SELECTION-BASED APPROACH TO EARLY BULKINESS FOR IMPROVED PROVITAMIN A CAROTENOID CONTENTS IN CROSSES OF YELLOW CASSAVA (*Manihot esculenta* Crantz) GENOTYPES IN NIGERIA

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PhD/SAAT/2017/1023

THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN CROP PRODUCTION (CROP BREEDING AND GENETICS)

JULY, 2023

ABSTRACT

The problem of poor yields and the need for lands encourages piecemeal harvesting whereby farmers harvest from five months after planting and mostly at the stage of reasonable yield but of a poor marketable size and value. This study therefore aims to provide farmers with biofortified cassava genotypes that bulks early so that farmers can harvest their cassava early enough with reasonable yield. This study was conducted under two experiments in different agroecologies. The first experiment was a bulking rate experiment conducted under a rainforest agroecology in two cropping seasons where 42 F_1 progenies obtained from crossing block involving 39 parental genotypes from different crossing combinations were evaluated at different harvesting periods of 6, 9 and 12 months after planting (MAP) in a 42x3 factorial experiment in a randomized complete block design in Ibadan. And the second experiment, a bulking rate experiment was conducted in a rainforest and southern guinea savanna zone where ten (10) cassava genotypes were evaluated at different harvesting periods of 3,6,9 and 12 months after planting at Ubiaja and Mokwa locations in a randomized complete block design. Data were collected on plant height, height at first branching, number harvested, root number, shoot weight, root weight, harvest index, root size, storage root diameter, pulp colour, inner skin colour, dry matter content, fresh storage root yield, total carotenoid, beta carotenoid content. In both experiments, fresh root yield of genotype progressively increased from earlier months up until 12 MAP while some shows discontinuous patterns of growth. Discontinuity in yield, that is a genotype/accessions showing retrogressive pattern in their root yield across months after planting had no effect on overall root yield performance. At 9 MAP, most cassava genotypes and accessions had lower dry matter (DM) with low root yield while in some others, their root yield increased as DM reduces. In the experiment at Ibadan, the path analysis shows that root weight had direct effect on fresh root yield while seasons significantly and negatively contributed to total carotenoids (TC). The cropping seasons (2019/2020) significantly and positively contributed to fresh root yield while MAP contributed negatively to DM. In both experiments, a negative correlation was observed between TC (total carotenoids) and DM (dry matter) as well as between TC and fresh storage root yield. However, the cassava progenies in Ibadan exhibited greater variability, with some cassava accessions demonstrating both high root yield and high total carotenoids content. In both experiments, early bulking of cassava demonstrated similarity, with both Experiment I and II recording early bulking rates exceeding 60%. In the experiment at Mokwa/Ubiaja, genotypes falling into the early bulking category, specifically IBA141092, exhibited notably higher beta carotenoid levels (10 µg/g). Conversely, in experiment at Ibadan, most accessions in the late bulking category demonstrated higher total carotenoid content compared to other bulking categories. In Ibadan, among the progeny, accession IBA180058 displayed the highest best linear unbiased prediction (BLUP) values for total carotenoids (4.85 µg/g), while IBA180146 emerged as the top-performing accession in terms of root yield (5.04 t/ha). To enhance the progeny's root yield and carotenoid content, cross-breeding with accessions boasting the highest BLUP values for root yield (IBA180146) and total carotenoids content (IBA180058) is recommended.

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List of Abbreviations

Acronym	Meaning
BLUE	Best Linear Unbiased Estimates
BLUP	Best Linear Unbiased Prediction
B-carot.	Beta Carotene
BRNHT/brnhtapc	First Apical Branch Height
CMD/MCMDS	Cassava Mosaic Disease
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional Agricultural Tropicale
DNA	Deoxyribonucleic acid
DMC/DM	Dry Matter Content
DSRY/DYLD	Dry Storage Root Yield
FSRY/FYLD	Fresh Storage Root Yield
GA	Genetic Advance
HPLC	High-Performance Liquid Chromatography
HQCF	High Quality Cassava Flour
GxE	Genotype by Environment Interaction
GCV	Genotypic Coefficient of Variation
HI	Harvest Index
IITA	International Institute of Tropical Agriculture
INNCOL	Inner Skin Colour
MAP	Months After Planting
MCMDS/CMD	Mean Cassava Mosaic Disease Severity/Cassava Mosaic Disease
NARES	National Agricultural and Research Extension System
NRCRI	National Root Crop Research Institute
NOHAV	Number of Harvested Plant
OUTCOL	Root Outer Colour
PAR	Photosynthetic Active Radiation
PCV	Phenotypic Coefficient of Variation
PLPCOL	Pulp colour

pVAC	Provitamin A Carotenoid
RTWT	Root Weight
RTNO	Root Number
SHTWT	Shoot Weight
SPGRV	Specific Gravity
SRD	Storage Root Diameter
Tchart	Total Carotenoid Chart
TCichk/tcichkC	Total Carotenoid using icheck
TC	Total Carotenoids
TME	Tropical *Manihot Esculenta*
TMS	Tropical Manihot Specie
Trancr	Transfer Crispr
VAD	Vitamin A Disease
WHO	World Health Organization
WChk	White Check
YChk	Yellow Check

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background to the Study

Cassava (*Manihot esculenta* Crantz) is a perennial shrub that originated in the neotropics. Its starchy roots are the most important product which provides a source of calories to millions of people in Sub-Saharan Africa (Stapleton, 2012; Norton, 2014). It is the fourth most important basic food worldwide after rice, wheat, and maize while in terms of calories consumed in sub-Saharan Africa, it is the second most important consumed food staple (Tarawali *et al.,* 2012).

The crop is regarded as the Africa's food insurance crop due to its resilience to withstand drought, low soil fertility, low intensity management, it is still able to produce good yields because of its potential to face the effects of climate change (Burns *et al.*, 2010). Its storage roots is a major source of carbohydrate and the leaves are eaten as a preferred green vegetable in many parts of Africa. Tuber flesh colour and good culinary quality are essential traits for consumption of cassava as staple food. In most of the cultivated cassava the tuber flesh is white or cream which contain negligible amount of carotenoids (Udoh *et al.,* 2017).

In terms of its nutrients, cassava tubers are rich in carbohydrates, but not in essential proteins and micronutrients. Pro-Vitamin A carotenoids (pVAC) which includes α-carotene, β-carotene and β-cryptozanthine are precursors of vitamin A, a micronutrient important for normal development and functioning of the human body (Eggersdorfer &

Wyss, 2018; Meléndez-Martínez *et al.*, 2022). Carotenes (α-carotene, β-carotene, lycopene) represent the most diversified group of pigments in nature, with colors varying from yellow to red, found in photosynthetic and non-photosynthetic tissues, such as roots, seeds and fruits. Once ingested, β-carotene is transformed in the liver, into Vitamin A (Meléndez-Martínez *et al.*,2022). Vitamin A is a micronutrient with functions related to vision, cell differentiation, growth development, reproduction and the immune system (Huang *et al.*, 2018). It exists in natural products in many different forms: as preformed retinoids stored in animal tissues and as provitamin A carotenoids (pVAC), which are synthesized as pigments by many plants and are found in different plant tissues (Sun *et al*., 2022; Blaner, 2020).

Cassava is major crop cultivated by millions of people particularly in Africa. However, cassava is deficient in essential micronutrients such as pro-vitamin A carotenoids. As a result, people who rely heavily on cassava as a dietary staple may be at risk for vitamin A deficiency. Vitamin A deficiency (VAD) is a preventable tragedy that affects millions of people, particularly in sub-Saharan Africa according to World Health Organization (WHO/FAO, 2003).

In addition to the problem of Vitamin A Deficiency, farmers often leave their cassava on the field for extended period in order to attain reasonable yields. This prevents the land from being used for other crops and can lead to loss of livelihoods due to bush fires and cattle invasion.

1.2. Statement of the Research Problem

Cassava is one of the most important sources of calories in the tropics and consumed as a staple food. However, roots contain little protein and few micronutrients when compared to sweet potatoes, beans, maize, or wheat and are deficient in vitamin A (Udoh *et al.*, 2017). The continued prevalence of micronutrient deficiency in many developing regions of the world necessitates the development of new varieties of staple food crops that are enriched in limiting nutrients with selection of preference traits such as early bulking.

Vitamin A deficiency (VAD) is the leading cause of blindness in children which is preventable and also increases the risk of disease and death from severe infections. For instance, in pregnant women, VAD causes night blindness and increases the risk of maternal mortality (WHO, 2009). Vitamin A deficiency is a public health problem among young children in more than half of all countries, particularly Africa and Southeast Asia. This is characterized by visual impairment and blindness, which significantly increases the risk of serious illness and death. VAD is particularly severe in pregnant women during the last trimester, when both the unborn child and mother have the greatest need for vitamin A, especially in low-income countries where VAD-related deaths have been reported. An estimated 250 million preschool children have VAD and it is likely that significant proportions of pregnant women were also affected in areas where VAD is prevalent. In sub-Saharan Africa, an estimated 250,000 to 500,000 children with vitamin A deficiency go blind each year, with half of them dying within 12 months of losing sight (WHO, 2009).

Also, another big issue is the problem of cattle invasion and bush fires that usually occurs in some areas common with cassava production as a result of overstaying of cassava on farmers' field due to low yield. This has therefore necessitated the need to provide farmers with early bulking pro-vitamin A cassava varieties with considerable yield attainment and consequently reducing the stay of the crop on farmers' field while also improving the nutritional status through biofortification. As a result of this development, the farmers would have harvested their crop before the usual invasion of animals or incidences of bushfires on their farm.

1.3. Justification of the Research

Biofortification of staple crops is a cost effective and sustainable approach that can help combat vitamin A and other micronutrient deficiencies in developing countries (Girum *et al.*, 2013). Carotenoid intake plays an important role in human nutrition and health owing to the association of their consumption levels with reduced risk of diseases such as cardiovascular disease, cancer, and age-related sight problems arising from deficiencies of lutein and zeaxantine (Gao *et al.*, 2018). The consumption of carotene rich foods is the most effective intervention for vitamin A deficiency. The most widely approach in biofortification is conventional breeding which involves selection of varieties that is high in micronutrients such as vitamins and at the same time high yielding. Vitamin A is an essential micronutrient for the normal functioning of the visual and immune systems, growth and development, maintenance of epithelial cellular integrity, and for reproduction (Huang *et al.*, 2018).

Roots of commercial cassava cultivars is deficient in provitamin A carotenoids but very rich in carbohydrates. Both conventional breeding and genetic modification are means through which their production and accumulation can be increased to fight vitamin A deficiency disorders (Welch & Graham, 2002). Bulkiness evaluation helps to identify cassava varieties that yield earlier over their growing periods. Although root bulkiness begins within first to third months after planting (MAP) of cassava and produce reasonable fresh storage root yield by 6 MAP, high yielding genotypes can be identified through high bulking rate within a short duration (early bulking) as reported by Hershey, 2012 and Okogbenin *et al.*, 2013, Okogbenin *et al.*,2016).

It is therefore important to evaluate the genetic variability of the yellow root cassava genotypes in response to provitamin A content and also to identify the genotypes with high pro vitamin A carotenoid (pVAC) content with early bulkiness. This will help to select early bulking pVAC cassava genotypes which can be recommended as high yielding yellow root cassava genotypes for possible introgression of their desirable traits through genetic modification in future breeding program of cassava improvement. As combining early buking traits with higher carotenoid content will improve the livelihoods of farmers, enhance food production and promote better health and nutrition.

1.4. Aim and Objectives of the Study

The aim of the study is to identify Cassava genotypes with early bulkiness and high pro-vitamin A carotenoid content (pVAC). The objectives are to determine:

i. the promising genotypes of provitamin A cassava with early bulkiness trait for advanced yield trial.

ii. the association between Pro Vitamin A Carotenoid (pVAC) and early root bulkiness of provitamin A cassava.

iii. the relationship between root yield and carotenoids, also to select genotype or accessions with high carotenoids contents among provitamin A cassava.

iv. the effect of different agroecology in terms of rainfall on total carotenoids, dry matter and root yield.

v. the genetic variability among the accessions or progenies.

vi. the generate F_1 progenies with early bulkiness and high provitamin A carotenoid contents among provitamin A cassava.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Origin and Distribution of Cassava

Cassava plant originated in North-East Brazil, with the likelihood of an additional centre of origin in Central America (Allem, 2002). It probably entered cultivation at these two centres of origin. It is believed that cassava reached the Caribbean Islands and Central America in the 11th century (Hillocks *et al.,* 2002) and Africa at the end of the 16th century (Sree *et al.,* 2011) and was introduced into India in the 19th century.

Cassava cultivation along the coastal parts of Nigeria was recognized as early as 1967 and can be traced back to Portuguese explorers and freed slaves from Brazil and the West Indies who came between the ports of Bonny and Koko on the southern coast of Nigeria (Hahn *et al*., 1992). Hence, cassava was actually introduced to Nigeria over 300 years ago, although its systematic cultivation was never generally accepted and practiced until the late 1890s. Cassava was widely accepted a little more than 130 years ago and was fully integrated into the cultivation systems of southern Nigeria (Hahn *et al*., 1992). The emancipated slaves from Brazil, the West Indies, and Sierra Leone, who returned to parts of southern Nigeria after the 1850s, played an important role in promoting cassava acceptance (Akoroda & Ikpi., 2007). These returnees, who knew how to process the harvest into food, mainly settled among the locals of Lagos, Badagry, Abeokuta and Ijebu, to whom they imparted their knowledge and also popularized the consumption of cassava in the local food industry (Akoroda & Ikpi, 2007).

However, its importance to the country got a boost in the late nineteen centuries when more slaves returned to their homelands. It has since then become a major economic sustenance crop and it has attained the status of largest producer in the world with recorded production of 34 million tonnes around 2002 but recently producing 59.48 million tonnes (FAO, 2018; Adeniji, 2005).

Cassava is known to be a very drought-tolerant crop with the ability to yield even when planted in poor soils. When it was first grown in Africa, it was used for subsidiary purposes, though it is now considered to be one of the most important food staple crops on the continent (Legg *et al.,* 2004). Wild populations of the subspecies *flabellifolia* of *M. esculenta*, which has been identified as the ancestor of domesticated cassava, are found in west-central Brazil, where it was probably first domesticated more than 10,000 years ago (Olsen & Schaal, 1999). Around 6,600 BC, Cassava pollen appears in the lowlands of the Gulf of Mexico at the archaeological site of San Andres. The oldest direct evidence of manioc cultivation comes from a 1,400-year-old Maya site, Joya de Cern, in El Salvador and the species *Manihot esculenta* Crantz, which probably originated further south in Brazil, Paraguay and Argentina. With its high nutritional potential, cassava had become a staple food for the indigenous people of northern South America, southern Mesoamerica and the Caribbean by the time of the Spanish conquest. Its cultivation was continued by the colonial Portuguese and Spanish. Forms of the modern domesticated species occur in the wild in southern Brazil. While several species of *Manihot* are wild, all of the varieties of *M. esculenta* are cultigens (Pope *et al.*,2001).

2.2. Taxonomy and Botanical Description of Cassava

Cassava (*Manihot esculenta* Crantz), belongs to the kingdom Plantae, family *Euphorbiaceae,* subfamily *Crotonodeae*, tribe *Manihoteae*, genus *Manihot* and species *esculenta* (Allem, 2002). This family is characterised by latex production (Hershey, 2005). Out of numerous species that belong to the genus *Manihot*, cassava is the only species that is widely cultivated for food production (Alves, 2002; Mkumbira, 2002; Nassar, 2005). Olsen and Schaal (1999) and Léotard *et al.* (2009) suggested that cultivated cassava emerged from populations of *M. esculenta* sp. *flabellifolia* (Pohl) Ciferri. The *Manihot* species have 2n = 36 chromosomes (Jennings & Iglesias, 2002). Nassar and Dorea (1982) reported that *Manihot* species behave meiotically as diploids. Cassava is therefore a functional diploid with 2n=2*x*=36 (Westwood, 1990; De Carvalho and Guerra, 2002; Nassar and Ortiz, 2008). Ceballos *et al.* (2012) suggested that certain portions of the genome are duplicated, indicating that cassava may be a segmental allotetraploid.

The cassava plant is a perennial that grows under cultivation to a height of about 2.4 m. The large, palmate leaves ordinarily have five to seven lobes borne on a long slender petiole. They grow only toward the end of the branches. As the plant grows, the main stem forks, usually into three branches which then divide similarly. The roots or tubers radiate from the stem just below the surface of the ground. Feeder roots growing vertically from the stem and from the storage roots penetrate the soil to a depth of 50-100 cm. This capacity of the cassava plant to obtain nourishment from some distance below the surface may help to explain its growth on inferior soils. Male and female flowers

arranged in loose plumes are produced on the same plant. The triangular-shaped fruit contains three seeds which are viable and can be used for the propagation of the plant. However, propagation through seeds produces less than 50% germination and propagation using botanical seeds are only for breeding purposes. The number of tuberous roots and their dimensions vary greatly among the different varieties (USDA, 2003).

2.3. Morphological and Agronomic Characteristics of Cassava

Cassava is a perennial woody shrub that generally grows from one to three metres in height (Hershey, 2005). Farmers usually harvest cassava during the first or second year. There are two different types of plants: erect, with or without branches at the top, or spreading types. The morphological properties of cassava are very variable, which indicates a high degree of interspecific hybridization. There are many varieties of cassava in several germplasm banks held by both international and national research institutes (Alves, 2002).

Cassava genotypes are usually characterized based on morphological and agronomic descriptors. Morphological descriptors such as lobe shape, root pulp color, stem outer color are more inheritable than agronomic descriptors (such as root length, number of roots per plant and root yield). Among the morphological descriptors, the following have been defined as the minimum or basic descriptors that should be considered in identifying a variety: (i) apical leaf colour; (ii) apical leaf pubescence; (iii) central lobe shape; (iv) petiole colour; (v) stem cortex colour; (vi) stem external colour; (vii) phyllotaxis length;

(viii) root peduncle presence; (ix) root external colour; (x) root cortex colour; (xi) root pulp colour; (xii) root epidermis texture; and (xiii) flowering. Given the large number of cassava genotypes cultivated commercially and the large diversity of ecosystems in which cassava is grown, it is difficult to make a precise description of the morphological descriptors as there is a genotype-by-environment interaction. Thus, in addition to morphological characterization, molecular characterization, based mainly on DNA molecular markers has been very useful in order to evaluate the germplasm genetic diversity (Burg, 2017).

Cassava leaves are simple and are made up of the lamina and petiole. The leaf is lobed with hand-shaped veins. There are generally an odd number of lobes ranging from three to nine (occasionally 11). Only a few varieties have three lobes in mature leaves that represent the primitive ancestral form. Leaves near the inflorescence are smaller in size and lobed (mostly trilobed), but the leaf closest to the inflorescence base is often simple and unlobed (Alves, 2002). At the nodes of the oldest parts of the stem, there are protuberances, the scars left by the first leaves of the plant. Cassava grown from stem cuttings can produce as many primary stems as there are viable buds on the cutting. In some varieties with strong apical dominance, only one stem develops. The cassava plant has sympodial branches. The main stem (s) divide di-, tri- or tetrachotomous, produces secondary branches that produce other successive branches. These branches induced by flowering are called reproductive branches (Okechukwu *et al.,* 2020). Stem morphological and agronomic properties are very important when characterizing a variety. The variation in these properties depends on the variety, cultural practice and

climatic conditions (Alves, 2002). Roots are the main storage organ in cassava. In plants propagated from real seeds, a typical primary taproot system is formed as in dicotyledonous species. The radicle of the germinating seed grows vertically downwards and forms the taproot from which the adventitious roots come. Later the taproot and some adventitious roots become storage roots.

2.3.1 Fibrous roots: In plants grown from stem cuttings, the roots are random and arise from the basal cut surface of the stake and occasionally from the buds underground. These roots develop into a fibrous root system. Some fibrous roots (between three and ten) begin to pile up and become storage roots. Most of the other fiber roots remain thin and continue to function in absorbing water and nutrients. Once a fiber root becomes a storage root, its ability to absorb water and nutrients decreases significantly. The storage roots result from secondary growth of the fiber roots; thus, the soil is penetrated by thin roots and their enlargement begins only after this penetration has occurred.

2.3.2. Storage roots: From an anatomical point of view, the cassava root is not a tuber root, but a real root that cannot be used for vegetative reproduction. The mature cassava root has three different tissues: bark (periderm), shell (or cortex) and parenchyma. The parenchyma, the edible part of the fresh root, makes up about 85% of the total weight and consists of xylem vessels that are distributed radially in a matrix of starchy cells (Alves, 2002). The shell layer consisting of sclerenchyma, cortical parenchyma and phloem makes up 11-20 % of the root weight (Odoemelam *et al.,* 2020). The periderm (3 % of the total weight) is a thin layer of a few cells which, as it grows, usually flakes off the outermost parts. Root size and shape depend on the variety and environmental conditions;

The size variability within a variety is greater than that found in other root crops (Yonis *et al.*,2020).

The roots are differentiated 6 Weeks After Planting (WAP) and some start thickening. Starch deposition in the roots begins when the supply of photosynthesis exceeds the requirements of growth of stems and leaves. The root harvesting must be delayed until an appreciable amount of starch has accumulated. The exact time to harvest cassava depends on the cultivar. This is because maturity period ranges from 7 – 18 months after planting (Hershey, 2005). In cassava breeding, flowering time is an important factor that needs to be considered. Understanding the critical role of flowering time in cassava breeding can help improve the quality and yield of cassava crop. Flowering time in cassava is a critical factor in cassava breeding because it determines the length of breeding cycle and crossing is usually made in cassava breeding program at 2.5 months after planting and most crossing made around 4-5 months after planting (Oluwasanya *et al.,* 2021). Flowering may begin as early as 5 - 6 WAP, although the exact time of flowering depends on the cultivar and the environment (Jennings & Iglesias, 2002; Hershey, 2005). Cassava flowers are monoecious and predominantly out-crossing (Ramos Abril *et al.,* 2019; Bakum, 2021). The flowering is controlled by complex interaction of a range of genetic and environmental factors. In some areas, cassava will flower abundantly all year round, while in other locations, flowering is seasonal (Alves, 2002). Flowers are regular in some varieties and rare to non-existing in others. Flower availability is influenced by plant habit and is generally formed in the insertion point of the reproduction branching (Jennings & Iglesias, 2002; Hershey, 2005).

2.4. Vitamin A Deficiency (VAD) and the needs for Biofortification

In sub-Saharan Africa, an estimated 980,000 pre-school children showed clinical signs of Vitamin A deficiency of which 480,000 reside in West and Central Africa. As many as 17.4 million people in West and Central Africa show sub-clinical signs of Vitamin A Deficiency (VAD). The average prevalence of clinical and sub-clinical vitamin A deficiency in 19 countries of West and Central Africa is estimated at 1.1% and 20.4% respectively (UNICEF, 1998).

Biofortification of cassava genotypes with high concentration of pro vitamin A Carotenoids mainly β-Carotene in the roots of agronomically superior varieties is as a result of hybridization among promising cassava that are locally adapted and high in Carotenoids. The new yellow varieties are high yielding and are resistant to many pests and diseases (WREN MEDIA, 2012).

In pregnant women Vitamin A Deficiency (VAD) causes night blindness and may increase the risk of maternal mortality. About 20 percent of pregnant women and 30 percent of children under five in Nigeria suffer from VAD. Since cassava is a major food staple, biofortification therefore shows great potential in alleviating Vitamin A Deficiency in Africa (FAVHEALTH, 2007).

In most of the cultivated cassava clones, the tuber flesh color is white or cream; these varieties contain negligible amounts of carotenoids (Bradbury & Holloway, 1988). However, several cassava varieties have yellow flesh color, and contain moderate amounts of carotenoids (Mc Dowell & Oduro, 1983). Yellow pigmented cassava is

known to be cultivated in a limited way in Colombia, Philippines, Jamaica, and some African countries.

The strategy of Harvest Plus research on cassava emphasizes developing genotypes with high concentrations of provitamin A carotenoids, mainly β-carotene, in the roots of agronomically superior varieties, then sharing the germplasm among collaborating agricultural research systems in the developing world. The International Center for Tropical Agriculture (CIAT, 1983), based in Cali, Colombia, coordinates the overall activities for cassava biofortification and has specific responsibility for research in Asia, Latin America, and the Caribbean. The International Institute for Tropical Agriculture (IITA), in Ibadan, Nigeria, is responsible for cassava Biofortification activities in Africa. (Ceballos & McClafferty, 2006)

Most pro-vitamin A carotenoids are beta carotene, alpha carotene and beta cryptoxanthin. Beta-carotene is the most important carotenoid as half of its structure makes up the vitamin A molecule (Rodriguez-Amaya & Kimura, 2004). And the selection of cassava material for new release is likely to be substantially dependent on some biochemical properties such as starch and dry matter, root color and garification (Ukenye *et al.,* 2013)

Therefore, cassava can be bio-fortified for β-carotene since there exists genetic variation that can be utilized in improving its micronutrient (Maziya-Dixon *et al*., 2000). Cassava breeding can improve on its beta-carotene content by exploiting the diversity that exists in yellow-orange root cassava accessions (Welch & Graham, 2002). The three genetic types of yellow fleshed cassava genotypes that are grown in Nigeria are UMUCASS36,

UMUCASS 37, UMUCASS 38 and effort on improvement and release of other genotypes are still ongoing (FAVHEALTH, 2007). Yellow cassava cannot be purchased from any producers currently, but a distribution system is being implemented in Nigeria providing 25,000 local households with stems under the condition that they will share their stems with other rural farmers the next season (WREN media, 2012; Consortium, 2012). Over 7.6 million farming households and 38 million people are already consuming biofortified crops including Vitamin A Yellow Cassava by the end of 2018 (HarvestPlus, 2018).

2.4.1. Biofortification in cassava

No other continents depend on Cassava to feed as many people as does Africa where over 500 million consume it daily (Tufan, 2013). The crop is called Africa's food insurance because it offers reliable yields even in the face of drought, low soil fertility, low intensity management, and because of its resilience to face the effects of climate change (Burns *et al.*, 2010). Five countries namely, Nigeria, Brazil, Indonesia, and Democratic Republic of Congo produced 60% of the world production (FAOSTAT, 2016).

Adequate supply of food in terms of nutrition and calories is more essential for human well-being and health (Amanda de Souza & Stephen, 2017) but cassava is high in carbohydrates and low in micronutrients such as vitamins and other essential minerals needed for health. Therefore, the common food of the people can be improved nutritionally thereby producing a better-quality food through biofortification. This also helps malnourished rural population who may not afford commercially marketed fortified

foods and supplements with easy reach of adequate and affordable nutrition. This will reduce the number of malnourished people and improve their nutritional status. According to data from the Nigeria Food Consumption and Nutrition Survey, 2001-2003, Cassava consumption is approximately 200-250 g/day among children 4 to 6 years and 350-400 g/day among women in southern region of Nigeria and prevalence of VAD is 29.5 % among children less than 5 years old and 13 % among women of child bearing age (Maziya-Dixon *et al*, 2007).

Cassava being a common staple food for more than 250 million people in Africa where there are more reported cases of Vitamin A Deficiency (VAD) (Gurdev *et al.*, 2012) and where micronutrients deficiency affects approximately 3 billion people worldwide, solution to solving the problem of this deficiencies is through biofortification. Conventional plant breeding yielded yellow cassava with higher concentration of beta carotene (10-15µg/g) fresh weight (Fabiana *et al.*, 2014). Concomitantly, efforts centered on improving cassava nutritional quality have been made (Montagnac *et al*., 2009; Gonzalez *et al*., 2011). World Health Organization (WHO) and Consultative Group on International Agricultural Research (CGIAR) have made fighting micronutrients deficiencies known as hidden hunger a high priority.

2.4.2. Vitamin A deficiency (VAD)

Biofortification is a new approach which aimed to incorporate needed micronutrients into crops. In preventing Vitamin A Deficiency. For instance, Nigerian government has mandated fortification of food such as sugar, wheat flour, vegetable oil with vitamin A

during immunization for age of 6 months to 5 years (Bouis & Saltzman, 2017). Cassava is a promising vehicle for biofortification since it is a widely consumed staple food in Nigeria (Ilona *et al*., 2017; Bouis & Saltzman, 2017). Its biofortification, therefore could offer a cheap, affordable and available plant source of vitamin A. since it has the potential of providing up to 25 % of daily vitamin A required for children and women (Adeola *et al.,* 2017).

