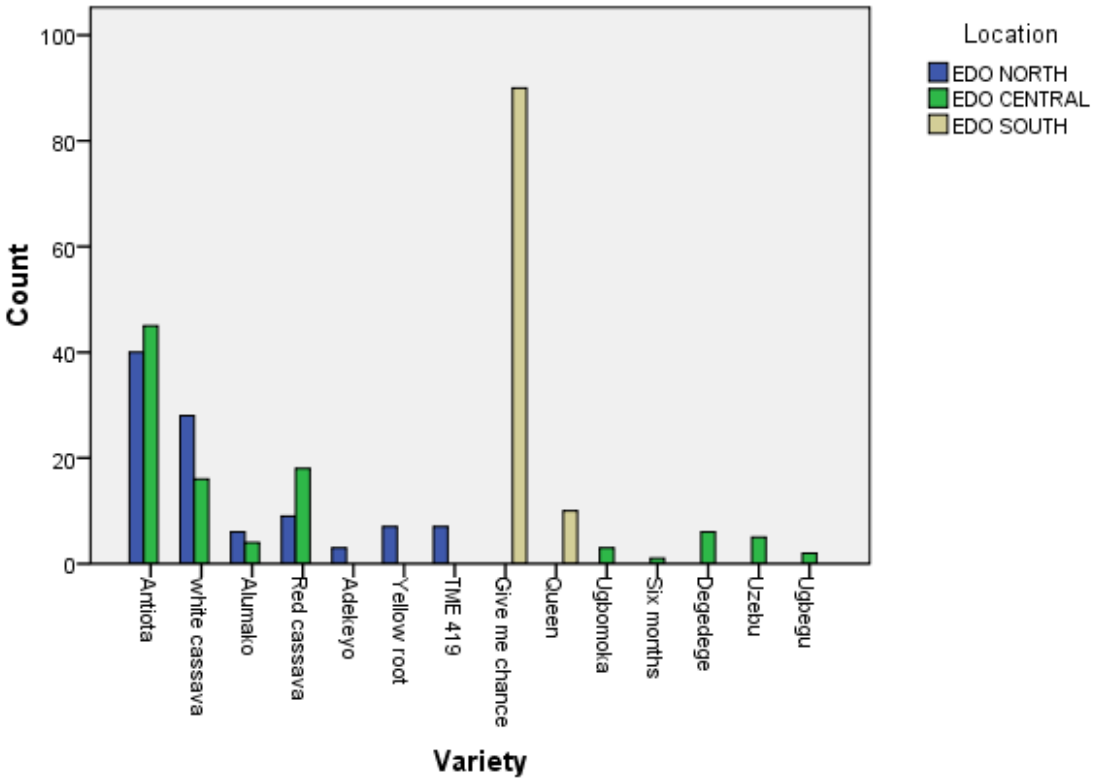

Figure 3.4: Cassava Varieties most preferred for Dry Matter Content by location

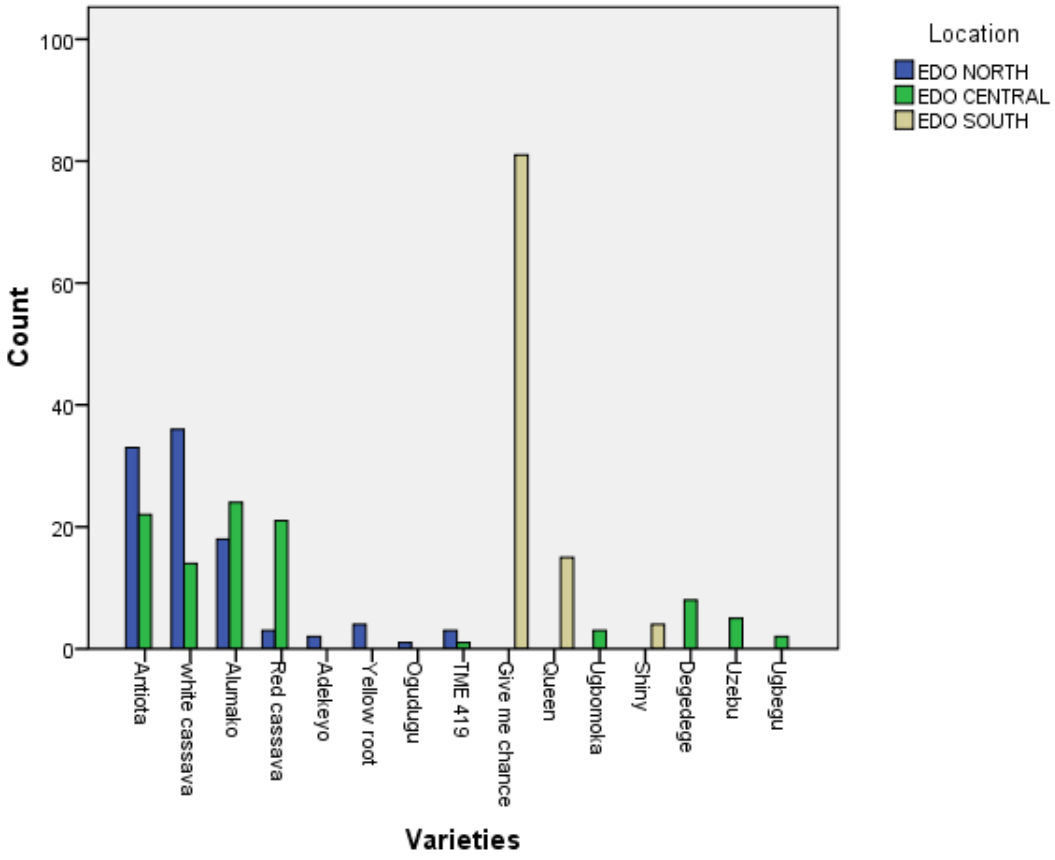

Figure 3.5: Cassava Varieties most preferred for Starch Content by location

3.3.7 Major constraints to cassava production

The constraints (identified by farmers) that affect cassava production in the study area were lack of funds to increase production, lack of farm land, insect pests and diseases, lack of planting material, climate change, weed infestation and low soil fertility (Figure 3.6). However, farmers ranked lack of funds as the number one major constraint to cassava production. In Edo North Senatorial Zone, 51% of the farmers identified lack of farmland as the second most important limiting factor. In Edo South Senatorial Zone, farmers identified pests and diseases and lack of planting material as being relatively more important limiting factors affecting cassava production.

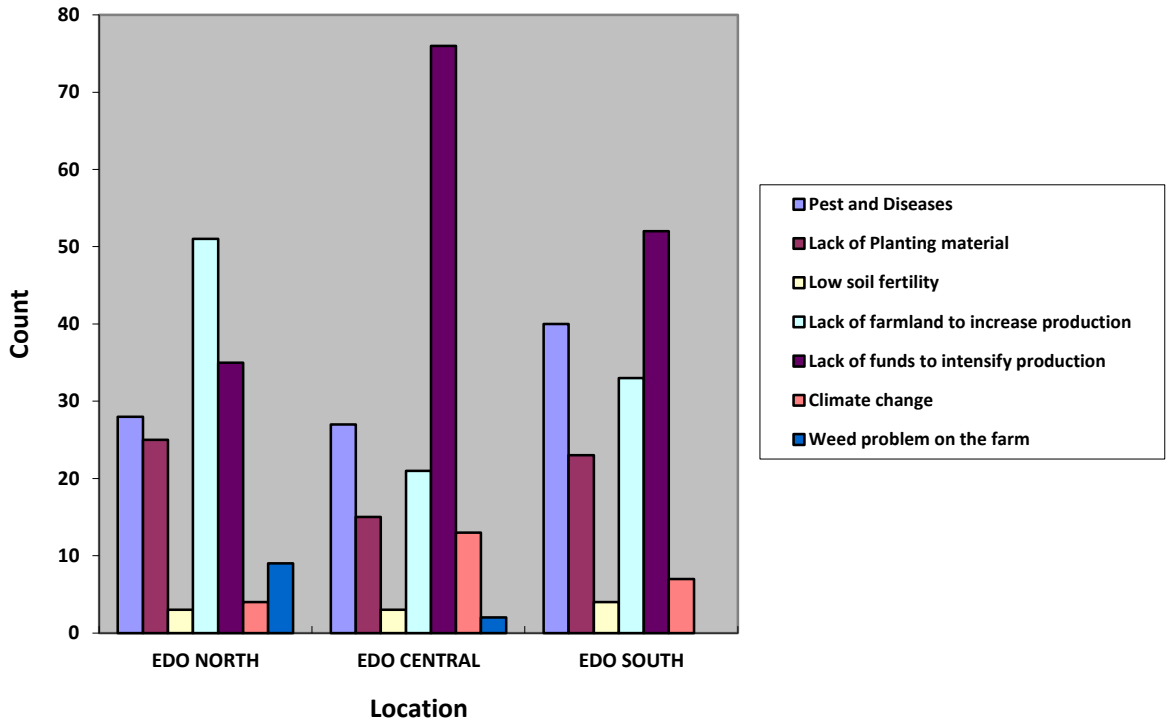

Figure 3.6: Major constraints to cassava production

3.3.8 Problems encountered in getting improved varieties

Problems encountered in getting improved varieties were classified into five categories: non availability of improved varieties, improved variety being expensive, long distance to the source of improved varieties, farmer's preference for local variety and no information on improved variety (Table 3.6).

Majority (47%) of the farmers indicated that non availability of improved varieties is not critical while 40% and 13% said it was very critical and critical respectively.

The cost of purchasing improved varieties was not critical for a majority (60.7%) of the farmers while 25.3% and 14.0% said it was very critical and critical respectively.

A good proportion of the farmers (53.3%) indicated that distance to the source of improved varieties is not a critical problem, while very critical and critical responses accounted for 35.3% and 11.3% respectively.

Majority (52.6%) of the farmers indicated that lack of information about improved varieties is a very critical problem while 39.7% and 7.7% responded not critical and critical, respectively.

Table 3.7: Problems encountered in getting improved varieties

	Location			Total	
Variable	**Edo North**	**Edo Central**	**Edo South**	**Frequency**	**Percentage**
Improved varieties are not available					
Not critical	54	43	44	141	47.0
Critical	18	20	1	39	13.0
Very critical	28	37	55	120	40.0
Total	**100**	**100**	**100**	**300**	**100**
Improved varieties are expensive to buy					
Not critical	60	68	54	182	60.7
Critical	23	18	1	42	14.0
Very critical	17	14	45	76	25.3
Total	**100**	**100**	**100**	**300**	**100**
Difficulty in acccessing improved varieties					
Not critical	54	58	48	160	53.3
Critical	19	15	0	34	11.3
Very critical	27	27	52	106	35.3
Total	**100**	**100**	**100**	**300**	**100**
Farmers prefer to plant local varieties					
Not critical	55	69	62	186	62.0
Critical	22	16	6	44	14.7
Very critical	23	15	32	70	23.3
Total	**100**	**100**	**100**	**300**	**100**
No information on improved varieties					
Not critical	39	61	19	119	39.7
Critical	14	9	0	23	7.7
Very critical	47	30	81	158	52.6
Total	**100**	**100**	**100**	**300**	**100**

3.3.9 Farmers' perception of involvement in cassava research

Most (72.7%) of the farmers wanted to be involved in initial planning (87.0%), in on-farm trials, (83.7%), and in varietal selection (Table 3.7)

Table 3.8: Farmers' perception on involvement in cassava research

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Initial Planning					
Not important	2	20	13	35	11.7
Less important	25	20	2	47	15.6
Very important	73	60	85	218	72.7
Total	**100**	**100**	**100**	**300**	**100**
On-farm trials assessment					
Not important	6	17	5	28	9.3
Less important	5	5	1	11	3.7
Very important	89	78	94	261	87.0
Total	**100**	**100**	**100**	**300**	**100**
Varietal Selection					
Not important	0	35	5	40	13.3
Less important	8	1	0	9	3.0
Very important	92	64	95	251	83.7
Total	**100**	**100**	**100**	**300**	**100**
No Involvement					
Not important	54	73	89	216	72.0
Less important	28	19	5	52	17.3
Very important	18	8	6	32	10.7
Total	**100**	**100**	**100**	**300**	**100**

3.3.10 Knowledge, perception and planting of improved varieties

Some (47%) of the farmers had knowledge about improved varieties, while 53.0% had no knowledge. Some (18.7%) grew local varieties and improved varieties, but 81.3% grow only their local varieties.

A few farmers (10.7%) preferred improved varieties to local varieties in terms of yield, but 89.3% preferred the local variety (Table 3.8).

Table 3.9: Knowledge, Growing and Perception of improved varieties

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Knowledge of improved cassava varieties					
Yes	64	46	31	141	47.0
No	36	54	69	159	53.0
Total	**100**	**100**	**100**	**300**	**100**
Growing of improved cassava varieties with local varieties					
Yes	34	17	5	56	18.7
No	66	83	95	244	81.3
Total	**100**	**100**	**100**	**300**	**100**
Preference of improved varieties to local varieties in terms of yield/acre					
Yes	17	11	4	32	10.7
No	83	89	96	268	89.3
Total	**100**	**100**	**100**	**300**	**100**

3.3.11 Source of information on improved cassava varieties

The majority (53%) of farmers had no information on improved cassava varieties (Table 3.9), 26.3% got information from friends and neighbors, 8.7% from Non-Governmental Organization, 2.3% from Radio, 3.3% from Field days and 6.3% from Agricultural Extension Officers.

Across the three senatorial zones, most (70%) of the farmers source their planting material from fellow farmers while 20.3%, 6.7%, 1.7% and 1.3% acquired their planting materials from farm settlements, open market, Government agency and IITA, respectively.

Table 3. 10: Source of information and planting materials of improved cassava varieties

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Source of information on improved cassava varieties					
No information	36	54	69	159	53.0
Non-Governmental Organisation	6	20	0	26	8.7
Radio	2	3	2	7	2.3
Field days	2	8	0	10	3.3
Agricultural extension officers	4	2	13	19	6.3
Other farmers, friends and neighbours	50	16	13	79	26.3
Total	**100**	**100**	**100**	**300**	**100**
Source of planting materials					
Government agency	0	0	5	5	1.7
Fellow Farmer	68	85	57	210	70.0
Farm settlement	27	10	24	61	20.3
Bought from the market	1	5	14	20	6.7
IITA	4	0	0	4	1.3
Total	**100**	**100**	**100**	**300**	**100**

3.3.12 Farmer participation in field days

Most (83.3%) of the farmers indicated that they had not participated in farmers field days in the last two years. Reasons for not participating were no reason, lack of information, inaccessibility, no trust and lack of interest. Most of the farmers (62%) had no reason for not attending field days while 17.3% gave lack of information as the reason (Table 3.10).

Table 3.11: Participation in field days

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Participation in field days in the last 2 years					
Yes	14	20	16	50	16.7
No	86	80	84	250	83.3
Total	**100**	**100**	**100**	**300**	**100**
Reasons for not participating in field days					
No reason	71	63	52	186	62
No information	7	12	33	52	17.3
Inaccessibilty	2	0	1	3	1.0
Participated	12	21	14	47	15.7
I do not trust them	8	3	0	11	3.7
Not interested	0	1	0	1	0.3
Total	**100**	**100**	**100**	**300**	**100**

3. 3.13 Labour demand

Labour demand was high for land preparation, planting and harvesting but was not as high for processing (turning cassava into garri and fufu), storage and marketing (Table 3.11).

Table 3.12: Labour demand of farmers in the study area

	Location			Total	
Variable	**Edo North**	**Edo Central**	**Edo South**	**Frequency**	**Percentage**
Land preparation					
Low	16	6	2	24	8.0
Moderate	15	20	13	48	16.0
High	69	74	85	228	76.0
Total	**100**	**100**	**100**	**300**	**100**
Planting					
Low	31	15	9	55	18.3
Moderate	15	32	28	75	25.0
High	54	53	63	170	56.7
Total	**100**	**100**	**100**	**300**	**100**
Harvesting					
Low	26	20	10	56	18.7
Moderate	18	32	30	80	26.7
High	56	48	60	164	54.6
Total	**100**	**100**	**100**	**300**	**100**
Processing					
Low	36	27	24	87	29.0
Moderate	28	45	26	99	33.0
High	36	28	50	114	38.0
Total	**100**	**100**	**100**	**300**	**100**
Storage and marketing					
Low	73	67	69	209	69.7
Moderate	21	19	19	59	19.7
High	6	14	12	32	10.6
Total	**100**	**100**	**100**	**300**	**100**

1-3 people = Low, 4-6 people = Moderate, 7 and above = High

3. 3.14 Diseases and Pests affecting Cassava plants in the study area

Cassava bacterial blight (CBB), Cassava mosaic disease (CMD), Cassava anthracnose disease (CAD) and Cassava mealy bug are the most economically important diseases and pests that reduce cassava yield.

Some (46%) of the farmers were not affected by CBB, while the incidence was very severe for 6.7%. Also 43.7% of the farms were not affected by CMD, but the incidence was very severe for 9.3%. Furthermore, 88.3% of the farms were not affected by CAD while 2.7% were very severely affected. Mealy bug does not affect the majority of farms, but it was very severe for 8.0% of farms (Table 3.12).

Table 3.13: Diseases and Pests affecting Cassava plants in the study area

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Cassava Bacterial Blight					
No incidence	42	48	48	138	46.0
Not severe	3	2	1	6	2.0
Severe	51	45	40	136	45.3
Very severe	4	5	11	20	6.7
Total	**100**	**100**	**100**	**300**	**100**
Cassava Mosaic Diseasse					
No incidence	53	39	39	131	43.7
Not severe	9	7	1	17	5.7
Severe	35	49	40	124	41.3
Very severe	3	5	20	28	9.3
Total	**100**	**100**	**100**	**300**	**100**
Cassava Anthracnose Disease					
No incidence	85	98	82	265	88.3
Not severe	0	2	0	2	0.7
Severe	7	0	18	25	8.3
Very severe	8	0	0	8	2.7
Total	**100**	**100**	**100**	**300**	**100**
Cassava Mealy Bug					
No incidence	62	54	67	183	61.0
Not severe	6	5	5	16	5.3
Severe	22	36	19	77	25.7
Very severe	10	5	9	24	8.0
Total	**100**	**100**	**100**	**300**	**100**

3.3.15 Gender differences in cassava production

Most (82%) of the farmers said that gender does not affect cassava production in the study area (Table 3.13). Both male and female farmers are involved in the main cassava production activities. They are equally involved in making decisions related to time of planting, variety to plant, planting material, routine agronomic practices and harvesting, However, some activities, such as frying of 'garri', preparing of 'fufu', and marketing, across the study area are exclusively done by women, while men are predominantly concerned with weed management and transportation.

Table 3.14: Gender differences among farmers in the study area

Variable	Location			Total	
	Edo North	Edo Central	Edo South	Frequency	Percentage
Does gender affect cassava production					
Yes	29	24	1	54	18
No	71	76	99	246	82
Total	**100**	**100**	**100**	**300**	**100**

3.3.16 Other crops planted with cassava in the study area

Farmers listed about 10 main crops that they grow in each zone and ranked them. They ranked major crops grown according to their order of importance either as a source of income or food (Figures 3.7, 3.8 and 3.9). Cassava, maize, yam, and water melon are important in all the three zones. Other main food crops grown across the zones are groundnut, cowpea, pepper, cocoyam, plantain, okra and tomatoes.

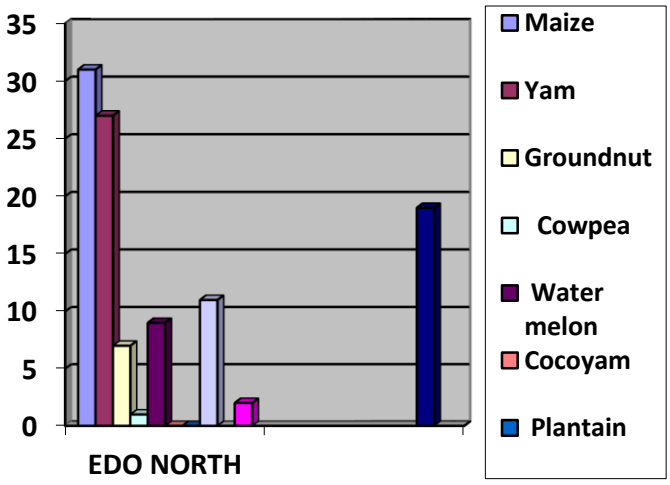

Figure 3. 7: List of other Crops planted with Cassava in Edo

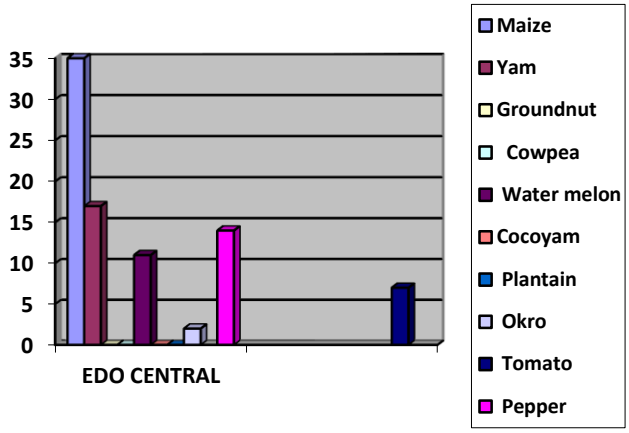

Figure 3. 8: List of other Crops planted with Cassava in Edo Central

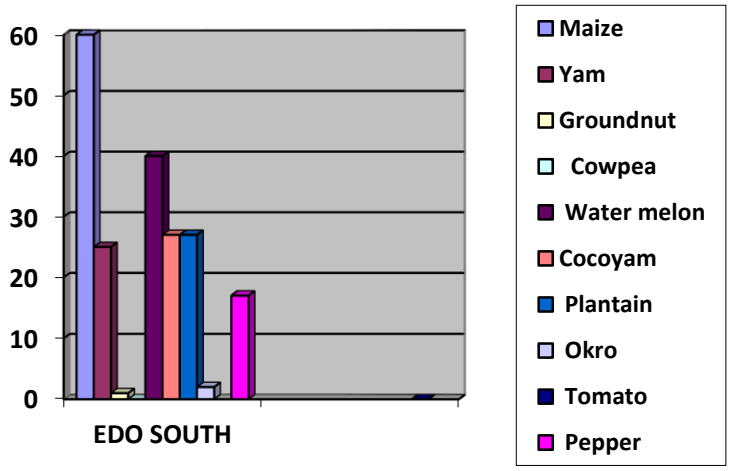

Figure 3. 9: List of other Crops planted with Cassava in Edo South

3.4 Discussion

The Participatory Rural Appraisal revealed farmer's perceptions of different cassava varieties and characteristics for preferred varieties. The study confirmed that cassava is an important staple and security food crop in all the three senatorial zones in Edo State Nigeria (EDADP Survey 2007, ESDSR 2009). It is mainly eaten in processed form (garri, fufu and tapioca). Other major crops cultivated in the zones were maize, yam, water melon, cowpea,

pepper, plantain, okra, tomato, groundnut, and cocoyam. Maize, yam and water melon were other cash crops in the study area. The cropping system practiced in the study area were mixed and mono cropping. Cassava was mostly grown as a sole crop or intercropped with other crops like maize, yam, water melon, cowpea, pepper, plantain, okra, tomato, groundnut, and cocoyam. The farmers had good knowledge of their local varieties and a few had knowledge of improved varieties. Most of the farm activities such as land preparation, planting, weeding, harvesting and processing used both hired and family labour. The size of farm land under crop production per household was small.