Vitamin A Deficiency (VAD) is the commonest cause of blindness among children and this has caused 500,000 children to become partially or totally blind due to VAD (WHO, 2009). Consumption of less amount of the micronutrient than required is one of the causes of VAD. This may be due to low availability or inadequate consumption (WHO, 2009). Two sources of Vitamin are the animal source which contain preformed Vitamin A(Retinol) and plant source which contain pro vitamin A carotenoids which metabolizes into Retinol (Joseph *et al*., 2016). World Health Organization (WHO) estimated average requirements for Vitamin A for children 4-6 years is 275µg retinol and 500µg for women.

Animal source of vitamin A are not affordable by the poor so, poor families depends on plant sources of Vitamin A (Tumuhimbise, 2013). However, the plant source of vitamin A is seasonal in availability (Ender *et al*., 2014). Therefore, effort has been made in biofortifying crops to supply these nutrients through special breeding programs. HarvestPlus biofortification program is a new food based public health intervention aimed at controlling micronutrients deficiency in poor countries (Wolfgang & Bonnie, 2007).

2.5. Breeding and Improvement of Cassava

Various crossbreeding schemes are used to produce botanical seeds in cassava. For open pollination, seeds are germinated under greenhouse conditions at the Centro Internacional de Agricultura Tropical (CIAT) and the resulting seedlings are transplanted into the field when they are 20-25 cm tall (Jennings and Iglesias, 2002). The same system is usually used at the International Institute of Tropical Agriculture (IITA), but in some nurseries, the seeds are planted directly in the field to take advantage of the availability of irrigation and high temperatures (Ceballos *et al*., 2004). Root systems of plants from botanical seeds versus vegetative cuttings can differ significantly. The tap roots from seedlings tend to store less starch than roots from cuttings (Rajendran *et al*., 2000). For this reason, it is difficult to correlate the root yield of clones at later stages of the evaluation or selection process with early results from plants obtained from botanical seeds (Morante *et al*., 2005). However, when seeds germinate in containers and are later transplanted, the taproot often does not develop, and the plant derived from seedlings may be more similar to subsequent plants in terms of starchy root conformation (Ceballos *et al*., 2012). The rate of reproduction of cassava by vegetative cuttings is low (Ceballos *et al*., 2004; 2012)

Under good environmental conditions, a cassava plant can easily produce up to 20 cuttings from a modern clone. However, when handling thousands of clones in a range of environments, a realistic rate of propagation is in the range of 5-10 cuttings per plant. This is a critical limitation as it takes several years before enough planting material is available for multi-site trials. Another complication is the number of factors that can affect the quality of the planting material. For example, the original positioning of the

vegetative cutting along the stem significantly affects the performance of the plant from which it originated. Cuttings from the middle section of the stem usually produce better performing plants than those from above or below, and these fluctuations in plant performance due to the physiological status of the vegetative cutting led to greater experimental errors and undesirable fluctuations in the evaluation process (Ceballos *et al*., 2004).

Although cassava is an important food crop, its scientific breeding began only recently compared to other crops (Egesi, 2011). The improvement in crops depends on the existence of genetic variability and how easily this variability can be introduced into genotypes with desirable agronomic traits. In order to include certain traits in an existing variety, the mode of inheritance of the trait should be known as this will determine the most appropriate breeding method.

Cassava can reproduce sexually or by propagation (Ceballos *et al*., 2004). The roots of cassava *(Manihot esculenta*) serve as the primary source of carbohydrates in the diets of people in many arid regions of the world, including more than 250 million people in sub-Saharan Africa (FAO, 2000). Unfortunately, the roots of commercial cassava cultivars are quite low in micronutrients, and micronutrient deficiencies are widespread in these regions (FAO, 2000).

Any breeding program basically involves creating variability and selecting from the variation that has been created. This variation can be created through domestication,

mutation, soma clonal variation, gene recombination, genetic engineering, hybridization e.t.c. (Sanjay, 2005).

2.5.1. Flowering and breeding in cassava

Little is known about the flowering in cassava and some clones are never known to have flowered. Flowering can begin 6 weeks after planting, although the exact flowering time will depend on the strain and the environment. It seems that cassava blooms best in moderate temperatures. Usually, flowering is about to be initiated when branching occurs and this is influenced by long photoperiods (Alves, 2002). Flowering is essential for breeders. Often the first forking does not produce flowers, although in the "V" formed by the fork, the vestiges of the initiated florescence can be seen. Cassava is monoecious, producing both male and female flowers on the same inflorescence. The female flowers are larger, but fewer in number than the male flowers which are found at the tip of the florescence. The female flowers open 1-2 weeks before the male flowers in the same inflorescence (Alves, 2002). In heavier branching types, male and female flowers may open at the same time at different branching points. Under natural conditions cassava is cross pollinated by insects but considerable selfing may also occur (Howeller, 2011).

2.5.2. Nutritional value of cassava

The nutritional quality of cassava roots in general is low, and contains mainly carbohydrates per 100 gram raw weight, white cassava provides 160 kcal mainly as carbohydrates (38g) and contains further water (60g), a little protein (1.4g), fat (0.3g) and trace elements of iron (0.3 mg), niacin 0.9 mg), thiamin (0.09mg), riboflavin (0.05mg),

calcium (16mg), potassium (271mg), zinc (0.3mg), and vitamin C (21g) (Motagnac *et al.*, 2009). People depending on a diet predominantly based on white cassava roots are at greater risk of having iron, zinc and Vitamin A Deficiency (VAD), as was shown in children in Kenya and Nigeria (Gegios *et al.*, 2010; UNICEF, 2006). Around 600 carotenoids have been isolated and characterized in nature, around 10% of which can be metabolized to vitamin A by mammals. The most important carotenoids with vitamin effects are β- and α-carotenes and cryptoxanthine. Some carotenoids that cannot be converted into vitamin A (e.g. lutein, zeaxanthin, and lycopene) are also found in the parenchyma of the cassava root. Not all pro Vitamin A Carotenoids (pVAC) have the same activity. β-carotene has about twice as much vitamin activity as the other pVAC carotenoids.

2.6. Economic Importance of Cassava

Cassava ranks first among crops in volume of production with 1476.8 million tons in Africa and accounting for over 50% of the world total production in 2014 (FAOSTAT, 2017) and currently, as of 2018, world cassava production stood at about 278 million tonnes (FAO 2018), Africa total production is about 170 million tonnes (about 56% of world production) (FAOSTAT, 2019). Nigeria accounts for 21% of the 277 million metric tonnes of global cassava production which made the country the largest producer of cassava in the world (59.5 million metric tonnes) followed by Thailand (31.7million metric tonnes), DR Congo (30 million metric tonnes), Ghana and Brazil (20.8 million and 17.6 million metric tonnes) respectively. Cassava supply is yet to meet the huge export demand for cassava derivatives such as starch and high-quality cassava flour (HQCF).

For instance, the demand for HQCF is 500,000 metric tonnes and supply could only cater for 15,000 metric tonnes. Also, starch demand about 300,000 with supply being able to meet less than 10,000 metric tonnes thereby creating a huge demand gap which if met could increase the economic potential of the crop in terms of foreign exchange and Nigeria would need 28.3milion metric tonnes of fresh cassava roots planted on 1.2 million ha in order to meet this demand (Price Waterhouse Coopers, 2020)

Economic potentials for cassava are very huge, a sum of $427million could be generated from domestic value addition and a sum of $2.98 billion could be realized from export of different cassava product. The highest cassava exporting country is Thailand with cassava exporting capacity of 6.4 million tonnes. Thailand contributes about 46% of the total 13.9 million tonnes cassava exported followed by Vietnam (0.8 million metric tonnes) and Cambodia (0.08 million metric tonnes). In terms of yield from a hectare, Nigeria still ranks low and in fact the lowest of 8.76 t/ha while Indonesia, Thailand, India, Vietnam, Brazil and Congo D.R had 24.45 t/ha, 23.07 t/ha, 20.96 t/ha, 19.28 t/ha, 14.36 t/ha and 10.76 t/ha respectively (FAOSTAT, 2018)

In Nigeria, cassava crop is a common crop in the tropics majorly cultivated by rural poor farmers and it serves as a major source of their income. Although, Nigeria is the largest producer in the world, export trade is still very low and this is as a result of diverse problems affecting farmers such as low capital, unavailability of land, unavailability to credit facilities, poor infrastructures such as processing facilities, poor marketing linkages, poor roads among others (www.afrimash.com). Also, as these factors affects cassava export, traditional method of cassava production and post-harvest losses also led

to the inability to meet the demand required in the international market (Price Waterhouse Coopers, 2020).

Its starchy root is a major source of dietary energy for over 500 million people. Apart from eating cassava, it is used for making tapioca, medications, fabrics, paper, building materials such as plywood. The importance of cassava in improving the livelihood of millions of people cultivating the crop can never be over emphasized as revealed in a song written by Flora Nwapa where she praised the crop as a lifesaver and important crop of all (Nwapa, 1986).

Production of cassava has a great potential for providing raw material for the food needs of ever-increasing population of the world (Raheem & Chukwuma, 2001). Latin American countries, particularly Brazil and Colombia have made progress in developing and marketing cassava snacks food like potato chips as well as frozen, heat and serve - cassava product (Raheem & Chukwuma, 2001).

2.7. Cassava Cultivation in Nigeria

Cassava (*Manihot esculenta* Crantz) production is vital to the economy of Nigeria as the world largest producer of the commodity (FAOSTAT, 2010) and it is majorly cultivated in the sub- Saharan Africa (FAOSTAT, 2016). Its current production was estimated in 2016 to be 54.8 million metric tons (FAOSTAT, 2016). In 2009, total harvested area was 3.13 million ha with an average yield of 11.7 tha^{-1} (FAOSTAT, 2010). It is produced predominantly (99 %) by small farmers with 1-5 ha of land intercropped with yams, maize, or legumes in the rainforest and savannah agro-ecologies of southern, Central, and

lately Northern Nigeria. In 2010, the average yield of cassava crops worldwide was 12.5 tonnes per hectare. The most productive cassava farms in the world are in India, with a nationwide average yield of 34.8 tonnes per hectare in 2010 (FAOSTAT, 2010).

In Nigeria, the crop is produced in 24 states of the country's 36 states. In 1999, Nigeria produced 33 million tonnes, while a decade later, it produced approximately 45 million tonnes, which is almost 19 % of production in the world (Adekanye *et al.*, 2005).

Cassava production is well-developed in Nigeria as an organized agricultural crop. It has a well-established multiplication and processing techniques for food products and cattle feed. There are more than 40 cassava varieties in use. Planting occurs during rainy seasons in the various agro-ecological zones.

The major states of Nigeria which produce cassava are Benue, Kogi, Cross River, Akwa Ibom, Rivers, Delta, Ogun, Ondo, Oyo, Enugu, Imo and Kaduna. North central is the highest cassava producer in Nigeria on per capita basis with 0.72 tons per person in 2002 (FAOSTAT, 2019).

Cassava is often grown as a temporary shade plant in young cocoa, coffee, rubber or oil palm plantations. It can easily thrive in sandy-loam soil with low organic matter, receiving low rainfall and high temperatures (Okechukwu & Okoli, 2019).

In Thailand, however, it is mostly grown as the sole crop and the farmer can grow cassava on the same land for ten years or more. If the price of cassava roots falls, the farmer can switch to another crop (e.g., sugar cane, corn or sorghum) until cassava becomes the more profitable crop again. Water is essential until the plant is well

established (Alves & Setter, 2000). In moist soils, germination occurs within the first week after planting. As a temporary shade plant, the cassava plant is not given special attention. When grown on their own, the plants require little maintenance after planting. When it is not raining, watering may be needed and chopping the soil will help maintain moisture in the subsoil, especially in dry sandy soils. The biggest problem is weed control. The main weed control practice is to weed the plants two or three times until the plants are well developed and their shade prevents weeds from growing (FAO, 1990).

2.8. Early Bulkiness in Cassava

Cassava has no specific maturation period; therefore, harvest can take place at 8-24 Months After Planting (MAP). Farmers preferred early bulking genotypes to late bulking genotypes because studies have revealed that late bulking is a contributory factor responsible for rejection of cassava genotypes in sub-Saharan Africa due to demographic and market pressures (Nweke *et al.*,1994; Nweke, 2004). Early bulking cassava genotypes is an important farmers' preferred trait, and this is usually so because threat of drought, bushfires and invasion by animals could be averted (Joseph *et al*., 2016). Root bulking begins about 3 months after planting but maintained rapid starch deposition does not occur before 6 months after planting (MAP) (Izumi, 1999). It has also been reported that root bulking increased with time and it differed among cultivars and varies over a long period due to changes in environmental conditions (Ekanayake *et al.,* 1998). Late bulking genotypes develop sufficient above ground mass before storage root bulking (El sharkawy, 2004; Alves, 2002) while early bulking genotypes begins storage root development and shoot simultaneously and usually due to genetic variability among

genotypes (Okogbenin *et al.,* 2008). Earliness in root yield is related to rapid bulking and it varies according to genotypes. Early bulkiness genotype has high source and sink capacities which translates into total biomass for the early bulking group (Okogbenin *et al.,* 2008; Adu-Gyamfi *et al.,* 2016).

2.8.1. Root yield and early bulkiness relationship

High and low yielding cassava cultivars differs in their bulking rate and the period at which they exhibit the maximum bulking rate (Suja *et al.,* 2010). Environmental conditions that limit storage root bulking will adversely affect late bulking genotypes due to differences in sink-source relationship at different stages in their phenology (Ober *et al.,* 2007). Early maturing genotypes exhibit maximum bulking rate during their early growth stages compared with late maturing genotypes and this depends on growth conditions particularly moisture content which may affect the choice of sink (Spollen *et al.,*2000). High yielding genotypes have a high bulking rate over a long period, while genotypes with low storage root yield have a low bulking rate for short duration or long duration (Hershey, 2012; Okogbenin *et al.,* 2013).

2.8.2. Breeding and selection for early bulking and high storage root yield

Currently, the largest producer of cassava in the world is Nigeria with 54.83million tons which is accountable to 19.9% of world production, followed by Thailand, Indonesia, Brazil and the Democratic Republic of the Congo (FAOSTAT, 2016). Despite its importance, increasing the yield of cassava has received relatively little attention or investment (El-Sharkawy, 2004; El-Sharkawy, 2006). This is vividly demonstrated by the

fact that between 1961 and 2014 the average cassava yields per unit of area in Nigeria, the largest global producer, did not increase. Over the same period, Nigerian corn yields per unit area increased 129%, approaching the 174% increase achieved by the world's largest corn producer, the United States. However, in sub-Saharan Africa, where cassava is essential to supplying a large portion of the population with calories, yields have fallen by 0.024 tha^{-1}. The average yields of African farmers currently on a dry weight basis are only 2.51 tha^{-1}, which is lower than the world average of 3.35 t ha^{-1} and 2.5 times lower than the yields achieved in Asia (Amanda de Souza & Stephen, 2017).

Distribution of carbohydrates to the different organs of cassava changes during growth cycle with the shoot being the major sink during the first 5 months and storage roots the major sink later (El-Sharkawy, 2004). The distribution of dry mass is particularly important in cassava because the development of leaves, stems and storage roots occur at the same time and assimilate are partitioned among them (Tumuhimbise *et al.,* 2013). Genotypes that allocate higher proportion of dry mass to storage roots than the stems and leaves give higher fresh storage root yield (FSRY) (Osiru & Hahn, 1998) and the growth of storage roots resulting from an increase in root size and mass, also depends on the sink strength, photosynthetic efficiency of leaves and the potential of leaves to export photo-assimilates (Lahai & Ekanayake, 2009).

Since early bulking and high storage root yield are usually co-selected, there is huge need for developing early bulking cassava genotypes due to greater demands by farmers (Tumuhimbise *et al.,* 2013). Unlike other crops where earliness could be measured by associated traits, same do not apply to cassava (Hershey, 2012; Tumuhimbise *et al.,*

2013). Cassava has differential partitioning of dry matter into the above ground mass and roots (Adu-Gyamfi *et al.,* 2016). In selection for high storage root yield, dry matter partitioning is important determinant and could be major criteria for selection in breeding programme for Fresh Storage Root yield (FSRY) (Okogbenin *et al.,* 2013). The distribution of dry mass is particularly important in cassava because the development of leaves, stems and storage roots occur at the same time and assimilate are partitioned among them (Tumuhimbise *et al.,* 2013). Genotypes that allocate higher proportion of dry mass to storage roots than the stems and leaves give higher root yield (Osiru & Hahn, 1998) Although, biomass allocation patterns to leaves, stems and roots can be influenced by the growth environment, plant size among others (Poorter *et al*., 2012).

2.9. Dry Matter Partitioning

The dry matter content of cassava roots is genotype dependent. Some varieties tend to always produce higher dry matter than others. Nevertheless, the dry matter content is also determined by the growing conditions (Spollen *et al.,* 2000; Ekanayake *et al.,*1998). There is reduction in cassava starch at the onset of rains after dry season, with the flush of new leaves, the dry matter content of the roots drops dramatically as a result of this, and increases once a new leaf canopy has formed. This reduction in dry matter content is probably due to mobilization of starch reserves in the roots to support the flush of new leaves (Lenis *et al.,* 2006).

During cassava growth, the carbohydrate from photosynthesis has to be distributed to assure good development of the source and provide dry matter to the sink. After the

fourth month, more dry matter is accumulated in the storage roots than the rest of the plant. At harvest (12 months after planting), dry matter is present mainly in roots, followed by stems and leaves. The period of maximum rates of dry matter accumulation depends on genotypes and growing conditions**.** High carbohydrate and translocation to root usually occur from 6-10 MAP and during this stage, photo assimilate is partitioned from leaves to root, making bulking of roots faster and the highest rates of dry matter is storage roots occur within this period (Cock *et al.*, 2000).

In Cassava, Harvest Index (HI) represents the efficiency of storage root production and is usually determined by the ratio of storage root weight to the total plant weight. Dry matter distribution is constant, and its accumulation depends upon photo assimilate availability (Source activity) and sink capacity of the storage roots and their mean weight are yield component that determine sink capacity (Alves, 2002). The dry matter content of cassava roots ranges from about 25% to up to 40%. Dry matter content is an extremely important characteristic of cassava, particularly if the roots are to be processed. In industrial crops with a high-water content the costs of harvesting, transport to a processing factory and the primary processing are all directly proportional to the fresh weight of the product, whereas the value of the product is in the dry weight. Hence, it is more cost effective to produce high dry matter products (Cock *et al.*, 2000).

2.10. Storage Root Formation

The total biomass produced by a cultivated plant results from the integral of photosynthetic assimilation over the vegetation period minus all respiratory losses. It depends on the efficiency with which the plant intercepts light and converts it into biomass over the course of the growing season (Parry *et al*., 2011; Reynolds *et al*., 2011). Cassava root formation depends on the photosynthetic abilities of the leaves (source) to make sugar (sucrose) to be transported to the sink (storage roots). The source ability to produce chemical energy needed for plant metabolism is dependent on plant's use of light energy and its ability to convert CO_2 into carbohydrates for plant use. The systematic distribution of photosynthate is known as assimilate partitioning (Mohammad, 2014).

The total radiation received by plant depends on the size, architecture, duration and speed of ground coverage (Amanda de Souza *et al.*,2017). Although Cassava storage roots reaches 50-60 % of the total dry matter around 4 months after planting (Alves, 2002). The rate of accumulation depends on the genotypes and the growing conditions. The distribution of dry matter to the roots can be measured by harvest index (HI) and can be used as a selection criterion for higher yield potential in cassava and HI values of 0.49-0.77 have been reported in cassava after 10-12 MAP (Alves, 2002).

Dry matter accumulation depends upon photo assimilate availability and the sink capacity of storage parts. When assimilates enters through the post sieve element of the companion cell complexes into the sink, it could either be used as metabolic pathway where it could be stored as starch in the storage root or be stored in organelles such as

amyloplast, protein bodies and vacuoles (Yong-Ling Ruan & Atkins, 1999). The number of storage roots and their mean weight are yield components that determine sink capacity. Individual tuberous roots have limited sink capacities, but this is offset by initiation of additional tuberous roots (Rosenthal *et al.*, 2012)

Leaves begin to grow from 2 MAP to 3 MAP and it has been shown to have a positive correlation with root yield. Tuberous root yield has been reported to be positively corelated with soluble sugars in the leaves (Luo & Huang, 2011). From 6 MAP to 10 MAP, photo- assimilates partition from the leaves is accelerated making the root bulking faster and highest rate of dry matter accumulation occurs at 10 MAP-12 MAP because at this period leaves are no more growing and the roots get maximum dry matter partitioning (Hilocks *et al*., 2002)

During cassava growth, the carbohydrate from photosynthesis has to be distributed to assure good development of the source and provide dry matter to the sink. After the fourth month, more dry matter is accumulated in the storage roots than the rest of the plant. At harvest (12 MAP), dry matter is present mainly in roots, followed by stems and leaves. The period of maximum rates of dry matter accumulation depends on genotypes and growing conditions**.** High carbohydrate and translocation to root usually occur from 6-10 MAP and during this stage, photo assimilate is partitioned from leaves to root, making bulking of roots faster and the highest rates of dry matter is storage roots occur within this period. In Cassava, Harvest Index (HI) represents the efficiency of storage root production and is usually determined by the ratio of storage root weight to the total plant weight.

Transport and partitioning of sugar from the source to the sink plays an important role in crop productivity (Aimsworth & Bush, 2011). In other words, transfer of sugar from the source to the sink is photosynthetic dependent, although environmental factors, biotic and abiotic conditions could affect the allocation of sugars to the roots. Roots at an early stage needs supplies of sucrose from the source for metabolic maintenance and for its development (Durand *et al.,* 2018). But the root requirements for sugar must be aggressive as this will determine the movement of assimilates from the chloroplast through the plasmodesmata in symplastic unloading of the phloem, thus ability of the root to unload the sugar from the phloem determines the sink strength.

2.11. Need for High Yielding, Early Bulking Genotypes with High Provitamin A Content

Cassava is deficient in micronutrient such as vitamin A, Fe and Zn and chiefly made up of carbohydrates. Vitamin A Deficiency has been reported from consumption of white cassava (Gegios *et al.,* 2010). Malnutrition is the most important factor causing mortality globally. More than a quarter of children less than five years old suffer from protein-energy malnutrition, as determined by rates of stunting and underweight. Of these, 70 percent are in Asia, 26 percent in Africa and 4 percent in Latin America. Stunting in resource-poor populations is usually associated with reduced mental development (Stephenson *et al.,* 2000). Biofortification as a strategy of breeding staple crops such as rice, wheat, maize and cassava with micronutrients in order to combat the manifestation of Vitamin A deficiency offers sustainable and cost-effective approach (Yusuf *et al.,* 2009).

Bio-fortification, commercial fortification and supplementation are complementary strategies for reaching malnourished populations (Wolfgang & Bonnie, 2007). It is therefore a great benefit breeding cassava genotypes that are enriched with precursor of vitamin A and at the same time high yielding.

Most cassava genotypes are usually harvested from 12 months and above since they form reasonable root size late (Okogbenin *et al.,* 2013). Late bulking cultivars occupy land for extended periods of time and consequently the land cannot be effectively utilized for other crops. Late bulking is the single most important factor responsible for rejection and abandonment of cassava cultivars in African countries (Okechukwu & Dixon, 2009; Kamau *et al.,* 2011). To better harness the potential of cassava in the face of changing climatic conditions, there is need to develop, evaluate and select early bulking and high yielding cultivars that can be harvested at 7-9 Months After Planting (MAP) with considerable amount of β-carotene. And with the increasing demands of an expanding market for cassava as a source of food, income, and industrial raw material there is high demand for cultivars that are early bulking and with desirable storage root qualities. (Tumuhimbise *et al.,* 2013).

2.12. Provitamin A Carotenoids and Biofortification of Cassava

Plants produce four pro-vitamin A carotenoids, distinguished by the possession of at least one retinyl group. Two of these molecules (α-carotene and β-carotene) accumulate in significant amounts whereas the others (γ-carotene and β-cryptoxanthin) are intermediates and tend to be converted rapidly into downstream products (Farre *et al*.,

2010; Zhu *et al*., 2010). Carotenoids are tetraterpenoids, i.e., they are composed of eight condensed C5 isoprenoid precursors generating a C40 linear backbone. In plants, this condensation reaction involves the isomeric precursors isopentenyl diphosphate (IPP) and dimethylallyl diphosphate (DMAPP) and occurs de novo within plastids (Sun *et al.*, 2022; Metibemu & Ogungbe, 2022).

Biofortification generally aimed at controlling micronutrient deficiencies in poor countries of the world. Iron (Fe), Zinc (Zn) and Vitamin A are the three micronutrients recognized by the World Health Organization to be limiting in human health. While biofortification may appear to be just a process that seek to incorporate a novel trait, it is an entirely new approach that is multidisciplinary by necessity, and makes improved public health a goal for agricultural research (Wolfgang & Bonnie, 2007).

2.13. Biofortification and Farmers' Preferences

Acceptance of biofortified crops by producers and consumers hinges on developing attractive traits packages without compromising agronomic and end user characteristics. Farmers preferences must be put into considerations. For instance, in eastern Uganda, men and women preferred the yellow root varieties because of its early maturity and its fresh root yield (Esuma *et al.*,2019; Abdoulaye *et al.*, 2014). For a successful adoption of biofortification innovation and favourable feedback from the end users, it must improve the socioeconomic status of the farmers (Wolfgang & Bonnie, 2007). In study conducted by Ayinde *et al*., (2017), it was reported that there is still low adoption of pro-vitamin A cassava among farmers in Oyo, south western Nigeria due to some determining factors

but by the end of 2018 over 7.6 million farming households and 38 million people are already consuming biofortified crops including Vitamin A Yellow cassava (HarvestPlus, 2018). In Uganda also, it was well adopted because it produces high root yield and matures early (Esuma *et al*, 2012). Factors that could measure the success of the biofortification innovation are adoption of biofortified products and agronomic superiority. As higher economic return, higher yield and stable production can determine variety adoption (Wolfgang & Bonnie, 2007). For instance, superior performing cassava varieties that bulks early, high yielding and with high amount of carotenoid content are best recommendation for farmers for income and livelihood. Higher root yields are thus a farmer preferred breeding trait and combining it with Pro Vitamin A cassava genotypes that matures early would tremendously improve the living standards of the end users (Ilona *et al.,* 2017)

2.14. Quantification of Carotenoids in Cassava

Carotenoids quantification is a major challenge as there is variation in the carotenoid composition of different crops (Rodriguez-Amaya, 2001). High performance liquid chromatography (HPLC) is the method of choice due to its sensitivity and selectivity (Wolfgang & Bonnie, 2007). Thin layer chromatography (TLC) another method of quantification does not give quantitative estimate of the different group of carotenoids; β-Carotene, α-Carotene, β-Cryptoxanthin, Lutein and Zeaxanthin. The HPLC is used to separate Provitamin A carotenoids from Lutein and Zeaxanthin and for their quantification. Carotenoids composition of different crops determines their method of quantification (De Azevedo-Meleiro & Rodriguez-Amaya, 2009).

In cassava, Beta carotene dominates the group of carotenoids, TLC could be used (Kimura *et al.*, 2007). Carotenoids is highly reactive, degradation could be caused by photodegradation, thermal degradation and oxidation. Sample preparation, extraction and laboratory set up must be optimized to ensure minimal degradation whilst ensuring accurate analysis.

Spectroscopy is an ideal method for carotenoids quantification in Cassava which has the majority of the total carotenoids as Beta-carotenoids. However, in samples containing mixture of Pro-Vitamin A Carotenoids (PVAC) and non-Pro-Vitamin A Carotenoids as in maize, this may not accurately quantify the carotenoids present (Guild *et al*., 2017).

2.14.1. Colour Analysis and Visual Screening of Pro Vitamin A Content (PVAC).

Screening crops with high carotenoids using color charts is possible because high level of carotenoids in cassava is closely related with color intensity (Sánchez *et al.*, 2014). The use of visual technique without the need for comprehensive analytical technique is beneficial (Guild *et al.*, 2017). Due to higher number of yellow cassava genotypes and in a bid to differentiate their quantification has mediated the use of High-Performance Liquid Chromatography (HPLC). Digital chromameter which gave a validated result of r^2 to spectroscopy is being developed to be able to quantify color intensity (Sánchez *et al*., 2014). Color charts can be used for cassava and orange-fleshed sweet potato of which their beta carotene constitute the major portion of provitamin A.

The conjugated double bonds which are also like a chromophore gives the yellow to red color in foods with high carotenoid contents (Rodriguez -Amaya, 2001). The feature of

the chromophore in the carotenoid sample is exploited in the quantification and the amount of light absorbed determines the concentration of the carotenoids. Carotenoids is extracted from the plant material using an organic solvent liquid extraction. The sample is exposed to light and the amount of light absorbed at the absorbance maxima (~450nm) is directly proportional to the concentration of the carotenoids (Rodriguez-Amaya, 2001)

2.14.2. iCheck Carotene

A quick spectrophotometric method for quantifying carotenoids content in Cassava is iCheck$^{TM.}$. It extracts and quantifies the total carotenoids in one step (Islam & Schweigert, 2015). This however cannot give the quantification of Pro-vitamin A Carotenoids (PVAC) in the presence of other carotenoids groups present in the sample. This method could only be used for cassava carotenoid quantification because it has majority of its carotenoids as β-carotenes. High-Performance Liquid Chromatography is able to identify and quantify carotenoids present in samples (Li & Rodriguez-Amaya., 2010)

2.15. Carotenoids and Postharvest Physiological Deterioration (PPD)

Cassava roots spoil quickly about two to three days after harvest due to PPD and therefore needs to be processed or consumed soon after harvest (Ceballos *et al*., 2017). Yellow cassava genotypes contained carotenoids. These carotenoids; β-carotenoids, α-carotenoids, ϒ-carotenoids and β-cryptoxanthin can be converted to Retinol, a component of Rhodopsin (Zhong *et al*., 2012) an important protein responsible for good eye sight

and therefore called a precursor of provitamin A (Grune *et al*., 2010). This however does come with an advantage and a disadvantage.

Carotenoids show an inverse relationship with DMC and starch and this is due to the down regulation of the genes essential for starch biosynthesis (Beyene *et al*., 2015) and it helps in delaying PPD in yellow roots. In study conducted by Beyene *et al.* (2015), they found out that engineered two cassava lines that co expressed Deoxy D Xylulose 5 Phosphate Synthase (DXS) and Phytoene Synthase (PS), gene responsible for carotenoid after 5 and 10 days shows PPD at 2% and 11% for first line and 1% and 0% for second line respectively while the non-transgenic lines recorded 50% PPD. This study also confirmed the work done by Beyene *et al.* (2015) as no root rots was recorded in the study. A major limitation hindering the use of cassava as a food crop is the short shelf life of the harvested cassava storage root (Djabou *et al*., 2017) due to PPD. PPD causes a significant loss of storage roots reducing feed, food, and market value of the crop. Cassava roots with Beta carotenoid shows delayed onset of postharvest physiological deterioration, a major constraint limiting the utilization of cassava product (Beyene *et al*., 2015).

Also, another constraint is the ability to transport harvested cassava storage root yields from farms to markets (Sayre *et al*., 2011). There is a positive correlation between PPD delay and carotenoid content of yellow cassava varieties (Sánchez *et al*., 2006).

Carotenoids are essential for photosynthesis process and protect plant from photo-oxidative damages (Stange *et al*., 2008; Welsch *et al*., 2010). PPD may be as a result of

reduced DMC and enhanced antioxidant capacity of root carotenoids to suppress the activities of chemically reactive chemical species (known as ROS- reactive oxygen species) accumulation in the storage roots.

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Crossing Block

Evaluation of Provitamin A Cassava Genotype Parents for yield attributes and Carotenoid Content to Generate F1 Progenies in Ibadan.

3.2. Experimental Site

The crossing block was cited at the International Institute of Tropical Agriculture (IITA) Trial Fields, Ibadan, Oyo state (Forest Transition Zone with Global Positioning System (GPS) co-ordinates of 07.50278 ^{o}N, 003.89459 ^{o}E and altitude of 209m) from April 2018 to June, 2019.

The map of Nigeria showing the location of the experimental location is presented in figure 3.1 and the three locations belonging to different agro ecological zones had varied climatic and soil characteristics.

Ibadan is a derived savanna in South-Western Nigeria and the ecological zone is characterized by forest attributes with a bimodal rainfall pattern followed by a dry season usually between November and March. The zone has potential for high crop yield and annual rainfall exceeds 1200 mm with length of growing period ranging from 211-270 days (Odekunle, 2004).

3.3. Experimental Material

Thirty-night (39) parental genotypes (Table 3.1) sourced from IITA germplasm was crossed using biparental crossing method. The genotypes were yellow fleshed-root cassava genotypes which flowers mostly at Ibadan, Oyo state because of the conducive edaphic, abiotic and other environmental conditions in terms of photoperiodism and temperature. The parental genotype and the progenies formed part of the experimental material used for the evaluation.

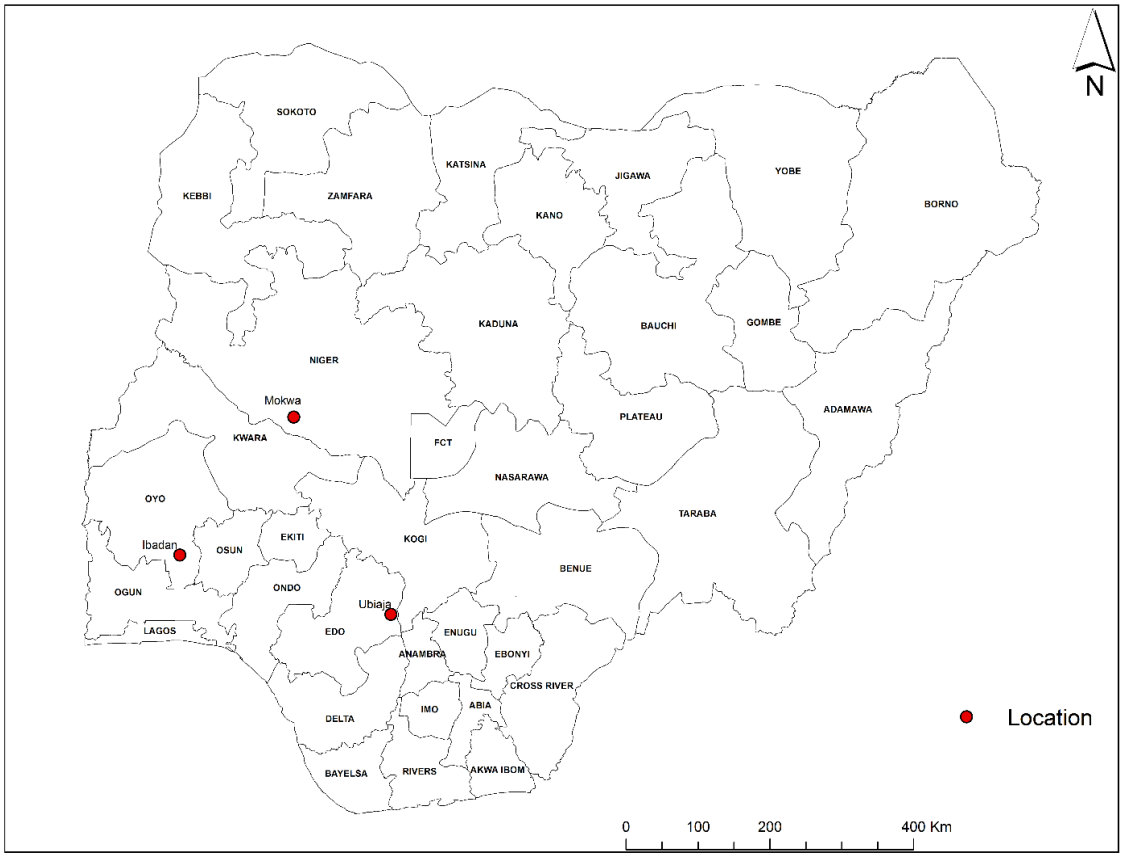


Plate 1: Map of Nigeria Showing Experimental Location. Source: IITA GIS Unit

Table 3.1. Parental Genotypes and their Progenies used in the Crossing Block

		Parents	
Accession No	accession_name	Female	male
1	IITA-TMS-IBA070593(YChk)	IITA-TMS-IBA011277	IITA-TMS-IBA990067
2	IITA-TMS-IBA180017	IITA-TMS-IBA061635	IITA-TMS-IBA160079
3	IITA-TMS-IBA180018	IITA-TMS-IBA061635	IITA-TMS-IBA163955
4	IITA-TMS-IBA180022	IITA-TMS-IBA160160	IITA-TMS-IBA141096
5	IITA-TMS-IBA180031	IITA-TMS-IBA160199	IITA-TMS-IBA160137
6	IITA-TMS-IBA180034	IITA-TMS-IBA070539	IITA-TMS-IBA160139
7	IITA-TMS-IBA180037	IITA-TMS-IBA070539	IITA-TMS-IBA160139
8	IITA-TMS-IBA180047	IITA-TMS-IBA160137	IITA-TMS-IBA160142
9	IITA-TMS-IBA180049	IITA-TMS-IBA070539	IITA-TMS-IBA160141
10	IITA-TMS-IBA180051	IITA-TMS-IBA160019	IITA-TMS-IBA160096
11	IITA-TMS-IBA180058	IITA-TMS-IBA160027	IITA-TMS-IBA160077
12	IITA-TMS-IBA180064	IITA-TMS-IBA141092	IITA-TMS-IBA141104
13	IITA-TMS-IBA180065	IITA-TMS-IBA141092	IITA-TMS-IBA011371
14	IITA-TMS-IBA180067	IITA-TMS-IBA160011	IITA-TMS-IBA160099
15	IITA-TMS-IBA180070	IITA-TMS-IBA160019	IITA-TMS-IBA160096
16	IITA-TMS-IBA180071	IITA-TMS-IBA141092	IITA-TMS-IBA011371
17	IITA-TMS-IBA180073	IITA-TMS-IBA141092	IITA-TMS-IBA011371
18	IITA-TMS-IBA180081	IITA-TMS-IBA141092	IITA-TMS-IBA140145
19	IITA-TMS-IBA180084	IITA-TMS-IBA160120	IITA-TMS-IBA160203
20	IITA-TMS-IBA180088	IITA-TMS-IBA160077	IITA-TMS-IBA160132
21	IITA-TMS-IBA180090	IITA-TMS-IBA160207	IITA-TMS-IBA160097
22	IITA-TMS-IBA180098	IITA-TMS-IBA160167	IITA-TMS-IBA160201
23	IITA-TMS-IBA180106	IITA-TMS-IBA160063	IITA-TMS-IBA160089
24	IITA-TMS-IBA180124	IITA-TMS-IBA160096	IITA-TMS-IBA160063
25	IITA-TMS-IBA180146	IITA-TMS-IBA160575	IITA-TMS-IBA160137
26	IITA-TMS-IBA180147	IITA-TMS-IBA160137	IITA-TMS-IBA160142
27	IITA-TMS-IBA180148	IITA-TMS-IBA160137	IITA-TMS-IKN130010
28	IITA-TMS-IBA180158	IITA-TMS-IBA160101	IITA-TMS-IBA160137
29	IITA-TMS-IBA180173	IITA-TMS-IBA160096	IITA-TMS-IBA160063
30	IITA-TMS-IBA180180	IITA-TMS-IBA160096	IITA-TMS-IBA160099
31	IITA-TMS-IBA180182	IITA-TMS-IBA160167	IITA-TMS-IBA160043
32	IITA-TMS-IBA180210	IITA-TMS-IBA160075	IITA-TMS-IBA160063
33	IITA-TMS-IBA180221	IITA-TMS-UBJ120003	IITA-TMS-IBA160099
34	IITA-TMS-IBA180231	IITA-TMS-IBA160021	IITA-TMS-IBA160077
35	IITA-TMS-IBA180244	IITA-TMS-IBA141096	IITA-TMS-IBA141092
36	IITA-TMS-IBA180256	IITA-TMS-UBJ120003	IITA-TMS-IBA141092
37	IITA-TMS-IBA180259	IITA-TMS-UBJ120003	IITA-TMS-IBA141092
38	IITA-TMS-IBA180271	IITA-TMS-IBA141104	IITA-TMS-IBA141096
39	IITA-TMS-IBA180294	IITA-TMS-IBA141096	IITA-TMS-IBA141092
40	IITA-TMS-IBA980581(WChk)		
41	TMEB419(WChk)		
42	TMEB693(WChk)		

WChk=White check
YChk=Yellow check

3.4. Crossing Block Establishment to Raise Progenies

The 39 parental genotypes were planted on the 12th April, 2018 for the sole purpose of obtaining seeds from their crosses. Different biparental crossing combination involving genotype IBA141092 (a high yielding genotype with appreciable level of total carotenoids) and others were made in Ibadan in October, 2018.

Biparental crossings were made to obtained progeny population through controlled pollination following standard procedures from which 42 progenies were later selected based on dry matter, root yield and total carotenoid content into the nursery stage (Ceballos *et al*., 2016).

Crosses were made in the morning when the flower was about opening by dusting the pollens of the male flower plant on the female. This is done by rubbing the anthers of the male flowers on the stigma of the recipient plant until it is visible that they are covered with pollen (Abril *et al.,* 2019). The plant to receive pollens was protected from contamination from the male flowers of other plants using an isolated bag. These are small white bags made of cotton material with twine at the mouth which can be tied. The crossed plant was initially tagged and bagged after crossing have been made using an isolation bag. This help protect the inflorescence. Two months later (Crosses were made in October) shattered seeds were collected in bags used to cover the crossed plant.

F_1 botanical seeds were harvested two months after pollination. Seeds were sown directly into a nursery field at 0.25 m × 1 m intra- and inter-row spacing with no replicates. These were planted in seedling nursery on the 9th December 2018 from which matured progenies in the seedling nursery were selected for 2019/2020 establishment. A total of 42 healthy F_1 plants were selected based on their total carotenoids content, fresh root

yield and dry matter content at 6 months after planting (MAP) in June, 2019 and were established for 2019/2020 progeny evaluation.

3.5. Treatments and Experimental Design

The 39 parental genotypes were arranged in a randomized complete block design with three replications. The total treatment plot per replicate was 236 m^2 and gross replicated area was 748 m^2. The parental genotypes were planted in April, at a spacing of 1 x 0.8m in 3 replicates in 2018 and their progenies planted in June, 2019.

Biparental crossing were made from the parents to generate the progenies that were used for bulking rate experiment in 2019 and 2020 cropping seasons. The progenies were planted in two cropping seasons (2019/2020) and evaluated for bulkiness and their carotenoid analysis in its 12^{th} month.

3.6. Cultural Practices

3.6.1. Land preparation and planting

The land was first mechanically prepared with a plough and ridger. Next, cassava stakes were planted on the ridges, which were 1 m apart and 4 m in length for each treatment plot per block. Cassava cuttings with 8 to 10 nodes number were cut at 5 cm length and planted on all the ridges at an orientation of angle 45^o making the planting distance of 0.8 m inter row and 1m intra row spacing with 36 plant population.

3.6.2. Field sanitation

The field was kept free of weeds by regular hand weeding monthly using hoe as from three (3) months after planting (MAP).

3.7. Pollination

Biparental crosses were made randomly using each of the parents to generate the progenies for bulking rate evaluation.

3.8. Harvesting

Harvesting was manually done by lifting the roots through the use of hand to pull out the cassava from the soil at 12 months after planting (MAP).

3.9. Data Collection

3.9.1. Data collection on growth and yield parameters

The following data were taken at 12 months after planting;

i. **Sprout:** This was taken one month after planting based on the proportion of stakes planted. (Fukuda *et al.,* 2010).

ii. **Plant vigour**: The plant vigour as constituted by vegetation and height was taken as follows based on scale 3,5 and 7 where, 3- Low, 5 -Intermediate, 7- High.

iii. **Number of harvested plants:** This was taken by visually counting the number of cassava plants that were harvested per unit area of experimental plot.

iv. **Branch height:** This is the height at first apical branching. And it was measured from the base of the plant to the point at which it first branches, and expressed in cm.

v. **Root number:** This was taken by counting the number of roots per plants.

vi. **Root size:** This was taken based on the groupings according to the girth, length and weight of the stems into 3 marketable sizes; small, medium and big with score of 3, 5 and 7 respectively (Fukuda *et al.*,2010).

vii. **Root weight:** This was taken using spring balance and expressed in kilogram. The roots were harvested and placed in a sack, hung on the spring balance from where the weight reading in kg was taken.

viii. **Storage root diameter:** This was taken with the aid of a measuring tape around the girth of the root in the mid region.

ix. **Fresh storage root yield**: After harvesting, this was obtained by multiplying weight (kg) of known number (n) of bulked root weight by 10,000 and dividing it by the known number of bulked roots multiplied by 1,000 and express in tha^{-1}. (x(kg) X 10,000/n) X1000 where x=weight of bulked roots, n= number of bulked roots.

x. **Dry matter content**

The dry matter percentage in tubers was determined by drying 100 g of fresh tuber slices/cubes or chopped pieces in an oven at 72 °C for 72 hours. From the weight of dried sample, percentage of dry matter was calculated using (W_m-D_m/W_m X 100) and DMC was calculated by subtracting percentage dry matter from 100. where W_m is the wet mass, D_m is the dry mass.

xi. **Specific gravity**: This was measured by weighing cassava samples in the water (W_w) and in air (W_a) and therefore dividing W_a by the subtraction of (W_a - W_w).

xii. **Dry storage root yield:** This was obtained by multiplying the percentage of DMC by the fresh storage root yield and dividing by 100 and expressed in tha^{-1}.i.e (DMC%X FSRY)/100.

xiii. **Shoot weight:** This was obtained by weighing the stalks using spring balance in kilogramme.

xiv. **Starch content**

Starch content (%) was calculated by inputting the specific gravity value into the equation 210.8(X)-213.4 where X is the specific gravity (Wholey and Booth, 1979)

xv. **Harvest index:** This was obtained by dividing the weight of the roots by the sum of weight of roots and the above ground mass as described by Kawano (1980).

xvi. **Inner skin colour:** This is the colour of root cortex; It was recorded visually on a scale of 1-4 where 1 is white or cream, 2 is yellow, 3 is pink and 4 is purple. (Fukuda *et al.,* 2010).

xvii. **Pulp colour:** The colour of root pulp (Parenchyma) was taken visually using a scoring scale of 1 to 5. 1 recorded for white, 2 for cream, 3 for yellow, 4 for orange and 5 for pink (Fukuda *et al.,*2010).

xviii. **Total carotenoid chart:** The total carotenoid chart was visually taken using a scale of 1-8. 1 for white, 2 for cream, 3 for light cream, 4 for light yellow, 5 for yellow, 6 for deep yellow, 7 for orange and 8 for pink.

xix. **Total Carotenoid iCheck:** icheck carotene by Bioanalyt, Teltow, Germany a portable spectrophotometer was used to measured carotenoid content (Jaramilo *et al.,*2018).

3.9.2. Carotenoid quantification

Carotenoid content of each of the parents was analysed using iCheck™ for both experiment one and two. Three storage roots samples of different sizes (big, small, medium) for total carotenoids were washed and cleaned. The anterior and the distal part

of the cassava samples were chopped and mixed. Five grams of the homogenous chopped samples were pounded with pestle in a mortar and 5 – 6 ml of water content was added to ease the grinding. The solution formed was then transferred into a 50 ml calibrated tube and thoroughly shaken. 0.4 ml from the prepared homogenous solution was injected into iEX^{TM} Carotene vials using a syringe. The vials were placed on a solid surface for about 5 minutes. The shaken was repeated this time and then allowed to stay until a two different solution was noticed in the vials. There was a distinct upper surface and a turbid lower phase. The absorbance of the upper contents in the vials was measured at 450 nm using the icheck^{TM} carotene device in dark room to minimize losses resulting from oxidation due to light exposure.

3.10. Nursery Establishment for the Progenies

One hundred and Forty-Three (143) progenies from the random biparental crosses obtained from the crossing block were planted in December 2018 in a seedling nursery block and 42 clones were selected based on root yield, dry matter and total carotenoid contents to be planted and evaluated for their bulking rate and carotenoid analysis at the two cropping seasons.

3.11. Experiment One: Bulking Rate and Carotenoid Evaluation of Progenies from Biparental Crosses of Provitamin A Cassava Genotype at two Croppin Seasons in Ibadan.

3.12. Experimental Site

The bulking rate experiment was cited at the International Institute of Tropical Agriculture (IITA) Trial Fields, Ibadan, Oyo state (Forest Transition Zone with Global Positioning System (GPS) co-ordinates of 07.50278 ^{o}N, 003.89459 ^{o}E and altitude of 209m) from June 2019 to June, 2020.

The map of Nigeria showing the location of the experimental location is presented in figure 3.1 and the three locations belonging to different agro ecological zones had varied climatic and soil characteristics.

Ibadan is a derived savanna in South-Western Nigeria and the ecological zone is characterized by forest attributes with a bimodal rainfall pattern followed by a dry season usually between November and March. The zone has potential for high crop yield and annual rainfall exceeds 1200 mm with length of growing period ranging from 211-270 days (IITA, 1999).

3.13. Experimental Material

The forty-two (42) accessions selected (based on their root yield, dry matter content and total carotenoids content) from progenies arising from the biparental crossing from the experiment one (crossing block) were planted 25th June, 2019 for bulking rate and carotenoid content evaluation at 6th ,9th, and 12th months after planting (MAP) and repeated in 25th June, 2020 for second cropping season evaluation.

3.14. Treatments and Experimental Design

The experiment was conducted using a 42x3 factorial design in a Randomized Complete Block Design (RCBD) with two replications. The treatments consisted of 42 accessions and 3 harvesting months. Harvesting was carried out at different months of 6^{th}, 9^{th}, and 12^{th} after planting (MAP).

Each plot per accession was 4 m x 2 m of two rows containing 10 plants in spacing of 1 m x 0.8 m. Each block contained 7 accessions of 14 rows of 4 m length and with area of 56 m^2. Area per replicate for each harvesting periods was 293 m^2 while total plot per replicate with different harvesting periods of 6^{th}, 9^{th} and 12^{th} months is 879 m^2 while total replicated area is 1758 m^2. The accessions were planted at a spacing of 1x0.8m in 2 replicates in 2019 and 2020.

3.15. Cultural Practices

3.15.1. Land preparation and planting

The land was mechanically prepared with tractor by using plough after which it was ridged and cassava stakes of 2.5 cm length was planted on ridges. The ridges in each treatment plots per block was 1 m apart and of 4 m length and Cassava cuttings with 8 to 10 nodes planted on all the ridges making the planting distance of 0.8 m inter row and 1 m intra row spacing with planting at an orientation of angle 45 ^{o}.

3.15.2. Field sanitation

Same as stated at Experiment one, section 3.6.2

3.16. Harvesting

Harvesting was manually done by lifting out cassava from the soil at different harvesting periods of 6^{th}, 9^{th} and 12^{th} months After Planting (MAP)

3.17. Data Collection

3.17.1. Data collection on growth and yield parameters

The following data were taken at 12 months after planting;

i. **Sprout:** This was taken one month after planting based on the proportion of stakes planted. (Fukuda *et al.,* 2010).

ii. **Plant vigour**: The plant vigour as constituted by vegetation and height was taken as follows based on scale 3,5 and 7 where, 3- Low, 5 -Intermediate, 7- High.

iii. **Number of harvested plants:** This was taken by visually counting the number of cassava plants that were harvested per unit area of experimental plot.

iv. **Branch height:** This is the height at first apical branching. And it was measured from the base of the plant to the point at which it first branches, and expressed in cm.

v. **Root number:** This was taken by counting the number of roots per plants.

vi. **Root size:** This was taken based on the groupings according to the girth, length and weight of the stems into 3 marketable sizes; small, medium and big with score of 3, 5 and 7 respectively (Fukuda *et al.*,2010).

vii. **Root weight:** This was taken using spring balance and expressed in kilogram. The roots were harvested and placed in a sack, hung on the spring balance from where the weight reading in kg was taken.

viii. **Storage root diameter:** This was taken with the aid of a measuring tape around the girth of the root in the mid region.

ix. **Fresh storage root yield**: This was obtained by multiplying weight (kg) of known number (n) of bulked root weight by 10,000 and dividing it by the known

number of bulked roots multiplied by 1,000 and express in tha^{-1}. (x(kg) X 10,000/n) X1000 where x=weight of bulked roots, n= number of bulked roots.

x. **Dry matter content**

The dry matter percentage in tubers was determined by drying 100 g of fresh tuber slices/cubes or chopped pieces in an oven at 72 °C for 72 hours. From the weight of dried sample, percentage of dry matter was calculated using (W_m-D_m/W_m X 100) and DMC was calculated by subtracting percentage dry matter from 100. where W_m is the wet mass, D_m is the dry mass.

xi. **Specific gravity**: This was measured by weighing cassava samples in the water (W_w) and in air (W_a) and therefore dividing W_a by the subtraction of (W_a - W_w).

xii. **Dry storage root yield:** This was obtained by multiplying the percentage of DMC by the fresh storage root yield and dividing by 100 and expressed in tha^{-1}.i.e (DMC%X FSRY)/100.

xiii. **Shoot weight:** This was obtained by weighing the stalks using spring balance in kilogramme.

xiv. **Starch content**

Starch content (%) was calculated by inputting the specific gravity value into the equation 210.8(X)-213.4 where X is the specific gravity (Wholey and Booth, 1979)

xv. **Harvest index:** This was obtained by dividing the weight of the roots by the sum of weight of roots and the above ground mass as described by Kawano, (1980).

xvi. **Inner skin colour:** This is the colour of root cortex; It was recorded visually on a scale of 1-4 where 1 is white or cream, 2 is yellow, 3 is pink and 4 is purple. (Fukuda *et al.,* 2010).

xvii. **Pulp colour:** The colour of root pulp (Parenchyma) was also taken visually using a scoring scale of 1 to 5. 1 recorded for white, 2 for cream, 3 for yellow, 4 for orange and 5 for pink (Fukuda *et al.,*2010).

xviii. **Total carotenoid chart:** The total carotenoid chart was visually taken using a scale of 1-8. 1 for white, 2 for cream, 3 for light cream, 4 for light yellow, 5 for yellow, 6 for deep yellow, 7 for orange and 8 for pink.

xix. **Total Carotenoid iCheck:** icheck carotene by Bioanalyt, Teltow, Germany a portable spectrophotometer was used to measured carotenoid content (Jaramilo *et al.,*2018).

3.17.2. Early bulkiness estimation

Early bulkiness for each of the genotypes and accessions used in these studies were from destructive sampling from harvesting at different months after planting (6,9 and 12) and this were calculated based on the proportion in percentage of root yield at earlier months in relation to the yield at harvesting period. These proportion in percentage were grouped relative to others and were categorized into high, medium and low. The genotypes or accessions with high, medium and low were regarded as early bulking, mid-bulking and late bulking respectively. Cassava accessions that yielded over 60 % of their root yield of 12 MAP at earlier month were regarded as early bulking, those that yielded between 43 % and 59 % of their root yield of 12 MAP earlier were regarded as mid bulking while

those that yielded between 0 % to 42 % of their root yield of 12 MAP earlier were late bulking in this experiment.

3.17.3. Carotenoid quantification

Carotenoid content of each of the parents was analysed using iCheck™ for this experiment. Three storage roots samples of different sizes (big, small, medium) for total carotenoids were washed and cleaned. The anterior and the distal part of the cassava samples were chopped and mixed. Five grams of the homogenous chopped samples were pounded with pestle in a mortar and 5 – 6 ml of water content was added to ease the grinding. The solution formed was then transferred into a 50 ml calibrated tube and thoroughly shaken. 0.4 ml from the prepared homogenous solution was injected into iEX™ Carotene vials using a syringe. The vials were placed on a solid surface for about 5 minutes. The shaken was repeated this time and then allowed to stay until a two different solution was noticed in the vials. There was a distinct upper surface and a turbid lower phase. The absorbance of the upper contents in the vials was measured at 450 nm using the icheck™ carotene device in dark room to minimize losses resulting from oxidation due to light exposure.