The average yield of cassava root production of most farmers in the study location was low. Actual yield was not well captured because of the lack of record keeping and the inconsistent way of harvesting. Harvesting occurs according to the purpose of the farmer ranging from harvest for immediate family need, market purposes, home consumption and selling of the whole farm at which time the cassava will be uprooted at once and sold to a trader. Area and yield estimates of Edo state have been reported to be 0.72-.1 tonnes/ha. Nearly 90% of the cassava production in Nigeria is for domestic food production and produced by small holder farmers and production yields are still extremely low (DADTCO 2011; FOA 2004).

A wide range of desired traits to be incorporated in improved varieties were listed by farmers. Ranking of the traits across the three senatorial zones indicated that high yield was the most important trait to be incorporated in the improved varieties, followed by disease resistance, high starch content, baking qualities, dry matter content, early maturity and drought resistance. However, the ranking of desirable traits varied across zones.

Farmers designated cassava varieties by local names which were often descriptive of the morphological characteristics of the plant. A majority of the farmers in Edo South grew 'Give me chance'. In Edo North, 'Antiota,' 'White cassava', 'Alumako', 'Red cassava', 'Adekeyo', Yellow root, TME 419 were grown but 'Antiota' was most preferred. 'Antiota', 'White cassava', 'Alumako', Red cassava, 'Ugbomoka', 'Six months', 'Degedege', 'Uzebu' and 'Ugbegu' were cultivated in Edo Central but 'Antiota' was most preferred.

Major cassava production constraints include the lack of credit to farmers for increased production, lack of farm land, insect pests and diseases, lack of planting materials, climatic change and poor weed control. Jean *et al.,* (2012) reported lack of access to credit as one of the production constraints in Rwanda. Yield loss by Cassava mosaic disease (CMD) could range from 20%-90% depending on the variety. (Thresh and Otim-Nape, 1994).

Cassava varieties most preferred by farmers across the study area for dry matter content (DMC) (garri) were Antiota, white cassava, Alumako, Red cassava, Ugbomoka, Six months, Degedege, and Uzebu, while Antiota, White cassava, Alumako, Red cassava and TME 419 were preferred for their starch content (fufu). This indicates that the preference for dry matter content and starch content are similar. This is in agreement with the report of Kawano *et. al*. (1987) which indicated that DMC was positively correlated with eating quality when roots are eaten after boiling. Similarly, Safo-Kantanka and Owusu-Nipah (1992) reported that mealier varieties had higher dry matter content and starch.

High dry matter content in cassava is vital in garri production and for a wide range of other uses. Graham *et al*., (1999) confirmed that high DMC in cassava root is important to ensure

high recovery of dried roots and, for a wide range of uses, varieties of high dry matter content are preferred.

Many (72.7%) of the farmers want to be involved in goal setting, 87% in an on-farm trials, and 83.7% in varietal selection. This confirms Pandit *et al*., (2007) findings that farmers possess the ability and knowledge for selecting crops varieties suitable to their environments, resources, quality and other consumer requirements. Morris and Bellon (2004) also reported that in participatory appraisal farmers evaluate varieties developed by plant breeders in their fields using their own management practices, identify agronomic traits to be improved, suggest the selection criteria and help to set the breeding objectives. The majority of the farmers (81.3%) interviewed grow their local varieties, and 53% had no knowledge of improved varieties. This supports the findings of Robooni *et al*., (2012) who reported that to a large extent breeding programmes in developing countries do not involve farmers, leading to low adoption rates of improved varieties.

Many (58%) farmers in this study lacked information on improved cassava varieties and sources of information on improved cassava varieties are mainly from fellow farmers, friends and neighbors. Research institutions and extension workers play minor role as seed providers. Farmers often do not have access to clean planting material, which may lead to high incidence of economic important diseases in the study area. (Jean *et al.*, 2012).

Most (83%) of the farmers have not participated in a farmers' field day. This clearly shows that most farmers do not get information on improved varieties.

3.5 Conclusions and Recommendations

Farmers plant different cassava varieties for various needs. Farmers in Edo state ranked high yielding cassava varieties as highest preference followed by disease resistant varieties, high starch content, baking qualities, dry matter content, early maturity, drought and weed resistance. Farmers continue to plant their local varieties because of the better yield they get from them compared to the available improved varieties in the study locations.

To provide new varieties that will satisfy farmers' preferences and suit their socio-economic needs, and also bridge the gap between farmers and breeders, it is important to design and adopt participatory methods that would identify farmers' preferences from the early stage of breeding (goal setting, on farm trial, and varietal selection) in Edo State Nigeria. Active farmer participation in plant breeding is critical in selection and breeding stages for successful adoption of improved cassava varieties. However, the distribution of some of the IITA's improved varieties to the PRA study area will alleviate the farmers' long wait for new varieties that satisfy famers' preferences and suit their socio-economic needs. In addition, the collection of some of the farmers' choice varieties in order to assess their performance compared to IITA's improved varieties is important.

Recommendation

For further study, the morphological and genetic characterization of the farmers' *germplasm* in the PRA study area may reveal whether what farmers call local are really local or previously distributed improved varieties from both National and International institutes.

Plate 3.1: Cross section of the respondents in Irrua Edo Central senatorial zone

Plate 3.2: Cross section of the respondents in Uromi Edo Central senatorial zone

Plate 3.3: Cross section of the respondents in Ayogwiri Edo North senatorial

Plate 3.4: Cross section of the respondents in Igbogiri Edo South senatorial zone

Plate 3.5: Cross section of the respondents in Iguomokhoa Edo South senatorial zone

Plate 3.6: Cross section of the respondents in Iguomokhoa Edo South senatorial zone.

CHAPTER FOUR

4.0 PHENOTYPIC AND YIELD CHARACTERIZATION OF THE S_2 PARENTS AND THEIR DERIVED F_1 PROGENIES

4.1 Introduction

Cassava is grown throughout tropical Africa, Asia, and the Americas. Its large, starchy roots and edible leaves provide food for 800 million people globally, Cassava is drought tolerant and requires little in terms of inputs (Ceballos *et al.,* 2010). Cassava will continue to assume greater importance with time as a major source of carbohydrate for human consumption in the tropics and subtropics, where the low per capital income will not permit a change in the dietary habits (Uchendu *et al.,* 2014). Cassava is an out breeding crop that shows extreme plasticity, the crop is well known for its major ability to produce cost-effective yields under relatively marginal rainfall and soil conditions (Adjebeng-Danquah *et al.,* 2012).

Phenotypic characterization of *germplasm* reveals genetic variability which is important in hybridization programme. The presence of genetic variability implies that significant genetic gain through phenotypic selection is possible for the traits assessed (Agre *et al.,* 2015).

Phenotypic characterization has been extensively used for various crop plant diversity assessments in numerous places in the world (Lacroix *et al*., 2005; Li *et al*., 2009; K'Opondo, 2011). Compared to other methods, morphological characterization is direct, inexpensive and easy to use. Despite environmental effects on the morphology of plant and the subjectivity of measurements, morphological evaluations are considered the strongest determinants of the agronomic value and taxonomic classification of plants (Li *et al*., 2009) and the first step in the assessment of plant diversity. This tool has been successfully used for sweet potato, to analyze

genetic diversity necessary for germplasm conservation, and to enhance crop breeding (Yada *et al.*, 2010; Karuri *et al*., 2010; Li *et al*., 2009; Tairo *et al*., 2008). It has also been used for Musa breeding (Ortiz 1995, IITA, 1990). It is one of the stronger tools for identification of local accessions in cassava breeding programmes. Many studies have shown that improved yields can be realized by utilization of additive and non-additive gene effects including complementary gene interactions associated with inheritance. A large portion of the genetic variation for forage yield has been explained by non-additive components, and two-thirds of the variance for yield in alfalfa was non- additive (*Tucak et al*., 2012). Increase in fresh root yield and dry matter content also has been attributed to non-additive genetic effects (Kamau *et al*., 2010: Ceballos *et al*., 2012).

Heterosis has been known as a phenomenon, for about a century that increases fruitiness, size, vigour, speed of development, and resistance to pest and diseases (Shull 1908; 1952). It is also a phenomenon that enhances hybrid performance (Hartl and Clark, 1997). There are three theories of the control of heterosis as propounded by Crow (1948);- the dominance the over-dominace and epistatsis. Burton (1968) reported that heterosis results from combined action and interaction of allelic and non-allelic factors and is usually closely and positively correlated with heterozogosity. There are two different measures of heterosis. Mid-parent defined as the increased vigour of the F_1 over the mean of the parents. Better parent heterosis is defined as the increased vigour of the F_1 over the greater parent (Crow, 1952, 1999). However, heterosis must provide hybrid yields better than the best commercial hybrid check as farmers do not grow inbred parents. Therefore, yield performance of newly developed hybrids must be compared with best check varieties available. Hybrids that do not out yield the best check are not useful regardless of their mid or high parent heterosis. Heterosis has been exploited by breeders to enhance productivity

of numerous crops and horticultural plants. It has been extensively explored and utilized for boosting various traits in corn, sorghum, millet, sun- flower, sorghum and rice (Duvick 1999; 2001). The magnitude of heterosis is highly variable depending on the traits measured and the choice of parents (Stupar *et al*., 2008). Heterosis has been illustrated in trees as well as in *Jatropha curcas* L a facultative cross pollinated plant that is in the family of E*uphebiaceae.*

Cassava plant is a vegetative plant that can benefit from heterosis. Several reports by Easwari Amma *et al*., (1995); Easwari and Sheela (1998); Perez *et al*., (2005); Sridhar *et al.,* (2009) have demonstrated vigour and inheritance of economic traits in heterozygous cassava, the vigour could be masked by many allelic and non-allelic interaction at different locus, as a result the hybrid comprises of many lethallic to deleterious alleles. Introduction of partial inbreds to reduce within family variation usually found in heterozygous hybrid could be an innovative breeding scheme in cassava programme. Reports on cassava (*Manihot esculenta)* improvement through heterosis using partial inbred are scarce, since cassava inbreds are not normally developed. However, the application of heterosis in cassava using partially inbred lines could increase fresh root yield and dry matter content. The specific objectives of this study were to:

1. Assess the performance of S_2 lines and their derived progenies
2. To estimate mid-parents and better parent heterosis and compare yields to the best check varieties for S_2F_1 derived progenies

4.2 MATERIALS AND METHODS

4.2.1 Plant material

Thirteen genotype were used, eight selfed (S_2) lines and two hybrid checks from International Institute of Tropical Agriculture (IITA) and two selfed (S_2) lines and one inbred check originating from the National Root Crop Research Institute (NRCRI) (Table 4.1). A crossing block was established at Ubiaja, an out station of IITA, for pollination in 2012 where the selfed lines from elite varieties known for their good agronomic traits were crossed randomly. The choice of parents for this study was mainly based on the ability to flower and produce a good number of seeds. Crossing was done in November 2012 using hand pollination. A total of 87 S_2F_1 hybrids derived from the random matings, the parents and three checks were used in the study. Genotypes were considered as fixed effect because they were not randomly sampled to represent an identifiable population of *germplasm.* They were evaluated in two locations in Nigeria.

Table 4.1: Genetic material for study

Clone	Lines	Source
NR1S2002-2	S2	NRCRI
NR1S2109-59	S2	NRCRI
TMS-IBA102888	S2	IITA
TMS-IBA102894	S2	IITA
TMS-IBA102896	S2	IITA
TMS-IBA102909	S2	IITA
TMS-IBA102915	S2	IITA
TMS-IBA102918	S2	IITA
TMS-IBA102924	S2	IITA
TMS-IBA102927	S2	IITA
NRIS2003-5	Check	NRCRI
TMEB419	Check	IITA
TMS30572	Check	IITA

4.2.2 Seed germination

Seeds were germinated and grown on the 16th of April 2013 in the seedling nursery bed in a jiffy pot according to families, at the International Institute of Tropical Agriculture (IITA) Ibadan. Watering was done twice a day to ensure sufficient water and good germination. Two months after sowing, the seedlings were transplanted on 3rd of June 2013 to the seedling nursery field in IITA research station. The seedlings were planted at a spacing of 1 m x 0.5 m and 2 cm depth. The seedlings were planted in a single unreplicated row. The seedlings were evaluated at the end of 8 months for ability to produce 5 stakes per seedling for the establishment of a preliminary yield trial to evaluate heterosis.

4.2.3 Experimental Design (Preliminary Yield trial)

The Preliminary Yield Trial was an incomplete block design (alpha lattice), with 87 progenies, 10 parents and three checks of five row plots of five plants/plot making 20 blocks per replicate. The genotypes were evaluated at two locations Ibadan (E003°54′286″, N07°29′234″) within forest savanna transition zone and Ikenne (E003°42′717″;N06°51′436″) within forest zone (Table 4.2). In each location, the trial was planted in two replications. The genotypes were grown under rain-fed conditions.

Table 4. 2: Agro-ecological characteristics of the experimental locations.

Location	Agroecological Zone	Soil type	Altitude(masl)	Mean average rainfall (mm)	Wet season	Temperature range (ºC)
Ibadan	Forest savanna transition	Ferric Luvisols	210	1320	Mar-Nov	20-35
Ikenne	Rain forest	Eutric Luvisols	44	1515	Mar-Oct	22-33

Source: IITA 2014

Establishment of preliminary yield trial (PYT) was done at 28th February 2014 in Ibadan eight months after seed germination and at Ikenne 4th October 2014 eight months after the first trial was established for unavailability of planting materials to establish the two trials. The stakes cut from the seedling nursery (25cm long) were planted at a spacing of 1 m x 0.8 m giving a population of 12,500 plants/ha (Ekanayake, 1996). The plot size was 4 m^2. No fertilizer was applied during the course of the research. Herbicide was applied a day after planting to suppress the weeds for a month before emergence. Hand weeding was done when necessary. The harvesting was done at 10 months after planting (MAP) (Aina, 2007; Adeniji *et al.*, 2011).

4.2.4 Data collection

Field data were collected from a plot of 5 plants (4 m^2); samples for dry matter were taken. Data on yield and its components were collected at each harvest as follows:

a. Fresh yield (included all roots of a plant)

b. Shoot weight (included leaves, stems and the stump)

c. Root number (the number of roots harvested per plant /plo)

d. Dry matter content; Sampling for root dry matter (RDMC) was done by selecting three representative roots from a bulk of roots harvested from 5 plants. Cassava roots were washed and shredded into pieces using a hand shredding machine (IITA, 2010) a standard measure of 100 g weight of the fresh samples were taken and oven dried with forced draught oven and the samples reweighed again to obtain a constant weight after 72 hrs of 65-70^{o}C temperature (Fukuda *et al*., 2010).

e. Total carotene was subjectively scored at 10 MAP on a scale of 1-5 using a colour chart (IITA, 1990; IITA, 2010; Fukuda *et al*, 2010) as follows: 1=white, 2=cream, 3=yellow, 4=orange, 5=pink

f. Harvest index (HI) determined by taking a ratio between storage root yield and:- total biomass (fresh weight of storage root /total plant weight).

g. Cassava mosaic disease (CMD) severity was subjectively scored at-1, 3 and 6 MAP on a scale of 1-5, according to (Mahungu and Kanju 1997; IPGRI, 2003; CIAT 2003) as follows: 1= No symptoms observed; 2= Mild chlorotic pattern on entire leaflets or mild distortion at base of leaflets, the rest of leaflets appearing green and healthy; 3= strong mosaic pattern on entire leaf, and narrowing and distortion of lower one-third of leaflets; 4= Severe mosaic with distortion of two-thirds of leaflets and general reduction of leaf size; 5= Severe mosaic, distortion of four-fifths or more of leaflets, twisted and misshapen leaves.

h. Cassava bacterial blight (CBB) severity was subjectively scored at - 1, 3 and 6 MAP on a scale of 1-5 (IPGRI, 2003; CIAT 2003; IITA, 2010) as follows: 1= No symptoms

observed, 2= Very mild, 3=Average 4=Severe 5= Candle stick and die back from the youngest of the leaves back to the stem of the cassava plant.

i. Plant height was measured as vertical height from the ground to the top of the canopy expressed in centimeter (cm).

4.2.5 Data analysis

4.2.5.1 Agro- morphological data

General analyses of variance for alpha lattice using PROC GLM in SAS (SAS, 2009). was performed for all genotypes for yield and other agronomic traits. Means were separated using Proc LS means procedure of SAS (SAS, 2009). The alpha lattice linear model used is as follows: $Y_{ijl}=\mu+\tau_i+\gamma_j+\rho I_{(j)}+E_{ijl}$.

Where τ_i=treatment effect, i=1,2...t

γ_j = replicate effect, j=1,2...r

ρI=block within replicate effect, I=1,2...s

4.2.5.2 Principal Components Analysis

Principal components analysis of the 10 morphological traits was performed to examine the percentage contribution of each trait to the total genetic variation using SAS (SAS, 2009).

4.2.5.3 Heritability

Restricted maximum likelihood (REML) estimates of the genotypes genetic and phenotypic variances were obtained with SAS PROC Varcomp and were used to compute broad-sense heritability for each trait.

Broad-sense heritability (H^2) was estimated as: $H^2 = \frac{\delta_g^2}{\delta_g^2 + \left(\frac{\delta_{ge}^2}{e}\right) + \left(\frac{\delta_e^2}{re}\right)}$

4.2.5.4 Correlation Analysis

Pearson correlation analysis was performed to estimate the relationship among traits.

4.2.5.5 Harvest index

The percent harvest index was computed as fresh yield divided by fresh yield plus top yield. Fresh yield/(fresh yield+ top yield).

4.2.5.6 Heterosis Estimation

$$MPH = \left(\frac{F_1 - MP}{MP}\right) x100$$

The values of the cross were computed for each trait as

$$BPH = \left(\frac{F_1 - BP}{BP}\right) x100$$

Where F_1 is the mean of the F1 hybrid performance

MP= the mean of the inbred parents that constituted the hybrids, and

BP = the mean of the better parent.

4.2.5.7 Cluster analysis

Cluster analyses using SAS 9.3 enterprise were performed to group observations together using hierarchical classification based on the principal component analyses performed.

4.2.5.8 Average performance of the best 20 and worst 20 genotypes ranked by yield

This was done by ranking the best performing hybrid for cassava fresh root yield and the corresponding high dry matter content.

4.4 Results

4.4.1 Agro- morphological data

The combined analysis of variance across environments and genotypes indicated significant ($P < 0.001$) differences among S_2F_1 hybrids for all traits (Table 4.3). There was significant genetic variability among the clones for growth and root yield characteristics. Genotype x environment interaction effects were also significant ($P < 0.05$) for most traits except mean plant height, mean cassava mosaic disease severity, mean cassava bacterial blight severity and fresh root yield. Environmental effects were highly significant ($P < 0.001$) for all traits except dry matter content, mean plant height and cassava bacterial blight severity.

Broad sense heritability estimates ranged from 35% for total carotene to 95% for plant height (Tables 4.3 and 4.4). Harvest index was highest for the hybrid TMS-IBA102896XTMS-IBAI102909 (TMS14-024-01) (0.62), followed by a parent IBA102909 (0.56) and a check NRIS2003-5 (0.53).

Table 4.3: Mean square values for plant height (cm), cassava mosaic disease and cassava bacterial blight

Sources	df	mpltht	mcmds	mcbbs
Location	1	0.00059ns	0.82**	0.239ns
Replicate	1	1.32147***	0.064ns	0.193ns
Block	19	0.11909***	0.14ns	1.237***
Clone	93	0.34299***	4.824***	1.257***
Loc x Clone	92	0.00085ns	0.1467ns	0.307ns
Residual		0.0343	0.130	0.422
CV%		10.2	17.2	33.4
R^2		0.89	0.96	0.73
H^2		95	97	72

df=degree of freedom, mpltht = mean plant height, mcmds=mean cassava mosaic disease severity, mcbbs= mean cassava bacterial blight severity. H^2 broad sense heritability *P<0.05, **P<0.01, ***P<0.001

Table 4.4: Mean square values for root number, fresh root yield total carotene content, top yield, dry matter content and harvest index

Sources	df	rtno	fyld	tc	tyld	dm	hi
Location	1	6313.67***	9541.10***	2.262***	290.81**	24.24ns	1.508**
Replicate	1	207.69*	394.96*	0.1198ns	160.20ns	15.00ns	0.026
Block	19	114.99**	178.87**	0.104ns	129.44ns	7.61ns	0.012ns
Clone	95	175.88***	229.80***	2.145**	231.0007***	48.33***	0.036***
LocxClone	84	85.24**	104.00ns	0.3.64*	126.22**	20.52***	0.02***
Residual		56.91	88.036	0.215	98.81	12.83	0.011
Cv%		52.9	65.6	23.1	53.5	10.7	25.8
R^2		0.81	0.77	0.89	0.71	0.81	0.82
H^2		60	57	35	49	65	54

rtno= root number fyld= fresh root yield, (t/ha), tc= total carotene content, tyld=top yield (t/ha), dm= dry matter content and hi= harvest index, *P<0.05, **P<0.01,***P<0.001

4.4.2 Principal Component Analysis

Principal component analysis (PC) of the 10 traits revealed that the first three components cumulatively accounted for 70.53% of the total variation observed among the genotypes (Tables 4.5 and 4.6). Traits with higher values, from two and above, were considered as contributing significantly to the variation among the genotypes. The first component with an Eigen value of 3.82 accounted for 38.3% of the variation. The traits that contributed most of the variation were mean plant height, root number, fresh root yield, top yield and selection index. The second PC also contributed 17.33% of the total variation and the traits includes mean cassava bacterial blight severity, root number, fresh root yield, and harvest index. The third PC with 14.9% contribution was associated with mean cassava mosaic disease severity, total carotene and dry matter content. The values in bold for each of the

principal component are the ones contributing to the major or total variation observed Table (4.6).