3.17.4. Quantitative and qualitative analyses

At 6th, 9th and 12th month after planting, three roots from each plant were selected at harvest, washed, peeled, chopped with mortar and pestle and mixed to obtain a single homogenous sample which was used for pro vitamin A quantification. The samples were divided into two sub-samples, one was used for qualitative assessment (color indicator chart/icheck™) and another for quantification of pro-vitamin A carotenoid. Carotenoids

quantification was determined by spectrophotometry. The protocol used was in accordance with the procedure described in the Harvest plus Handbook and in Rodriguez-Amaya & Kimura (2004). Measurements were made for the parents and their progenies

3.18. Experiment Two: Evaluation of Provitamin A Cassava Genotypes for Early Bulkiness and Carotenoid Content in Mokwa (Southern Guinea Savanna) and Ubiaja (Rainforest Zone) Locations.

3.19. Experimental Material

The ten (10) genotypes namely IKN 120036, IKN 120016, IBA 130896 and IBA 141092, TMEB419(check), IBA980581(check), IBA130818, IBA090581, IBA090525, IBA070593(check) sourced from IITA germplasm. The genotypes were yellow fleshed-root cassava genotypes and were planted in Ubiaja and Mokwa and were evaluated in 2018.

3.20. Experimental Site

The study was conducted at the International Institute of Tropical Agriculture (IITA) Trial Fields Ubiaja, (06.7608 ^{o}N, 006.5358 ^{o}E, 202.1 m) Edo state- a rainforest zone and Mokwa, (06.32812 ^{o}N, 005.63599 ^{o}E 212.7 m) Niger state- a Southern Guinea Savannah Zone from 2018 to 2019.

Ubiaja is in Edo State, South-Western part of Nigeria. The experimental station is situated in the IITA station, Ubiaja. The ecological zone is also characterized by forest attributes with a bimodal rainfall pattern followed by a dry season usually between November and March. The zone has potential for high crop yield and annual rainfall exceeds 1200 mm with length of growing period ranging from 211-270 days (IITA, 1999).

Mokwa is in Niger State, the North-Central part of Nigeria. The experimental station is situated in the IITA station within the Ahmadu Bello University farm station. This zone is characterized by a monomodal pattern of rainfall with a growing period 181-201 days and long-term rainfall of 1100 mm (IITA, 1999).

3.21. Treatments and Experimental Design

The treatments were genotypes IKN 120036, IKN 120016, IBA 130896 and IBA 141092, TMEB419(check), IBA980581(check), IBA130818, IBA090581, IBA090525, IBA070593(check) and with harvesting periods of 3rd, 6th, 9th and 12th Months After Planting MAP arranged in a 10 x 4 factorial experiment in randomized complete block design with three replications.

Treatment plots consisted of six ridges of 4 m length and1 m apart. The net plot was 360 m^2 while the gross plot was 900 m^2. The genotypes were planted at a spacing of 1x0.8m in 3 replicates in 2018 at two different agroecologies of Ubiaja and Mokwa.

3.22. Cultural Practices

3.22.1. Land preparation and planting

The land was mechanically prepared with tractor by using plough after which it was ridged and cassava stakes of 5 cm length were planted (on ridges). The ridges in each treatment plots per block was 1m apart and of 4 m length and Cassava cuttings with 8 to 10 nodes planted on all the ridges making the planting distance of 0.8m inter row and 1m intra row spacing with 36 plant population. Planting was done at a planting distance of 1 m x 0.8 m and at an orientation of angle 45 ^{o} and data were taken from each of the blocks on the net plot area only. The 36 cuttings/stakes of each genotype were planted on each of the ridged field per treatment plot which measured 6 m x 4 m. The net plot is 24 m^2

with 16 plant stands while the experimental size area is 30 m x 14 m (0.0420 m^2) which contained 540 plants stands.

3.22.2. Field sanitation

Same as stated in experiment one, section 3.6.2

3.23. Harvesting

Harvesting was manually done by lifting out cassava from the soil at 3rd, 6th and 9th and 12th months after planting (MAP) so as to evaluate the genotypes for early bulkiness traits.

3.24. Data Collection

For the bulking rate evaluation, twelve (12) plants were tagged for different harvesting periods at 6th, 9th and 12th MAP to evaluate bulkiness. The carotenoid analysis was also conducted at 12th MAP. And data were taken as highlighted in the experiment I, section 3.9.1.

3.24.1. Carotenoid quantification

Carotenoid content of each of the parents was analysed using iCheck™ for this experiment. Three storage roots samples of different sizes (big, small, medium) for total carotenoids were washed and cleaned. The anterior and the distal part of the cassava samples were chopped and mixed. Five grams of the homogenous chopped samples were pounded with pestle in a mortar and 5 – 6 ml of water content was added to ease the grinding. The solution formed was then transferred into a 50 ml calibrated tube and thoroughly shaken. 0.4 ml from the prepared homogenous solution was injected into iEX™ Carotene vials using a syringe. The vials were placed on a solid surface for about 5 minutes. The shaken was repeated this time and then allowed to stay until a two

different solution was noticed in the vials. There was a distinct upper surface and a turbid lower phase. The absorbance of the upper contents in the vials was measured at 450 nm using the icheck^{TM} carotene device in dark room to minimize losses resulting from oxidation due to light exposure.

3.25. Soil Sampling and Analysis

Soil Sampling**:** Soil samples at the experimental site was taken and analyzed for physical and chemical properties using standard laboratory procedures. Soil samples were taken randomly on the experimental site at the depth of 0 – 20 cm using an auger and bulked.

Fields were demarcated into uniform portions. Each of the demarcated field were sampled separately. Fifteen (15) different samples were taken as composite samples bulked for laboratory analysis. The soil was mixed, and efforts taken such as to ensure that a representative soil sample of the experimental site was provided for the analysis. The bulked samples were air dried and sieved using a 0.5 mm sieve and soil texture determined by hydrometer method in which the soil sample was dispersed with Calgon (Sodium Metaphosphate) after which the soil particle was determined using hydrometer. Soil pH was obtained using a calibrated pH meter and by immersing electrode into the soil water suspension to obtain the reading from the pH meter (FAO, 2018a). The total Nitrogen was determined by semi-micro Kjeldahl method (Fawcet, 1954) and the total Phosphorous by the NaOH melt-calorimetry method while soil Potassium was analyzed using flame photometer (FAO, 2018a).

3.26. Meteorological Data

Meteorological data: Meteorological data for 2018 – 2021 was obtained from the International Institute of Tropical Agriculture Experimental Trial Fields, Ubiaja and Ibadan Station, Edo and Oyo state respectively.

3.27. Data collection on Growth and Yield Parameters

(As highlighted in experiment I, section 3.9.1)

3.28. Quantitative and Qualitative Analyses

At 12^{th} month, three roots from each plant were selected at harvest, washed, peeled, chopped, and mixed to obtain a single homogenous sample which was used for pro vitamin A quantification. The samples were divided into two sub-samples, one was used for qualitative assessment (color indicator chart/icheck™) and another for quantification of pro-vitamin A carotenoid. Carotenoids quantification was by spectrophotometry. The protocol used was in accordance to the procedure described in the Harvest plus Handbook and in Rodriguez-Amaya & Kimura (2004). Measurements was made for the parents and their progenies.

3.28.1. Beta-Carotenoid extraction

Root samples were collected at the 12^{th} month stage for the analysis of β-Carotene using HPLC (High Performance Liquid Chromatography) where total carotenoids are partitioned into different carotenoids components. And this was done by passing pressurized liquid and sample mixture through a column filled with adsorbent. Carotenoids was extracted and separated based on the procedure described in Association of Official Agricultural Chemists using alumina as adsorbent. The concentration of total carotenoids and β-carotene was calculated by determining O.D (Optical Density) at 450

nm. A calibration curve with standard β-carotene was used for the calculation of β-carotene in the test sample (Association of Official Analytical Chemist, (AOAC) 1984).

3.29. Data Analysis

Data was analyzed using the restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) procedure, proposed by Piepho *et al.* (2008) where variance components and genetic parameters were estimated for the two experiments using the model $Y_{ijkn} = U + G_i + M_j + L_k + ML_{jk} + R_{n(jk)} + GM_{ij} + AL_{ik} + GML_{ijk} + E_{ijk}$ and $Y_{ijk} = U + A_i + M_j + Y_k + MY_{jk} + R_{n(jk)} + AM_{ij} + AY_{ik} + AYM_{ijk} + ER_{ijkn}$ respectively where, Y_{ijkn} = value of the traits for ith genotypes/accessions, U is the population mean, G_i is the effect of the ith genotypes, M_j is the effect jth MAP, L_k is the effect of kth location, ML_{jk} is the effect of interaction between jth MAP and kth location, $R_{n(jk)}$ is the effect of nth rep in the jth MAP and kth location, GM_{ij} is the effect of interaction between the ith genotype and jth MAP, AL_{ik} is the effect of the interaction between the ith genotype and the location, GML_{ijk} is the effect of the interaction between the ith genotype, jth MAP and kth location, E_{ijk} is the error term associated with the ith genotype in the nth replicate in the jth MAP in the kth location, A_i is the effect of ith accession, Y_k is the effect of kth season, M_i is the effect of ith MAP, MY_{jk} is the effect of interaction between jth MAP and kth season, AM_{ij} is the effect of the interaction between the ith accession and jth MAP, AY_{ik} is the effect of interaction between ith accession and kth season while AYM_{ijk} is the effect of interaction between ith accession, jth season and kth MAP, ER_{ijkn} is the error term associated with the ith accession in the nth replicate in the jth MAP in the kth season

Mixed model procedure based on restricted maximum likelihood (REML) estimation method was used in analyzing the data, variance component of the main, interaction effects and other genetic parameters was estimated using lme4 package by Bates *et al.*, (2015) in R software. Means were separated using Tukey-Honest Significant Difference test. Pearson correlation between different traits was determined using rcorr in R package (R Development Core Team, 2018). Path analysis was conducted using lavaan package in R (Rosseel, 2012).

3.29.1. Genetic parameters

Genotypic Variance (δ^2_g)

Genotypic variances will be obtained from the analysis of variance table according to Comstock and Robinson (1952)

The genotypic variance were calculated using the formula;

$$\delta^2_g = \frac{M1 - M2}{r}$$

Where; M1 = Treatment Mean Square

M2 = Error/Residual

r = Number of replicate

Phenotypic Variance (δ_{ph})

Phenotypic variances were obtained from the analysis of variance table according to Comstock and Robinson (1952)

The phenotypic variance were calculated using the formula;

$$\delta_{ph} = M2 + \frac{(M1 - M2)}{r}$$

Where; M1 = Treatment Mean Square

M2 = Error/Residual

r = Number of replicate

Environmental Variance (δ_e)

$$\delta_e = M2$$

Where; M2 = Error/Residual

Genotypic Coefficient of Variation (GCV)

Genotypic Coefficient of Variation (GCV), according to Singh & Singh (2015). The genotypic coefficient of variation were calculated using the formula;

$$\textbf{GCV (\%)} = (\sqrt{\delta^2_g}/x) \times 100$$

Where; δ^2_g = genotypic variance

X = population mean

Phenotypic Coefficient of Variation (PCV)

Phenotypic Coefficient of Variation (GCV), according to Singh & Singh (2015). The phenotypic coefficient of variation were calculated using the formula;

$$\textbf{PCV (\%)} = (\sqrt{\delta^2_{ph}}/x) \times 100$$

Where; δ^2_{ph} = phenotypic variance

x = population mean

Genetic Advance (GA)

Genetic advance (GA) were calculated with the method suggested by Allard (1960);

$$\textbf{GA} = (\delta^2_g / \delta_{ph}) \times (100/x)$$

Where; δ^2_g = genotypic variance

δ_{ph} = phenotypic variance

x = population mean

Heritability (H)

Heritability (H) were estimated according to Falconer & Mackay (1998);

$$\mathbf{H = \delta^2_g / (\delta_{ph} + \delta_e)}$$

Where; δ^2_g = genotypic variance

δ_{ph} = phenotypic variance

δ_e = environmental variance

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1. Environment

4.2. Weather

The meteorological data of the environment during the period of the experiment from 2018 to 2021 at Ibadan, Mokwa and Ubiaja as presented in the Appendices III, IV &V shows that the temperature was within the best range as revealed in study conducted by Santanoo *et al.* (2022), where it was reported that cassava growth is favourable under the mean annual temperature of 25-29 ^{o}C and can also tolerate temperature of 16-38 ^{o}C. The peak of rainfall for each environment was within the production period and was fairly distributed throughout the period.

4.3. Soil Properties

The soil physical and chemical properties for the three locations varies as shown in the Appendices VI and VII. The physical and chemical properties of the soil before land preparation during the period of the experiment as shown in Appendix VI revealed that for 2018/2019 at Mokwa and Ubiaja, the pH ranges from 5.9 to 7.1. Phosphorous, Nitrogen and Potassium was higher in Mokwa than Ubiaja as revealed in the table (Appendix VI) and the soil texture was sandy loamy.

At Ibadan, the 2019/2020 and 2020/2021 cropping season shows that soil pH ranges from 5.7 to 6.5 and Nitrogen was higher at 2019/2020 cropping season than 2020/2021 while Nitrogen and Potassium was higher at 2020/2021 as revealed in Appendix VII

4.4. Experiment I: Bulking Rate Identification and Selection for High Provitamin A Carotenoid Content among F_1 Population obtained from Parental Genotypes at 2019-2020 and 2020-2021 Season in Ibadan.

4.4.0. Source of Variations for Evaluated Traits at 6, 9 and 12 MAP Across Cropping Seasons.

Analysis of traits at different months and seasons shows that accessions, MAP, interaction of MAP with season, interaction of accessions with seasons and interaction of accession with MAP and seasons were either significant or not significant for traits evaluated.

Average performance of accessions in terms of different traits across the months of evaluation and cropping seasons shows that variability exist among the accessions and therefore, accessions can be improved for some of these desirable traits. Sprout, vigour, shoot weight, plant height, number of plants harvested, root number, root weight and total carotenoids were highly significant ($p<0.001$) and significant for DM ($p<0.01$). However, fresh root yield and harvest index were not significant.

Months after planting was significant ($p<0.05$) for shoot weight, and significant for root weight while it was not significant for other traits. Months after planting (MAP) and seasons were significant for fresh root yield and harvest index ($p<0.05$) while it was not significant for other traits.

Interaction between replication, MAP and seasons were highly significant for plant height, number harvested, root number, root weight, harvest index, dry matter and total carotenoid contents ($p<0.001$) and reverse was the case for fresh root yield, sprout and vigour.

Interaction of accession and seasons were highly significant ($p<0001$) for number harvested and total carotenoid contents while it was non-significant for other traits. The interaction of accession with MAP and seasons was significant for harvest index ($p<0.05$) while it was non-significant for other traits (Table 4.1).

Table 4.1: Source of Variation for Evaluated Traits at Different Months and Year

Source of variation	df	FYLD(t/ha)	Sprout	Vigour	SHTWT(kg)	PLTHT(cm)	NOHAV	RTNO	RTWT(kg)	HI	DM(%)	TC(µg/g)
Accession	41.00	ns	0.83***	41.19***	13.21***	15.95***	17.57***	24.5***	16.06***	ns	6.56*	17.00***
MAP	1.00	ns	ns	ns	8.99**	ns	ns	ns	5.08*	ns	ns	ns
MAP*Seasons	2.00	5.12*	ns	ns	ns	ns	ns	ns	ns	5.16*	ns	ns
REP*MAP*Seasons	2.00	ns	ns	ns	31.17*	17.92***	17.97***	24.74***	40.12***	34.21***	95.91***	13.18***
Accession*Seasons	41.00	ns	ns	ns	ns	ns	34.67***	ns	ns	ns	4.85*	21.04***
Accession*MAP*Seasons	41.00	ns	ns	ns	ns	ns	ns	ns	ns	7.13*	ns	ns
CV		0.57	0.52	0.27	0.54	0.19	0.46	0.47	0.42	0.29	0.19	0.26
Mean		10.36	0.84	4.45	13.99	166.05	0.27	20.91	7.34	0.3	24.18	14.26

*, **, ***=Significant at P< 0.05, 0.01 and 0. 001respectively.Sprt=Sprout. ns=Non-Significant, df=degree of freedom

4.5. Best Linear Unbiased Estimate for evaluated traits of progenies across the months and year.

The BLUE of traits of progenies revealed that fresh root yield, root weigh, height at first branching, shoot weight, harvest index, root rot and total carotenoid (TC) content were not significant among the accessions. Number harvested and dry matter and plant height were significant ($p<0.05$). The number of roots harvested was very significant ($p<0.05$) while the sprout and vigour were highly significant ($p<0.001$) (Table 4.2)

Table 4.2: Best linear unbiased estimates (BLUE) of progenies at different months and year

Traits	BLUE	Pvalue
FYLD	8.46	0.15
SPROUT	0.81***	0.00
VIGOR	4.52***	0.00
BRNHT	2.70	0.09
SHTWT	10.93	0.09
PLTHT	151.01*	0.04
NoHAV	6.81*	0.04
RTNO	19.47**	0.02
RTWT	6.42	0.11
HI	3.82	0.1
RTROT	0.36	0.37
DM	18.48*	0.04
TC	13.50	0.15

*, **, ***=Significant at P< 0.05, 0.01 and 0. 001respectively.Sprt=Sprout. ns=non-Significant. FYLD-Fresh root yield, BRNHT-Branch height, SHTWT-Shoot weight, PLTHT-Plant height, NoHAV-Number of plant harvested, RTNO-Root number, RTWT-Root weight, HI-Harvest index, RTROT-Root rot, DM-Dry matter, TC-Total carotenoid.

4.6. Mean Summary of Evaluated Traits for Progenies

Fresh root yield for accessions ranges from 2.93 (IBA180173) to 21.42(IBA980581) while the average mean value was 12.35 t/ha. Dry matter content ranges from 10 % (IBA180031) to 30.52 % for white check (TME693) with the average mean value of 20.29 % and accession IBA180081 recorded the highest dry matter content of 25.71 % more than the yellow check IBA070593 (25.64 %). Accession IBA180058 recorded the highest total carotenoids content (19.40 µg/g) than the yellow check which had 10.81 µg/g and it ranges from 7.01 µg/g (IBA180031) to 19.40 µg/g (IBA180058) with average mean value of 13.45 µg/g. Shoot weight ranges from 2.79 kg (IBA180031) to 26.98 kg (IBA180124) while the average mean value was 13.32 kg. Harvest index values was from 0.12 for IBA180231, IBA180173 and IBA180018 to 0.51 (IBA180244) with the average mean value of 0.31. Root size for accessions ranges from 1.50 cm (IBA180018) to 5.33 cm (white check IBA980581) while the average mean value was 3.73cm. Root weight ranges from 1.41 kg (IBA180231) to 22.33 kg (IBA180081) with the average mean values of 8.76 kg. Root number of accessions ranges from 5.25 (IBA180018) to 47.42 (IBA180081) with the average mean value of 21.94. For plant height, it ranges from 59.75 cm (IBA180031) to 244.42 cm (TMEB693) with the average mean of 169.12 cm. Vigour ranges from 2.33 (IBA180182) to 6.67 (TMEB419) while the average mean was 4.37. Sprout range from 0.43 (IBA180231) to 4.00 (IBA180081, IBA180088) with the average mean values of 2.69 (Appendix I)

4.7. Performance of Progenies in terms of Nutritional and Yield Related Traits at 6, 9 and 12 Months after Planting.

Total carotenoid (TC) content of accessions increased at 6 MAP, reduced at 9 MAP and was stabled at 12 MAP (Figure 1). At 6 MAP, 24 accessions had total carotenoids more than the average value of 13.77 µg/g, with highest of 21.38 µg/g being for IBA180058 and the least value of 5.80 µg/g was recorded by yellow check IBA180031. At 9 MAP, 24 accessions had TC more than the average TC of 13.52 µg/g with the highest of 22.53 µg/g recorded for IBA180084 while the least of 8.95 µg/g was recorded by IBA180031. At 12 MAP, 25 accessions had TC value above the mean of 13.05 µg/g while the highest at 12 MAP was IBA180088 with 18.37 µg/g and the least was recorded by IBA180294 with 4.47 µg/g.

The progeny dry matter (DM) increased at 6 MAP, reduced at 9 MAP and slightly increased at 12 MAP. This is similar to total carotenoids (TC) performance in relation to months after planting (MAP) where it increases at 6 MAP, reduces at 9 MAP and slightly increases at 12 MAP (Figure 2). At 6 MAP, 25 accessions had DM content above the mean average of 25.70 %. The white check (TMEB 693) recorded the highest DM of 40.00 % while accession IBA180031 had the least DM content with 10 %. At 9 MAP, 25 accessions had DM content above the mean average of 16.41 % while the white check TMEB 693 recorded the highest DM with 24.35 % while the least was recorded by accession IBA180294 with 4.35 %. At 12 MAP, 25 accessions had DM content than the mean average DM of 18.77 %. While the white check TMEB 693 recorded the highest DM of 26.90 %, accession IBA180294 recorded the least DM value of 7.63 % (Figure 3).

The boxplot of the relationship between months after planting (MAP) and fresh root yield (FYLD) shows that FYLD was at the lowest at 6 MAP and increased at 9 MAP and 12 MAP (Figure 4). At 6 MAP, 18 accessions had yield value beyond the FYLD mean average of 3.64 t/ha. Accession IBA980581 had the highest fresh root yield of 9.40t/ha while the least yield was recorded by accession IBA180031 with 0.18 t/ha. At 9 MAP, 21 accessions had FYLD above the mean average of 13.93 t/ha with accession IBA180146 recording the highest yield of 47.50t/ha while the accession IBA180031 recorded the least value of 0.53 t/ha. At 12 MAP, 20 accessions had yield value above the mean yield value average of 19.55 t/ha. Accession IBA180210 recorded the highest root yield of 38.03 t/ha while the least yield value was recorded by accession IBA180031 with 3.29 t/ha (Figure 5, Table 4.3).

Accession IBA180098, an early bulking was the highest yielding at 6MAP (with dry matter content of 18.4%) and shows that it was efficient in directing assimilates towards the roots at this stage by having the highest root yield at 6MAP when there was no rain than at 9MAP when rainfall has started. Accession IBA180294 on the other hand, an early bulking had low yield at 6MAP (with DM of 30.78 at 6MAP). This revealed that root yield and dry matter partitioning varies among genotypes and with environment. At 9MAP when DM was reducing due to rainfall onset, accession IBA180146 had the highest root yield of 57.50t/ha (Table 4.3).

At 6 MAP, 20 accessions had harvest index (HI) value above the mean average of 0.26. The accession IBA180037 had the highest HI of 0.53 while the accession IBA180018 and IBA180173 had the least with 0.05. At 9 MAP, 19 accessions had HI value above the

mean average of 0.32 with accession IBA180081 having the highest HI value of 0.53 with accession IBA180259, IBA180294, IBA180084, IBA180031 and IBA180098 having the least HI value of 0.15. At 12 MAP, 19 accessions had the HI value above the mean average of 0.35. The accession IBA180244 recorded the highest HI value of 0.62 while the least value of 0.08 was recorded by IBA180018.

At 6 MAP, 20 accessions had shoot weight value more than the mean average of 8.32 kg. The highest shoot weight value was recorded by accession IBA180088 with 15.65 kg and the least was recorded by IBA180031 with shoot weight of 2.10 kg. At 9 MAP, 22 accessions had shoot weight value than the mean average of 10.50 kg. The highest shoot weight of 21.28 kg was recorded by the white check IBA980581 while the least was recorded for IBA180294 with shoot weight value of 2.80 kg. At 12 MAP, 18 accessions had shoot weight value than the mean average of 21.18. While the white check IBA090581 had the highest value of 42.19 kg and the least shoot weight value of 1.90 kg was recorded by IBA180031(Table 4.4).