Table 4.5: Eigenvalues of the principal component for the ten traits of cassava

	Eigenvalue	Difference	Proportion	Cumulative
1	3.82586785	2.09273853	0.3826	0.3826
2	1.73312932	0.24010871	0.1733	0.5559
3	1.49302061	0.49475323	0.1493	0.7052
4	0.99826738	0.23991304	0.0998	0.8050
5	0.75835434	0.27500279	0.0758	0.8809
6	0.48335155	0.09898941	0.0483	0.9292
7	0.38436214	0.12800715	0.0384	0.9676
8	0.25635499	0.19794481	0.0256	0.9933
9	0.05841018	0.04952855	0.0058	0.9991
10	0.00888163		0.0009	1.0000

Table 4.6: Principal component analysis of ten traits showing their contribution to the total variation among 87 S_2F_1 hybrids in cassava genotypes

	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10
mpltht	**0.321824**	-.220659	0.165769	**0.482576**	0.074080	-.432729	**0.626097**	0.044458	-.013058	-.022208
mcmds	-.198754	0.179715	**0.330534**	**0.648960**	**0.390052**	-.037196	-.492162	-.022083	0.037507	-.012484
mcbbs	-.190914	**0.476352**	0.027259	**0.361762**	-.516186	**0.396605**	**0.292933**	**0.308866**	-.007823	-.003568
rtno	**0.395182**	**0.346325**	-.004109	0.088872	-.055605	**0.200285**	0.060677	-.797113	0.090195	0.159883
fyld	**0.461943**	**0.232698**	0.109918	-.084425	0.017046	-.074802	-.191172	**0.311998**	-.595650	**0.467628**
tyld	**0.433618**	-.273057	-.048952	0.139882	-.243566	0.122289	-.296254	**0.265864**	**0.634681**	**0.282672**
Tc	0.056944	-.208482	**0.639467**	-.208079	**0.303624**	**0.580716**	**0.251357**	0.068889	0.038580	0.047378
dm	0.046032	0.032755	**-.646429**	0.168218	**0.578594**	**0.357662**	**0.202643**	0.155494	0.011373	0.150250
Hi	0.094510	**0.629975**	0.133096	-.327319	**0.293629**	-.309651	0.132184	**0.232191**	**0.458658**	-.074111
Si	**0.498598**	0.045222	-.059389	0.042134	0.006371	0.179902	-.173944	0.126035	-.143604	-.803047
Eigen values	3.825	1.733	1.493	0.998	0.758	0.483	0.384	0.256	0.058	0.008
%Variance	38.3	17.3	14.9	9.9	7.5	4.8	3.8	2.6	.5	09
% cumulative	38.3	55.6	70.5	80.5	88.9	92.9	96.8	99.3	99.9	100

Figures in bold represent significant traits in the various principal components; mpltht= mean plant height, mcmds=mean cassava mosaic disease severity, mean cassava bacterial blight, rtno= root number fyld= fresh root yield, (t/ha), tc= total carotene content, tyld=top yield (t/ha), dm= dry matter content and hi= harvest index, selection index.

4.4.3 Pearson Correlation Analysis

The phenotypic correlations among the traits evaluated are presented in Table 4.7 Most of the traits were positively and significantly correlated. The result revealed that mcbbs was positively correlated with cmds but negatively correlated with plant height, rtno was positively correlated with mpltht but negatively correlate with cmds, fyld was positively correlated with mplht and rtno and negatively correlated with cmds. Top yield was positively correlated with mpht, rtno, fyld and negatively correlated with mcbbs and mcmds. TC is positively correlated with mpltht and fyld, while negatively correlated with mcbbs. Dry matter did not correlate with any other trait with the exception of tc that was negatively correlated. Harvest index was positively correlated with mcbbs, rtno and fyld but negatively correlated with tyld while selection index was positively correlated with

mpltht, rtno, fyld, tyld, dm, tc and with hi, but negatively correlated with mcbbs and mcmds.

4.4.4 Heterosis Estimation

The mid-parent and better parent heteroses expressed differently among the different traits. There was positive and negative heterosis observed for the different crosses.

For root number, 20 crosses exhibited positive mid-parent heterosis ranging from 23.78 to 147.10% and 20 other crosses exhibited negative heterosis which ranged from -114.5 to -39.66% as presented in Table 4.8, 4.10, Appendix 4.1 and Appendix 4.2. Nineteen crosses exhibited positive better parent heterosis which ranged from 0.51-122.99% and 20 other crosses exhibited negative better parent heterosis which ranged from -112.44 to -50.49%. The performance of fresh root yield averaged across 87 hybrids compared with their parents are summarized in Table 4.8 and Appendix 4.1. The actual yield data is in Table 4.12 and 4.13. Twenty hybrids exhibited positive mid-parent heterosis ranging from 6.54 to 350.08%, while 15 crosses exhibited better parent heterosis which ranged from 6.4 to 276.27%**.** The range for both negative mid-parent heterosis and better parent heterosis was -103.18 to -56.31% and -102.26 to -67.50 %**,** respectively. Dry matter content performance averaged across 87 hybrids compared with their parent are presented in Table 4.9 and Appendix 4.1. Twenty crosses exhibited positive mid-parent heterosis, ranging from 3.83% to 18.3 % and 16 other crosses exhibited positive BPH ranging from1.43 to 13.24%. Negative mid-parent heterosis and better parent heterosis was seen in 20 crosses and ranged from -49.99 to -10.07, -55.36 to -15.55%**,** respectively (Table 4.11 and Appendix 4.2). Positive mid-parent heterosis and better parent heterosis for harvest index was observed

for 20 crosses and the range of heterosis was 10.63 to 39.21% and 2.44 to 33.86%**.** The negative hetrosis also ranged from -51.50 to -33.22% and -54.40 to -34.91 for mid-parent heterosis and better parent heterosis (Table 4.11 and Appendix 4.2).

4.4.5 Cluster Analysis

From the hierarchical cluster analysis, all the parameters showed a high diversity according to the root mean square of the major variable determined by principal component one, with average distance of 0.25 within the 100 (87 S_2F_1 hybrids, 10 parents and 3 checks) genotypes evaluated.

The genotypes were grouped into three main (3) clusters based on the diversity that existed among them. Cluster one consisted of 36 genotypes, cluster two 29 genotypes and cluster three 26 genotypes (Fig 4.1).

In cluster one, there were 29 different hybrids, four parents and three checks**.** One of the checks, TMEB419 was from IITA and is a landrace from Togo and also a popular high starch variety in Nigeria. The check IBA30572 has the pedigree 58308/Branca de Santa Caterina and is a national check used in many trials in Nigeria; the last check is an inbred S_2 genotype NRIS2003-5 from the National root crop Research Institute Umudike, Nigeria (IITA, 2010).

The second cluster consisted of 28 different hybrids and two parents.

The third cluster contained 21 hybrids and five parents.

Table 4.7: Phenotypic correlation on plant height, cassava mosaic disease, cassava bacterial blight, root number, fresh root yield (t/ha), total carotene content, top yield (t/ha), dry matter content and harvest index

	mpltht	mcmds	mcbbs	rtno	fyld	tyld	tc	dm	hi
mpltht									
mcmds	-0.05109ns								
mcbbs	-0.25888***	0.30699***							
rtno	0.22011***	-0.09494*	0.02438ns						
fyld	0.29342***	-0.1463**	-0.03955ns	0.70495***					
tyld	0.42***	-0.22141***	-0.19638***	0.41487***	0.64804***				
tc	0.18462***	0.07743ns	-0.16113**	0.05216ns	0.13967**	0.05239ns			
dm	-0.13012ns	-0.07424ns	0.01579ns	0.06024ns	-0.01808ns	0.02873ns	-0.28092**		
hi	-0.06399ns	0.02811ns	0.15353**	0.45709***	0.52409***	-0.2012***	0.07768ns	-0.00039ns	
si	0.33176***	-0.21747****	-0.11835*	0.7305***	0.9173***	0.83699***	0.1094*	0.17194**	0.25084***

mpltht = mean plant height, mcmds=mean cassava mosaic disease severity, mcbbs= mean cassava bacterial blight severity.rtno= root number fyld= fresh root yield, (t/ha), tc= total carotene content, tyld=top yield (t/ha), dm= dry matter content and hi= harvest index, *P<0.05, **P<0.01,***P<0.001

Table 4.8: Mean performance of parents, F_1 hybrids and percentage increase over mid-parent (relative heterosis) and better parent (heterobeltiosis) for root number and fresh root yield.

rtno	mph	rtno	bph	Fyld (t/ha)	mph	Fyld (t/ha)	bph
NRIS2002-2XTMS-IBA102894	147.10	TMS-IBA102918XTMS-IBA102924	122.99	NRIS2002-2XTMS-IBA102894	350.08	NRIS2002-2XTMS-IBA102894	276.27
TMS-IBA102918XTMS-IBA102924	137.07	TMS-IBA102918XTMS-IBA102924	97.16	NRIS2002-2XTMS-IBA102894	259.91	NRIS2002-2XTMS-IBA102894	200.88
NRIS2002-2XTMS-IBA102894	110.38	NRIS2002-2XTMS-IBA102894	80.42	TMS-IBA102918XTMS-IBA102924	168.07	TMS-IBA102918XTMS-IBA102924	162.62
TMS-IBA102918XTMS-IBA102924	109.61	TMS-IBA102888XTMS-IBA102924	59.02	NRIS2002-2XTMS-IBA102894	128.81	TMS-IBA102888XTMS-IBA102894	109.79
NRIS2002-2XTMSIBA102894	99.14	NRIS2002-2XTMS-IBA102894	53.61	TMS-IBA102888XTMS-IBA102894	110.10	TMS-IBA102888XTMS-IBA102894	104.80
TMS-IBA102888XTMS-IBA102894	97.92	TMS-IBA102888XTMSIBA102894	51.34	TMS-IBA102888XTMS-IBA102894	105.10	NRIS2002-2XTMS-IBA102894	91.28
TMS-IBA102888XTMS-IBA102924	81.06	NRIS2002-2XTMS-IBA102894	45.40	TMS-IBA102918XTMS-IBA102924	90.23	TMS-IBA102918XTMS-IBA102924	86.36
TMS-IBA102888XTMS-IBA102927	79.11	NRIS2109-59XTMS-IBA102924	43.38	TMS-IBA102888XTMS-IBA102894	54.83	TMS-IBA102888XTMS-IBA102894	54.60
TMS-IBA102888XTMS-IBA102927	59.85	TMS-IBA102918XTMS-IBA102924	39.05	TMS-IBA102918XTMS-	46.06	TMS-IBA102918XTMS-IBA102924	43.08
TMSIBA102888XTMS-IBA102927	58.86	TMS-IBA102888XTMS-IBA102927	26.72	NRIS2002-2XTMS-IBA102894	42.00	TMS-IBA102888XTMS-IBA102894	29.76
NRIS2109-59XTMS-IBA102924	57.85	TMS-IBA102896XTMS-IBA102909	21.56	TMS-IBA102888XTMS-IBA102894	29.95	NRIS2109-59XTMS-IBA102924	23.69
TMS-IBA102888XTMS-IBA102927	57.78	TMS-IBA102888XTMS-IBA102927	13.10	NRIS2109-59XTMS-IBA102924	29.04	NRIS2002-2XTMS-IBA102894	18.71
TMS-IBA102888XTMS-IBA102924	50.38	TMS-IBA102888XTMS-IBA102927	12.39	NRIS2109-59XTMS-IBA102924	18.91	TMS-IBA102896XTMS-IBA102909	14.97
TMS-IBA102918XTMS-IBA102924	47.84	TMS-IBA102888XTMS-IBA102927	11.63	TMS-IBA102888XTMS-IBA102924	15.65	NRIS2109-59XTMS-IBA102924	13.98
TMS-IBA102888XTMS-IBA102894	44.53	TMS-IBA102888XTMS-IBA102894	10.51	TMS-IBA102896XTMS-IBA102909	14.97	TMS-IBA102896XTMS-IBA102909	6.54
TMS-IBA102927XTMS-IBA102924	37.76	TMS-IBA102927XTMS-IBA102924	6.67	NRIS2002-2XTMS-IBA102894	11.41	-	-
TMS-IBA102896XTMS-IBA102909	33.26	TMS-IBA102888XTMS-IBA102924	6.39	TMS-IBA102927XTMS-IBA102924	10.79	-	-
TMS-IBA102927XTMS-IBA102924	25.80	NRIS2109-59XTMS-IBA102924	6.11	TMS-IBA102915XTMS-IBA102909	8.84	-	-
TMS-IBA102888XTMS-IBA102927	25.26	TMS-IBA102896XTMS-IBA102909	0.51	TMS-IBA102888XTMS-IBA102927	8.70	-	-
TMS-IBA102927X TMS-IBA102924	23.78	-	-	TMS-IBA102896XTMS-IBA102909	6.54	-	-

mph=mid-parent heterosis, bph=better parent heterosis, rtno= root number, fyld= fresh root yield **hybrids with the same parents are different from each other

Table 4.9: Mean performance of parents, F_1 hybrids and percentage increase over mid-parent (relative heterosis) and better parent (heterobeltiosis) for dry matter content and harvest index

dm (%)	mph	dm (%)	bph	hi	mph	hi	bph
TMS-IBA102888XTMS-IBA102927	18.3	TMS-IBA102888XTMS-IBA102927	13.2	TMS-IBA102918XTMS-IBA102924	39.21	TMS-IBA102888XTMS-IBA102927	33.86
TMS-IBA102888XTMS-IBA102927	17.5	TMS-IBA102888XTMS-IBA102927	12.4	NRIS2002-2XTMS-IBA102894	38.23	TMS-IBA102888XTMS-IBA102927	32.82
NRIS2109-59XTMS-IBA102924	14.4	NRIS2002-2XTMS-IBA102894	11.1	TMS-IBA102918XTMS-IBA102924	31.15	NRIS2002-2XTMS-IBA102894	20.28
NRIS2002-2XTMS-IBA102894	13.9	TMS-IBA102896XTMS-IBA102909	7.7	TMS-IBA102927XTMS-IBA102924	25.42	TMS-IBA102888XTMS-IBA102927	19.72
NRIS2109-59XTMS-IBA102924	12.4	TMS-IBA102888XTMS-IBA102927	7.0	NRIS2109-59XTMS-IBA102924	21.93	TMS-IBA102888XTMS-IBA102924	19.61
TMS-IBA102888XTMS-IBA102927	11.8	TMS-IBA102888XTMS--IBA102894	6.7	TMS-IBA102888XTMS-IBA102894	20.07	TMS-IBA102918XTMS-IBA102924	15.96
TMS-IBA102915XTMS-IBA102909	10.7	NRIS2002-2XTMS-IBA102894	6.6	TMS-IBA102888XTMS-IBA102894	19.42	TMS-IBA102888XTMS-IBA102927	15.49
TMS-IBA102888XTMS-IBA102894	10.4	TMS-IBA102927XI102924	5.8	NRIS2002-2XTMS-IBA102894	18.34	TMS-IBA102896XTMS-IBA102909	12.50
TMS-IBA102927XTMS-IBA102924	9.5	TMS-IBA102888XTMS-IBA102927	4.18	TMS-IBA102888XTMS-IBA102894	17.55	TMS-IBA102888XTMS-IBA102927	11.00
NRIS2109-59XTMS-IBA102924	9.4	TMS-IBA102888XTMS-IBA102894	3.6	NRIS2109-59XTMS-IBA102924	16.41	TMS-IBA102918XTMS-IBA102924	9.24
NRIS2002-2XTMS-IBA102894	9.3	TMS-IBA102888XTM-IBA102924	3.0	TMS-IBA102888XTMS-IBA102927	15.40	TMS-IBA102888XTMS-IBA102924	8.80
TMS-IBA102888XTMS-IBA102927	8.8	TMS-IBA102888XTMS-IBA102894	3.0	TMS-IBA102927XTMS-IBA102924	15.25	NRIS2109-59XTMS-IBA102924	6.96
TMS-IBA102896XTMS-IBA102909	8.6	TMS-IBA102896XTMS-IBA102909	3.0	NRIS2109-59XTMS-IBA102924	15.11	TMS-IBA102888XTMS-IBA102894	6.73
TMS-IBA102915XTMS-IBA102909	8.3	TMS-IBA102888XTMS-IBA102927	2.7	TMS-IBA102888XTMS-IBA102927	14.50	TMS-IBA102888XTMS-IBA102894	3.74
TMS-IBA102888XTMS-IBA102924	7.6	TMS-IBA102927XTMS-IBA02924	2.0	TMS-IBA102888XTMS-IBA102924	12.83	TMS-IBA102888XTMS-IBA102927	3.23
TMS-IBA102888XTMS-IBA102927	7.2	TMS-IBA102888XTMS-IBA102894	1.4	TMS-IBA102896XTMS-IBA102909	12.74	TMS-IBA102888XTMS-IBA102894	3.18
TMS-IBA102888XTMS-IBA102894	6.6	-	-	NRIS2002-2XTMS-IBA102894	12.55	NRIS2002-2XI102894	2.97
TMS-IBA102927XTMS-IBA102924	5.6	-	-	TMS-IBA102888XTMS-IBA102894	11.58	TMS-IBA102927XTMS-IBA102924	2.57
TMS-IBA102888XTMS-IBA102927	4.3	-	-	NRIS2109-59XTMS-IBA102924	10.84	TMS-IBA102888XTMS-IBA102927	2.46
TMS-IBA102896XTMS-IBA102909	3.8	-	-	TMS-IBA102927XTMS-IBA102924	10.63	TMS-IBA102888XTMS-IBA102924	2.44

mph=mid-parent heterosis, bph=better parent heterosis, dm= dry matter content and hi= harvest index, **hybrids with the same parents are different from each other

Table 4.10: Mean performance of parents, F_1 hybrids and percentage decrease over mid-parent (relative heterosis) and better parent (heterobeltiosis) for root number and fresh root yield.

rtno	mph	Rtno	bph	Fyld (t/ha)	mph	Fyld (t/ha)	bph
TMS-IBA102888XTMS-IBA102924	-39.66	TMS-IBA101927XTMS-IBA102924	-50.49	TMS-IBA102888XTMS-IBA102927	-56.31	TMS-IBA102888XTMS-IBA102927	-67.50
TMS-IBA102915XITMS-IBA02909	-42.81	TMS-IBA102915XTMS-IBA102909	-51.03	TMS-IBA102888XTMS-IBA102927	-58.97	TMS-IBA102888XTMS-IBA102927	-69.48
TMS-IBA102896XTMS-IBA102909	-43.56	TMS-IBA102896XTMS-IBA102909	-51.64	TMS-IBA102888XTMS-IBA102924	-60.87	TMS-IBA102888XTMS-IBA102924	-70.89
TMS-IBA102888XTMS-IBA102927	-43.89	TMS-IBA102888XMS-IBA102927	-52.25	TMS-IBA102888XTMS-IBA102927	-61.61	TMS-IBA102888XTMS-IBA102927	-71.44
TMS-IBA102896XITMS-IBA102909	-46.99	TMS-IBA102918XTMS-IBA102924	-55.37	TMS-IBA102888XTMS-IBA102927	-62.51	TMS-IBA102888XTMS-IBA102927	-72.11
TMS-IBA102888XTMS-IBA102927	-48.29	TMS-IBA102888XTMS-IBA102927	-60.30	TMS-IBA102888XTMS-IBA102924	-63.67	TMS-IBA102888XTMSIBA102924	-72.18
TMS-IBA102888XITMS-IBA02924	-50.73	TMS-IBA102915XTMS-IBA102909	-61.08	TMS-IBA102915XTMS-BA102909	-65.92	TMS-IBA102915XTMS-IBA102909	-72.80
TM-IBA101927XTMS-IBA102924	-51.39	TMS-IBA101927XTMS-IBA102924	-62.36	TMS-IBA102888XTMS-IBA102927	-68.21	TMS-IBA102888XTMS-IBA102924	-72.98
TMS-IBA102918XTMS-IBA102924	-52.55	TMS-IBA102888XTMS-IBA102927	-63.42	TMS-IBA102888XTMS-IBA102927	-68.22	TMS-IBA102888XTMS-IBA102924	-74.82
TMS-IBA102888XTMS-IBA102927	-53.24	TMS-IBA102896XTMS-IBA102909	-64.74	TMS-IBA101927XTMS-IBA102924	-68.25	TMS-IBA102888XTMS-IBA102927	-76.35
TMS-IBA102915XTMS-IBA102909	-54.55	I102888XI102924	-65.14	TMS-IBA101927XTMS-IBA102924	-70.98	TMS-IBA102888XTMS-IBA102927	-76.36
TMS-IBA102888XTMS-IBA102927	-55.45	TMS-IBA102896XTMS-IBA102909	-66.37	TMS-IBA102888XTMS-IBA102924	-72.14	TMS-IBA101927XTMS-IBA102924	-76.36
TMS-IBA102888XTMS-IBA102924	-56.05	TMS-IBA102888XTMS-IBA102927	-66.92	TMS-IBA102888XTMS-IBA102924	-74.79	TMS-IBA102896XTMS-IBA102909	-77.65
TMS-IBA102896XTMS-IBA102909	-61.35	I102888XI102927	-68.48	TMS-IBA102896XTMS-IBA102909	-77.65	TMS-IBA102896XTMS-IBA102909	-78.37
TMS-IBA102896XTMS-IBA102909	-63.14	TMS-IBA102888XTMS-IBA102924	-68.91	TMS-IBA102896XTMS-IBA102909	-78.37	TMS-IBA102927XTMS-IBA102924	-78.40
TMS-IBA102888XTMS-IBA102924	-63.45	I102888XI102924	-74.14	TMS-IBA102888XTMS-IBA102924	-81.04	TMS-IBA102896XTMS-IBA102909	-82.89
TMS-IBA102888XTMS-IBA102927	-71.64	TMS-IBA102888XTMS-IBA102927	-79.93	TMS-IBA102896XITMS-IBA02909	-82.89	TMS-IBA102888XTMS-IBA102924	-85.90
TMS-IBSA102888XTMS-IBA102924	-75.05	TMS-IBA102888XTMS-IBA102924	-82.34	TMS-IBA102888XTMS-IBA102927	-90.73	TMS-IBA102888XTMS-IBA102927	-93.10
TMS-IBA101927XTMS-IBA102924	-81.92	TMS-IBA101927XTMS-IBA102924	-86.00	TMS-IBA102896XTMS-IBA102909	-97.86	TMS-IBA102896XTMS-IBA102909	-97.86
TMS-IBA102915XTMS-IBA102909	-114.52	TMS-IBA102915XTMS-IBA102909	-112.44	TMS-IBA102888XTMS-IBA102924	-103.18	TMS-IBA102888XTMS-IBA102924	-102.36

mph=mid-parent heterosis, bph=better parent heterosis rtno= root number fyld= fresh root yield **hybrids with the same parents are different from each other

Table 4.11: Mean performance of parents, F_1 hybrids and percentage decrease over mid-parent (relative heterosis) and better parent (heterobeltiosis) for dry matter content and harvest index.

dm (%)	mph	dm (%)	bph	hi	mph	hi	bph
TMS-IBA102888XTMS-IBA102924	-10.07	TMS-IBA102888XTMS-IBA102927	-15.55	TMS-IBA102927XTMS-IBA102924	-33.22	TMS-IBA102888XTMS-IBA102924	-34.91
TMS-IBA102918XTMS-IBA102924	-10.15	TMS-IBA102915XTMS-IBA102909	-15.58	TMS-IBA102888XTMS-IBA102894	-34.07	TMS-IBA102896XTMS-IBA102909	-35.94
TMS-IBA101927XTMS-IBA102924	-10.20	TMS-IBA102918XTMS-IBA102924	-15.68	TMS-IBA102888XTMS-IBA102927	-34.45	TMS-IBA102888XTMS-IBA102924	-36.90
NRIS2002-2XTMS-IBA102894	-10.94	TMS-IBA102896XTMS-IBA102909	-17.16	TMS-IBA102927XTMS-IBA102924	-34.52	TMS-IBA102888XTMS-IBA102927	-38.18
TMS-IBA102888XTMS-IBA102927	-11.77	TMS-IBA102896XTMS-IBA102909	-17.54	TMS-IBA102896XTMS-IBA102909	-35.81	TMS-IBA102888XITMS-IBA02924	-38.87
TMS-IBA102888XTMS-IBA102924	-12.27	TMS-IBA102918XITMS-IBA02924	-17.76	TMS-IBA102918XTMS-IBA102924	-35.98	TMS-IBA102888XTMS-IBA102924	-39.16
TMS-IBA101927XTMS-IBA102924	-12.35	TMS-IBA102888XTMS-IBA102927	-18.04	TMS-IBA102888XTMS-IBA102927	-37.08	TMS-IBA102888XTMS-IBA102894	-40.13
TMS-IBA102896XTMS-IBA102909	-14.13	TMS-IBA102888XITMS-IBA02924	-18.77	TMS0IBA102918XTMS-IBA102924	-37.25	TMS-IBA102888XTMS-IBA102924	-42.03
TMS-IBA102888XTMS-IBA102927	-14.38	NRIS2109-59XTMS-IBA102924	-19.03	NRIS2002-2XTMS-IBA102894	-38.80	TMS-IBA102888XTMS-IBA102927	-43.74
TMS-IBA102896XTMSIBA102909	-14.70	TMS-IBA102918XTMS-IBA102924	-19.39	TMS-IBA102888XTMS-IBA102924	-40.78	I101927XI102924	-45.39
TMS-IBA102896XTMS-IBA102909	-16.49	NRIS2002-2XTMS-IBA102894	-20.35	TMS-IBA102888XITMS-IBA102924	-41.91	TMS-IBA101927XTMS-IBA102924	-46.45
TMS-IBA102896XTMS-IBA102909	-16.88	TMS-IBA102888XTMS-IBA102927	-20.73	TMS-IBA102888XTMS-IBA102924	-42.79	TMSIBA102918XTMS-IBA102924	-46.68
TMS-IBA102888XTMS-IBA102927	-17.19	TMS-IBA102918XTMS-IBA102924	-22.89	TMS-IBA102888XTMS-IBA102894	-44.69	NRIS2002-2XTMS-IBA102894	-46.75
NRIS2002-2XTMS-IBA102894	-18.32	I102888XI102924	-23.67	TMS-IBA102888XTMS-IBA102924	-45.61	I102888XI102924	-47.25
TMS-IBA102918XTMS-IBA102924	-20.16	NRIS2109-59XTMS-IBA102924	-26.02	TMS-IBA102888XTMS-IBA102927	-46.70	TMS-IBA102918XTMS-IBA102924	-47.73
TMS-IBA102888XTMS-IBA102924	-20.26	TMS-IBA102888XTMS-IBA102927	-27.11	TMS-IBA102915XTMS-IBA102909	-47.23	TMS-IBA102888XTMS-IBA102924	-48.05
TMS-IBA102888XITMS-IBA02927	-23.85	TMS-IBA102888XI102894	-30.46	TMS-IBA102896XTMS-IBA102909	-48.19	TMS-IBA102896XTMS-IBA102909	-48.30
TMS-IBA102888XTMS-IBA102924	-27.58	TMS-IBA102888XTMS-IBA102924	-30.68	TMS-IBA102896XTMS-IBA102909	-49.62	TMS-IBA102896XTMS-IBA102909	-49.72
TMS-IBA102888XTMS-IBA102894	-28.04	TMS-IBA102918XTMS-IBA102924	-31.48	TMS-IBA102888XTMS-IBA102924	-50.02	TMS-IBA102888XTMS-IBA102894	-49.78
TMS-IBA102918XTMS-IBA102924	-47.99	TMS-IBA102918XITMS-IBA102924	-55.36	TMS-IBA102888XTMS-IBA102927	-51.50	TMS-IBA102915XTMS-IBA102909	-54.40

mph=mid-parent heterosis, bph=better parent heterosis, dm= dry matter content and hi= harvest index **hybrids with the same parents are different from each other

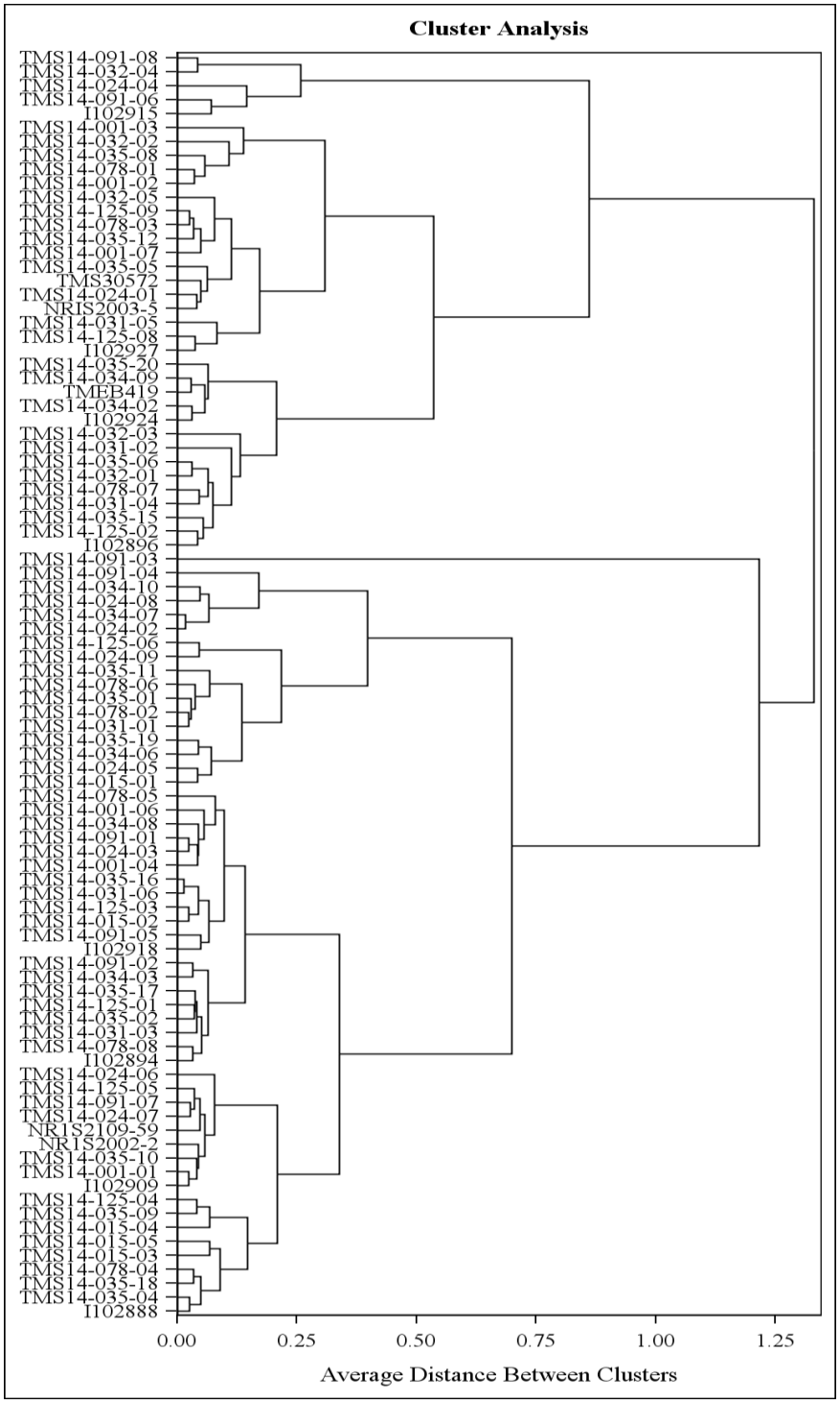

Figure 4.1: Dendrogram of the 100 genotypes showing the relationship between 87 S_2F_1 cassava and their parents

The genetic variability shown by this dendrogram reveals a very high diversity among these genotypes and the parents.

4.4.6 Average performance of the best 20 and worst 20 genotypes ranked by yield

For fresh root yield the best 20 hybrids ranged from 4.3(t/ha) for TMS-IBA102888XTMS-IBA102894 (TMS14-032-01) with a corresponding dry matter of 34.7% to 7.6 (t/ha) for TMS-IBA102918XTMS-IBA102924 (TMS14-091-08) with a corresponding dry matter of 33.4% (Table 4.12 and 4.13). Two hybrids TMS-IBA102918XTMS-IBA102924 (TMS14-091-08) and TMS-IBA102896XTMS-IBA102909 (TMS14-024-04) performed better than the check TMS30572 and the best parents for fresh root yield were TMS-IBA102896, TMS-IBA102927 and TMS-IBA102915 (Table 4.12 and 4.13). Across the two locations the genotypes that were outstanding for fresh root yield were TMS-IBA102918XTMS-IBA102924 (TMS14-091-08) and TMS-IBA102896XTMS-IBA102909 (TMS14-024-04). For dry matter it ranged from TMS-IBA102888X TMS-IBA102894 (TMS14-032-02) with the value 23.4% to TMS-IBA102888X TMS-IBA102927 (TMS14-035-11) with the value 41.4%. The best genotypes were TMS-IBA1028888XTMS-IBA102927 (TMS14-035-11), TMS-IBA102896X TMS-IBA102909 (TMS14024-04), TMS-IBA102896X TMS-IBA102909 (TMS14024-04), TMS-IBA102896X TMS-IBA102909 (TMS14024-01), TMS-IBA102888X TMS-IBA102927 (TMS14-035-08) TMS-IBA102888X TMS-IBA102927 (TMS14-035-20), TMS-IBA102888X102924 (TMS14-078-04), TMS-IBA 102927XTMS-IBA2924 (TMS14-125-01), TMS-IBA 102927XTMS-IBA2924 (TMS14-125-06).

Table 4.12: Average performance of the best 20 genotypes ranked by yield

S/N	Pedigree	F1	fyld (t/ha)	dm (%)
13	TMS-IBA102918XTMS-IBA102924	TMS14-091-08	7.6	33.4
14	TMS IBA102896XTMS-IBA102909	TMS14-024-04	6.5	39.7
15	**NR1S2003-5**	NRIS2003-5	6.2	31.6
16	**TMS30572**	TMS30572	6.1	32.9
17	TMS-IBA102896X TMS-IBA102909	TMS14-024-01	6.0	38.0
18	NRIS2002-2XTMS-IBA102894	TMS14-001-07	5.9	25.0
19	TMS-IBA102888XTMS-IBA102894	TMS14-032-02	5.8	23.4
20	TMS-IBA102888X TMS-IBA102894	TMS14-032-04	5.6	33.2
21	TMS-IBA102896	TMS-IBA102896	5.6	36.3
22	TMS-IBA102918XTMS-IBA102924	TMS14-091-06	5.6	36.9
23	TMS-IBA102927	TMS-IBA102927	5.4	27.1
24	TMS-IBA102915	TMS-IBA102915	4.9	31.1
25	TMS-IBA102888XTMS-IBA102924	TMS14-078-01	4.9	34.7
26	NRIS2002-2XTMS-IBA102894	TMS14-001-02	4.7	34.9
27	TMS-IBA102927XTMS-IBA102924	TMS14-125-08	4.7	34.3
28	TMS-IBA102888XTMS-IBA102927	TMS14-035-12	4.6	33.1
29	TMS-IBA102927XTMS-IBA102924	TMS14-125-09	4.4	33.5
30	TMS-IBA102915XTMS-IBA102909	TMS14-031-05	4.3	36.1
31	TMS-IBA102888XTMS-IBA102924	TMS14-078-03	4.3	28.1
32	TMS-IBA102888XTMS-IBA102894	TMS14-032-01	4.3	34.7
	Grand mean		**14.3**	**33.5**
	Se		**6.5**	**1.95**

dm= dry matter content, fyld= fresh root yield, **Note:** crosses with the same parents are different from each other

Table 4.13: Average performance of the worst 20 genotypes ranked by yield

S/N	Pedigree	F1	fyld (t/ha)	dm (%)
77	TMS-IBA102888XTMS-IBAI102927	TMS14-035-11	1.6	41.4
78	TMS-IBA102888XTMS-IBA102927	TMS14-035-18	1.6	38.4
79	TMS-IBA102888X TMS-IBA102924	TMS14-078-04	1.5	38.0
80	NRIS2109-59XTMS-IBA102924	TMS14-015-02	1.5	36.9
81	NRIS2002-2XTMS-IBA102894	TMS14-001-03	1.5	33.5
82	TMS-IBA102915XTMSIBA102909	TMS14-031-03	1.3	30.1
83	TMS-IBA102888XTMS-IBA102924	TMS14-034-03	1.3	37.6
84	TMS-IBA102888XITMS-IBA102927	TMS14-035-01	1.3	29.2
85	TMS-IBA102888XTMS-IBA102927	TMS14-035-20	1.3	39.4
86	TMS-IBA102927XTMSIBA102924	TMS14-125-01	1.3	39.0
87	TMS-IBA102896XTMS-IBA102909	TMS14-024-07	1.3	30.5
88	TMS-IBA102896XITMS-IBA102909	TMS14-024-02	1.2	31.2
89	TMS-IBA102927XITMS-IBA102924	TMS14-125-06	1.2	38.4
90	TMS-IBA102894	I102894	1.1	31.4
91	TMS-IBA102896X TMS-IBA102909	TMS14-024-03	1.0	33.0
92	TMS-IBA102888XTMS-IBA102924	TMS14-078-06	0.8	25.5
93	TMS-IBA102888XTMS-IBA102924	TMS14-034-07	0.8	33.9
94	TMS-IBA102888XTMS-IBA102924	TMS14-034-08	0.7	36.2
95	TMS-IBA102888XTMS-IBA102927	TMS14-035-09	0.4	34.0
96	TMS-IBA102896XTMS-IBA102909	TMS14-024-05	0.1	30.4
	Grand mean		**14.3**	**33.5**
	Se		**6.5**	**2.0**

dm= dry matter content, fyld= fresh root yield**Note:** crosses with the same parents are different from each other

4.5 Discussion

4.5.1 Agro- morphological data

Significant genotypic variation for all characters in the S_2F_1 hybrids implies differential response among the cassava clones and the degree of inherent variation for these characters. Similar results have been reported for agronomic and yield characters in cassava harvested at 10 to 12 months after planting. (Aina *et al* 2007; Adeniji *et al*, 2011).

The large environmental effect detected for root number, fresh root yield and most traits at the two locations suggests that the S_2F_1 hybrids are variable across the environments. This variation means that, by selecting and hybridizing among these elite S_2F_1 hybrids, good progress in the improvement of fresh root yield and yield related traits could be achieved. Similarly, significant genotype x environment interactions were detected for fresh root yield. This is an indication that there is large environmental effect on the phenotypic expression of this character. This agrees with reports of Aina *et al*., (2009) and Tumuhimbise *et al.*, (2014). The moderate heritability estimates for total carotene and plant top yield suggests that selection for these traits would be effective. The high broad sense heritability for fresh root yield and cassava mosaic disease severity indicates that they have both additive and non- additive variance. This agrees with the report of Akinwale *et al.*, (2010) that high broad sense heritability indicates the presence of large components of heritable portion of variation This also agrees with the results of DaSilva (2008): Parkes, (2011) and Chipetal *et al*., (2013) These results agrees with Kawano *et al.*, 1988 suggestion that heritability of cassava after hybridization is mainly broad sense in nature. A harvest index of 0.53 to 0.62% was detected in these hybrids. This result agrees with the results of Lorenzi (1978); Caval Canti (1985) and Pinho *et al.*, (1995).

4.5.2 Principal Components Analysis

The principal components analysis of traits revealed that the genotypes were diverse for all traits measured. These traits are distinct and vary with different genotypes and will be useful in selection. The important traits that distinguished the varieties were plant height which reflects the growth rate of the plant, fresh root yield, which reflects the total yield of

genotype per hectare and harvest index. Fresh root yield and plant height are quantitative traits, and are likely to be controlled by many genes and are therefore highly influenced by environment (Kang, 1998; Piepho, 2000; Aina *et al.*, 2009; Ntawuruhunga and Dixon, 2010). They are very important characteristics to consider in breeding programmes for cassava improvement.

4.5.3 Pearson Correlation Analysis

The positive association between cassava mosaic disease and cassava bacterial blight indicated that breeding for resistance for one would not affect the other. The negative correlation between cassava mosaic disease and root number suggests that severe CMD attack can result in low yield. Similarly, cassava mosaic disease had a significant negative influence on plant height and top yield. A previous study (Egesi *et al.*, 2007a) associated it with significant yield reduction due to reduction in leaf area and plant height. The positive correlation between fresh root yield, and root number suggests that indirect selection for fresh root yield could be achieved through selection for the number of roots. Cassava yield can greatly be reduced when root numbers are small. This also suggests that breeding for any one of these traits will not reduce the desired level of the others. This confirms with results of Kamau *et al*., (2010); Akinwale *et al.*, (2010) and Chipeta *et al.*, (2010). Akinwale (2009) further reported that traits which are significantly and positively correlated with root yield are crucial in cassava breeding aimed at improving tuberous root yield. The positive correlation of fresh root yield with root number, and harvest index suggests that they can be used as indices for yield selection. This indicates that selecting high harvest index will not compromise yield because it is an important trait as it measures the efficiency of a

genotype in partitioning dry matter to the storage roots. The negative association between total carotene content and dry matter content suggests a selection compromise (Adeniji *et al*., 2011) Breeding for high beta carotene content will compromise dry matter and vice versa.

4.5.4 Mid parent and better parent Heterosis

The highest mid-parent and better parent heterosis in rank order for root number was recorded for the hybrids TMS14-001-03 with 147% increase and TMS14-091-08 with 122% increase. Fresh root yield is generally associated with higher productivity. The highest positive mid-parent and better parent heterosis for fresh root yield were recorded for hybrid TMS14-001-07 with 350.08% for mid-parent heterosis and with 276% for better parent heterosis. Dry matter content is associated with higher productivity. The best mid-parent heterosis for dry matter content was recorded for the hybrid TMS14-035-5 with 18.3%, and the same hybrid had the best for better parent heterosis with 13.24%. For harvest index, the best hybrids for mid-parent heterosis were TMS14 091-04, with 39.2% and TMS14-035-06 with 33.9% increase respectively. High mid-parent heterosis between yield components and seed yield have been reported. (Thaker *et al.,* (2005) and Patel and Pathak (2006). High heterosis (328%) for seed yield was reported by Singh *et al*., (1983). Delgado (1972) produced several high yielding hybrids that had best parent heterosis which ranged from 200-275%. Islam *et al.,* (2011) reported a high mid-parent heterosis of seed yield of 254% and better parent heterosis of 202% on Jatropha of the *Euphobiaceae* family. Dwivedi *et al*., (1989) found 220% better parent heterosis for fruits per plant, while Prasath and Ponnuswani (2008) reported about 137% better parent heterosis. Kamau *et al*., (2010)

also reported a yield increase in cassava ranging from 0.8-1.46% for root weight per plant. Significant positive values for better parent heterosis and better parent heterosis were found in six progenies for different traits (root number, fresh root yield, dry matter content and harvest index). These results indicate that overdominance, complementary partial to complete dominance and epistasis contribute towards improved performance in cassava. Negative heterosis obtained in these cross combination could be a non- complementary gene effect of the parents.

4.5.5 Cluster Analysis

Cluster analysis based on morphological parameters showed a high diversity among the 100 (87 S_2F_1 hybrids, 10 parents and 3 checks) genotypes studied. The genotypes were grouped into three (3) main clusters. Cluster one included 29 different hybrids grouped by families, four parents and three checks. The second cluster included 28 different hybrids and one parents. The third cluster incuded five parents and 21 hybrids. The genetic variability shown by the dendrogram revealed a very high diversity among the genotypes and their parents.

4.6 Conclusion

The aim of this study was to evaluate cassava (S_2F_1 hybrids) by crossing different S_2 lines. The analysis of variance showed that the genotypes were diverse in disease resistance, root number, dry matter, fresh root yield, top yield and harvest index.

The magnitude of heterosis over mid-parent and better parent varied from cross to cross. The result for phenotypic superiority of hybrids over parents with respect to root number, fresh root yield, dry matter content and harvest index was promising for the development of superiror yield in cassava hybrids between S_2 lines. High broad sense heritability, wide genetic variability, and significant phenotypic association between traits were identified from the study. The significant genotype by environment variation observed implied that further selection should be done in replicated trials at more than two locations.