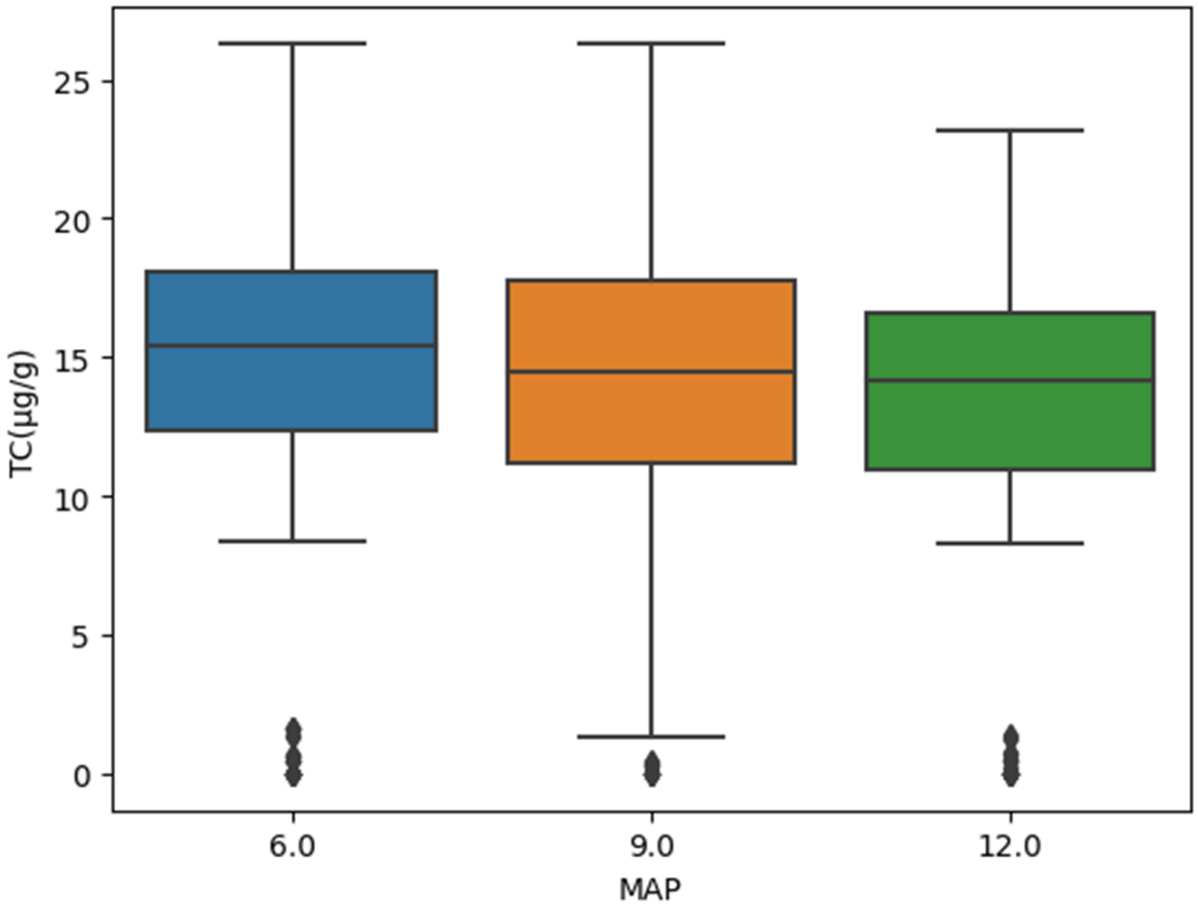


Figure 1: Boxplot of Total Carotenoids (TC) for Accessions at different Months After Planting (MAP) across the Year

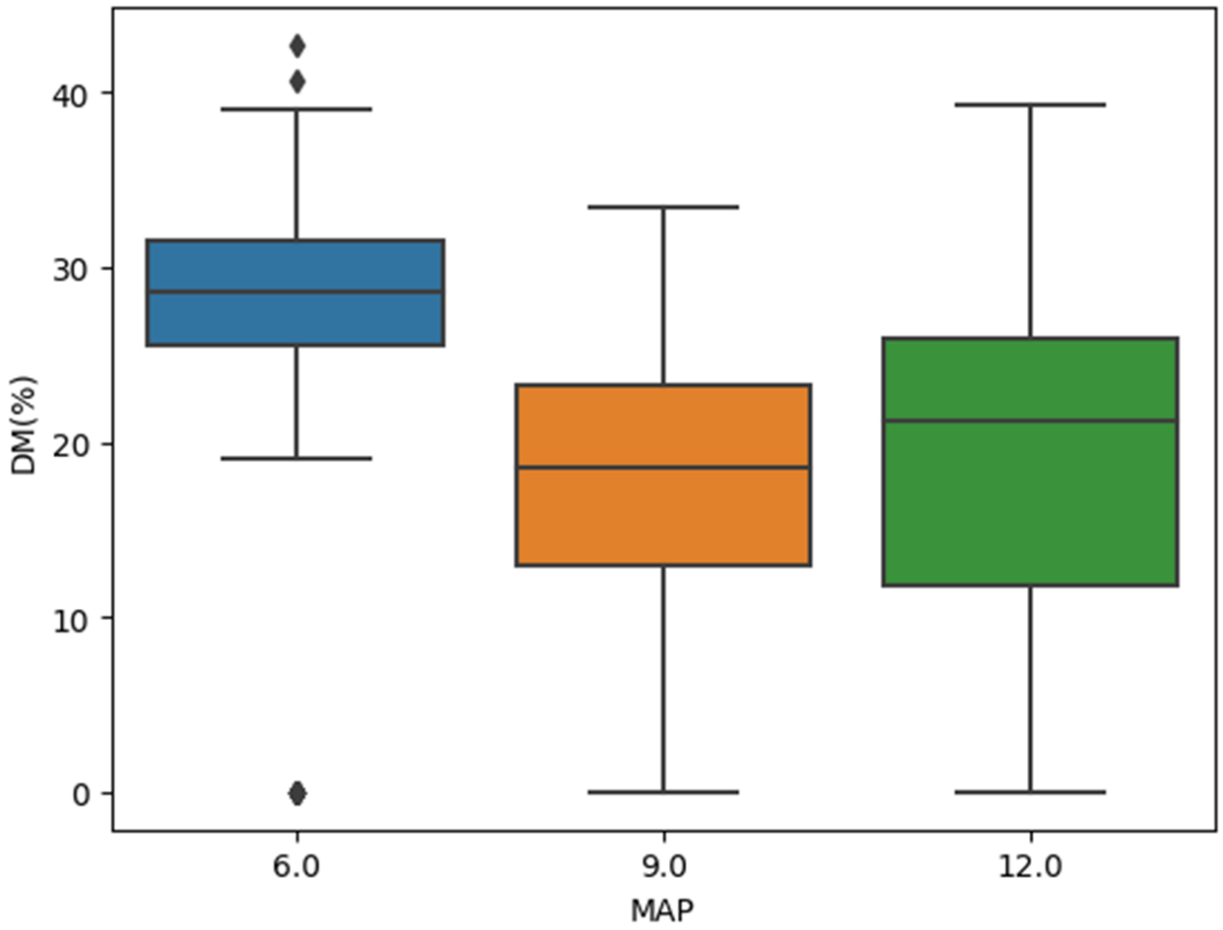


Figure 2: Boxplot of Dry Matter (DM) Content for Accessions at different Months After Planting (MAP) across the Year

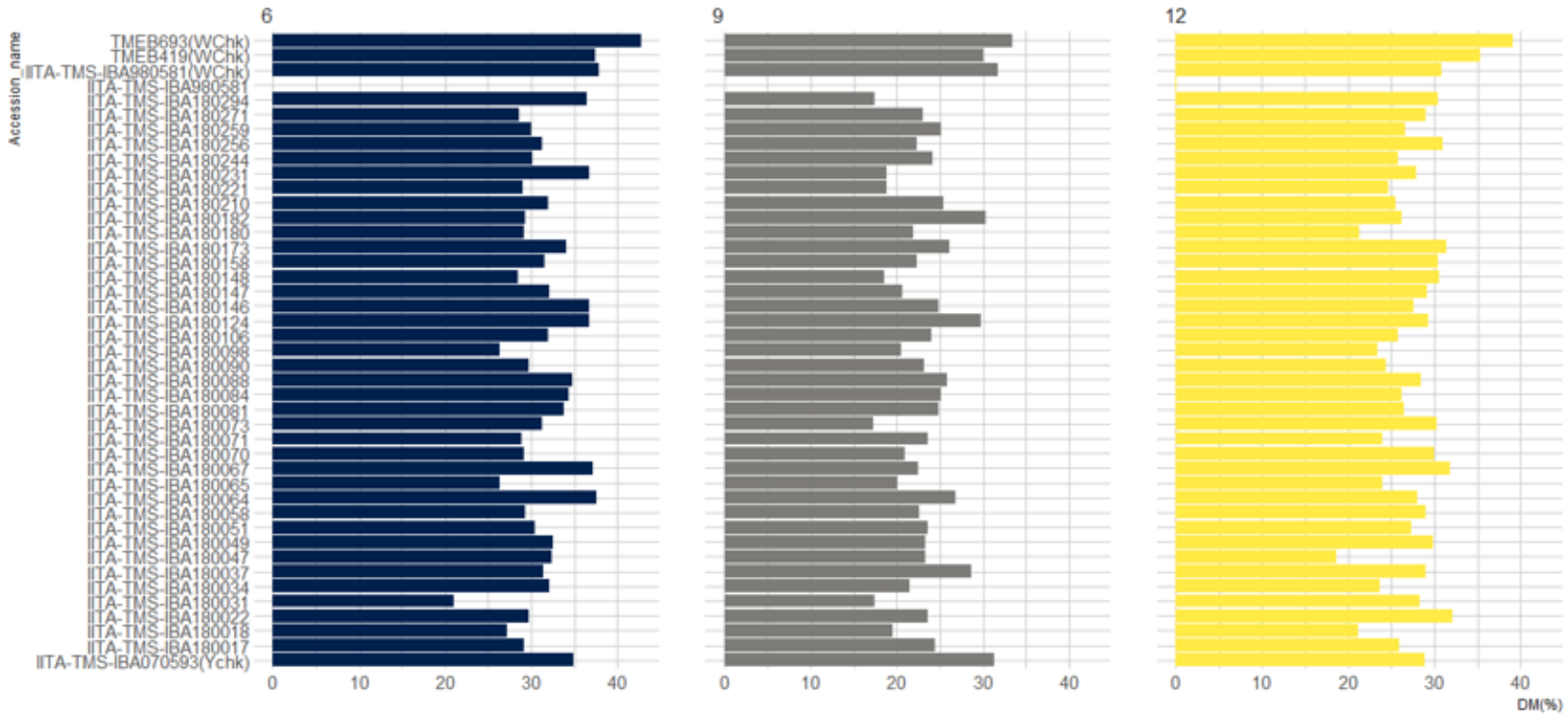


Figure 3: Dry matter contents of accessions at different months and year

Table 4.3: Total Carotenoids, Dry Matter and Fresh Root Yield of Accessions at different Months and Year.

TRAITS	TC(µg/g)			DM(%)			FYLD(t/ha)		
Accession_name	6 MAP	9MAP	12MAP	6MAP	9MAP	12MAP	6MAP	9MAP	12MAP
IITA-TMS-IBA180022	13.05	14.13	17.49	27.83	20.20	24.87	6.05	11.63	22.10
TMEB419(WChk)	1.10	0.95	7.60	32.15	22.30	23.53	4.38	7.00	16.08
IITA-TMS-IBA180221	14.20	13.30	12.17	27.23	17.08	18.65	2.83	13.00	23.69
IITA-TMS-IBA180148	18.53	17.40	17.66	20.20	17.58	20.85	3.55	7.50	28.42
IITA-TMS-IBA180047	17.98	15.68	14.12	28.70	15.48	21.51	2.08	21.85	14.11
IITA-TMS-IBA180064	19.45	18.95	15.75	32.43	17.53	22.71	3.45	16.13	14.78
IITA-TMS-IBA180081	15.28	16.73	13.99	30.58	20.75	20.79	4.48	27.43	34.74
IITA-TMS-IBA180037	18.13	16.85	15.60	29.23	23.88	22.02	8.25	18.03	18.30
IITA-TMS-IBA180124	15.93	14.35	15.35	33.90	20.18	23.05	4.63	14.40	18.52
IITA-TMS-IBA180071	15.85	12.58	15.57	26.78	19.55	18.21	3.85	9.50	30.62
IITA-TMS-IBA180106	16.10	13.38	14.76	30.08	17.60	21.06	2.80	15.23	23.93
IITA-TMS-IBA180271	9.35	9.38	8.83	19.85	14.55	14.07	2.20	3.48	10.71
IITA-TMS-IBA180090	16.55	17.68	14.85	27.63	15.58	18.38	5.23	10.23	12.48
IITA-TMS-IBA180084	19.48	22.53	15.73	32.28	17.40	18.82	3.20	5.38	13.64
TMEB693(WChk)	0.63	0.43	7.51	40.30	24.35	26.90	3.53	10.83	26.06
IITA-TMS-IBA180031	5.80	8.95	6.28	10.00	7.63	12.38	0.18	0.53	3.29
IITA-TMS-IBA180034	15.88	13.58	14.99	28.13	18.90	18.10	2.15	15.08	18.09
IITA-TMS-IBA180058	21.38	20.18	16.64	20.53	18.80	20.47	4.20	14.80	24.45
IITA-TMS-IBA180244	17.23	13.80	9.73	27.18	20.15	16.80	6.03	15.93	33.17
IITA-TMS-IBA070593(Ychk)	9.03	9.83	13.59	33.90	20.50	22.51	5.08	12.63	28.96
IITA-TMS-IBA180259	14.20	15.93	10.36	22.43	16.63	14.39	2.98	9.45	5.48
IITA-TMS-IBA180173	9.65	10.30	15.24	17.03	11.00	22.99	0.55	1.23	7.02
IITA-TMS-IBA180231	9.48	14.08	7.47	17.48	8.58	12.33	0.28	17.98	10.98
IITA-TMS-IBA180049	13.75	15.88	17.29	22.55	15.95	19.07	5.25	20.83	26.17
IITA-TMS-IBA180294	12.80	13.55	4.47	30.78	4.35	7.63	2.70	10.95	2.85
IITA-TMS-IBA180210	18.30	18.85	10.86	29.78	17.33	14.88	5.45	16.00	38.03
IITA-TMS-IBA180146	11.75	13.48	17.05	22.33	19.18	20.33	2.28	47.50	29.23
IITA-TMS-IBA180088	16.50	14.03	18.37	31.88	18.23	22.60	4.80	10.05	20.22
IITA-TMS-IBA180070	17.80	16.95	17.07	21.00	14.10	22.84	1.70	22.00	6.59
IITA-TMS-IBA180256	12.13	10.30	10.23	22.70	9.88	10.11	3.40	20.40	10.56
IITA-TMS-IBA180017	14.48	13.40	14.70	26.65	16.43	19.19	5.25	11.25	37.59
IITA-TMS-IBA180067	17.48	17.15	16.35	32.80	16.10	22.47	2.13	6.20	22.24
IITA-TMS-IBA180098	12.55	14.50	11.86	18.40	17.05	13.74	7.43	5.35	11.54
IITA-TMS-IBA180065	12.00	14.38	13.80	12.68	14.68	17.98	0.60	36.35	13.45
IITA-TMS-IBA180051	18.45	17.30	17.30	27.18	19.65	20.53	4.43	5.23	14.09
IITA-TMS-IBA180158	16.00	11.75	10.19	22.90	8.53	20.18	2.20	1.43	5.45
IITA-TMS-IBA180182	11.68	12.65	10.97	20.18	19.23	13.94	3.40	18.10	26.10
IITA-TMS-IBA980581(WChk)	1.00	0.90	6.39	35.33	22.35	20.88	9.40	17.88	37.00
IITA-TMS-IBA180018	10.55	12.28	8.61	13.40	8.95	10.31	0.30	13.05	4.26
IITA-TMS-IBA180073	17.18	15.05	13.80	26.98	12.60	20.12	3.08	22.10	30.81
IITA-TMS-IBA180180	12.30	11.25	12.62	18.40	14.20	16.53	2.38	13.65	14.26
IITA-TMS-IBA180147	17.33	13.30	14.76	27.90	14.23	19.65	4.63	7.38	30.89
Mean	13.77	13.52	13.05	25.70	16.41	18.77	3.64	13.93	19.55
SD	4.94	4.61	3.68	6.63	4.52	4.29	2.06	8.98	10.21
SE±	0.76	0.71	0.57	1.02	0.70	0.66	0.32	1.39	1.58
CV	0.36	0.34	0.28	0.26	0.28	0.23	0.57	0.64	0.52

SD=standard deviation, SE=standard error, CV=coefficient of variation, Ychk=Yellow check, Wchk=White check

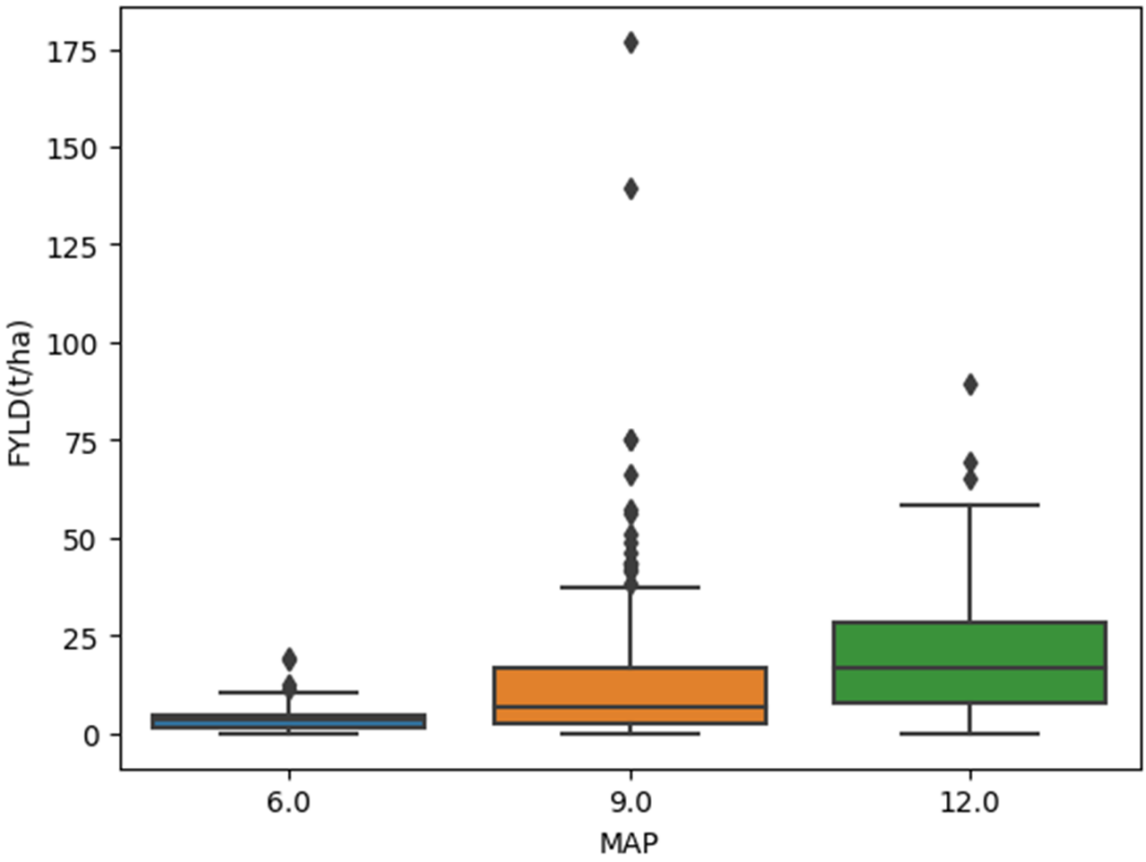


Figure 4: Boxplot of Fresh Root Yield (FYLD) of Accessions at different Months After Planting (MAP) across the Year

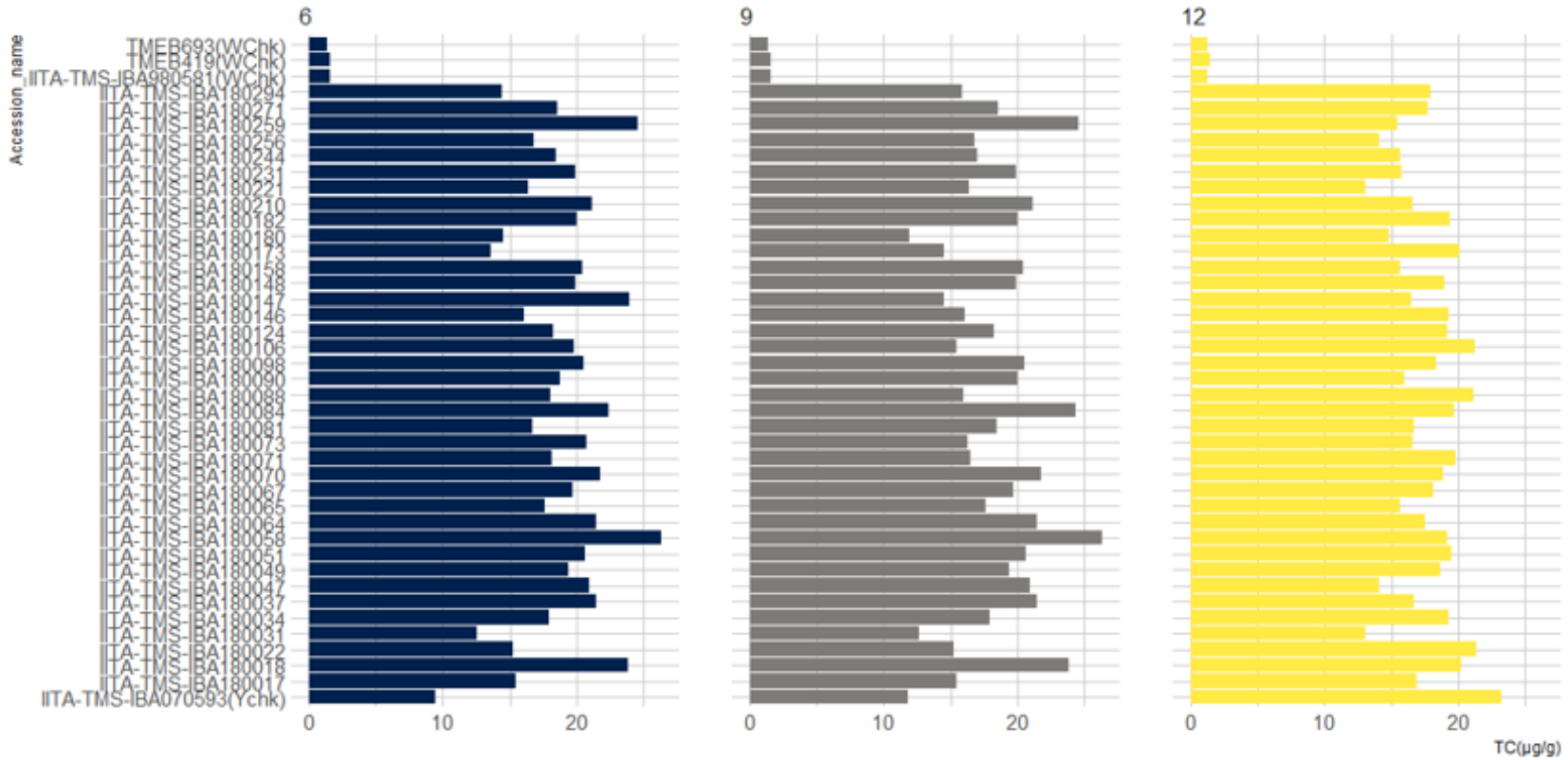


Figure 5: Total carotenoids of accessions at different months and year

Table 4.4: Harvest Index and Shoot Weight of Accessions at Different Months and Year.

TRAITS	HI			Shoot Weight (kg)		
Accession_name	6MAP	9MAP	12MAP	6MAP	9MAP	12 MAP
IITA-TMS-IBA180022	0.35	0.28	0.39	9.53	10.35	19.13
TMEB419(WChk)	0.40	0.30	0.38	6.95	11.33	18.24
IITA-TMS-IBA180221	0.28	0.30	0.36	8.45	12.38	31.90
IITA-TMS-IBA180148	0.48	0.38	0.63	4.88	11.30	11.42
IITA-TMS-IBA180047	0.18	0.35	0.35	7.80	16.13	17.25
IITA-TMS-IBA180064	0.25	0.43	0.34	10.08	12.98	21.79
IITA-TMS-IBA180081	0.28	0.53	0.59	10.88	14.55	19.70
IITA-TMS-IBA180037	0.53	0.48	0.40	9.43	10.10	30.33
IITA-TMS-IBA180124	0.18	0.30	0.27	15.63	23.70	39.13
IITA-TMS-IBA180071	0.20	0.28	0.49	12.20	9.68	17.48
IITA-TMS-IBA180106	0.25	0.45	0.51	8.95	13.40	29.02
IITA-TMS-IBA180271	0.18	0.18	0.27	7.28	9.60	17.19
IITA-TMS-IBA180090	0.40	0.30	0.28	6.28	4.65	18.81
IITA-TMS-IBA180084	0.20	0.15	0.30	12.98	10.35	22.98
TMEB693(WChk)	0.20	0.35	0.43	10.23	13.55	31.03
IITA-TMS-IBA180031	0.08	0.15	0.24	2.10	5.00	1.90
IITA-TMS-IBA180034	0.20	0.43	0.31	8.08	11.83	36.05
IITA-TMS-IBA180058	0.33	0.35	0.40	7.55	16.78	19.95
IITA-TMS-IBA180244	0.35	0.58	0.62	12.25	8.33	13.53
IITA-TMS-IBA070593(Ychk)	0.28	0.43	0.44	13.20	13.35	31.78
IITA-TMS-IBA180259	0.25	0.15	0.16	4.90	9.88	18.85
IITA-TMS-IBA180173	0.05	0.13	0.19	7.03	5.20	28.27
IITA-TMS-IBA180231	0.08	0.20	0.09	3.08	5.68	12.73
IITA-TMS-IBA180049	0.30	0.25	0.29	4.50	15.70	37.76
IITA-TMS-IBA180294	0.30	0.15	0.09	7.08	2.80	7.40
IITA-TMS-IBA180210	0.30	0.40	0.33	9.30	11.73	16.72
IITA-TMS-IBA180146	0.28	0.30	0.47	5.50	11.68	15.46
IITA-TMS-IBA180088	0.23	0.45	0.38	15.65	12.13	26.84
IITA-TMS-IBA180070	0.20	0.33	0.27	5.60	3.48	11.78
IITA-TMS-IBA180256	0.40	0.28	0.23	3.05	5.03	14.49
IITA-TMS-IBA180017	0.30	0.48	0.51	12.45	9.53	27.20
IITA-TMS-IBA180067	0.13	0.25	0.30	11.13	13.05	30.44
IITA-TMS-IBA180098	0.48	0.15	0.23	4.90	8.05	18.72
IITA-TMS-IBA180065	0.10	0.30	0.34	4.35	7.93	18.59
IITA-TMS-IBA180051	0.33	0.40	0.39	8.63	8.30	20.92
IITA-TMS-IBA180158	0.18	0.25	0.11	4.95	7.35	11.60
IITA-TMS-IBA180182	0.23	0.35	0.35	12.30	9.48	13.15
IITA-TMS-IBA980581(WChk)	0.33	0.38	0.42	13.83	21.28	42.19
IITA-TMS-IBA180018	0.05	0.23	0.08	3.30	4.28	6.90
IITA-TMS-IBA180073	0.30	0.48	0.59	7.23	8.33	14.96
IITA-TMS-IBA180180	0.25	0.28	0.28	6.68	12.50	22.23
IITA-TMS-IBA180147	0.33	0.28	0.51	9.40	8.55	23.84
Mean	0.26	0.32	0.35	8.32	10.50	21.18
SD	0.11	0.11	0.14	3.49	4.41	9.11
SE±	0.02	0.02	0.02	0.54	0.68	1.41
CV	0.43	0.35	0.40	0.42	0.42	0.43

SD=standard deviation, SE=standard error, CV=coefficient of variation, Wchk=White check, Ychk= Yellow check

4.8. Fresh Root Yield, TC and Best Linear Unbiased Prediction (BLUP) of Accessions at different Months and Year

Fresh root yield of accessions across the months and year ranges from 1.33t/ha to 26.33 t/ha with the accession IBA180244 having the highest fresh root yield of 26.33 t/ha and the accession IBA180031 having the least root yield of 1.33 t/ha below the average mean value of 12.37 t/ha.

The mean values across the MAP and seasons (year) ranges from 3.63 t/ha to 19.54 t/ha (Table 4.5). Accessions shows reduction in their root yield as months progresses. Accessions IBA180098 and IBA180158 were discontinuous in their yield at 6 MAP with their yield reducing at 9 MAP and accessions IBA180018, IBA18065, IBA180256, IBA180065, IBA180070, IBA180146, IBA180294, IBA180231, IBA180259, IBA180064 and IBA180047 show discontinuity in their root yield at 9 MAP and had higher yield at 9 MAP than at 12 MAP.

The BLUP values for accessions at different months and seasons range from 0.05 to14.5 with accession IBA180071 having the least BLUP of 0.05 and the accession IBA180146 having the highest BLUP of 5.04 which was above the mean BLUP of 0.0. The TC of accessions at different months and seasons ranges from 0.16 µg/g to 4.85 µg/g with accession IBA180259 having the least BLUP of 0.16µg/g for total carotenoids content and accession IBA180058 having the highest TC BLUP value of 20.18 µg/g above the mean of 0.00 (Table 4.5).

Table 4.5: BLUP of Fresh Root Yield and Total Carotenoids of Accessions at different Months and Year.

FYLD (t/ha) Accession_name	6MAP	9MAP	12MAP	Mean	BLUP FYLD(t/ha)	BLUP TC(µg/g)
IITA-TMS-IBA180022	6.05	11.63	22.10	13.26	0.32	1.26
TMEB419(WChk)	4.38	7.00	16.08	9.15	-1.15	-9.90
IITA-TMS-IBA180221	2.83	13.00	23.69	13.17	0.29	-0.06
IITA-TMS-IBA180148	3.55	7.50	28.42	13.16	0.28	3.63
IITA-TMS-IBA180047	2.08	21.85	14.11	12.68	-0.15	2.43
IITA-TMS-IBA180064	3.45	16.13	14.78	11.45	-0.32	3.78
IITA-TMS-IBA180081	4.48	27.43	34.74	22.21	3.55	1.62
IITA-TMS-IBA180037	8.25	18.03	18.30	14.86	0.90	2.83
IITA-TMS-IBA180124	4.63	14.40	18.52	12.51	0.82	1.52
IITA-TMS-IBA180071	3.85	9.50	30.62	14.66	0.05	1.09
IITA-TMS-IBA180106	2.80	15.23	23.93	13.98	0.58	1.15
IITA-TMS-IBA180271	2.20	3.48	10.71	5.46	-2.49	-3.28
IITA-TMS-IBA180090	5.23	10.23	12.48	9.31	-1.10	2.44
IITA-TMS-IBA180084	3.20	5.38	13.64	7.40	-1.79	4.73
TMEB693(WChk)	3.53	10.83	26.06	13.47	0.39	-10.15
IITA-TMS-IBA180031	0.18	0.53	3.29	1.33	-3.98	-5.01
IITA-TMS-IBA180034	2.15	15.08	18.09	11.77	-0.21	1.20
IITA-TMS-IBA180058	4.20	14.80	24.45	14.48	0.76	4.85
IITA-TMS-IBA180244	6.03	15.93	33.17	18.37	2.17	0.23
IITA-TMS-IBA070593(Ychk)	5.08	12.63	28.96	15.55	1.15	-1.98
IITA-TMS-IBA180259	2.98	9.45	5.48	5.97	-2.30	0.16
IITA-TMS-IBA180173	0.55	1.23	7.02	2.93	-3.40	-1.25
IITA-TMS-IBA180231	0.28	17.98	10.98	9.74	-0.94	-2.36
IITA-TMS-IBA180049	5.25	20.83	26.17	17.41	1.82	1.86
IITA-TMS-IBA180294	2.70	10.95	2.85	5.50	-2.48	-2.41
IITA-TMS-IBA180210	5.45	16.00	38.03	19.83	2.69	2.15
IITA-TMS-IBA180146	2.28	47.50	29.23	26.33	5.04	0.63
IITA-TMS-IBA180088	4.80	10.05	20.22	11.69	-0.24	2.39
IITA-TMS-IBA180070	1.70	22.00	6.59	10.10	-0.82	3.16
IITA-TMS-IBA180256	3.40	20.40	10.56	11.45	-0.33	-1.92
IITA-TMS-IBA180017	5.25	11.25	37.59	18.03	2.05	0.71
IITA-TMS-IBA180067	2.13	6.20	22.24	10.19	-0.79	2.94
IITA-TMS-IBA180098	7.43	5.35	11.54	8.11	-1.54	-0.26
IITA-TMS-IBA180065	0.60	36.35	13.45	16.80	1.60	0.07
IITA-TMS-IBA180051	4.43	5.23	14.09	7.91	-1.61	3.49
IITA-TMS-IBA180158	2.20	1.43	5.45	3.03	-3.37	-0.52
IITA-TMS-IBA180182	3.40	18.10	26.10	15.87	1.26	-1.22
IITA-TMS-IBA980581(WChk)	9.40	17.88	37.00	21.42	3.27	-9.92
IITA-TMS-IBA180018	0.30	13.05	4.26	5.87	-2.34	-2.25
IITA-TMS-IBA180073	3.08	22.10	30.81	18.66	2.27	1.63
IITA-TMS-IBA180180	2.38	13.65	14.26	10.09	-0.82	-0.99
IITA-TMS-IBA180147	4.63	7.38	30.89	14.30	0.90	1.53
Mean	3.64	13.93	19.55	12.37	0.00	0.00
SD	2.06	8.98	10.21	5.44	1.96	3.56
SE±	0.32	1.39	1.58	0.84	0.30	0.55
CV	0.57	0.64	0.52	0.44	0.00	0.00

SD=standard deviation, SE=standard error, CV=coefficient of variation, Wchk=white check, Ychk=Yellow check

4.9. Pearson Correlation of Progenies at 6MAP for Different Traits

The Fresh storage root yield (FYLD) was highly significant at $p<0.001$ and positively correlated with Harvest index (HI) (R=0.79), Shoot weight (SHTWT) (R=0.51), Root weight (RTWT) (1.0), Rtno (0.90), and RTSZ (0.50). It was very significant at $p<0.01$ and positively correlated with Plant Height (PLTHT) (0.28) and was significant at $p<0.05$ and positively with dry matter (DM) (R=0.26). Height at first apical branch (BRNHT) was highly significant at $p<0.001$ and positively correlated with Total carotenoid (TC) (R=0.72).

DM was highly significant at $p<0.001$ and positively correlated with Root size (RTSZ)(R=0.45), SHTWT(R=0.54), Number of plants harvested (NOHAV) (R=0.56), PLTHT (R=0.65), Vigour (R=0.61), sprout (0.53). It was very significant at $p<0.01$ and positively correlated with root number (R=0.30) and significant at $p<0.05$ and positively correlated with fresh storage root yield (FYLD) (R=0.26) and Rtwt (R=0.26).

TC was highly significant $p<0.001$ and positively correlated with Brnht (R=0.72), PLTHT (R=0.41) and RTSZ (R=0.47) (Figure 6).

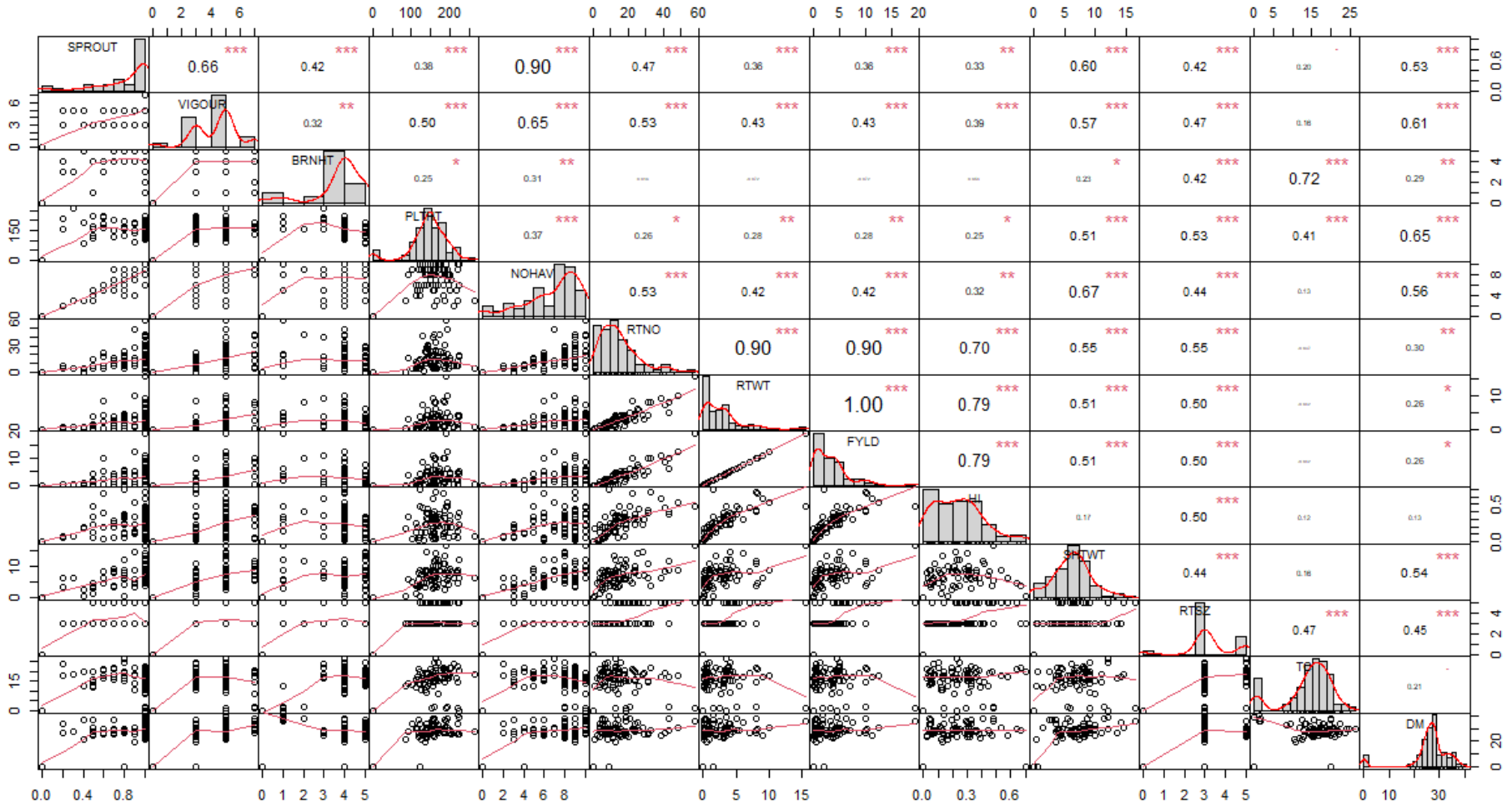


Figure 6: Pearson correlation of progenies evaluated for different evaluated traits at 6 MAP

BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, TC=Total carotenoid, DM=Dry matter content.

4.10. Pearson Correlation of Progenies Evaluated for different Traits at 9 Months After Planting

Fresh root yield (FYLD) was highly significant at $p<0.001$ and positively correlated with harvest index (HI) (R=0.81), Shoot weight (SHTWT) (R=0.56), Root weight (RTWT) (R=0.87), Root number (RTNO) (R=0.70), and Root size (RTSZ) (R=0.77), dry matter (DM) (R=0.43), plant height (PLTHT) (R=0.58), Root rot (RTROT) (R=0.32). Height at first apical branch (BRNHT) was very significant at $p<0.01$ and positively correlated with TC (R=0.32).

Dry matter (DM) was highly significant at $p<0.001$ and positively correlated with RTSZ (R=0.57), SHTWT (R=0.40), FYLD (R=0.43), RTWT (R=0.53), RTNO (R=0.58), PLTHT (0.38). It was very significant at $p<0.01$ and positively correlated with NOHAV (R=0.38). HI was highly significant at $p<0.001$ and positively correlated dry matter (DM) (R=0.44) (Figure 7).

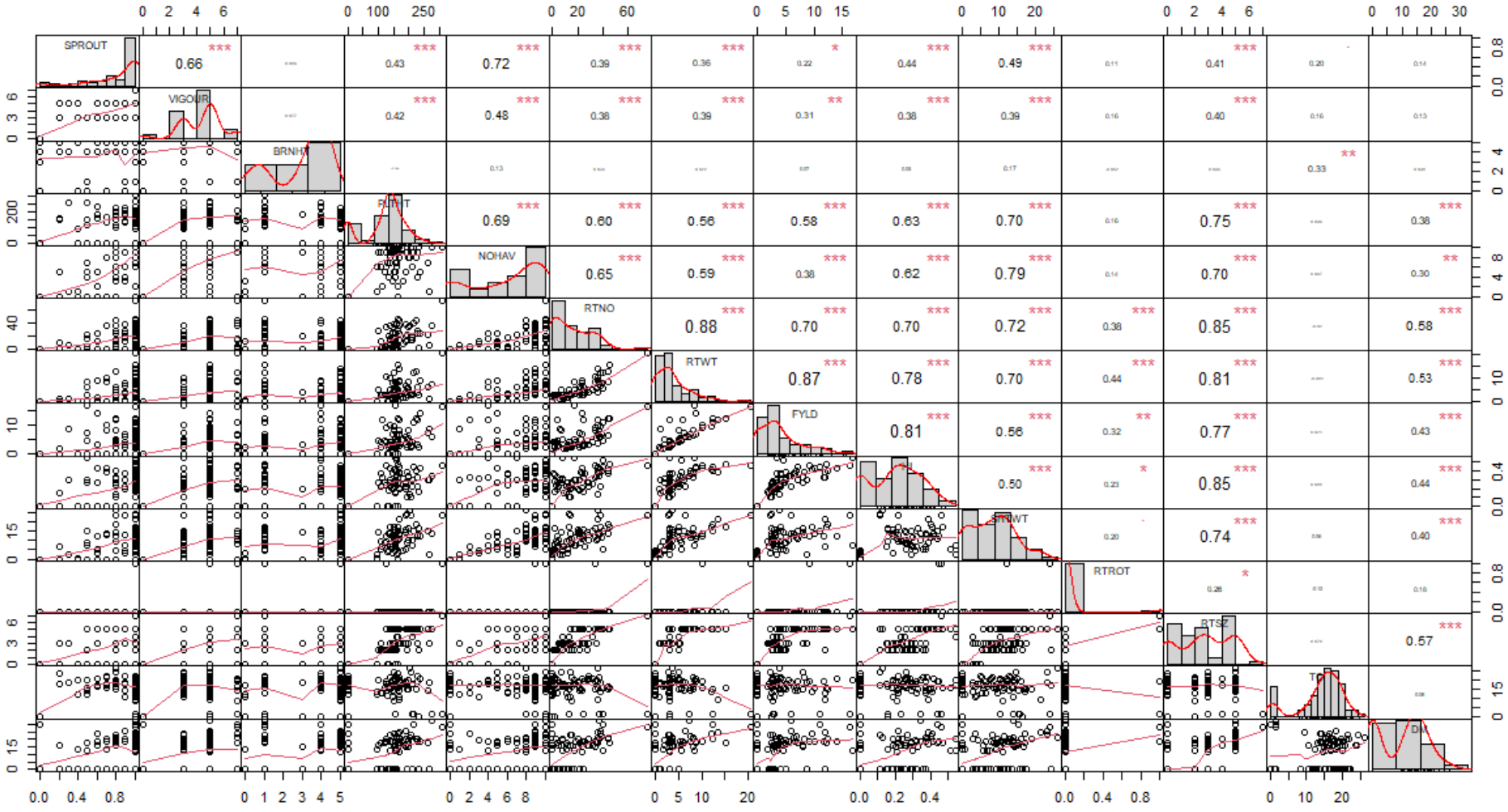


Figure 7: Pearson Correlation of Progenies at 9 MAP Evaluated for different Traits

BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, TC=Total carotenoid, DM=Dry matter content.

4.11. Pearson Correlation of Progenies Evaluated at 12 MAP for Different Traits

Fresh root yield (FYLD) was highly significant at $p<0.001$ and positively correlated with Harvest index (HI) (R=0.82), shoot weight (SHTWT) (R=0.42), root weight (RTWT) (0.91), root number (RTNO) (0.90), root size (RTSZ) (0.75), root number (RTNO) (R=0.75), Vigour (R=0.44), Sprout (R=0.56), dry matter (DM) (R=0.42), plant height (PLTHT) (R=0.50). It was significant at $p<0.01$ and positively correlated with PLTHT (0.28) and was significant at $p<0.05$ and positively with DM (R=0.26). Height at first apical branch was significant at $p<0.01$ and positively correlated with TC (R=0.31).

Dry matter (DM) was significant at $p<0.001$ and positively correlated with RTSZ (R=0.70), SHTWT (R=0.51), FYLD (R=0.42), RTWT (R=0.41), RTNO (R=0.47), NOHAV (R=0.77), PLTHT (R=0.73), sprout (0.66) and HI (R=0.58). It was very significant at $p<0.01$ and positively correlated with vigour (R=0.66)

Total carotenoids (TC) were significant $p<0.001$ and positively correlated with HI (R=0.45), Nohav (R=0.54) and Sprout(R=0.37). Rtsz (R=0.47). It was significant at $p<0.05$ and positively correlated with PLTHT (R=0.28) and significant at $p<0.01$ and positively correlated with height at first apical branch (Brnht) (R=0.31) (Figure 8).

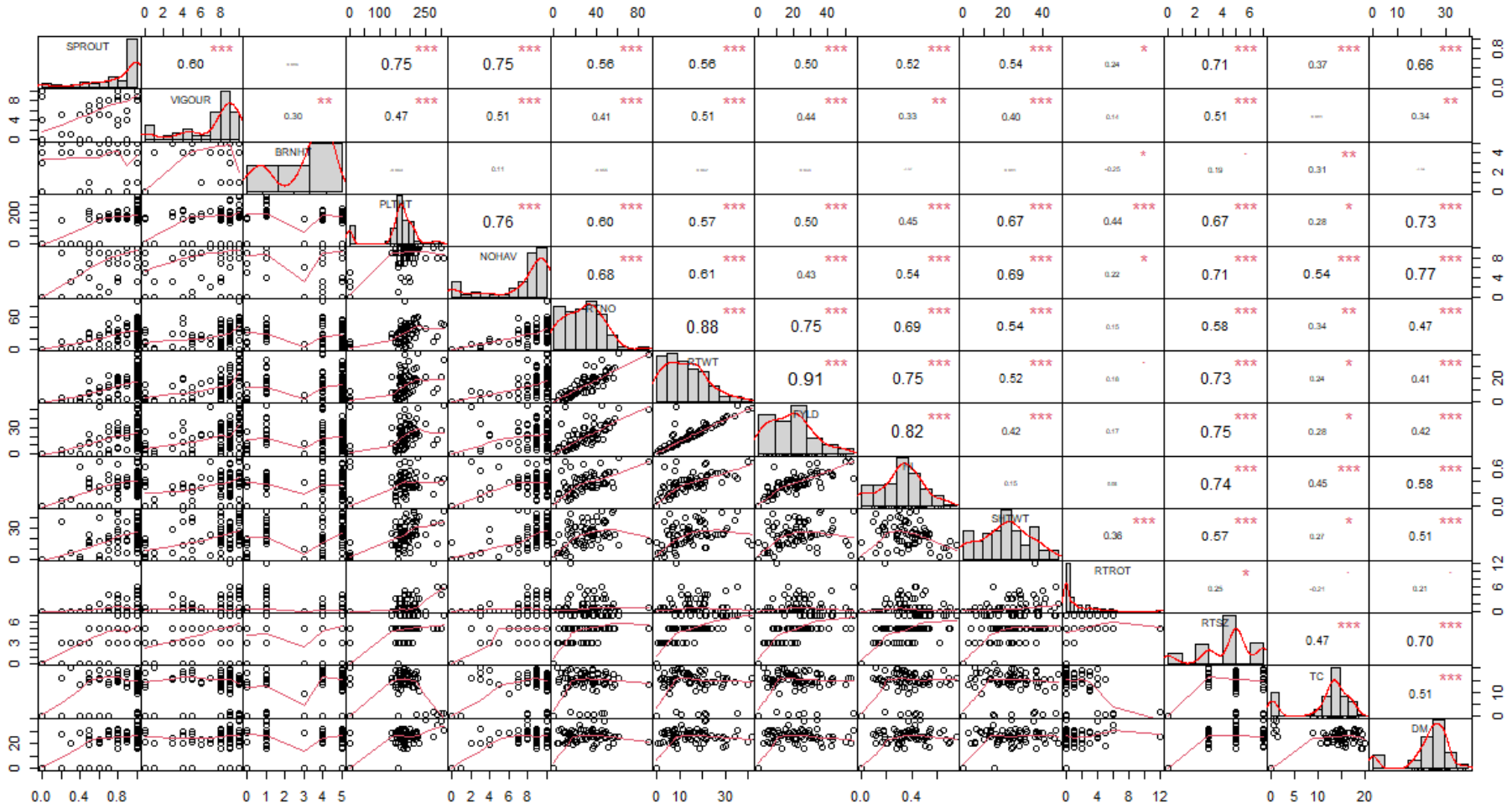


Figure 8: Pearson correlation of progenies evaluated at 12MAP for different traits

BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, TC=Total carotenoid, DM=Dry matter content.

4.12. Pearson correlation of parental Fresh Storage Root Yield (FYLD) and Dry Matter (DM) with other Traits.

Fresh root yield (FYLD) was not significant and negatively correlated (R = -0.42) with total carotenoids as shown in table 4.6. It was not significant and negatively correlated(R=-0.11) with dry matter (DM). Fresh storage root yield was highly significant ($p<0.001$) with root number and positively correlated (R=0.75). But was positively correlated (R=0.10) not significant with number of plants harvested (NoHav). Fresh storage root yield was highly significant ($p<0.001$) with shoot weight (SHTWT) and positively correlated (R=0.67). Fresh root yield (FYLD) was not significant and positively correlated (R = 0.13) with Sprout. Fresh root yield (FYLD) was significant ($p<0.01$) and positively correlated (R=0.46) with HI.

Dry matter (DM) was not significant and positively correlated (R = 0.19) with Total Carotenoids, it was also not significant and positively correlated (R=0.0) with shoot weight (SHTWT) and not significant ($p<0.05$) and positively correlated with HI (R=0.51) (Table 4.6).

Table 4.6: Pearson correlation of 39 parental genotypes

Traits	SPROUT	MCMDS	MCMDI	DM	DYLD	FYLD	HI	TCiCHK	TCHART	PLTHT	SHTWT	RTWT	NOHAV	RTNO	RTROT	SPGRV	RTINNCOL	RTOUTCOL	PLPCOL	RTSHP	RTSZ
SPROUT	1																				
MCMDS	-0.2	1																			
MCMDI	-0.21	0.92***	1																		
DM	0.25	-0.26	-0.25	1																	
DYLD	0.12	-0.11	0.16	0.2	1																
FYLD	0.13	-0.45*	-0.49*	-0.11	-0.11	1															
HI	-0.18	-0.34*	-0.36*	0.26	0.19	0.46*	1														
TCiCHK	-0.43*	0.28	0.22	-0.19	-0.31	-0.42*	-0.11	1													
TCHART	0.02	0.02	0.01	0.32	0.17	-0.32	0.13	0.36*	1												
PLTHT	0	-0.07	-0.23	-0.09	-0.03	0.49*	0.19	-0.1	-0.26	1											
SHTWT	0.50*	-0.36*	-0.34*	0	0.11	0.67***	-0.13	-0.56**	-0.34*	0.3	1										
RTWT	0.23	-0.54**	-0.49*	0.2	0.33	0.80***	0.60***	-0.55**	-0.09	0.29	0.66***	1									
NOHAV	0.65***	-0.36*	-0.29	0.45*	0.56**	0.1	0.14	-0.46*	0.21	-0.15	0.46*	0.54**	1								
RTNO	0.42*	-0.37*	-0.35*	0.17	0.3	0.75***	0.42*	-0.48*	-0.09	0.24	0.74***	0.89***	0.61***	1							
RTROT	0.08	-0.26	-0.17	-0.08	-0.11	0.48*	-0.09	-0.11	-0.3	-0.34	0.63**	0.39	0.11	0.43*	1						
SPGRV	0.54*	-0.16	-0.04	0.2	0.2	-0.35	0.18	-0.71*	0.07	-0.24	-0.03	0.24	0.53*	0.13	-0.17	1					
RTINNCOL	-0.1	0.3	0.17	-0.28	-0.35*	0.05	-0.17	0.24	-0.03	0.48*	-0.08	-0.3	-0.39*	-0.2	-0.14	-0.34	1				
RTOUTCOL	0.13	0.33*	0.23	0.05	-0.2	-0.44*	-0.52*	0.06	-0.11	0.06	-0.08	-0.54**	-0.15	-0.38*	-0.03	0.13	0.18	1			
PLPCOL	-0.11	-0.24	-0.22	0.22	0.02	0.02	0.25	0.33	0.52*	-0.13	-0.25	0.06	-0.01	0	0.01	-0.46	-0.11	-0.1	1		
RTSHP	0.14	-0.33*	-0.32	0.26	0.07	0.13	0.12	-0.07	0.21	0.14	0.18	0.31	0.36*	0.21	-0.05	-0.05	-0.08	-0.23	0.07	1	
RTSZ	-0.14	-0.45*	-0.41*	0.21	0.25	0.59**	0.65***	-0.41*	0.07	0.2	0.3	0.75***	0.23	0.47*	0.36	0.24	-0.21	-0.40*	0.15	0.25	1

*, **, *** = Significant at P< 0.05, 0.01 and 0. 001respectively ns=non-Significant. MCMDS- mean cassava mosaic disease severity, MCMDI-mean cassava mosaic disease incidence, DM-dry matter, DYLD-dry root yield, DM-dry matter, DYLD-dry root yield, FYLD-fresh storage root yield, HI-Harvest index, TCiCHK-Total carotenoids as determined by icheck, TCHART-Total carotenoids chart, PLTHT-Plant height, SHTWT-Shoot weight, RTWT-Root weight, NOHAV-Number harvested, RTNO-Root number, RTROT-Root rot, SPGRV-Specific gravity, RTINNCOL-Root inner skin colour, RTOUTCOL-Root outer skin colour, PLPCOL-Pulp colour, RTSHP-Root shape, RTSZ-Root size.

4.13. Performance of Progenies in Relation to the Parental Genotypes in terms of Total Carotenoids and Root yield.

Total Carotenoids (TC) contents for some accessions were higher than the yellow genotype check among the accessions. Some of the progenies had TC contents higher than some of their parental genotypes. The least TC content for the parents IITA-TMS-IBA160142 was 7.18µg/g while the highest of the parents IITA-TMS-IBA160137 was 21.27µg/g (Appendix II). Also, the least and highest for the progenies were IITA-TMS-IBA070593 and IITA-TMS-IBA180058 with 9.50µg/g and 19.21µg/g respectively.

Mean performance of the parental genotype shows that for fresh storage root yield, the parental genotype with highest value was IITA-TMS-IBA160011 with the value of 36.88tha^{-1} while the lowest being 1.88 tha^{-1} for IITA-TMS-IBA160141. For F1 population, across the months, the accession with the highest fresh storage root yield was the check IITA-TMS- IBA980581 with the value of 21.07 tha^{-1} and followed by accession IBA180244 with 20.98 tha^{-1} while the accession with lowest fresh yield value was IITA-TMS-IBA180231 with 2.37 tha^{-1} (Appendix II). Comparing the mean performance of the best performing progenies with their parental genotypes revealed that there is progress and improvement in some traits over the other (Table 4.7).

Root colour intensity distribution of the F_1 population shows that among the 42 accessions, 97.4% of the progenies had yellow root color, about 2.56% had deep yellow colour (Figure 9), compare to the parents where 83% had yellow pulp colour and 17% had cream colour (Figure 10).

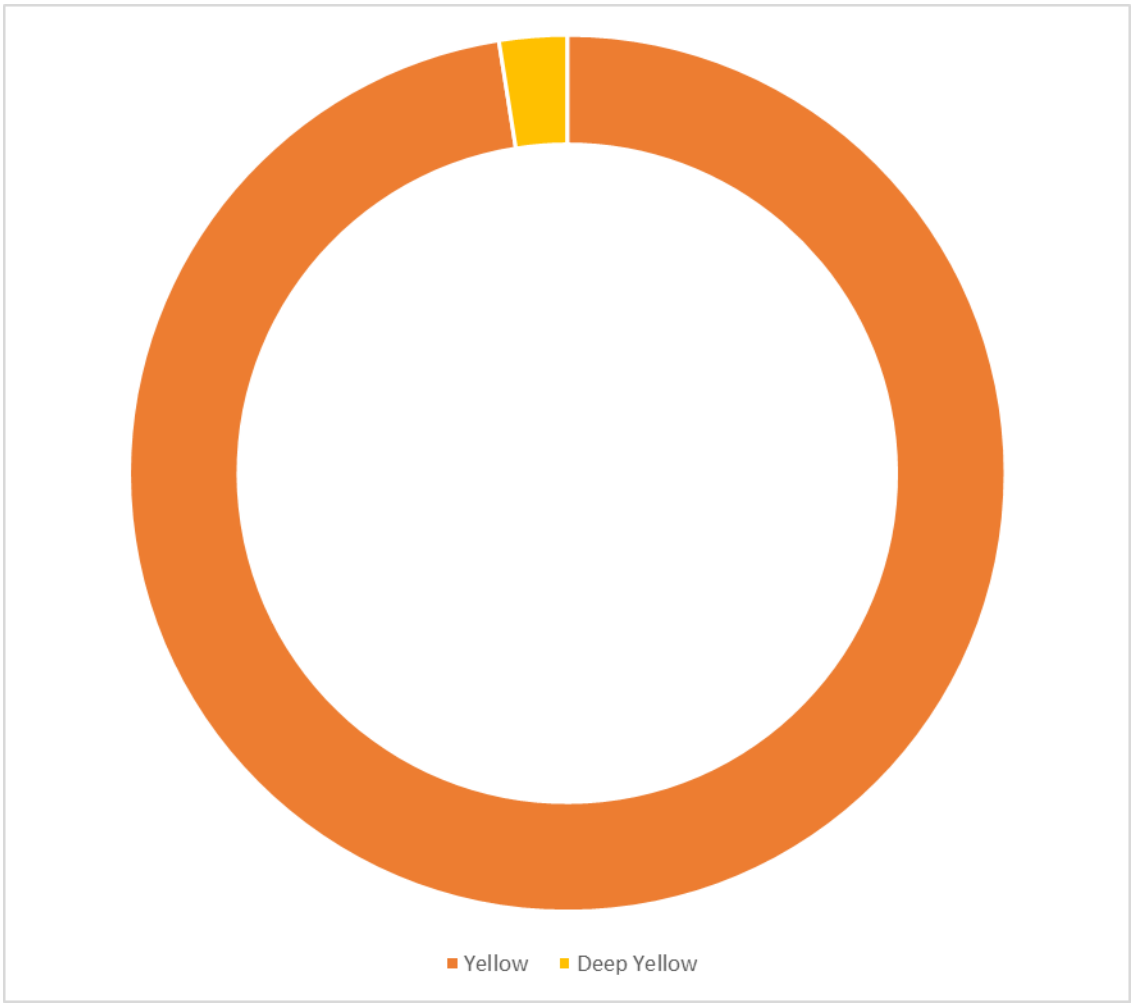


Figure 9: Colour intensity distribution of the evaluated progeny for carotenoids

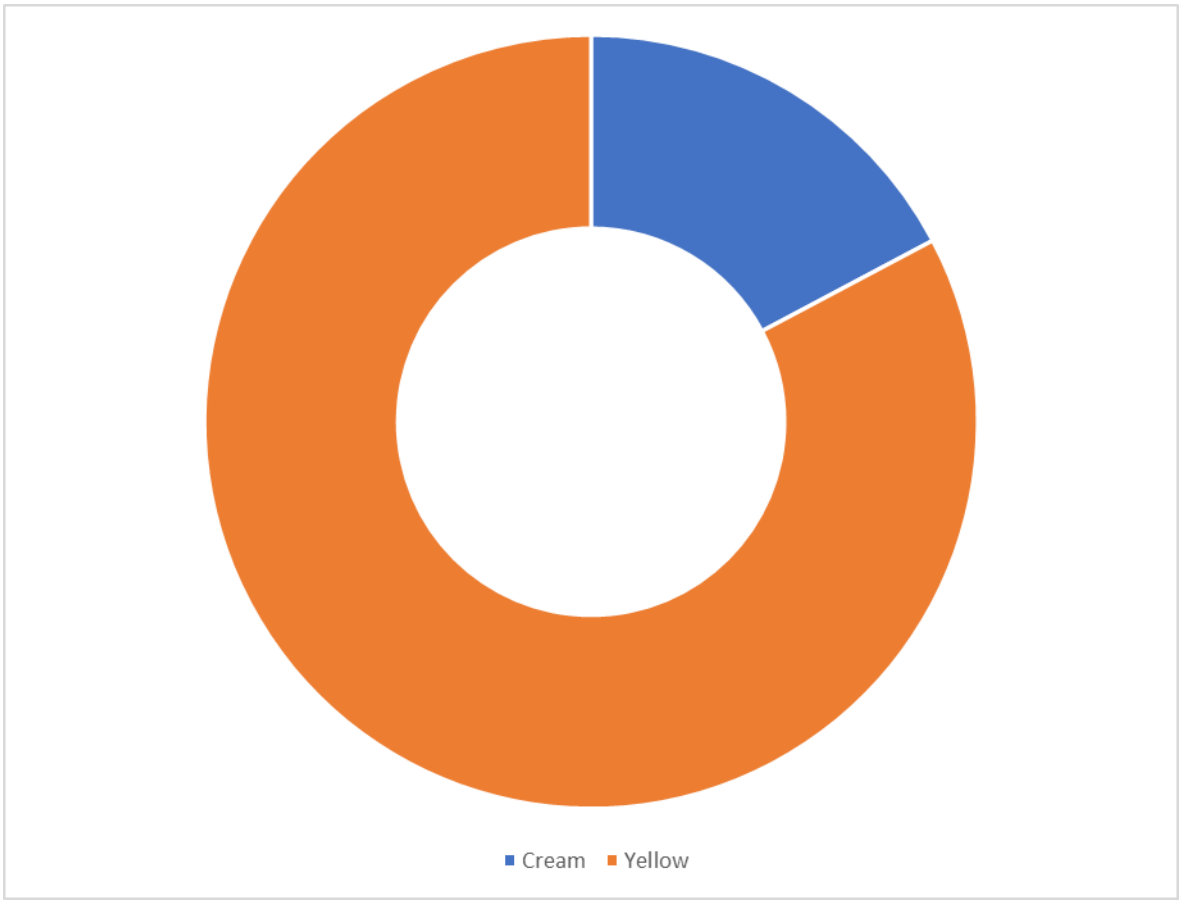


Figure 10: Colour intensity distribution of the parental genotypes evaluated for carotenoids

4.14. Improvement over Selection for traits in F1 Population in Relation to the Parents

The heritability of FYLD, RTWT, HI, RTSZ and DM of parents were higher for parents than the progenies while the heritability of TC for the progenies were higher than the parents as shown in table 4.7. The average mean performance of TC, RTSZ and SHTWT of progenies were higher than the parents while the average mean of FYLD, RTWT, HI and DM were higher for the parents than the progenies. The genetic advance of progenies was higher for DM, TC, RTSZ and SHTWT (Table 4.7).