This study suggests that inbreeding with the parental clones would facilitate the gradual and consistent assembly of favorable gene combinations.

CHAPTER FIVE

5.0 COMBINING ABILITY AND HETEROSIS IN ELITE S_2 CASSAVA LINES USING HALF DIALLEL MATING DESIGN

5.1 Introduction

The performance of a parental line and its performance in hybrid combination are the two fundamental factors for commercial production of hybrids. The performance of a line in hybrid combination is evaluated through the estimation of general combining ability (GCA) and specific combining ability (SCA) effects.

Combining ability of an inbred lines is the ultimate factor for determining future effectiveness of the lines and aids in categorizing inbred lines relative to their cross combinations.

Combining ability analysis is a significant method to estimate the prepotency of strategies to be used in breeding programme and to assess the gene action involved in various characters so as to design a suitable and efficient breeding method. Combining ability analysis is often used by plant breeders to select parents with a high general combining ability and hybrids with high specific combining ability effects. Additive genetic effects, is associated with general combining ability variance while that of specific combinig ability includes non-additive genetic effects, arising mainly from dominance and epistatic deviations with respect to certain traits. In a systematic breeding program, it is crucial to identify superior parents for hybridization and crosses to expand the genetic variability for selection of superior genotypes (Praveen *et al.,* 2014).

Specific combining ability effects and heterosis for yield and its related traits have been reported by Faiz *et al*., (2006), Saleem *et al*., (2008), Kamau *et al*., (2010) Aminul Islam

et al., (2011), Tucak *et al*., (2012) and Muhammad *et al*., (2014). General combining ability (GCA) is related to additive and additive by additive gene effects and is hypothetically fixable. On the other hand, specific combining ability is non-additive gene action and is and is non-fixable. Heretability depends on the type of genetic control for diverse agro-morphological traits (Vivek *et al.*, 2000, Mishra and Verma, 2002; Matoh *et al*., 2003) therefore, there is need to study gene action in yield (fresh root yield and dry matter content) and yield related traits (carotene content) for better understanding of inheritance so as to identify superior genotypes.

Plant breeders and geneticists often use *diallel* mating design to study the genetic control of traits (Sprague and Tatum, 1942; Griffing, 1956; Eberhart and Gardner, 1966). Hayman (1954a, 1954b) defined *diallel* cross as the set of all possible crosses between several genotypes, which may be individuals, clones, and homozygous lines. Among the various diallel methods, the half diallel method has certain advantages over the others, by giving maximum information about genetic architecture of a trait, parents and allelic frequency. (El-Maghraby *et al*., 2005; Igbal *et al*., 2007). In addition, the diallel cross technique provides early information on the genetic behaviour of attributes in the first generation (Schuelter *et al*., 2010). In this study, half *diallel* mating design was employed to generate the progenies from crosses between elite S_2 parents in an attempt to reduce the huge 'within family' variation that is frequently pragmatic in a heterozygous hybrids after hybridization (Ceballos *et al*., 2015).

The specific objectives were to:

1. To estimate the general and specific combining ability

2. To estimate heterosis for dy matter yield, fresh root yield and beta carotene content using the half-*diallel* mating design

5.2 Materials and Methods

5.2.1 Germplasm source and progeny Development

Six selfed (S_2) lines were used; three from National Root Crop Research Institute and three from International Institute of Tropical Agriculture (Table 5.1). Six parents were planted in a crossing block in Ubiaja an IITA out station in the year 2013. Controlled pollinations were carried out following the standard procedures described by Kawano (1980). The six parents were crossed in a half diallel mating design, Griffing's method 2 (Griffing, 1956) to produce 15 F_1 families. Seeds were generated from 12 crosses. There were unequal numbers of seedlings per cross.

Table 5. 1 Genetic material used for the study

Clone	Line	Source
IBA102888	S2	IITA
IBA102927	S2	IITA
IBA102923	S2	IITA
NR1S2003-3	S2	NRCRI
NR1S2109-10	S2	NRCRI
NR1S2109-14	S2	NRCRI

5.2.2 Seed germination

Seeds from all the 12 cross combination were planted in jiffy pots in the seedling nursery bed at International Institute of Tropical Agriculture (IITA) Ibadan on the 7th of January 2014. Watering was done twice a day to ensure sufficient water and good germination. A months after sowing, the seedlings were transplanted on the 7th of February 2014 to the

seedling nursery field in IITA research station. The seedlings were planted at a spacing of 1 m x 0.5 m and 2cm depth in an unreplicated plot in a single row to produce adequate stem cuttings. The seedlings were evaluated at 7months after planting on the basis of their ability to produce enough good quality vegetative cuttings (six stakes of 25cn long per seedling) required for preliminary yield trial (PYT). For each seedling that gave up to six stakes each stake was cut and well labeled. The stakes were randomized and divided into three replicates for the two locations.

5.2.3 Experimental design for Preliminary Yield Trial

An alpha lattice of a 7 x 3 incomplete block design with three replication was used to plant 21 entries consisting of 12 F_1's, six parents and three checks at two locations. The genotypes were evaluated at Ibadan (E003°54′114″; N07°29′921″), forest savanna transition zone and Ikenne E003°42′721″; N06°51′494″) forest zone (Table 5.2). The genotypes were grown under rain-fed conditions in October 2014. Each plot of 30 m^2 contained one plant of 30 stakes from each of the 12 cross combinations. This was done because the preliminary yield trial was established directly from the seedling nursery and the F_1's are uniquely different from each other. The stakes cut from the seedling nursery (25cm long) were planted at a spacing of 1m x 1m giving a population of 10,000 plants/ha (Ekanayake, 1996). No fertilizer was applied during the course of the research. Herbicide was applied a day after planting to suppress the weeds for at least one month before emergence, hand weeding was done when necessary. The harvesting was done at 10 months after planting (MAP) (Aina *et al.*, 2007; Adeniji *et al.*, 2011).

Table 5.2: Agro-ecological characteristics of the locations where evaluation was performed, 2014/2015

Location	Agroecological Zone	Soil type	Altitude(masl)	Mean average rainfall (mm)	Wet season	Temperature range (°C)
Ibadan	Forest savanna transition	Ferric Luvisols	210	1320	Mar-Nov	20-35
Ikenne	Rain forest	Eutric Luvisols	44	1515	Mar-Oct	22-33

5.2.4 Data collection

The families were screened for diseases at one, three, and six months after planting and evaluated for yield and yield components at harvest. Field data were collected and assessed on per plant basis; samples for dry matter were taken. Data on yield and its components were collected at 10 months after planting.

Fresh yield included all roots on a plant. Sampling for root dry matter (RDMC) was done by selecting three representative roots from a bulk of roots harvested from each plant. Cassava roots were washed and shredded into pieces using a hand shredding machine (IITA, 2010) A 100 g weight of fresh samples was taken and oven dried with a forced draught oven and the samples reweighed again to obtain a constant weight after 72 hrs at 65-70^{o}C (Fukuda *et al*., 2010). Total carotene was subjectively characterized on a scale of 1-5 using a colour chart (IITA, 1990; IITA, 2010; Fukuda *et al*., 2010) as follows; 1=white, 2=cream, 3=yellow, 4=orange, 5=pink.

Data on fresh root yield, dry matter content and total carotene content were collected from 491 out of 1,890 F_1 genotypes. The best five hybrids for fresh root yield, dry matter content and total carotene content were selected as shown in Table 5.3.

Table 5.3: Performance of the best 5 F_1 hybrids between S_2 Cassava Lines over three reps and two locations

Genotypes	Female	Male	Code	fryld	dm	tc
TMS140337-33	IBA102888	NRIS2109-14	1X4	13.8	37.2	2.0
TMS140337-29	IBA102888	NRIS2109-14	1X4	11.3	36.2	1.0
TMS140337-27	IBA102888	NRIS2109-14	1X4	11.3	39.6	2.0
TMS140337-100	IBA102888	NRIS2109-14	1X4	10.0	36.2	1.0
TMS140349-01	IBA102927	NRIS2109-10	3X5	20.5	36.7	2.0
P1	NA	NA	Parent	1.5	33.6	2.5
P2	NA	NA	Parent	3.8	21.7	2.9
P3	NA	NA	Parent	2.6	36.6	2.4
P4	NA	NA	Parent	3.4	25.3	2.4
P5	NA	NA	Parent	2.2	23.5	2.6
P6	NA	NA	Parent	3.4	29.2	3.4
C1	NA	NA	Check	3.3	33.3	1.0
C2	NA	NA	Check	3.2	35.6	1.0
C3	NA	NA	Check	3.8	30.6	1.0

P1=I102888, P2=I102923, P3=I102927, P4=NRIS2109-14 P5= NRIS2109-10, P6=NRIS2003-3, C1=TMEB693, C2=TMEB419, C3=Farmers Variety (Give me chance). The highlighted ones are the best parent and best check for yiled and dry matter

This result suggests that there is a high level of heterosis and specific combining ability between the cassava S_2 lines especially with the crosses 1x4, and 3x5. This indicates that parent 4 is anti parent 1 and parent 3 anti-parent 5. The data for all F_1 hybrids were subjected to statistical analysis for general and specific combining ability.

5.2.5 Data analysis

5.2.5.1 Estimation of combining ability

The analysis of variance (ANOVA) for general combining ability (GCA) and specific combining ability for mean cassava mosaic disease severity, (mcmds) dry matter (dm) fresh root yield, (fryld), top yield (tyld) and total carotene (tc) was carried out according to Griffing's method 2 (parents and F_1 progenies. The following linear mixed model was fitted to the data to estimate the variance components:

$$Y_{ijkl} = \mu+B_i+G_j+G_k+S_{jk}+E_{ijkl}$$

Where
Y_{ijkl} is the i-th observation of the i-th block for the k-th cross;
μ is the overall mean
Bi is the fixed effect of the i-th block, i=1 to b;
G_j or G_k is the random general combining ability effect of the j-th female or the k-th male- normally distributed and independently distributed (NID) $(0,\sigma^2 G)$, j, k,=1 to p and j<k;
S_{jk} is the random specific combining ability effect of the j-th and the k-th parents ($j\neq k$) – NID $(0,\sigma^2 S)$;
E_{ijkl} is the random within plot error term- NID $(0,\sigma^2 E)$

The general combining (parent) effects, specific combining ability (crosses) effects and the error term were considered random. (Isik, 2009). SAS codes were developed to estimate a single GCA variance by aggregating the effects of parents since SAS does not have a simple procedure to take into account the 'double' effects of parents (Zang and Kang, 1997; Johnson and King, 1998, Wu and Matheson, 2000, 2001; Xiang and Li, 2001).

5.2.5.2 Heritability

Restricted maximum likelihood (REML) estimates of the genotypes genetic and phenotypic variances were obtained with SAS PROC Varcomp and were used to compute narrow-sense heritability for each trait.

Narrow-sense heritability (h^2) was estimated as:

$$h^2_i = \frac{\sigma^2_A}{\sigma^2_P}$$

5.2.5.3 Heterosis Estimation

The Mid-parent heterosis (MPH) which describes the performance of crosses (F_1) relative to average performance of their parent (P_1 and P_2), and better parent heterosis (BPH), which describes performance of crosses (F_1) relative to the highest yielding parent were estimated according to Hallauer and Miranda (1988). The values of the cross were computed for each trait as:

$$MPH = \left(\frac{F_1 - MP}{MP}\right) x100$$

$$BPH = \left(\frac{F_1 - BP}{BP}\right) x100$$

Where F_1 is the mean of the F_1 hybrid performance

MP= $\frac{P_1 + P_2}{2}$ the mean of the inbred parents that constituted the hybrids.

BP = the mean of the better parent.

5.3 Results

5.3.1 Estimation of combining ability

There were significant differences among the genotypes for all the characters observed (Table 5.4 and 5.5). General combining ability (GCA) mean square values were not significant for all the traits in the two locations, but specific combining ability mean square values were highly significant for all characters across the locations.

Table 5.4: Mean square values and estimates of genetic components for cassava mosaic disease severity, (mcmds) dry matter (dm), fresh yield, (fyld t/ha), top yield (tyld t/ha) and total carotene (tc) at Ibadan.

Source	mcmds	mcmdi	tyld (t/ha)	fyld (t/ha)	tc	dm (%)
Genotype	0.3066**	0.08511***	55.1626***	1.9563**	0.5243***	7.6223*
GCA	0.01173	0.004	34.5881	0.0000	0.0789	1.317
SCA	0.2871***	0.078***	47.7086**	2.023**	0.4075***	2.966
Error	0.2332	0.05834	47.5767	8.2652	0.2821	24.291
σ^2gca	0.000139	0.000015	650.92	-	0.003412	1.8337
σ^2sca	0.001484	0.000104	94.53	0.7092	0.005795	9.1932
σ^2A	0.04696	0.016	138.35	-	0.3156	5.268
σ^2D	1.1484	0.312	190.83	8.092	1.63	11.864
PR	0.16	0.22	0.93	-	0.57	0.29
$(\sigma_D^2 \mid \sigma_A^2)^{1/2}$	4.94	4.41	1.17	2.84	2.27	1.50
h^2	8.60	11.30	85.30	-	37.10	17.60

df=degree of freedom, GCA= general combining ability,SCA=specific combining ability σ^2= variance, PR= prediction ratio, A=additive, D=dominance, h^2=narrow sense heritability, *0.05 **<.001*** <.0001

5.3.2 Gene action and relative importance of general and specific combining ability

The specific combining ability variances (σ^2sca) for all traits in this study were higher than the general combining ability variances (σ^2gca) (Tables 5.4 and 5.5). The prediction (PR) ratio, i.e. the additive to total variance ratio, for all the characters was less than one, while the average degree of dominance $\{(\sigma_D^2 \mid \sigma_A^2)^{1/2}\}$ for all characters was greater than a unit.

Table 5.5: Mean square values and estimates of genetic components for cassava mosaic disease severity, (mcmds) dry matter (dm), fresh yield, (fyld t/ha), top yield (tyld t/ha) and total carotene (tc) at Ikenne.

Source	mcmds	mcmdi	tyld (t/ha)	fyld (t/ha)	tc	dm (%)
Genotype	1.0425***	0.1638***	3.4514***	1.1727***	0.3257***	18.5194***
GCA	0.02601	0.0111	0.07581	0.1058	0.06927	5.271
SCA	0.9823***	0.1443***	3.4775**	1.0748***	0.2162***	13.684***
Error	0.2408	0.0431	5.2519	2.6061	0.2105	9.8219
σ^2gca	0.000683	0.000095	0.0128	0.01165	0.002338	14.0534
σ^2sca	0.01027	0.000232	0.3187	0.06576	0.001237	6.2540
σ^2A	0.10404	0.0444	0.3032	0.4232	0.2770	21.084
σ^2D	3.9292	0.5772	13.91	4.2992	0.8648	54.736
PR	0.5	0.45	0.074	0.26	0.79	0.81
$(\sigma_D^2 \mid \sigma_A^2)\ ^1/_2$	6.15	3.60	3.72	3.18	1.76	1.61
h^2	8.10	21.10	3.40	10.70	48.90	61.00

df=degree of freedom, GCA= general combining ability,SCA=specific combining ability σ^2= variance, PR= prediction ratio, A=additive, D=dominance, h^2=narrow sense heritability, *0.05 **<.001*** <.0001

5.3.3 Heritability

Narrow sense heritability estimates ranged from 3.40% for top yield to 85% for dry matter content (Tables 5.4 and 5.5). The results revealed high narrow sense heritability for top yield and total carotene at Ibadan and total carotene and dry matter content at Ikenne.

5.3.4 General combining ability

The GCA effects for all the traits are presented in Table 5.6 for the two locations. GCA effect for dry matter was observed for the genotypes IBA102927 with a value of 0.41 and NRIS2109-10 with a value 0.05 for Ibadan, while at Ikenne it was observed for IBA102888 with the value (2.34), on IBA102927 with the value (2.99) and NRIS2003-3 (2.03). There was no significant GCA effect on fresh root yield. The worst combiner for DM in the two locations was genotype IBA102923 (-5.53) which had significant negative (P<.001) GCA effect. For fresh root yield, two parents at Ibadan and three at Ikenne, NRIS2109-10 (0.56), NRIS2109-14 (0.27), IBA102923 (0.57), NRIS2003-3 (0.43), and NRIS2109-14 (0.21) had positive GCA effect. GCA effect for total carotene was positive and significant (P<.001) for NRIS2003-3 (1.06), (0.48) at Ibadan and Ikenne respectively. This was followed by NRIS2109-10, NRIS2109-14 with positive values. Across the locations, the parent NRIS2109-14 showed positive GCA values for fresh root yield and total carotene. Likewise, the parent NRIS2109-10 exhibited positive GCA values for all traits at Ibadan. The parent NRIS2003-3 showed positive GCA values for all the traits at Ikenne as well as significant positive values for total carotene across the two locations.

Table 5.6: Mean and GCA effects of genotypes for dry matter (dm) and fresh yield, (fyld t/ha), and total carotene (tc) for Ibadan and Ikenne

Parental gentoypes	Ibadan					
	*dm (%)		fyld (t/ha)		tc	
	Mean	GCA	Mean	GCA	Mean	GCA
IBA102888	31.21	-0.06	2.17	-0.51	1.91	1.91
IBA102923	22.51	-1.46	3.94	0.09	3	3
IBA102927	35.2	0.41	3	-0.34	2.26	2.26
NRIS2003	29.3	-0.11	3.29	-0.75	3.33	3.33
NRIS2109-10	24.83	0.05	2.67	0.56	2.69	2.69
NRIS2109-14	26.62	-0.34	4.11	0.27	2.32	2.32
SE		**1.35**		0		0.06
				Ikenne		
IBA102888	31.21	2.34	2.17	-0.9	1.91	-0.18
IBA102923	22.51	-5.53**	3.94	0.57	3	0.09
IBA102927	35.2	2.99	3	-0.02	2.26	-0.29
NRIS2003	29.3	2.03	3.29	0.43	3.33	0.48*
NRIS2109-10	24.83	-0.94	2.67	-0.23	2.69	0.31
NRIS2109-14	26.62	-2.81	4.11	0.21	2.32	0.14
SE		**3.74**		**0.1**		**0.04**

*dm=dry matter, fyld =fresh yield, (t/ha) tc= total carotene *0.05 **<.001*** <.0001

5.3.5 Specific combining ability

Specific combining ability effects for the F_1 crosses in the different sites are presented in Tables 5.7, 5.8, 5.9 and Appendix 5.1 and 5.2. Hybrid SCA effects for fresh root yield, dry matter content, and total carotene content varied across the location and for the different traits. For fresh root yield, in Ibadan hybrids IBA102927 X NRIS2109-14 (TMS14-0350-01 and TMS140350-02) were promising hybrids as their means and SCA effects were significant. While, at Ikenne eight hybrids had positive significant SCA effect for fresh root yield. They are IBA102888 X IBA102923 (TMS140339-29 and TMS140339-54), IBA102888 X NRIS2109-14 (TMS140337-29, TMS140337-30, TMS140337-40 and TMS140337-46), IBA102923 X NRIS2109-10 (TMS140333-03), IBA102927 X NRIS2003-3 (TMS14-0348-03). There was no significant SCA effect for dry matter in

Ibadan, but, at Ikenne there were 8 promising hybrids which had positive SCA effects. For total carotene content, there were 11 hybrids with positive SCA effect, while at Ikenne 12 hybrids showed both positive SCA effect. In this study, the crosses were established directly from individual F_1 seedling stake which are genetically different from each other even though they have the same parents for example;- These two cassava hybrids TMS140339-29 and TMS140339-54, came from the same cross IBA102888 X IBA102923;- The code of the entries indicates TMS = Tropical Manihot Selection, 14 = the year of cross, 0339 is the number of cross made for that year. The -29 and -54 tells that the first one came from seed 29, while the second one came from seed 54. In reporting when I write the cross I will write in bracket the actual hybrids. The Appendix gives the complete results.

5.3.6 Heterosis

The heterotic responses of S_2F_1 hybrids over mid-parent (MP) and better parent (BP) for three characters are presented in Tables 5.10, 5.11 and Appendix 5.3 respectively. Both positive and negative heterosis was observed for dry matter for better parent heterosis. The other characters showed positive heterosis for MP and BP heterosis. Mid-parent heterosis varied for the different characters. For fresh yield it ranged from 72.89% to 204.68%, for dry matter it ranged from 9.72% to 63.98% and for total carotene it ranged from 5.39% to 73.22%. BP heterosis also varied for fresh root yield, it ranged from 43.83% to 176.50%, for dry matter from -0.76% to 51.31% and for total carotene it ranged from 0.24% to 73.10%. There was significant variation for both mid-parent and better parent heterosis for the traits measured. Ten, three and seven hybrids showed significant heterosis for fresh root yield, dry matter and total carotene respectively for both MP and BP heterosis.

Table 5.7: Mean and SCA effects of the F1 crosses for fresh yield, (fyld t/ha), dry matter (dm) and total carotene (tc) for Ibadan

	fyld (t/ha)		dm (%)		tc	
F1 Crosses	**Mean**	**SCA**	**Mean**	**SCA**	**Mean**	**SCA**
IBA102888XIBA102923	5.41	0.12	28.30	-0.44	3.33	0.70*
IBA102888XIBA102923	6.51	1.33	33.80	-	3.27	0.99*
IBA102888XNRIS2109-14	4.58	0.88	33.04	0.08	1.20	-0.85*
IBA102888XNRIS2109-14	2.47	-0.63	32.61	-	4.01	1.11**
IBA102888XNRIS2109-14	7.91	1.71	34.09	0.47	1.66	-0.84**
IBA102888XNRIS2109-14	5.91	-0.12	34.95	0.26	3.33	1.27**
IBA102888XNRIS2109-14	4.27	0.69	35.35	0.15	3.18	1.11**
IBA102888XNRIS2109-10	3.91	-1.00	26.30	0.25	1.34	-0.63*
IBA102888XNRIS2109-10	7.38	1.32	24.52	-1.47	0.98	-0.63*
IBA102888XNRIS2109-10	3.28	-0.65	32.78	0.70	0.94	-0.63*
IBA102888XNRIS2109-10	2.13	-0.71	23.34	-0.80	2.53	0.94**
IBA102923XIBA102927	2.41	-0.43	32.36	0.85	2.28	-0.68*
IBA102923XIBA102927	7.61	0.79	28.16	0.17	1.97	-0.68*
IBA102923XNRIS2003-3	5.19	0.31	27.90	0.13	3.96	0.78*
IBA102923XNRIS2003-3	2.15	-0.50	33.05	1.40	2.22	-0.70*
IBA102923XNRIS2003-3	5.46	0.51	21.87	-1.14	1.97	-0.70*
IBA102927XNRIS2109-14	9.15	2.65*	29.57	-0.56	2.70	0.51
IBA102927XNRIS2109-14	9.00	4.05***	30.76	0.66	0.99	-0.85**
IBA102927XNRIS2109-14	2.95	-0.05	26.59	-1.63	1.27	-0.72*
IBA102927XNRIS2109-14	5.48	0.65	30.08	-0.08	3.97	1.24**
I102927XNRIS2109-14	2.85	-0.84	26.81	-0.71	2.98	0.78*
IBA102927XNRIS2003-3	4.28	0.38	19.22	-2.86	3.44	1.27***
IBA102927XNRIS2003-3	4.20	0.07	29.26	-	3.30	0.77*
Grand mean	**3.47**		**30.04**		**2.14**	
SE	**0.84**		**3.03**		**0.08**	

*0.05 **<.001*** <.0001 **Note:** crosses with the same parents are uniquely different from each other

Table 5.8: Mean and SCA effects of the F_1 crosses for fresh yield, (fyld t/ha), dry matter (dm) and total carotene (tc) for Ikenne

	fyld (t/ha)		Dm (%)		tc	
F_1 Crosses	**Mean**	**SCA**	**Mean**	**SCA**	**Mean**	**SCA**
IBA102888XIBA102923	6.67	1.89**	33.78	3.05	2.00	-0.47*
IBA102888XIBA102923	5.33	1.25	26.94	-4.03*	2.97	0.28
IBA102888XIBA102923	2.75	-0.27	25.24	-4.19*	3.02	-0.50
IBA102888XIBA102923	0.51	2.07**	34.10	5.77**	2.96	0.03
IBA102888XNRIS2109-14	1.25	-0.30	32.62	-	1.33	-0.91**
IBA102888XNRIS2109-14	4.58	-0.37	33.04	-	1.20	-0.57*
IBA102888XNRIS2109-14	3.33	-0.57	34.88	-	2.57	0.89**
IBA102888XNRIS2109-14	4.25	0.55	32.32	-	0.99	-0.83**
IBA102888XNRIS2109-14	7.91	2.37***	34.09	0.70	1.66	0.07
IBA102888XNRIS2109-14	7.86	2.45**	35.71	2.57	1.33	-0.49
IBA102888XNRIS2109-14	7.45	1.93*	29.14	-1.63	3.07	0.59*
IBA102888XNRIS2109-14	5.91	1.67*	34.95	1.03	3.33	0.51
IBA102888XNRIS2109-14	4.27	-0.18	35.35	-	3.18	0.58*
IBA102888XNRIS2109-14	4.60	0.33	34.78	2.05	0.95	-0.93***
IBA102888XNRIS2109-14	2.43	-0.34	27.17	-5.45*	1.25	-0.24
IBA102888XNRIS2109-10	1.75	-0.87	33.77	3.87	1.28	-0.47*
IBA102888XNRIS2109-10	4.57	0.77	31.48	4.93*	2.45	0.28
IBA102888XNRIS2109-10	4.06	0.13	21.70	-4.81**	1.53	-0.22
IBA102888XNRIS2109-10	3.91	0.95	26.30	-3.52*	1.34	-0.22
IBA102888XNRIS2109-10	7.38	1.27	24.52	-0.55	0.98	-0.71**
IBA102888XNRIS2109-10	3.28	-0.44	32.78	-	0.94	-0.65*
IBA102888XNRIS2109-10	3.57	-0.33	31.58	1.66	2.38	0.28
IBA102888XNRIS2109-10	3.77	0.31	35.13	2.80	1.18	-0.47*
IBA102888XNRIS2109-10	3.17	-0.44	26.39	-5.93*	1.21	-0.65*
IBA102888XNRIS2109-10	1.43	-0.73	-	-	2.95	0.63*
IBA102888XNRIS2109-10	3.80	0.94	33.94	5.58**	2.66	0.63*
IBA102888XNRIS2003-3	2.18	-0.23	34.00	3.04	1.95	-0.56*
IBA102888XNRIS2003-3	6.58	1.33	28.01	-2.76	1.99	-0.56*
Grand mean	**3.47**		**30.04**		**2.14**	
SE	**0.26**		**2.50**		**0.04**	

*0.05 **<.001*** <.0001 **Note:** crosses with the same parents are uniquely different from each other

Table 5.9: Mean and SCA effects of the F_1 crosses for fresh yield, (fyld t/ha), dry matter (dm) and total carotene (tc) for Ikenne

	fyld (t/ha)		dm(%)		tc	
F_1 Crosses	**Mean**	**SCA**	**Mean**	**SCA**	**Mean**	**SCA**
IBA102923XIBA102927	3.86	0.24	34.44	2.00	2.85	-1.05**
IBA102923NRIS2109-14	1.54	-0.50	40.28	6.92**	1.98	-0.36
IBA102923XNRIS2109-10	5.71	1.64*	28.26	0.77	2.04	-0.03
IBA102923XNRIS2109-10	4.39	-0.23	22.44	-4.28*	4.00	0.72***
IBA102923XNRIS2003-3	2.84	0.25	36.84	7.12***	2.52	-0.28
IBA102923XNRIS2003-3	1.37	-0.39	13.79	-6.75**	3.00	-0.10
IBA102923XNRIS2003-3	3.88	0.58	24.18	-4.57*	2.29	-0.23
IBA102923XNRIS2003-3	5.46	1.03	21.87	-1.62	-	-0.61*
IBA102923XNRIS2003-3	3.66	0.49	23.23	-3.98*	2.59	0.78**
IBA102927XNRIS2109-14	2.95	-0.58	26.59	1.79	2.46	-0.71*
IBA102927XNRIS2109-14	5.48	-0.04	30.08	-1.39	3.30	0.67*
IBA102927XNRIS2109-10	4.25	0.39	31.26	4.40*	2.48	0.35
IBA102927XNRIS2003-3	6.04	2.45***	29.08	-0.43	2.85	0.02
IBA102927XNRIS2003-3	3.84	0.93	36.55	4.76*	3.70	-0.14
IBA102927XNRIS2003-3	4.90	0.63	34.54	3.83*	3.29	0.27
IBA102927XNRIS2003-3	1.74	-0.47	8.31	-6.48*	2.28	0.27
IBA102927XNRIS2003-3	1.94	-0.24	24.56	-2.66	2.96	0.84**
IBA102927XNRIS2003-3	4.28	0.53	19.22	-6.49***	2.23	0.27
IBA102927XNRIS2003-3	3.27	0.81	31.00	1.08	2.34	0.52*
IBA102927XNRIS2003-3	4.06	0.07	21.64	-4.14	2.53	0.69*
IBA102927XNRIS2003-3	5.28	0.99	26.01	-4.55*	2.13	0.52*
NRIS2109-10XNRIS2003-3	3.78	0.56	19.79	-4.55*	2.53	0.21
NRIS2109-10XNRIS2003-3	3.51	-0.35	21.67	-1.09	1.52	-0.55*
NRIS2109-10XNRIS2003-3	1.82	-0.23	0.00	-	1.62	-0.53*
NRIS2109-10XNRIS2003-3	2.97	-0.44	23.18	-	1.33	-0.58*
NRIS2109-10XNRIS2003-3	2.68	-0.74	28.46	-	1.32	-0.69*
NRIS2109-10XNRIS2003-3	1.64	-0.27	14.04	-5.18*	3.10	0.27
NRIS2109-10XNRIS2003-3	4.69	0.29	30.45	5.57**	2.44	0.21
Grand mean	**3.47**		**30.04**		**2.14**	
SE	**0.26**		**2.50**		**0.04**	

*0.05 **<.001*** <.0001 **Note:** crosses with the same parents are uniquely different from each other

Table 5.10: Mid-parent heterosis for fresh yield, dry matter and total carotene content

Cross	fyld (t/ha)	Cross	Dm (%)	Cross	tc
IBA102888 X IBA102923	118.08**	IBA102888 X I102923	45.97	IBA102888 X IBA102923	46.53
IBA102888 X IBA102923	112.90	IBA102888 X I102923	36.62	IBA102888 X I102923	39.66
IBA102888 X IBA102923	100.40**	IBA102888 X I102923	36.30	IBA102888 X IBA102923	39.66
IBA102888 X NRIS2109-14	151.76***	IBA102888 X I102923	34.57	IBA102888 X NRIS2109-14	89.77**
IBA102888 X NRIS2109-14	150.07**	IBA102888 X NRIS2109-10	25.34	IBA102888 X NRIS2003-3	31.57
IBA102888 X NRIS2109-14	137.15*	IBA102888 X NRIS2003-3	18.63	IBA102923 X IBA102927	30.05
IBA102888 X NRIS2109-14	115.97	IBA102923 X IBA102927	43.39	IBA102923 X NRIS2109-10	40.24***
IBA102888 X NRIS2109-14	92.72	IBA102923 X IBA102927	30.16	IBA102923 X NRIS2003-3	24.96*
IBA102888 X NRIS2109-14	88.13*	IBA102923 X IBA102927	28.32	IBA102923 X NRIS2003-3	16.83**
IBA102888 XNRIS2109-10	204.68	IBA102923 X IBA102927	23.74	IBA102923 X NRIS2003-3	14.75
IBA102888 X NRIS2109-10	138.27	IBA102923 X IBA102927	22.47	IBA102923 X NRIS2003-3	14.04
IBA102888 X NRIS2003-3	154.05	IBA102923 X IBA102927	21.10	IBA102923 X NRIS2003-3	8.48
IBA102923 X IBA102927	173.15	IBA102923 X NRIS2109-14	63.98**	IBA102923 X NRIS2003-3	5.39
IBA102923 X IBA102927	119.14	IBA102927 X NRIS2109-14	13.66***	IBA102923 X NRIS2003-3	5.39
IBA102923 X NRIS2109-10	106.76	IBA102923 X NRIS2003-3	42.20	IBA102923 X NRIS2003-3	5.39
IBA102923 X NRIS2109-10	72.89*	IBA102927 X NRIS2109-14	24.90	IBA102923 X NRIS2003-3	5.39
IBA102927 X NRIS2109-14	157.31*	IBA102927 X NRIS2003-3	13.29*	IBA102923 X NRIS2003-3	5.39
IBA102927 X NRIS2109-14	153.08***	IBA102927 X NRIS2003-3	9.72	IBA102927 X NRIS2109-14	73.22**
IBA102927 X NRIS2003-3	100.87***	-	-	IBA102927 X NRIS2003-3	41.56**
NRIS2109-10 X NRIS2003-3	114.67	-	-	IBA102927 X NRIS2003-3	22.98***

*0.05 **<.001*** <.0001 **Note:** crosses with the same parents are uniquely different from each other

Table 5.11: better-parent heterosis for fresh yield, dry matter and total carotene content

Cross	Fyld (t/ha)	Cross	Dm (%)	Cross	tc
IBA102888 X IBA102923	69.25**	IBA102888 X IBA102923	25.61	IBA102888 X IBA102923	19.83
IBA102888 X IBA102923	65.23	IBA102888 X IBA102923	17.56	IBA102888 X IBA102923	14.21
IBA102888 X IBA102923	55.53**	IBA102888 X IBA102923	17.29	IBA102888 X IBA102923	14.21
IBA102888 X NRIS2109-14	92.48***	IBA102888 X IBA102923	15.80	IBA102888 X NRIS2109-14	73.10**
IBA102888 X NRIS2109-14	91.19**	IBA102888 X NRIS2109-10	12.53	IBA102888 X NRIS2003-3	3.50
IBA102888 X NRIS2109-14	81.31*	IBA102888 X NRIS2003-3	15.00	IBA102923 X IBA102927	13.97
IBA102888 X NRIS2109-14	65.11	IBA102923 X IBA102927	17.51	IBA102923 X NRIS2109-10	32.89***
IBA102888 X NRIS2109-14	47.34	IBA102923 X IBA102927	6.66	IBA102923 X NRIS2003-3	18.85*
IBA102888 X NRIS2109-14	43.83*	IBA102923 X IBA102927	5.16	IBA102923 X NRIS2003-3	11.12**
IBA102888 XNRIS2109-10	176.50	IBA102923 X IBA102927	1.40	IBA102923 X NRIS2003-3	9.14
IBA102888 X NRIS2109-10	116.23	IBA102923 X IBA102927	0.37	IBA102923 X NRIS2003-3	8.46
IBA102888 X NRIS2003-3	118.97	IBA102923 X IBA102927	-0.76	IBA102923 X NRIS2003-3	3.18
IBA102923 X IBA102927	140.76	IBA102923 X NRIS2109-14	51.31**	IBA102923 X NRIS2003-3	0.24
IBA102923 X IBA102927	93.15	IBA102923 X NRIS2003-3	25.71***	IBA102923 X NRIS2003-3	0.24
IBA102923 X NRIS2109-10	73.42	IBA102927 X NRIS2109-14	9.65	IBA102923 X NRIS2003-3	0.24
IBA102923 X NRIS2109-10	45.01*	IBA102927 X NRIS2109-14	-0.22	IBA102923 X NRIS2003-3	0.24
IBA102927 X NRIS2109-14	122.69*	IBA102927 X NRIS2003-3	3.77*	IBA102923 X NRIS2003-3	0.24
IBA102927 X NRIS2109-14	119.03***	IBA102927 X NRIS2003-3	0.50	IBA102927 X NRIS2109-14	75.32**
IBA102927 X NRIS2003-3	100.87***	-	-	IBA102927 X NRIS2003-3	18.85**
NRIS2109-10 X NRIS2003-3	102.67	-	-	IBA102927 X NRIS2003-3	3.25***

*0.05 **<.001*** <.0001 **Note:** crosses with the same parents are uniquely different from each other

5.4 Discussion

5.4.1 Estimation of combining ability variances

The significant mean square for the genotypes and SCA values for all the traits revealed variability and the possibility of genetic improvement in most of the traits studied (Punia, 1982; Khan *et al*., 2004). The existing variability in the material was due to non-additive gene effects. GCA effects were not significant for dry matter (dm), and fresh root yield, (fyld t/ha), but were for total carotene. This finding contrasts the report of Chipeta *et al*., (2013) who reported positive significant GCA for fresh root weight but agrees with DaSilva, (2008) who reported that GCA was not significant for average root number, fresh root weight and cassava mealy bug. It also agrees with the report of Ceballos *et al*., (2015) that SCA is more important for yield and yield traits like dry matter and fresh root yield.

5.4.2 Heritability

Narrowsense heritability compares the additive genetic variance to the total phenotypic variance. It measures the relative importance of the additive portion of the genetic variance that can be transmitted to the next generation of the offspring (Fehr, 1991; Chipeta *et al*., (2013). Narrowsense heritability was very low for some traits, high for other traits and varied across the locations signifying the presence of masking effects of environment on genotypic expression (Singh, 1993, Wunna *et al*., 2009). Selection for characters with low heritability (less than 0.4) is difficult or virtually impossible because of the masking effects of environment on genotypic expression (Singh, 1993, Wunna *et al*., 2009). Understanding

of variability and heritability of characters is vital for identifying those amenable to genetic improvement through selection (Vidya *et al*., 2002).

5.4.3 General combining ability

GCA is associated primarily with additive genetic variance so is important. Defensive traits, e.g CMD, dry matter content and maturity are often controlled additively. However, there were no significant GCA effects on dry matter and fresh root yield.

Parent IBA102923 was the worst combiner for dry matter, while parent NRIS2003-3 was the best combiner for total carotene. The positive values of GCA observed for some of the traits indicates that recombination is possible to incorporate important traits in selected genotypes.

5.4.4 Specific combining ability

Specific combining ability determines the value of a particular cross combination in the exploitation of heterosis. In this study, SCA effects in ten crosses were highly significant and positive for fresh root yield, and 8 crosses were also significant for dry matter content. This agrees with the results of Bagheri and Jelodar, (2010) who reported highly significant positive SCA for grain yield. The high significant SCA for the mean square indicated that high SCA effect is more dominant than the GCA effect in this study. This implied that non-additive gene effects were predominant for yield. This is similar to the result of (Dhaliwal and Sharma 1990; Ceballos *et al*., 2012, 2015). This means there was SCA between certain cassava parents even though it is difficult to estimate GCA and SCA in cassava. Hybrids based on SCA are likely to be superior to hybrids found in open pollinated varieties as is

the case with maize. The GCA of the parental lines was not correlated to the SCA of the hybrids. High levels of SCA were derived from parents with high and low GCA values. The best hybrid did not come from best general combiners. Hence, the performance of hybrids was independent of parent's GCA. This implies that good hybrids might not only be derived from parents GCA effects. This was also observed in the studies of Kamau *et al*., (2010); Mtunda (2009) and Owolade *et al*., 2008).

The promising hybrids for fresh root yield based on SCA were IBA102927 X NRIS2109-14 (TMS140350-01 and TMS140350-02), IBA102888 X IBA102923 (TMS140339-29 and TMS140339-54), IBA102888 X NRIS2109-14 (TMS140337-29, TMS140337-30, TMS140337-40 and TMS140337-46), IBA102923 X NRIS2109-10 (TMS140333-03), IBA102927 X NRIS2003-3 (TMS140348-03), and the best hybrids for dry matter content were IBA102888 X IBA102923 (TMS140339-54), IBA102888 X NRIS2109-10 (TMS140336-03 and TMS140336-35), IBA102923 X NRIS2109-14 (TMS140334-04), IBA102923 X NRIS2003-3 (TMS140342-01), IBA102927 X NRIS2109-10 (TMS140349-04), IBA102927 X NRIS2003-3-3 (TMS140348-06 and TMS140348-07), NRIS2109-10 X NRIS2003-3 (TMS140328-34).

5.4.5 Gene action and relative importance of general and specific combining ability

The prediction ratio [PR= $2\sigma^2$gca/ ($2\ \sigma^2$ gca + σ^2 sca)] indicated that all the traits were less than 1, which means that non-additive gene effects are more predominant in the expression of the studied traits. However, both types of gene effects should be considered when developing breeding schemes for the selection of superior genotypes as suggested by Arunga *et al*., (2010). Since specific combining ability variances (σ^2SCA), were greater

than general combining ability variances (σ^2GCA) for all the traits in this study. This means that the SCA was more important in predicting progeny performance. Similar results were reported by (Ceballos *et al*., 2015; Parkes, 2011 and DaSilva, 2008) in cassava for various traits and concluded that SCA was more important in predicting progeny performance. The average degree of dominance ((σ^2_D/σ^2_A) $^1/_2$)) for all the traits was greater than 1. This reveals the presence of over-dominance in these traits. Since cassava is highly heterozygous, these results suggest that once an elite homozygous hybrid clone has been identified and selected, it can be perpetuated through vegetative propagation thereby carrying along the desired trait.

5.4.6 Heterosis

The aim of this study was to identify the best heterotic combinations and exploit heterosis for further cassava breeding improvement. Ten hybrids recorded significant MP and BP heterosis for fresh root yield. Six of these were highly significant. Six hybrids have positively significant heterosis for total carotene. Low heterosis effects were observed for dry matter. Three hybrids had significant heterosis but only two hybrids showed highly significant heterosis. The highest MP and BP heterosis for FRYLD was the cross IBA102888 X NRIS2109-10, and for DM the cross IBA102923 X NRIS2109-14. The MP heterosis was as high as 204.68%, 63.98% and 89.77%, BP heterosis was as high as 176.50%, 51.31% and 75.32% for the three traits respectively. These crosses were good combiners producing heterotic values of 10, 3, and 7 each.

5.5 Conclusions

These results suggest that there was a high level of heterosis and specific combining ability between certain cassava S_2 lines. The crosses NRIS2109-14 (1x4) produced 4 F_1 hybrids and NRIS2109-10 (3x5) produced another F_1 hybrid that were significantly higher in fresh root yield and dry matter content than their respective parents. These hybrids were also higher yielding and had higher DMC than any of the parents used in the study and the three check varieties. Clones from these hybrids will be evaluated further in more replications and locations to verify these results. Parent 4 and 1 and 3 and 5 appeared to have complementary heterotic responses and may prove to valuable sources of superior new hybrids.

The results of this study indicate that SCA is more important in explaining the variation for the different traits studied. The significant positive SCA effect demonstrates the relative importance of SCA in determining yield of the progenies. Non-additive gene effects were responsible for fresh root yield and dry matter. The significant SCA and positive heterosis effects revealed that heterotic group could be developed with partial inbred parents and F_1 hybrids heterosis can be exploited. The differences observed in the genotypes in the two sites suggested that a combination of the effects: environment, epistasis and over-dominance were involved.

CHAPTER SIX

6.0 GENERAL CONCLUSION AND RECOMMENDATION

The participatory rural appraisal (PRA) was a component of this research conducted to identify farmers' prferences for cassava varities revealed that farmers in Edo State of Nigeria plant different cassava varieties for various needs and they desire high yielding cassava varieties with disease resistance. It also revealed that farmers prefer their local varieties because of the better yield they get from them compared to the available improved varieties in the study locations.

To provide new varieties that will satisfy farmers' preferences and suit their socio-economic needs, and also bridge the gap between farmers and breeders, it is important to design and adopt participatory methods that would identify farmers' preferences from the early stages of breeding (goal setting, on farm trial, and varietal selection) in Edo State Nigeria. Active farmer participation in plant breeding is critical in selection and breeding for successful adoption of improved cassava varieties.

Genetic variability was significant for the traits studied and much of this genetic variation was non-additive in nature. The combined analysis of variance across environments and genotypes revealed there was significant genetic variability among the hybrids for growth and root yield characteristics. The significant mean square for the genotypes and SCA values for all the traits revealed variability and the possibility of genetic improvement in most of the traits studied.

The high narrosense heritability for some of the traits studied indicated high breeding value for the traits

High heritability was found for plant height, dry matter content, top yield, harvest index and total carotene content. Heritability for yield was low. Root yield was influenced by environmental conditions and genotypes as shown by the strong genotype x environment interaction.