4.15. Estimates of Genetic Parameter of F1 Progenies

The genotypic variance for the progenies ranges from 0.10 to 6699.33 with HI having the least and PLTHT with the highest. The phenotypic variance ranges from 0.38 to 9924.71 with root rot having the least and PLTHT having the highest. Environmental variance ranges from 0.21 to 3225.38 with root rot having the least environmental variance and PLTHT having the highest. The magnitude of phenotypic coefficient of variation (PCV) was not close to the genotypic coefficient of variation (GCV) for all the traits studied. The PCV ranges from 0.00 to 156.00 with number harvested having the least and root rot having the highest. PCV value ranges from of 0.00 to 149.00 with number harvested having the least magnitude and harvest index having the highest. Heritability estimates ranges from 0.00 to 138.52 with harvest index having the least value of 0 % and vigour having the highest Hb value of 84 % while the GA ranges from 0 to 138.52 with HI and PLTHT having the least value (0) and Highest value (138.52) respectively (Table 4.8)

Table 4.7: Improvements in the Genetic Advance and Broad Sense Heritability of Traits for Parents and Progeny for Yield Related and Total carotenoids Traits

Traits	Parents Hb(%)	Progeny Hb(%)	Parents GA	Progeny GA	Parental mean	Progeny mean
FYLD	0.37	0.11	5.35	4.17	17.68	10.36
RTWT	0.70	0.63	3.87	3.87	9.08	7.34
HI	0.80	0.00	0.02	0.02	0.37	0.30
DM	1.00	0.43	8.18	11.59	21.59	20.29
TC	1.00	0.82	3.61	19.45	13.79	14.26
RTSZ	0.00	0.00	0.00	3.40	3.97	4.04
SHTWT	1.00	0.48	10.64	14.64	4.95	13.32

Hb=Heritability, GA=Genetic advance, FYLD=fresh root yield, RTWT=root weight, HI=Harvest index, DM=dry matter content, TC=Total carotenoids content, RTSZ=root size, SHTWT=shoot weigh

Table 4.8: Estimates of genetic variation for the progeny

Traits	σ^2G	σ^2p	σ^2E	PCV	GCV	Hb	GA
Sprout	1.04	11.23	10.18	124.61	38.03	0.09	0.64
Vigour	6.34	7.46	1.13	62.51	24.26	0.84	4.78
PLTHT	6699.33	9924.71	3225.38	58.98	48.38	0.67	138.52
NOHAV	25.19	31.59	6.39	0.00	0.00	0.79	9.23
RTNO	666.74	890.16	223.43	136.03	117.23	0.74	46.03
RTWT	119.80	186.52	68.71	156.32	124.61	0.63	17.97
FYLD	36.27	32o.95	284.68	144.84	48.69	0.11	4.17
HI	0.10	76.77	108.97	230.77	149.45	0.00	0.00
SHTWT	103.20	210.92	107.72	108.99	76.23	0.48	14.64
RTROT	0.21	0.38	0.21	0.01	0.01	0.56	0.42
RTSZ	4.45	7.25	2.79	72.14	56.54	0.61	3.40
TC	107.84	130.45	22.61	85.95	78.15	0.82	19.45
DM	73.95	72.92	98.96	64.48	42.17	0.43	11.59

σ^2G= genotypic variance, σ^2p=phenotypic variance, σ^2E=environmental variance, PCV=phenotypic coefficient of variation, GCV=genotypic coefficient of variation, Hb=heritability variance, GA=genetic advance

4.16. Estimates of Genetic Parameter for the Parental Traits

The genotypic variance for the parental genotypes ranges from 0 to 68 with HI, sprout, RTINCOL, PLPCOL, RTSHP and RTSZ having the least while RTNO having the highest as shown in table 4.9. The phenotypic variance ranges from 0 to 70 with HI, SPROUT, RTINCOL, PLPCOL, RTSHP and RTSZ having the least and RTNO having the highest. There is slight difference between the genotypic and phenotypic variance and the Heritability magnitude ranges between 0 % for root size and sprout and 100 % for Dry matter and Dry root yield (DYLD). The GA ranges from 0 to 18.89 with RTNO having the highest value while RTSZ, PLPCOL and Sprout had the least.

The magnitude of Phenotypic Coefficient of Variation (PCV) was closer to the Genotypic Coefficient of Variation (GCV) for all the traits studied. The GCV ranges from 0% to 22% while PCV ranges from 0 % to 22 % for traits studied. Root Number (RTNO) had the highest GCV and PCV of 22 % followed by Dry matter (DM) of 13 % for both GCV and PCV. While the least PCV and GCV. Heritability ranges from 0 % (RTSZ, SPROUT) to 100 % (Tchart, RTOUTCOL, NoHAV, DYLD, RTWT, SHTWT, DM) (Table 4.9).

Table 4.9: Estimate of genetic variation for the parental genotypes

Traits	σ^2G	σ^2p	σ^2E	PCV	GCV	Hb	GA
DM	25.01	25.12	4	0.13	0.13	1	8.18
DYLD	5.16	5.18	0.83	0.06	0.06	1	1.69
FYLD	1.65	4.43	106.05	0.06	0.03	0.37	5.35
SHTWT	60.19	60.44	9.63	0.2	0.2	1	10.64
RTWT	1.81	2.57	29.04	0.04	0.04	0.7	3.87
NOHAV	4.64	4.66	0.74	0.06	0.06	1	1.68
RTNO	68.63	70.47	69.7	0.22	0.22	0.97	18.49
RTWT	1.76	1.77	0.28	0.03	0.03	1	0.84
TCHART	0.74	0.74	0.12	0.02	0.02	1	0.56
Tcichk	1.02	1.45	16.37	0.03	0.03	0.7	3.61

σ^2G= genotypic variance, σ^2p=phenotypic variance, σ^2E=environmental variance, PCV=phenotypic coefficient of variation, GCV=genotypic coefficient of variation, Hb=heritability variance, GA=genetic advance

4.17. Bulking Rate of Progenies Evaluated at 6, 9 and 12 MAP

In the bulking rate experiment at Ibadan, cassava accessions that yield over 60 % of their final root yield of 12 MAP at 6 MAP were regarded as early bulking, those that yield between 40 % and 59 % of their yield at 12 MAP at 6 MAP were regarded as mid bulking while those that yield between 0 % and 39 % of their yield of 12 MAP at 6 MAP were late bulking (Table 4.10).

The accessions IBA180294 and IBA180098 were early bulking based on their early bulking percentage at 6 MAP. These accessions had a higher bulking rate than the white checks (IBA980581, TMEB419 and TMEB693) and yellow check (IBA070593) which were late bulking. The accessions fall within the category of early bulking (EB), mid-bulking (MB) and late bulking (LB) with two (2), four (4) and thirty-six (36) accessions in the EB, MB and LB category respectively. At 9 MAP, genotype IBA18037 and IBA180180 bulked more than 90 % of 12MAP their final while accession that had bulking percentage more than 100 % had higher root yield at 9 MAP than at 12 MAP.

At 12 MAP, accession IBA180294 and IBA180098 which were the only accession in the early bulking category were not among the top 6 performing accessions in terms of yield at 12 MAP and across the months. The highest root yield at 12 MAP was recorded by IBA180210 with 38.03 t/ha above all the checks while across the months, genotype IBA180244 had the highest root yield of 26.33 t/ha. The top 6 performing accessions across the months and seasons were all in low bulking category (Table 4.10).

Table 4.10: Bulking rate of accessions at 6 months after planting (MAP) relative to final harvesting period at 12 MAP

	MAP	6	9	12	mean	Bulking rate at 6MAP	Bulking category	Bulking at 9MAP
Sno	Accession_name	FYLD						
1	IITA-TMS-IBA180022	6.05	11.63	22.10	13.26	27	LB	53
2	TMEB419(WChk)	4.38	7.00	16.08	9.15	27	LB	44
3	IITA-TMS-IBA180221	2.83	13.00	23.69	13.17	12	LB	55
4	IITA-TMS-IBA180148	3.55	7.50	28.42	13.16	12	LB	26
5	IITA-TMS-IBA180047	2.08	21.85	14.11	12.68	15	LB	155
6	IITA-TMS-IBA180064	3.45	16.13	14.78	11.45	23	LB	109
7	IITA-TMS-IBA180081	4.48	27.43	34.74	22.21	13	LB	79
8	IITA-TMS-IBA180037	8.25	18.03	18.30	14.86	45	MB	98
9	IITA-TMS-IBA180124	4.63	14.40	18.52	12.51	25	LB	78
10	IITA-TMS-IBA180071	3.85	9.50	30.62	14.66	13	LB	31
11	IITA-TMS-IBA180106	2.80	15.23	23.93	13.98	12	LB	64
12	IITA-TMS-IBA180271	2.20	3.48	10.71	5.46	21	LB	32
13	IITA-TMS-IBA180090	5.23	10.23	12.48	9.31	42	MB	82
14	IITA-TMS-IBA180084	3.20	5.38	13.64	7.40	23	LB	39
15	TMEB693(WChk)	3.53	10.83	26.06	13.47	14	LB	42
16	IITA-TMS-IBA180031	0.18	0.53	3.29	1.33	5	LB	16
17	IITA-TMS-IBA180034	2.15	15.08	18.09	11.77	12	LB	83
18	IITA-TMS-IBA180058	4.20	14.80	24.45	14.48	17	LB	61
19	IITA-TMS-IBA180244	6.03	15.93	33.17	18.37	18	LB	48
20	IITA-TMS-IBA070593(Ychk)	5.08	12.63	28.96	15.55	18	LB	44
21	IITA-TMS-IBA180259	2.98	9.45	5.48	5.97	54	MB	173
22	IITA-TMS-IBA180173	0.55	1.23	7.02	2.93	8	LB	17
23	IITA-TMS-IBA180231	0.28	17.98	10.98	9.74	3	LB	164
24	IITA-TMS-IBA180049	5.25	20.83	26.17	17.41	20	LB	80
25	IITA-TMS-IBA180294	2.70	10.95	2.85	5.50	95	EB	385
26	IITA-TMS-IBA180210	5.45	16.00	38.03	19.83	14	LB	42
27	IITA-TMS-IBA180146	2.28	47.50	29.23	26.33	8	LB	163
28	IITA-TMS-IBA180088	4.80	10.05	20.22	11.69	24	LB	50
29	IITA-TMS-IBA180070	1.70	22.00	6.59	10.10	26	LB	334
30	IITA-TMS-IBA180256	3.40	20.40	10.56	11.45	32	LB	193
31	IITA-TMS-IBA180017	5.25	11.25	37.59	18.03	14	LB	30
32	IITA-TMS-IBA180067	2.13	6.20	22.24	10.19	10	LB	28
33	IITA-TMS-IBA180098	7.43	5.35	11.54	8.11	64	EB	46
34	IITA-TMS-IBA180065	0.60	36.35	13.45	16.80	4	LB	270
35	IITA-TMS-IBA180051	4.43	5.23	14.09	7.91	31	LB	37
36	IITA-TMS-IBA180158	2.20	1.43	5.45	3.03	40	MB	26
37	IITA-TMS-IBA180182	3.40	18.10	26.10	15.87	13	LB	69
38	IITA-TMS-IBA980581(Wchk)	9.40	17.88	37.00	21.42	25	LB	48
39	IITA-TMS-IBA180018	0.30	13.05	4.26	5.87	7	LB	306
40	IITA-TMS-IBA180073	3.08	22.10	30.81	18.66	10	LB	72
41	IITA-TMS-IBA180180	2.38	13.65	14.26	10.09	17	LB	96
42	IITA-TMS-IBA180147	4.63	7.38	30.89	14.30	15	LB	24

Wchk=White check, Ychk=Yellow check, MAP-Months after planting, FYLD-Fresh storage root yield, EB-Early bulking, MB-mid-bulking, LB-late bulking

4.18. Bulking Rate Comparison Between the Two Experiments

The overall bulking rate experiment in Ibadan was similar to the bulking rate experiment in Mokwa and Ubiaja in that the early bulking genotype and accessions are within the same percentage range as shown in the table 4.11. In the bulking rate experiment in Mokwa and Ubiaja, the highest percentage range was 69 % (IBA141092) and the least was 22 % (IBA120016) while in the bulking rate experiment in Ibadan, the highest bulking rate was 95 % (IBA180294) and the least bulking rate was 3 % (IBA180231).

Table 4.11: Comparison of bulking rate of cassava accessions and genotypes in the two experiments.

	Bulking Rate (%)				
Experiment	Early Bulking (EB)	Mid-Bulking (MB)	Late bulking (LB)	Bulking Category EB (%)	Bulking Category LB (%)
At Ibadan	>60	35-59	0-34	95(IBA180294)	3 (IBA180231)
At Mokwa and Ubiaja	>60	35-59	0-34	69(IBA141092)	22 (IBA120016)

4.19. Performance of the Best Early Bulking Genotype in Bulking Rate Experiment At Mokwa and Ubiaja as a Parent in the Bulking Experiment at Ibadan.

Genotype IBA141092 as an early bulking genotype in the bulking rate experiment at Mokwa and Ubiaja, was used as a parent in different crossing combination at Ibadan (Table 4.12). And the BLUP values for the root yield of the progenies (accessions) shows that they were among the top 6 performing accessions in terms of their fresh root yield and were low bulking as shown in table 4.12.

4.20. Total Carotenoids, Dry Matter and Fresh Storage Root Yield relationship with Rainfall at Different Months After Planting (MAP)

Rainfall increased with months after planting (MAP). At 6 MAP, when there was no rainfall, the root yield was less than 5 t/ha. At 9 MAP, when rainfall was above 50 mm, the root yield increased and at 12 MAP when the rainfall increased to above 100 mm, the FYLD also increased as shown in the appendix X. Therefore, the fresh root yield (FYLD) increased with increase in rainfall.

At 6MAP (December), when there was no rainfall, Total Carotenoid (TC) content increased. As soon as rain started in the 9th month after planting (March), it declined and also reduced when the rainfall at 12MAP (June) peaked at close to 110mm. The TC content of the accessions showed that there is no difference among the progenies in terms of TC values. Therefore, selection could be made for any with higher BLUP values among the progenies.

Dry matter content of accessions was affected by rainfall similarly to total carotenoid content. Dry matter content increased when there was no rainfall at 6 MAP, declined at

9MAP when rainfall was starting. And increased again at 12 MAP when rainfall has fully established but the DM content was not as high as when there was no rainfall (Appendix XXIV).

4.21. Relationship of Yield, Yield Related Traits and Total Carotenoids across the Months and Year

The scatterplot as presented in Figure 11 shows that relationship between FYLD and HI are linear and positively correlated (R=0.19) and highly significant ($p<0.001$) (Figure 12). The scatterplot of FYLD was not strongly correlated with DM (R=0.10) and was highly significant ($p<0.001$). The scatter plot also shows that TC had no relationship with FYLD although some accessions had higher fresh root yield with higher TC (IBA180049, IBA180244, IBA180022). Fresh root yield was highly significant ($p<0.001$) with shoot weight and positively corelated (R=0.39). Scatterplot and Pearson correlation of Total carotenoids and Dry matter relationships shows that there was a low positive correlation (R=0.16) and a very significant relationship ($p<0.01$). Also, TC and DM relationship shows that TC increases with increase in DM and was highly significant($p<0.001$), however, there are some accessions that had their TC increased as their DM reduces (Figure 11).

Table 4.12: Genotypic Values for Fresh Root Yield of Top 10 Accessions based on Best Linear Unbiased Prediction across the Evaluated Months

Parents	Accession_Name	Bulking rate	BLUP	Mean(t/ha)
IBA160575XIBA160137	IITA-TMS-IBA180146	LB	5.04	26.38
IBA141092XIBA011371	IITA-TMS-IBA180081	LB	3.55	22.21
	IITA-TMS-IBA980581(WChk)	LB	3.27	21.42
IBA160075XIBA160063	IITA-TMS-IBA180210	LB	2.69	19.83
IBA141092XIBA011371	IITA-TMS-IBA180073	LB	2.27	18.66
IBA141096XIBA141092	IITA-TMS-IBA180244	LB	2.16	18.37

EB=Early bulking, MB=Mid-bulking, LB=late bulking, Wchk=White check

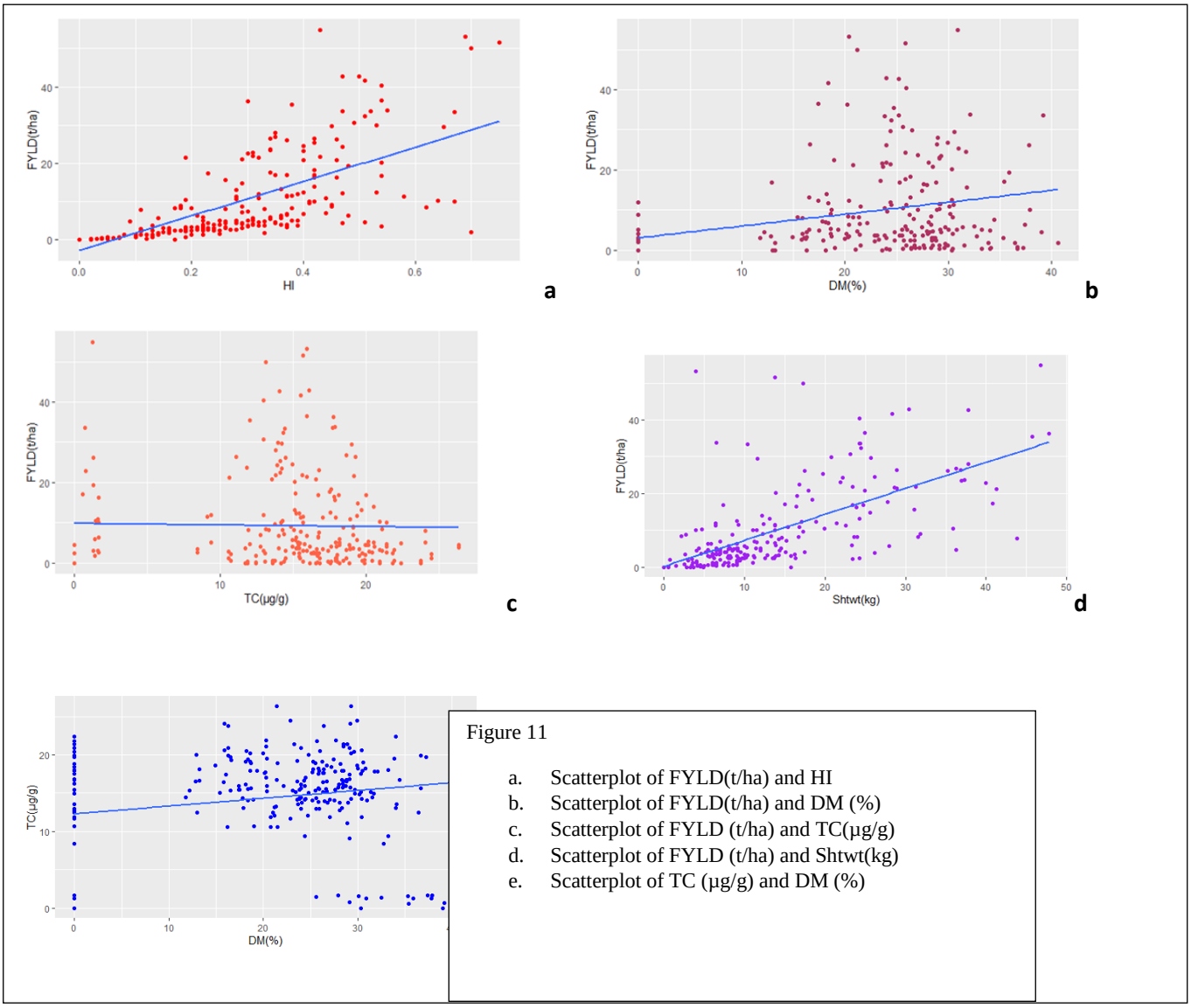


Figure 11

a. Scatterplot of FYLD(t/ha) and HI
b. Scatterplot of FYLD(t/ha) and DM (%)
c. Scatterplot of FYLD (t/ha) and TC(µg/g)
d. Scatterplot of FYLD (t/ha) and Shtwt(kg)
e. Scatterplot of TC (µg/g) and DM (%)

Figure 11: Scatterplot of relationship among different traits of fresh root yield (FYLD), harvest index (HI), dry matter (DM), shoot weight (SHTWT)

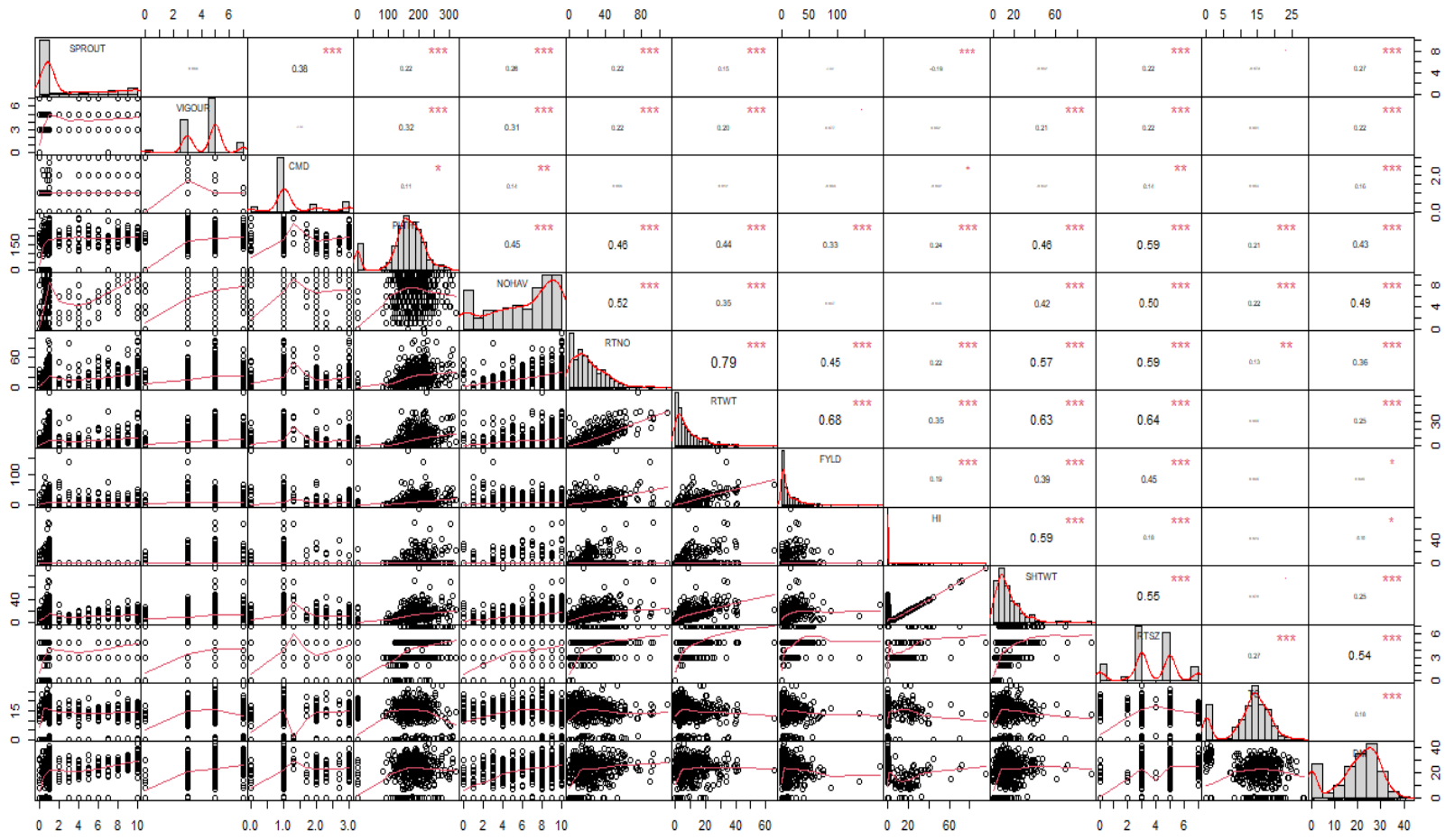


Figure 12: Pearson correlation of accessions evaluated for different traits across the months and year

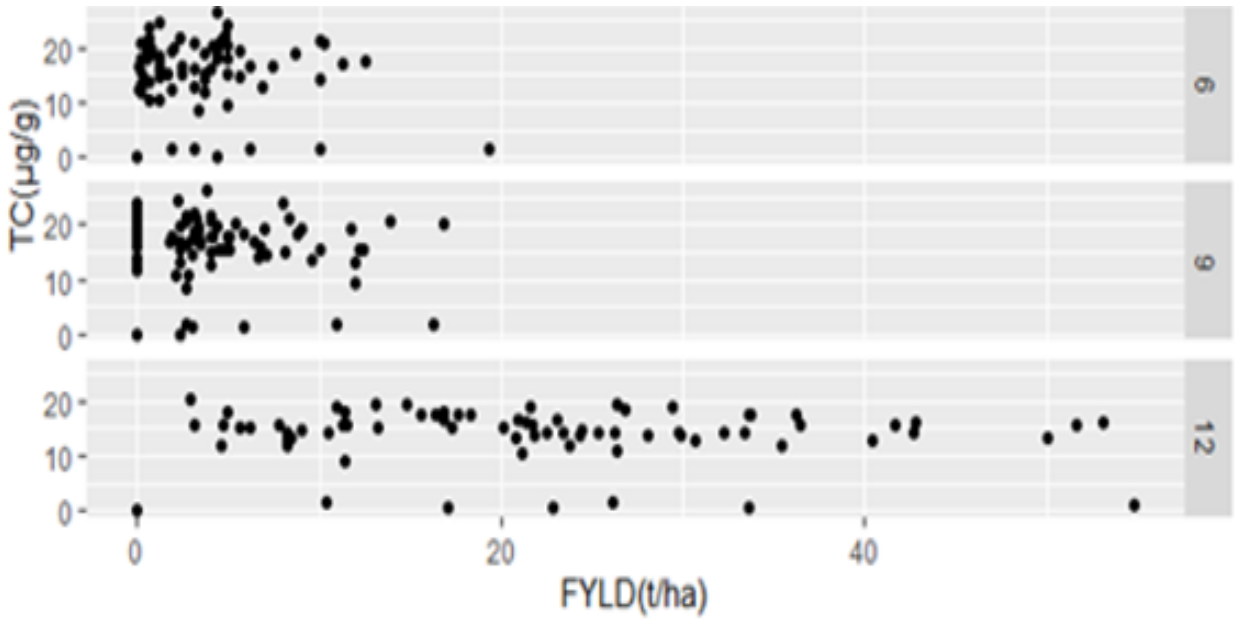
BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, TC=Total carotenoid, DM=Dry matter content.