The phenotypic superiority of hybrids over parents with respect to root number, fresh root yield, dry matter content and harvest index is promising for potential yield in cassava. Significant phenotypic associations between traits were identified from the study

Based on average fresh root yield from the multi-environment analysis, two hybrids TMS14-091-08 and TMS14-024-04 did better than the check TMS30572 and the best parents for fresh root yield were three TMS-IBA102896, TMS-IBA102927 and TMS-IBA102915. Eight genotypes were the best for dry matter and these are TMS14-035-1, TMS14024-04, TMS14024-04, TMS14024-01, TMS14-035-08, TMS14-035-20, TMS14-078-04, TMS14-125-01 and TMS14-125-06

The magnitude of heterosis over mid-parent and better parent values varied from cross to cross. There was significant heterosis for ten hybrids for fresh root yield, three hybrids for dry matter content and seven hybrids for total carotene for both mid-parent and better parent heterosis.

The significant positive specific combining ability effects demonstrate the relative importance of SCA in determining yield of the hybrids between the S_2 lines. Non-additive gene effects are responsible for fresh root yield and dry matter. The significant SCA and

positive heterosis effects reveal that heterotic groups could be developed with partial inbred parents and F_1 hybrids and that heterosis can be exploited. The differences observed in the genotypes in the two sites suggest a combination of effects; environment, epistasis and over dominance are involved.

This study revealved that between-family variations was observed more than within-family variations, this was demonstrated by the GCA table that showed non-significant GCA effect. It also suggested that inbreeding in the parental clones would facilitate the gradual and consistent assembly of favorable gene combinations**.** There was a high level of heterosis and specific combining ability between the cassava S_2 lines, especially with the crosses 1x4, and 3x5.

6.2 RECOMMENDATIONS

1. Further study of the morphological and genetic characterization of the farmers' *germplasm* in the PRA study area may reveal whether what farmers call local are really local or previously distributed improved varieties from both National and International institutes.

2. Breeding efforts should focus on developing new farmer preferred cassava varieties that are high in dry matter content and are high yielding.

3. The significant genotype by environment interactions observed implies that further selection should be done in replicated trials at more than two locations.

4 The best hybrids for dry matter content and yield should be further screened for stability.

5 The parent lines that combine well yield and dry matter should be used as testers in the cassava breeding programme

6 The hybrids that showed superior performance to the best parents and checks should be evaluated further.

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APPENDICES

APPENDIX 3.1

Questionnaire to determine farmers' perception of different cassava varieties and characteristics for preferred varieties

State……. Local Government Area ……
Village …….. Community …….
Latitude …… Longitude …….
Interviewed by ……. Date ……

A. Background information

1. Name……
2. Age: a) < 25 years [ ] b) 25- 44years[ ] c) 45 -64years [ ] d) 65 years and above[ ]
3. Sex a) Male [ ] b) Female [ ]
4. Marital Status a) Married [ ] b) Single [ ] c) widow/widower [ ]
5. Household size : a) 1-5 [ ] b) 6-10[ ] c) 11-15 [ ] d) 15 and above [ ]
6. Are you a member of any farmer group? a)Yes [ ] b) No [ ]

If yes please specify ……. If No, why? .....

7. Educational level:

a) No formal education [ ] b) primary [ ] c) secondary [ ] d) tertiary [ ]

8. Annual income a) ₦1,000- ₦45,000 [ ] b) ₦46,000 - ₦90,000 [ ]
c) ₦91,000 - ₦145,000 [ ] d) ₦146,000 and above [ ]
9. What is the size of your farmland? a) < 1ha[ ] b) 1-3ha[ ] c) 3-5ha[ ] other
10. Average yield of Cassava …….

B. General information on farming practices

11. How long have you been cultivating cassava?
……..
12. How did you acquire the land you use for your cultivation? a) rent b) own c) inherited

d) share cropping [ ] d) family land [ ] e) other (specify)

13. How many times do you cultivate cassava in a year? a) once b) twice c) More than twice
14. What type of cropping system do you use? a) mono-cropping [ ] b) mixed cropping[ ]
c) other (specify)……

If your cropping system is mixed-cropping, list the other the crops
……

15. What kind of labour do you use for cassava farming? (Tick as many as applicable)

a) family [ ] b) hired [ ] c)communal [ ] d) others (specify)…….

16. Have you participated in a field day in the last 2 years (tick only 1) a) Yes[ ] b) No[ ]
If yes, who organized it? a) Student[ ] b) Government agencies[ ] c) NGO[ ]
If No, why……

C. Varietal preferences

17. List some of the Cassava varieties grown in your area……
……

18. Rank them in order of preference with the desirable characteristics (traits) that influences your choice such as high yielding, early maturing, late maturing, disease resistance, tolerant to low soil fertility, good market, e.t.c.

Variety	**Rank**	**Reason (Characteristics)**

19. Which one do you prefer for planting material (Stakes)?

……

20. Which one do you prefer for garri quality (DMC)?

……

21. Which one do you prefer for fufu quality?

……

22. Does gender affect cassava production? a) Yes [ ] b) No [ ]

23. Labour demand:

Activity	**Labour demand (1=low,2=moderate,3=high)**
Land preparation	
Planting	
Harvesting	
Processing	
Storage and marketing	

24. What are your major constraints to cassava production in your area?
    a) Diseases [ ] b) Pest [ ] c) Planting material [ ] c) Low soil fertility [ ]
    b) d) Lack of Farmland to increase production [ ] e) Lack of funds to intensify production f) Climate change [ ] g) Others (specify)

D. Perceptions on Insect Pest and Diseases that affect Cassava production

25. Mention, describe and tick severity some of the diseases that affects cassava production in your area

Disease	Description	Part of the plant affected	Severity			
			Not affected	Not severe	Severe	Very severe

26. Mention, describe and tick severity some of the insect pests that affects cassava production in your area

Insect pest	Description	Part of the plant affected	Severity			
			Not affected	Not severe	Severe	Very severe

27. List the varieties you grow and their response to this disease

Varieties	Is it tolerant to CMD/CBB disease? (Yes=1, No=0)

E. Control of Insect Pest and Diseases in Cassava production

28. How do you control CMD and CBB outbreak in your field? a) use chemical [ ] b) plant resistant/tolerant varieties [ ] c) do nothing [ ] d) local method (specify) Weeding…….. ……..

F. Improved cassava varieties

29. Do you know about improved cassava varieties? a) Yes [ ] b) No [ ]
30. If yes, have you ever grown improved varieties? a)Yes [ ] b) No [ ]

31. Do you grow improved alone or with your local variety? a)Yes [ ] b) No [ ]
32. If yes, do you prefer improved to local variety in terms of yield/acre? a)Yes [ ] b) No [ ]

33. How do you get information on improved varieties? NGOs [ ] Radio [ ] Television [ ] Field days [ ] Agric. Extension [ ] other farmers [ ] other sources [ ]

34. Problems encountered in getting improved varieties in your area.

Item			
	Not Critical	**Critical**	**Very critical**
Improved varieties are not available			
Expensive to buy improved varieties			
Farmers prefer to plant local varieties			
Long distance to get the variety			
No information on improved			
No information varieties			
other			

35. **Source of planting material:** a) Government agency [ ] b) NGO [ ] c) Fellow farmer [ ] d) Farm settlement [ ] e) Bought from the market [ ] f) IITA g) Others specify…….
36. What varieties of cassava do you plant currently?

Source: a) Government agency [ ] b) NGO [ ] c) Fellow farmer [ ] d) Farm settlement [ ] e) Bought from the market [ ] f) IITA [ ]
g) Others specify…….

37. What should farmers' involvement in cassava research be? Please tick all that apply.

	Farmers' involvement in research	Score		
		Not important	Less important	Very important
a)	Goal setting			
b)	On-farm trials assessment			
c)	Varietal selection			
d)	No involvement			
e)	others			

38. What other traits of cassava should breeders incorporate in cassava varieties for you?

List in other of priority.

a)……
……

b)……
……

c)……
……...

F. Marketing of cassava

39. Why do you produce cassava?
    a) For income [ ] b) For home consumption [ ] c) For both home consumption and income [ ]
40. If both, what percentage of cassava do you sell in a growing season?.....……..
41. Who buys your cassava? a) market women [ ] b) company [ ] c) consumers [ ] d) government agency [ ] e) NGO [ ] f) others specify……
42. Is it difficult to sell the cassava you produce? a) Yes0 [ ] b) No [ ]
43. If Yes, what is the major reason for the lack of market for the cassava you produce?

a) Bad road and high cost of transportation[ ] b) Glut [ ] c) poor storage[ ] d) activities of middlemen [ ] e) other (specify) [ ]

44. Do you make profits from growing cassava? a) Yes[ ] b) No[ ]

Thank you

Appendix 4.1 Mean performance of parents, F_1 hybrids and percentage increase over mid-parent (relative heterosis) and better parent (heterobeltiosis)

Pedigree	rtno	mph	Pedigree	rtno	bph
NRIS2002-2XI102894	TMS14-001-03	147.10	I102918XI102924	TMS14-091-08	122.99
I102918XI102924	TMS14-091-08	137.07	I102918XI102924	TMS14-091-06	97.16
NRIS2002-2XI102894	TMS14-001-02	110.38	NRIS2002-2XI102894	TMS14-001-03	80.42
I102918XI102924	TMS14-091-06	109.61	I102888XI102924	TMS14-034-09	59.02
NRIS2002-2XI102894	TMS14-001-07	99.14	NRIS2002-2XI102894	TMS14-001-02	53.61
I102888XI102894	TMS14-032-04	97.92	I102888XI102894	TMS14-032-04	51.34
I102888XI102924	TMS14-034-09	81.06	NRIS2002-2XI102894	TMS14-001-07	45.40
I102888XI102927	TMS14-035-06	79.11	NRIS2109-59XI102924	TMS14-015-05	43.38
I102888XI102927	TMS14-035-12	59.85	I102918XI102924	TMS14-091-01	39.05
I102888XI102927	TMS14-035-15	58.86	I102888XI102927	TMS14-035-06	26.72
NRIS2109-59XI102924	TMS14-015-05	57.85	I102896XI102909	TMS14-024-04	21.56
I102888XI102927	TMS14-035-05	57.78	I102888XI102927	TMS14-035-12	13.10
I102888XI102924	TMS14-078-01	50.38	I102888XI102927	TMS14-035-15	12.39
I102918XI102924	TMS14-091-01	47.84	I102888XI102927	TMS14-035-05	11.63
I102888XI102894	TMS14-032-01	44.53	I102888XI102894	TMS14-032-01	10.51
I102927XI102927	TMS14-125-08	37.76	I102927XI102927	TMS14-125-08	6.67
I102896XI102909	TMS14-024-04	33.26	I102888XI102924	TMS14-078-01	6.39
I102927XI102927	TMS14-125-09	25.80	NRIS2109-59XI102924	TMS14-015-04	6.11
I102888XI102927	TMS14-035-08	25.26	I102896XI102909	TMS14-024-01	0.51
I102927XI102927	TMS14-125-02	23.78	-	-	-

Appendix 4.1 continued. Mean performance of parents, F_1 hybrids and percentage increase over mid-parent (relative heterosis) and better parent (heterobeltiosis)

Pedigree	fyld	mph	Pedigree	fyld	bph
NRIS2002-2XI102894	TMS14-001-07	350.08	NRIS2002-2XI102894	TMS14-001-07	276.27
NRIS2002-2XI102894	TMS14-001-02	259.91	NRIS2002-2XI102894	TMS14-001-02	200.88
I102918XI102924	TMS14-091-08	168.07	I102918XI102924	TMS14-091-08	162.62
NRIS2002-2XI102894	TMS14-001-01	128.81	I102888XI102894	TMS14-032-02	109.79
I102888XI102894	TMS14-032-02	110.10	I102888XI102894	TMS14-032-04	104.80
I102888XI102894	TMS14-032-04	105.10	NRIS2002-2XI102894	TMS14-001-01	91.28
I102918XI102924	TMS14-091-06	90.23	I102918XI102924	TMS14-091-06	86.36
I102888XI102894	TMS14-032-01	54.83	I102888XI102894	TMS14-032-01	54.60
I102918XI102924	TMS14-091-01	46.06	I102918XI102924	TMS14-091-01	43.08
NRIS2002-2XI102894	TMS14-001-06	42.00	I102888XI102894	TMS14-032-05	29.76
I102888XI102894	TMS14-032-05	29.95	NRIS2109-59XI102924	TMS14-015-04	23.69
NRIS2109-59XI102924	TMS14-015-04	29.04	NRIS2002-2XI102894	TMS14-001-06	18.71
NRIS2109-59XI102924	TMS14-015-05	18.91	I102896XI102909	TMS14-024-04	14.97
I102888XI102924	TMS14-078-01	15.65	NRIS2109-59XI102924	TMS14-015-05	13.98
I102896XI102909	TMS14-024-04	14.97	I102896XI102909	TMS14-024-01	6.54
NRIS2002-2XI102894	TMS14-001-03	11.41	-	-	-
I102927XI102927	TMS14-125-08	10.79	-	-	-
I102915XI102909	TMS14-031-05	8.84	-	-	-
I102888XI102927	TMS14-035-12	8.70	-	-	-
I102896XI102909	TMS14-024-01	6.54	-	-	-

Appendix 4.1: continued. Mean performance of parents, F_1 hybrids and percentage increase over mid-parent (relative heterosis) and better parent (heterobeltiosis)

Pedigree	dm	mph	Pedigree	dm	bph
I102888XI102927	TMS14-035-05	18.30	I102888XI102927	TMS14-035-05	13.24
I102888XI102927	TMS14-035-11	17.45	I102888XI102927	TMS14-035-11	12.42
NRIS2109-59XI102924	TMS14-015-02	14.40	NRIS2002-2XI102894	TMS14-001-01	11.05
NRIS2002-2XI102894	TMS14-001-01	13.88	I102896XI102909	TMS14-024-04	7.74
NRIS2109-59XI102924	TMS14-015-04	12.36	I102888XI102927	TMS14-035-20	6.97
I102888XI102927	TMS14-035-20	11.75	I102888XI102894	TMS14-032-03	6.66
I102915XI102909	TMS14-031-06	10.67	NRIS2002-2XI102894	TMS14-001-03	6.59
I102888XI102894	TMS14-032-03	10.36	I102927XI102927	TMS14-125-03	5.75
I102927XI102927	TMS14-125-03	9.50	I102888XI102927	TMS14-035-18	4.18
NRIS2109-59XI102924	TMS14-015-03	9.36	I102888XI102894	TMS14-031-06	3.62
NRIS2002-2XI102894	TMS14-001-03	9.31	I102888XI102924	TMS14-078-04	3.04
I102888XI102927	TMS14-035-18	8.84	I102888XI102894	TMS14-032-01	3.00
I102896XI102909	TMS14-024-04	8.62	I102896XI102909	TMS14-024-01	2.99
I102915XI102909	TMS14-031-05	8.32	I102888XI102927	TMS14-035-02	2.65
I102888XI102924	TMS14-078-04	7.64	I102927XI102927	TMS14-125-02	1.98
I102888XI102927	TMS14-035-02	7.24	I102888XI102894	TMS14-031-05	1.43
I102888XI102894	TMS14-032-01	6.58	-	-	-
I102927XI102927	TMS14-125-02	5.60	-	-	-
I102888XI102927	TMS14-035-16	4.27	-	-	-
I102896XI102909	TMS14-024-01	3.83	-	-	-

Appendix 4.1 continued. Mean performance of parents, F_1 hybrids and percentage increase over mid-parent (relative heterosis) and better parent (heterobeltiosis)

Pedigree	hi	mph	Pedigree	hi	bph
I102918XI102924	TMS14-091-04	39.21	I102888XI102927	TMS14-035-06	33.86
NRIS2002-2XI102894	TMS14-001-07	38.23	I102888XI102927	TMS14-035-15	32.82
I102918XI102924	TMS14-091-01	31.15	NRIS2002-2XI102894	TMS14-001-07	20.28
I102927XI102927	TMS14-125-03	25.42	I102888XI102927	TMS14-035-16	19.72
NRIS2109-59XI102924	TMS14-015-05	21.93	I102888XI102924	TMS14-078-01	19.61
I102888XI102894	TMS14-031-01	20.07	I102918XI102924	TMS14-091-04	15.96
I102888XI102894	TMS14-031-05	19.42	I102888XI102927	TMS14-035-17	15.49
NRIS2002-2XI102894	TMS14-001-01	18.34	I102896XI102909	TMS14-024-01	12.50
I102888XI102894	TMS14-032-02	17.55	I102888XI102927	TMS14-035-12	11.00
NRIS2109-59XI102924	TMS14-015-01	16.41	I102918XI102924	TMS14-091-01	9.24
I102888XI102927	TMS14-035-06	15.40	I102888XI102924	TMS14-078-03	8.80
I102927XI102927	TMS14-125-09	15.25	NRIS2109-59XI102924	TMS14-015-05	6.96
NRIS2109-59XI102924	TMS14-015-03	15.11	I102888XI102894	TMS14-032-02	6.73
I102888XI102927	TMS14-035-15	14.50	I102888XI102894	TMS14-031-01	3.74
I102888XI102924	TMS14-034-09	12.83	I102888XI102927	TMS14-035-02	3.23
I102896XI102909	TMS14-024-01	12.74	I102888XI102894	TMS14-031-05	3.18
NRIS2002-2XI102894	TMS14-001-02	12.55	NRIS2002-2XI102894	TMS14-001-01	2.97
I102888XI102894	TMS14-032-04	11.58	I102927XI102927	TMS14-125-03	2.57
NRIS2109-59XI102924	TMS14-015-04	10.84	I102888XI102927	TMS14-035-11	2.46
I102927XI102927	TMS14-125-08	10.63	I102888XI102924	TMS14-034-09	2.44

Appendix 4.2 Mean performance of parents, F_1 hybrids and percentage decrease over mid-parent (relative heterosis) and better parent (heterobeltiosis)

Pedigree	rtno	mph	Pedigree	rtno	bph
I102888XI102924	TMS14-034-08	-39.66	I101927XI102924	TMS14-125-05	-50.49
I102915XI102909	TMS14-031-06	-42.81	I102915XI102909	TMS14-031-06	-51.03
I102896XI102909	TMS14-024-06	-43.56	I102896XI102909	TMS14-024-05	-51.64
I102888XI102927	TMS14-035-09	-43.89	I102888XI102927	TMS14-035-19	-52.25
I102896XI102909	TMS14-024-05	-46.99	I102918XI102924	TMS14-091-05	-55.37
I102888XI102927	TMS14-035-20	-48.29	I102888XI102927	TMS14-035-09	-60.30
I102888XI102924	TMS14-078-06	-50.73	I102915XI102909	TMS14-031-02	-61.08
I101927XI102924	TMS14-125-01	-51.39	I101927XI102924	TMS14-125-01	-62.36
I102918XI102924	TMS14-091-05	-52.55	I102888XI102927	TMS14-035-20	-63.42
I102888XI102927	TMS14-035-11	-53.24	I102896XI102909	TMS14-024-02	-64.74
I102915XI102909	TMS14-031-02	-54.55	I102888XI102924	TMS14-078-06	-65.14
I102888XI102927	TMS14-035-01	-55.45	I102896XI102909	TMS14-024-07	-66.37
I102888XI102924	TMS14-078-04	-56.05	I102888XI102927	TMS14-035-11	-66.92
I102896XI102909	TMS14-024-02	-61.35	I102888XI102927	TMS14-035-01	-68.48
I102896XI102909	TMS14-024-07	-63.14	I102888XI102924	TMS14-078-04	-68.91
I102888XI102924	TMS14-078-05	-63.45	I102888XI102924	TMS14-078-05	-74.14
I102888XI102927	TMS14-035-04	-71.64	I102888XI102927	TMS14-035-04	-79.93
I102888XI102924	TMS14-078-08	-75.05	I102888XI102924	TMS14-078-08	-82.34
I101927XI102924	TMS14-125-06	-81.92	I101927XI102924	TMS14-125-06	-86.00
I102915XI102909	TMS14-031-03	-114.52	I102915XI102909	TMS14-031-03	-112.44

Appendix 4.2 continued. Mean performance of parents, F_1 hybrids and percentage decrease over mid-parent (relative heterosis) and better parent (heterobeltiosis)

Pedigree	fyld	mph	Pedigree	fyld	bph
I102888XI102927	TMS14-035-04	-56.31	I102888XI102927	TMS14-035-04	-67.50
I102888XI102927	TMS14-035-19	-58.97	I102888XI102927	TMS14-035-19	-69.48
I102888XI102924	TMS14-078-05	-60.87	I102888XI102924	TMS14-078-05	-70.89
I102888XI102927	TMS14-035-11	-61.61	I102888XI102927	TMS14-035-11	-71.44
I102888XI102927	TMS14-035-18	-62.51	I102888XI102927	TMS14-035-18	-72.11
I102888XI102924	TMS14-078-04	-63.67	I102888XI102924	TMS14-034-07	-72.18
I102915XI102909	TMS14-031-03	-65.92	I102915XI102909	TMS14-031-03	-72.80
I102888XI102927	TMS14-035-01	-68.21	I102888XI102924	TMS14-078-04	-72.98
I102888XI102927	TMS14-035-20	-68.22	I102888XI102924	TMS14-034-08	-74.82
I101927XI102924	TMS14-125-01	-68.25	I102888XI102927	TMS14-035-01	-76.35
I101927XI102924	TMS14-125-06	-70.98	I102888XI102927	TMS14-035-20	-76.36
I102888XI102924	TMS14-034-07	-72.14	I101927XI102924	TMS14-125-01	-76.36
I102888XI102924	TMS14-034-08	-74.79	I102896XI102909	TMS14-024-07	-77.65
I102896XI102909	TMS14-024-07	-77.65	I102896XI102909	TMS14-024-02	-78.37
I102896XI102909	TMS14-024-02	-78.37	I101927XI102924	TMS14-125-06	-78.40
I102888XI102924	TMS14-078-06	-81.04	I102896XI102909	TMS14-024-03	-82.89
I102896XI102909	TMS14-024-03	-82.89	I102888XI102924	TMS14-078-06	-85.90
I102888XI102927	TMS14-035-09	-90.73	I102888XI102927	TMS14-035-09	-93.10
I102896XI102909	TMS14-024-05	-97.86	I102896XI102909	TMS14-024-05	-97.86
I102888XI102924	TMS14-078-08	-103.18	I102888XI102924	TMS14-078-08	-102.36

Appendix 4.2 continued. Mean performance of parents, F_1 hybrids and percentage decrease over mid-parent (relative heterosis) and better parent (heterobeltiosis)

Pedigree	dm	mph	Pedigree	dm	bph
I102888XI102924	TMS14-078-02	-10.07	I102888XI102927	TMS14-035-15	-15.55
I102918XI102924	TMS14-091-05	-10.15	I102915XI102909	TMS14-031-04	-15.58
I101927XI102924	TMS14-125-08	-10.20	I102918XI102924	TMS14-091-08	-15.68
NRIS2002-2XI102894	TMS14-001-06	-10.94	I102896XI102909	TMS14-024-07	-17.16
I102888XI102927	TMS14-035-15	-11.77	I102896XI102909	TMS14-024-05	-17.54
I102888XI102924	TMS14-034-09	-12.27	I102918XI102924	TMS14-091-01	-17.76
I101927XI102924	TMS14-125-09	-12.35	I102888XI102927	TMS14-035-04	-18.04
I102896XI102909	TMS14-024-09	-14.13	I102888XI102924	TMS14-034-09	-18.77
I102888XI102927	TMS14-035-04	-14.38	NRIS2109-59XI102924	TMS14-015-05	-19.03
I102896XI102909	TMS14-024-02	-14.70	I102918XI102924	TMS14-091-02	-19.39
I102896XI102909	TMS14-024-07	-16.49	NRIS2002-2XI102894	TMS14-001-07	-20.35
I102896XI102909	TMS14-024-05	-16.88	I102888XI102927	TMS14-035-01	-20.73
I102888XI102927	TMS14-035-01	-17.19	I102918XI102924	TMS14-091-05	-22.89
NRIS2002-2XI102894	TMS14-001-07	-18.32	I102888XI102924	TMS14-078-03	-23.67
I102918XI102924	TMS14-091-06	-20.16	NRIS2109-59XI102924	TMS14-015-01	-26.02
I102888XI102924	TMS14-078-03	-20.26	I102888XI102927	TMS14-035-19	-27.11
I102888XI102927	TMS14-035-19	-23.85	I102888XI102894	TMS14-032-02	-30.46
I102888XI102924	TMS14-078-06	-27.58	I102888XI102924	TMS14-078-06	-30.68
I102888XI102894	TMS14-032-02	-28.04	I102918XI102924	TMS14-091-06	-31.48
I102918XI102924	TMS14-091-04	-47.99	I102918XI102924	TMS14-091-04	-55.36

Appendix 4.2 continued.Mean performance of parents, F_1 hybrids and percentage decrease over mid-parent (relative heterosis) and better parent (heterobeltiosis)

Pedigree	hi	mph	Pedigree	hi	bph
I101927XI102924	TMS14-125-01	-33.22	I102888XI102924	TMS14-034-07	-34.91
I102888XI102894	TMS14-032-05	-34.07	I102896XI102909	TMS14-024-05	-35.94
I102888XI102927	TMS14-035-08	-34.45	I102888XI102924	TMS14-078-06	-36.90
I101927XI102924	TMS14-125-06	-34.52	I102888XI102927	TMS14-035-04	-38.18
I102896XI102909	TMS14-024-05	-35.81	I102888XI102924	TMS14-034-06	-38.87
I102918XI102924	TMS14-091-07	-35.98	I102888XI102924	TMS14-034-02	-39.16
I102888XI102927	TMS14-035-01	-37.08	I102888XI102894	TMS14-032-05	-40.13
I102918XI102924	TMS14-091-05	-37.25	I102888XI102924	TMS14-078-08	-42.03
NRIS2002-2XI102894	TMS14-001-06	-38.80	I102888XI102927	TMS14-035-20	-43.74
I102888XI102924	TMS14-078-02	-40.78	I101927XI102924	TMS14-125-01	-45.39
I102888XI102924	TMS14-034-03	-41.91	I101927XI102924	TMS14-125-06	-46.45
I102888XI102924	TMS14-034-08	-42.79	I102918XI102924	TMS14-091-07	-46.68
I102888XI102894	TMS14-032-03	-44.69	NRIS2002-2XI102894	TMS14-001-06	-46.75
I102888XI102924	TMS14-078-06	-45.61	I102888XI102924	TMS14-034-03	-47.25
I102888XI102927	TMS14-035-04	-46.70	I102918XI102924	TMS14-091-05	-47.73
I102915XI102909	TMS14-031-02	-47.23	I102888XI102924	TMS14-034-08	-48.05
I102896XI102909	TMS14-024-07	-48.19	I102896XI102909	TMS14-024-07	-48.30
I102896XI102909	TMS14-024-06	-49.62	I102896XI102909	TMS14-024-06	-49.72
I102888XI102924	TMS14-078-08	-50.02	I102888XI102894	TMS14-032-03	-49.78
I102888XI102927	TMS14-035-20	-51.50	I102915XI102909	TMS14-031-02	-54.40

Appendix 5.1: Mean and SCA effects of the F_1 crosses for fresh yield, (fyld t/ha), dry matter (dm) and total carotene (tc) for Ibadan

			fyld (t/ha)		dm (%)		tc	
Cross	**Code**	**F_1**	**mean**	**SCA**	**mean**	**SCA**	**mean**	**SCA**
IBA102888XIBA102923	1X2	TMS140339-37	5.41	0.12	28.30	-0.44	3.326	0.701*
IBA102888XIBA102923	1X2	TMS140339-41	6.51	1.33	33.80	0.00	3.266	0.994*
IBA102888XNRIS2109-14	1X4	TMS140337-100	4.58	0.88	33.04	0.08	1.204	-0.845*
IBA102888XNRIS2109-14	1X4	TMS140337-16	2.47	-0.63	32.61	0.00	4.013	1.107**
IBA102888XNRIS2109-14	1X4	TMS140337-29	7.91	1.71	34.09	0.47	1.659	-0.843**
IBA102888XNRIS2109-14	1X4	TMS140337-46	5.91	-0.12	34.95	0.26	3.326	1.270**
IBA102888XNRIS2109-14	1X4	TMS140337-55	4.27	0.69	35.35	0.15	3.175	1.108**
IBA102888XNRIS2109-10	1X5	TMS140336-14	3.91	-1.00	26.30	0.25	1.341	-0.635*
IBA102888XNRIS2109-10	1X5	TMS140336-15	7.38	1.32	24.52	-1.47	0.980	-0.635*
IBA102888XNRIS2109-10	1X5	TMS140336-21	3.28	-0.65	32.78	0.70	0.942	-0.635*
IBA102888XNRIS2109-10	1X5	TMS140336-33	2.13	-0.71	23.34	-0.80	2.533	0.941**
IBA102923XIBA102927	2X3	TMS140347-03	2.41	-0.43	32.36	0.85	2.281	-0.680*
IBA102923XIBA102927	2X3	TMS140347-04	7.61	0.79	28.16	0.17	1.969	-0.680*
IBA102923XNRIS2003-3	2X6	TMS140342-03	5.19	0.31	27.90	0.13	3.962	0.782*
IBA102923XNRIS2003-3	2X6	TMS140342-08	2.15	-0.50	33.05	1.40	2.215	-0.698*
IBA102923XNRIS2003-3	2X6	TMS140342-43	5.46	0.51	21.87	-1.14	1.965	-0.698*
IBA102927XNRIS2109-14	3X4	TMS140350-01	9.15	2.65*	29.57	-0.56	2.698	0.505
IBA102927XNRIS2109-14	3X4	TMS140350-02	9.00	4.05***	30.76	0.66	0.989	-0.845**
IBA102927XNRIS2109-14	3X4	TMS140350-04	2.95	-0.05	26.59	-1.63	1.271	-0.718*
IBA02927XNRIS2109-14	3X4	TMS140350-10	5.48	0.65	30.08	-0.08	3.969	1.237**
IBA102927XNRIS2109-14	3X4	TMS140350-13	2.85	-0.84	26.81	-0.71	2.985	0.775*
IBA102927XNRIS2003-3	3X6	TMS140348-25	4.28	0.38	19.22	-2.86	3.441	1.265***
IBA102927XNRIS2003-3	3X6	TMS140348-30	4.20	0.07	29.26	0.00	3.298	0.773*

Appendix 5.2: Mean and SCA effects of the F_1 crosses for fresh yield, (fyld t/ha), dry matter (dm) and total carotene (tc) for Ikenne

			fyld (t/ha)		**dm (%)**		**tc**	
Cross	**Code**	**F_1**	**Mean**	SCA	**Mean**	SCA	**Mean**	SCA
IBA102888XIBA102923	1X2	TMS140339-29	6.67	1.89**	33.78	3.05	2	-0.47*
IBA102888XIBA102923	1X2	TMS140339-32	5.33	1.25	26.94	-4.03*	2.97	0.28
IBA102888XIBA102923	1X2	TMS140339-38	2.75	-0.27	25.24	-4.19*	3.02	-0.50
IBA102888XIBA102923	1X2	TMS140339-54	0.51	2.07**	34.10	5.77**	2.96	0.03
IBA102888XNRIS2109-14	1X4	TMS140337-01	1.25	-0.30	32.62	0.00	1.33	-0.91**
IBA102888XNRIS2109-14	1X4	TMS140337-100	4.58	-0.37	33.04	0.00	1.20	-0.57*
IBA102888XNRIS2109-14	1X4	TMS140337-113	3.33	-0.57	34.88	0.00	2.57	0.89**
IBA102888XNRIS2109-14	1X4	TMS140337-14	4.25	0.55	32.32	0.00	0.99	-0.83**
IBA02888XNRIS2109-14	1X4	TMS140337-29	7.91	2.37***	34.09	0.70	1.66	0.07
IBA102888XNRIS2109-14	1X4	TMS140337-30	7.86	2.45**	35.71	2.57	1.33	-0.49
IBA102888XNRIS2109-14	1X4	TMS140337-40	7.45	1.93*	29.14	-1.63	3.07	0.59*
IBA102888XNRIS2109-14	1X4	TMS140337-46	5.91	1.67*	34.95	1.03	3.33	0.51
IBA102888XNRIS2109-14	1X4	TMS140337-55	4.27	-0.18	35.35	0.00	3.18	0.58*
IBA102888XNRIS2109-14	1X4	TMS140337-78	4.60	0.33	34.78	2.05	0.95	-0.93***
IBA102888XNRIS2109-14	1X4	TMS140337-94	2.43	-0.34	27.17	-5.45*	1.25	-0.24
IBA102888XNRIS2109-10	1X5	TMS140336-01	1.75	-0.87	33.77	3.87	1.28	-0.47*
IBA102888XNRIS2109-10	1X5	TMS140336-03	4.57	0.77	31.48	4.93*	2.45	0.28
IBA102888XNRIS2109-10	1X5	TMS140336-13	4.06	0.13	21.70	-4.81**	1.53	-0.22
IBA102888XNRIS2109-10	1X5	TMS140336-14	3.91	0.95	26.30	-3.52*	1.34	-0.22
IBA102888XNRIS2109-10	1X5	TMS140336-15	7.38	1.27	24.52	-0.55	0.98	-0.71**
IBA102888XNRIS2109-10	1X5	TMS140336-21	3.28	-0.44	32.78	0.00	0.94	-0.65*
IBA102888XNRIS2109-10	1X5	TMS140336-24	3.57	-0.33	31.58	1.66	2.38	0.28
IBA102888XNRIS2109-10	1X5	TMS140336-26	3.77	0.31	35.13	2.80	1.18	-0.47*
IBA102888XNRIS2109-10	1X5	TMS140336-31	3.17	-0.44	26.39	-5.93*	1.21	-0.65*
IBA102888XNRIS2109-10	1X5	TMS140336-34	1.43	-0.73	0.00	0.00	2.95	0.63*
IBA102888XNRIS2109-10	1X5	TMS140336-35	3.80	0.94	33.94	5.58**	2.66	0.63*

Appendix 5.2: continued. Mean and SCA effects of the F_1 crosses for fresh yield, (fyld t/ha), dry matter (dm) and total carotene (tc) for Ikenne

			fyld (t/ha)		dm		tc	
Cross	**Code**	**F_1**	**Mean**	SCA	**Mean**	SCA	**Mean**	SCA
IBA102888XNRIS2003-3	1X6	TMS140335-06	2.18	-0.23	34.00	3.04	1.95	-0.56*
IBA102888XNRIS2003-3	1X6	TMS140335-08	6.58	1.33	28.01	-2.76	1.99	-0.56*
IBA102923XIBA102927	2X3	TMS140347-10	3.86	0.24	34.44	2.00	2.85	-1.05**
IBA102923NRIS2109-14	2X4	TMS140334-04	1.54	-0.50	40.28	6.92**	1.98	-0.36
IBA102923XNRIS2109-10	2X5	TMS140333-03	5.71	1.64*	28.26	0.77	2.04	-0.03
IBA102923XNRIS2109-10	2X5	TMS140333-08	4.39	-0.23	22.44	-4.28*	4.00	0.72***
IBA102923XNRIS2003-3	2X6	TMS140342-01	2.84	0.25	36.84	7.12***	2.52	-0.28
IBA102923XNRIS2003-3	2X6	TMS140342-18	1.37	-0.39	13.79	-6.75**	3.00	-0.10
IBA102923XNRIS2003-3	2X6	TMS140342-26	3.88	0.58	24.18	-4.57*	2.29	-0.23
IBA102923XNRIS2003-3	2X6	TMS140342-43	5.46	1.03	21.87	-1.62	0.00	-0.61*
IBA102923XNRIS2003-3	2X6	TMS140342-45	3.66	0.49	23.23	-3.98*	2.59	0.78**
IBA102927XNRIS2109-14	3X4	TMS140350-04	2.95	-0.58	26.59	1.79	2.46	-0.71*
IBA102927XNRIS2109-14	3X4	TMS140350-10	5.48	-0.04	30.08	-1.39	3.30	0.67*
IBA102927XNRIS2109-10	3X5	TMS140349-04	4.25	0.39	31.26	4.40*	2.48	0.35
IBA102927XNRIS2003-3	3X6	TMS140348-03	6.04	2.45***	29.08	-0.43	2.85	0.02
IBA102927XNRIS2003-3	3X6	TMS140348-06	3.84	0.93	36.55	4.76*	3.70	-0.14
IBA102927XNRIS2003-3	3X6	TMS140348-07	4.90	0.63	34.54	3.83*	3.29	0.27
IBA102927XNRIS2003-3	3X6	TMS140348-16	1.74	-0.47	8.31	-6.48*	2.28	0.27
IBA102927XNRIS2003-3	3X6	TMS140348-24	1.94	-0.24	24.56	-2.66	2.96	0.84**
IBA102927XNRIS2003-3	3X6	TMS140348-25	4.28	0.53	19.22	-6.49***	2.23	0.27
IBA102927XNRIS2003-3	3X6	TMS140348-27	3.27	0.81	31.00	1.08	2.34	0.52*
IBA102927XNRIS2003-3	3X6	TMS140348-28	4.06	0.07	21.64	-4.14	2.53	0.69*
IBA102927XNRIS2003-3	3X6	TMS140348-58	5.28	0.99	26.01	-4.55*	2.13	0.52*
NRIS2109-10XNRIS2003-3	5X6	TMS140328-08	3.78	0.56	19.79	-4.55*	2.53	0.21
NRIS2109-10XNRIS2003-3	5X6	TMS140328-12	3.51	-0.35	21.67	-1.09	1.52	-0.55*
NRIS2109-10XNRIS2003-3	5X6	TMS140328-17	1.82	-0.23	0.00	0.00	1.62	-0.53*
NRIS2109-10XNRIS2003-3	5X6	TMS140328-24	2.97	-0.44	23.18	0.00	1.33	-0.58*
NRIS2109-10XNRIS2003-3	5X6	TMS140328-28	2.68	-0.74	28.46	0.00	1.32	-0.69*
NRIS2109-10XNRIS2003-3	5X6	TMS140328-32	1.64	-0.27	14.04	-5.18*	3.10	0.27
NRIS2109-10XNRIS2003-3	5X6	TMS140328-34	4.69	0.29	30.45	5.57**	2.44	0.21

Appendix 5.3: Mid-parent heterosis for fresh yield, dry matter and total carotene content

Fyld mph	Code	Cross	F1	dm mph	Code	Cross	F_1	tc	Code
118.08**	1x2	I102888 X I102923	TMS140339-25	39.21	1x2	I102888 X I102923	TMS140339-08	46.53	1x2
112.90	1x2	I102888 X I102923	TMS140339-03	36.70	1x2	I102888 X I102923	TMS140339-02	39.66	1x2
100.40**	1x2	I102888 X I102923	TMS140339-21	36.61	1x2	I102888 X I102923	TMS140339-09	39.66	1x2
151.76***	1x4	I102888 X I102923	TMS140339-20	36.15	1x2	I102888 X NRIS2109-14	TMS140337-16	89.77**	1x4
150.07**	1x4	I102923 X I102927	TMS140337-53	41.39	1x4	I102888 X NRIS2003-3	TMS140335-13	31.57	1x6
137.15*	1x4	I102923 X I102927	TMS140337-33	37.57	1x4	I102923 X I102927	TMS140347-06	30.05	2x3
115.97	1x4	I102923 X I102927	TMS140337-34	37.04	1x4	I102923 X NRIS2109-10	TMS140333-08	40.24***	2x5
92.72	1x4	I102923 X I102927	TMS140337-30	35.71	1x4	I102923 X NRIS2003-3	TMS140342-03	24.96*	2x6
88.13*	1x4	I102923 X I102927	TMS140337-55	35.35	1x4	I102923 X NRIS2003-3	TMS140342-45	16.83**	2x6
204.68	1x5	I102923 X I102927	TMS140337-46	34.95	1x4	I102923 X NRIS2003-3	TMS140342-49	14.75	2x6
138.27	1x5	I102888 X NRIS2109-10	TMS140336-26	35.13	1x5	I102923 X NRIS2003-3	TMS140342-50	14.04	2x6
154.05	1x6	I102888 X NRIS2003-3	TMS140335-12	35.90	1x6	I102923 X NRIS2003-3	TMS140342-48	8.48	2x6
173.15	2x3	I102923 X NRIS2109-14	TMS140334-04	40.28**	2x4	I102923 X NRIS2003-3	TMS140342-04	5.39	2x6
119.14	2x3	I102923 X NRIS2003-3	TMS140342-01	36.84***	2x6	I102923 X NRIS2003-3	TMS140342-07	5.39	2x6
106.76	2x5	I102927 X NRIS2109-14	TMS140350-12	38.62	3x4	I102923 X NRIS2003-3	TMS140342-10	5.39	2x6
72.89*	2x5	I102927 X NRIS2109-14	TMS140350-08	35.14	3x4	I102923 X NRIS2003-3	TMS140342-13	5.39	2x6
157.31*	3x4	I102927 X NRIS2003-3	TMS140348-06	36.55*	3x6	I102923 X NRIS2003-3	TMS140342-30	5.39	2x6
153.08***	3x4	I102927 X NRIS2003-3	TMS140348-45	35.40	3x6	I102927 X NRIS2109-14	TMS140350-10	73.22**	3x4
100.87***	3x6	-	-	-	-	I102927 X NRIS2003-3	TMS140348-24	41.56	3x6**
114.67	5x6	-	-	-	-	I102927 X NRIS2003-3	TMS140348-25	22.98	3x6***

Appendix 5.4: Better-parent heterosis for fresh yield, dry matter and total carotene content

Fyld bph	Code	Cross	F1	dm bph	Code	Cross	F1	bph tc	Code
69.25**	1x2	I102888 X I102923	TMS140339-25	25.61	1x2	I102888 X I102923	TMS140339-08	19.83	1x2
65.23	1x2	I102888 X I102923	TMS140339-03	17.56	1x2	I102888 X I102923	TMS140339-02	14.21	1x2
55.53**	1x2	I102888 X I102923	TMS140339-21	17.29	1x2	I102888 X I102923	TMS140339-09	14.21	1x2
92.48***	1x4	I102888 X I102923	TMS140339-20	15.80	1x2	I102888 X NRIS2109-14	TMS140337-16	73.10	1x4**
91.19**	1x4	I102923 X I102927	TMS140337-53	17.51	1x4	I102888 X NRIS2003-3	TMS140335-13	3.50	1x6
81.31*	1x4	I102923 X I102927	TMS140337-33	6.66	1x4	I102923 X I102927	TMS140347-06	13.97	2x3
65.11	1x4	I102923 X I102927	TMS140337-34	5.16	1x4	I102923 X NRIS2109-10	TMS140333-08	32.89	2x5***
47.34	1x4	I102923 X I102927	TMS140337-30	1.40	1x4	I102923 X NRIS2003-3	TMS140342-03	18.85	2x6*
43.83*	1x4	I102923 X I102927	TMS140337-55	0.37	1x4	I102923 X NRIS2003-3	TMS140342-45	11.12	2x6**
176.50	1x5	I102923 X I102927	TMS140337-46	-0.76	1x4	I102923 X NRIS2003-3	TMS140342-49	9.14	2x6
116.23	1x5	I102888 X NRIS2109-10	TMS140336-26	12.53	1x5	I102923 X NRIS2003-3	TMS140342-50	8.46	2x6
118.97	1x6	I102888 X NRIS2003-3	TMS140335-12	15.00	1x6	I102923 X NRIS2003-3	TMS140342-48	3.18	2x6
140.76	2x3	I102923 X NRIS2109-14	TMS140334-04	51.31**	2x4	I102923 X NRIS2003-3	TMS140342-04	0.24	2x6
93.15	2x3	I102923 X NRIS2003-3	TMS140342-01	25.71***	2x6	I102923 X NRIS2003-3	TMS140342-07	0.24	2x6
73.42	2x5	I102927 X NRIS2109-14	TMS140350-12	9.65	3x4	I102923 X NRIS2003-3	TMS140342-10	0.24	2x6
45.01*	2x5	I102927 X NRIS2109-14	TMS140350-08	-0.22	3x4	I102923 X NRIS2003-3	TMS140342-13	0.24	2x6
122.69*	3x4	I102927 X NRIS2003-3	TMS140348-06	3.77*	3x6	I102923 X NRIS2003-3	TMS140342-30	0.24	2x6
119.03***	3x4	I102927 X NRIS2003-3	TMS140348-45	0.50	3x6	I102927 X NRIS2109-14	TMS140350-10	75.32	3x4**
100.87*	3x6	-	-	-	-	I102927 X NRIS2003-3	TMS140348-24	18.85	3x6**
102.67	5x6	-	-	-	-	I102927 X NRIS2003-3	TMS140348-25	3.25	3x6***