4.22. Total Carotenoids and Yield-Related Traits Relationships

The progenies in this experiment were from crosses among high total carotenoid population. Majority of the accessions had higher root yield with reasonable higher total carotenoid contents. There is not much difference in the relationship of fresh root yield (FYLD) and Total Carotenoids (TC) at 6 and 9 MAP but the accessions increased in their relationship for these traits at 12 MAP as shown in figure 13. Total carotenoids reduced and their fresh root yield increased at 6 MAP and 9 MAP. At 12 MAP, accessions increased in their FYLD with reduction in their TC (for instance IBA180244 had TC of 9.73 µg/g with root yield of 33.17 t/ha, IBA180210 had TC of 10.86 µg/g with root yield of 38.03 t/ha, IBA180070 had TC of 17.07 µg/g with root yield of 6.59 t/ha, IBA180017 had TC of 14.70 µg/g with root yield of 37.59 t/ha while others (IBA180256 with TC of 10.23 µg/g and root yield of 10.56 t/ha, IBA180047 with TC of 14.12 µg/g and root yield of 14.11 t/ha and IBA180098 with TC of 11.86 µg/g and root yield of 11.54 t/ha) increased in TC as their FYLD increases. Most accessions' FYLD increased with TC throughout the evaluated months, however, some accessions increased in yield with no respective change or decrease in their TC. For the progenies, Fresh storage root yield and Total carotenoid relationship shows that FYLD increases with TC at 12MAP (Figure 13).

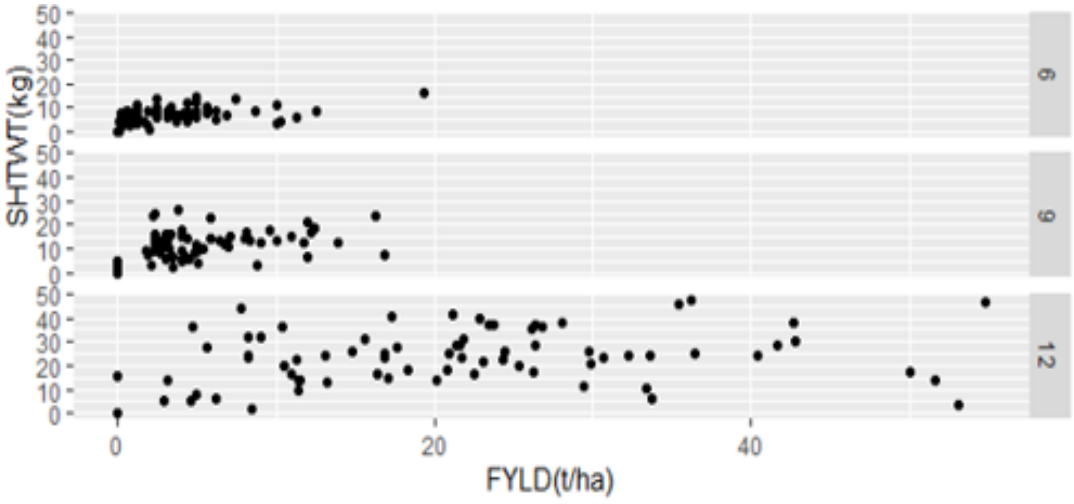
At 6 and 9MAP, the shoot weight increased with not much increase in the FYLD. At 12MAP, some accessions increased in shoot weight with increase in FYLD (IBA180047, IBA180106, white check TMEB693 and IBA980581, Yellow check IBA070593, IBA180058, IBA180088) while some accessions increased in shoot weight with

decreased in fresh root yield (IBA180210, IBA180146, IBA180173, IBA180244, IBA180071, IBA180081 and IBA180034) (Figure 14).



TC-Total Carotenoids, FYLD-Fresh Root Yield

Figure 13: FYLD and TC relationship of accessions evaluated at different months in Ibadan



SHTWT-Shoot weight, FYLD-Fresh Storage Root Yield

Figure 14: SHTWT and FYLD relationship of accessions evaluated at different months in Ibadan.

4.23. Colour Intensity Distribution of Accessions in Relations to their Total Carotenoid Chart

Total carotenoids increase with colour intensity (Figure 15). Almost all the accessions were yellow in colour with total carotenoid chart ranging from 2.5 to 6 with accessions IBA180037 having a deep yellow pulp colouration with total carotenoid chart of 4.5 (Figure 16).

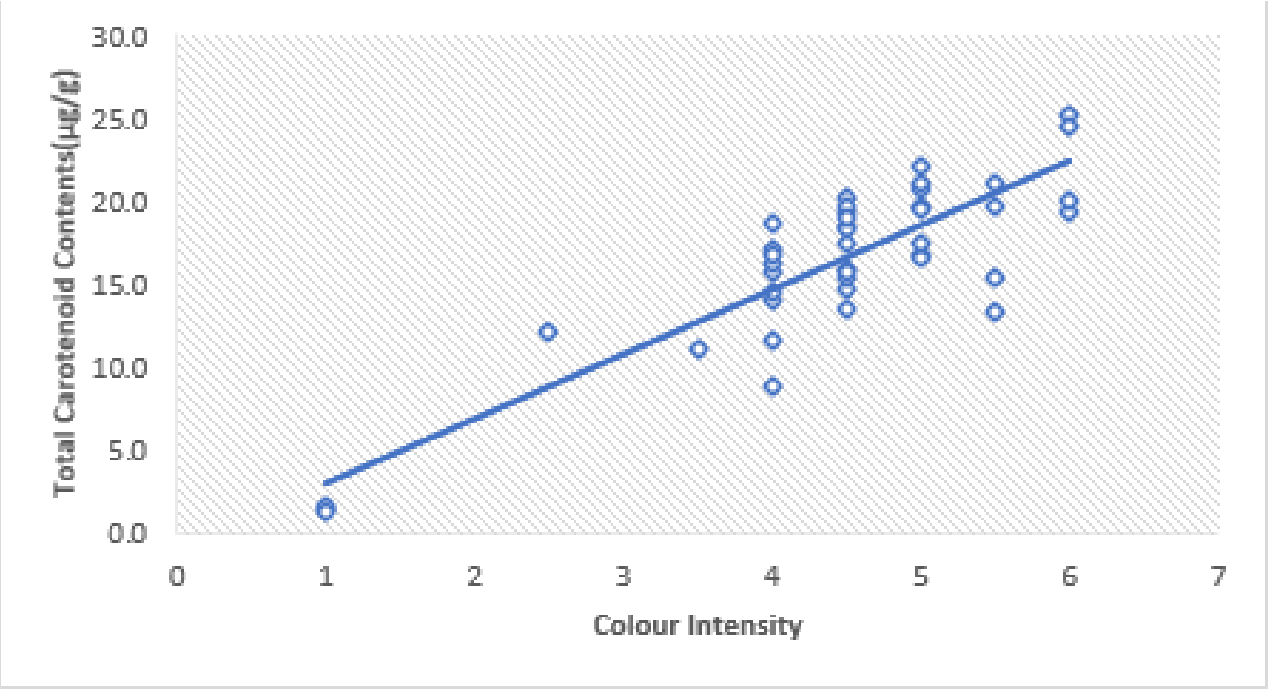


Figure 15: Relationship between Total Carotenoids and Colour Intensity

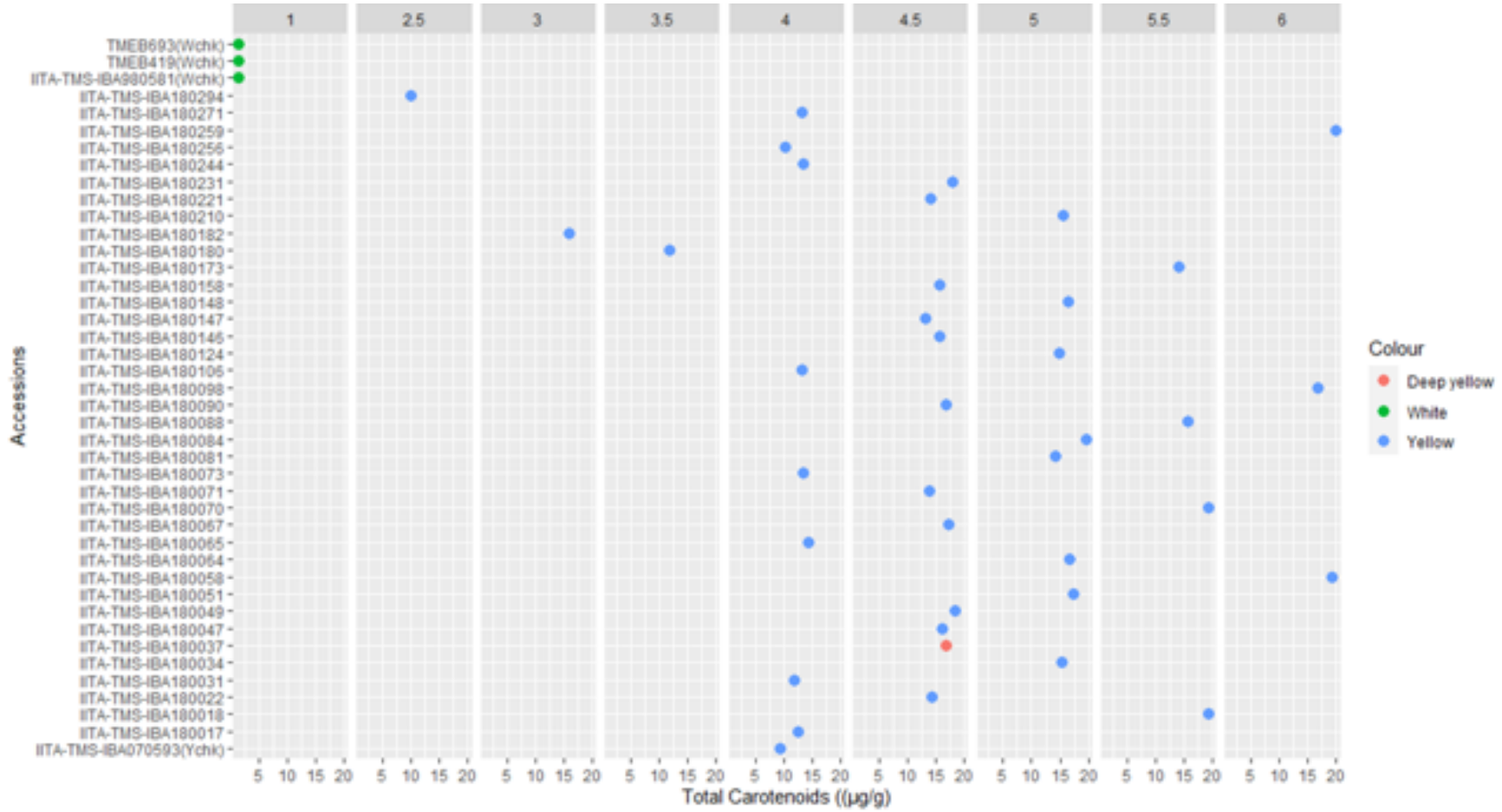


Figure 16: Accessions with their Total Carotenoid Chart and Colour Relationship

4.24. Total Carotenoids and Fresh Root Yield Relationship

There was variability among the accessions for total carotenoids and fresh root yield. Accessions were highly significant for total carotenoids ($p<0.001$). Some accessions had their root yield decreased with total carotenoid contents while some accessions' TC increased with yield increase and accession (Figure 17-17a).

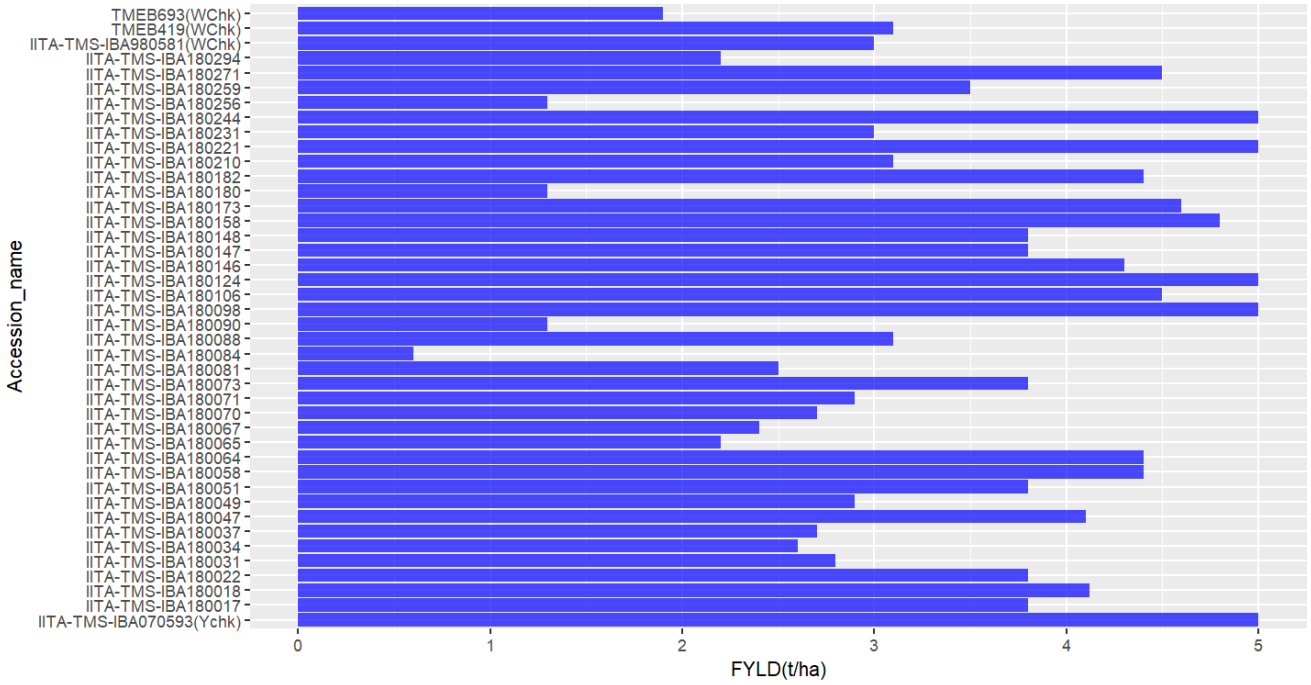


Figure 17: Fresh root yield among accessions

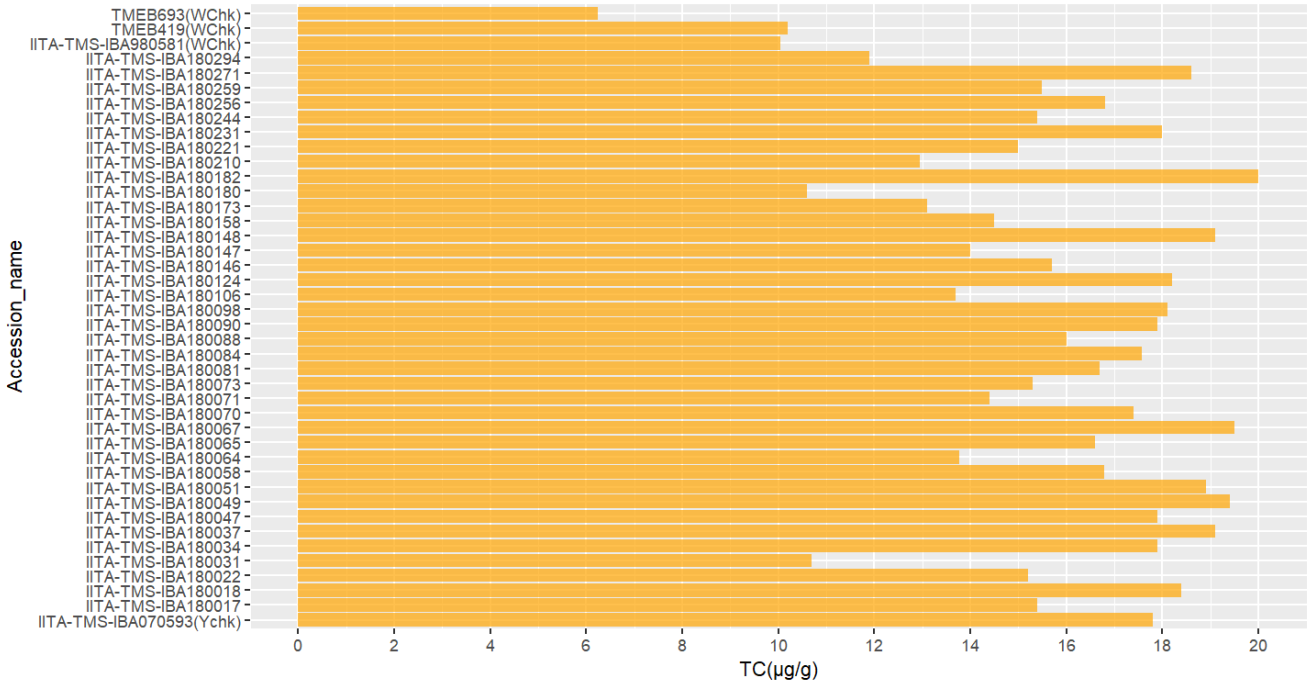


Figure 17a: Total carotenoids among accessions

4.25. Bulking Rate and Relationship with Total Carotenoids

Genotypes in the early bulking category of the bulking rate experiment at Mokwa and Ubiaja had their carotenoids ranging from 8.8 µg/g to 10.0 µg/g while in the bulking experiment at Ibadan, carotenoids of the accessions it ranges was between 0 µg/g and 16.45 µg/g. The mid-bulking category in the experiment at Mokwa and Ubiaja had their genotypes within the carotenoids ranges of 0 µg/g to 8.0 µg/g while at Ibadan, it ranges between 8.17 µg/g to 20.18 µg/g. The late bulking category of the genotypes at Mokwa and Ubiaja ranges between 0 µg/g to 9.2 µg/g while the accessions at Ibadan ranges between 7.01 µg/g (IBA180031) to 19.40 µg/g (IBA180058). This shows that the genotypes in the early bulking category of the bulking rate experiments at Mokwa and Ubiaja had higher carotenoids contents while accessions in the low-bulking category of the bulking experiments at Ibadan had higher carotenoids contents. Early bulking and total carotenoids vary with genotypes and environments (Appendices XVI and XVII).

4.26. Path Analysis of Evaluated Traits

There was no indirect effect associated with fresh storage root yield based on MAP and Seasons. The direct effects of four variables found to be associated with fresh storage root yield were dry matter, root number, root weight and plant height as presented in table 4.13. These four variables explained about 50.2 % of the total variation for fresh storage root yield (r^2=0.50). Root weight contributed the highest direct effect on root yield (P=1.51) while plant height contributed the least (P=0.028) while root number(P=-0.21) and dry matter (P=-0.18) had negative direct effect on root yield. Therefore, root

weight exerts the greatest direct effect on root yield and direct selection for both will greatly improve cassava root yield.

The path analysis diagram based on the effect of MAP, Seasons and fresh root yield on DM, SHTWT and TC shows that seasons negatively correlated and had a very significant effect ($p<0.001$) on TC. Months after planting positively correlated and had a very significant effect ($p<0.001$) on shoot weight. Month after planting had a very significant relationship with shoot weight and DM and while MAP negatively correlated with DM, shoot weight positively correlated. Seasons was positively correlated with shoot weight and was significant ($p<0.05$). Shoot weight affect fresh root yield and was highly significant and cropping seasons also had a highly significant relationship with fresh root yield (Figure 18).

Table 4.13: Calculated direct and indirect path effects for 42 cassava accessions

Direct effect (Path Coeff.) of DM on FYLD =	-0.18**
Direct effect (Path Coeff.) of Shtwt on FYLD =	0.04ns
Direct effect (Path Coeff.) of TC on FYLD=	0.05ns
Direct effect (Path Coeff.) of Rtno on FYLD=	-0.22***
Direct effect (Path Coeff.) of RTSZ on FYLD=	0.49ns
Direct effect (Path Coeff.) of Rtwt on FYLD=	1.52***
Direct effect (Path Coeff.) of Vigour on FYLD=	-0.67ns
Direct effect (Path Coeff.) of Pltht on FYLD=	0.03*
Direct effect (Path Coeff.) of Seasons on FYLD=	1.53
Total indirect effect=	0
R^2	0.5
Direct effect (Path Coeff.) of MAP on DM=	-0.08***
Direct effect (Path Coeff.) of MAP on Shtwt=	0.09***
Direct effect (Path Coeff.) of MAP on TC=	-0.03ns
Direct effect (Path Coeff.) of MAP on Rtno=	-0.036ns
Direct effect (Path Coeff.) of MAP on Shtwt=	0.09***
Direct effect (Path Coeff.) of MAP on Rtsz=-	-0.05ns
Direct effect (Path Coeff.) of MAP on TC=	-0.00ns
Direct effect (Path Coeff.) of MAP on Rtwt=	0.11***
Direct effect (Path Coeff.) of MAP on Vigour=	-0.01ns
Direct effect (Path Coeff.) of MAP on Pltht=	0
Direct effect (Path Coeff.) of MAP on HI=	0.01ns
Total indirect effect	0.01
R^2	0.33
Direct effect (Path Coeff.) of Seasons on DM=	-0.01**
Direct effect (Path Coeff.) of Seasons on Shtwt=	-0.02**
Direct effect (Path Coeff.) of Seasons on TC=	-0.02**
Direct effect (Path Coeff.) of Seasons on Rtno=	-0.01ns
Direct effect (Path Coeff.) of Seasons on Rtsz=	0.02ns
Direct effect (Path Coeff.) of Seasons on Rtwt=	0.01***
Direct effect (Path Coeff.) of Seasons on Vigour=	-0.03*
Direct effect (Path Coeff.) of Seasons on Pltht=	0.00***
Direct effect (Path Coeff.) of Seasons on HI=	0.02***
Direct effect (Path Coeff.) of Seasons on MAP=	-0.04***
Total indirect effect	0
R^2	0.33

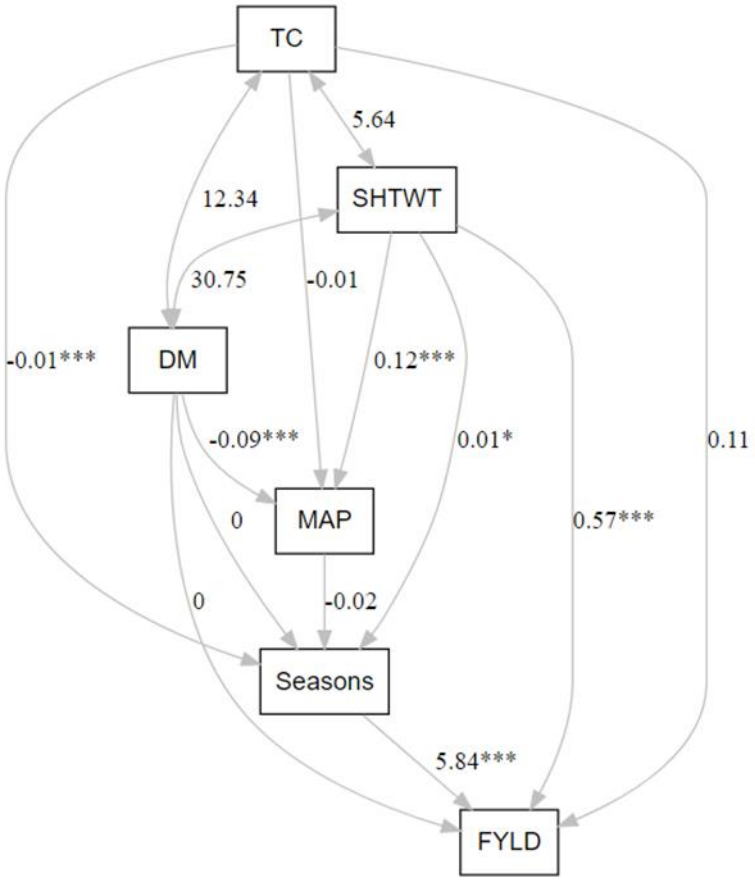


Figure 18: Path analysis of TC, DM, SHTWT and FYLD on MAP and cropping seasons

4.27. Experiment II: Bulking Rate of Genotypes and Selection for High Provitamin A Carotenoid Content (pVAC) at two agroecologies of Mokwa and Ubiaja.

4.27.1. Sources of variation and effects on traits and performance of genotypes based on the evaluated traits across locations and months.

The mean squares from combined analysis of genotypes evaluated for their attributes showed that genetic variability exists among the genotypes as results shows significant mean squares for some evaluated yield related traits as presented in table 4.14. Genotype effect was highly significant ($p<0.001$) on fresh storage root yield (FYLD), Harvest Index (HI), Branch height (Brnht), root size (Rtsz), inner skin colour (Inncol). Genotype effect was very significant ($p<0.01$) on Dry matter content, significant ($p<0.05$) for HI and non-significant on shoot weight (Shtwt), Number harvested (NoHav), root number (RtNo) and Root weight (Rtwt).

Months after planting was highly significant ($p<0.001$) on dry matter content (DMC), dry yield (Dyld), root size (RtSz), and very significant ($p<0.01$) on fresh storage root yield (FSRY) and HI (Harvest index). It was non-significant on harvest index (HI), branch height (Brnht), Shoot weight (Shtwt), Number harvested (Nohav), Root number (Rtno) and Root weight (Rtwt).

Genotype by months after planting was highly significant ($p<0.001$) for FSRY, HI, DYLD, RTSZ and very significant ($p<0.01$) for DMC and significant ($p<0.05$) for Shtwt, HI and β-carotene while it was non-significant for Brnht, Nohav, RTNO.

Effect of interaction of location, genotype and months after planting were highly significant for Nohav and Rtwt, It was very significant for Rtno and significant for FSRY while it was non-significant for DMC, Brnht, Dyld, Rtsz (Table 4.14).

4.27.2. Performance of genotypes based on the evaluated traits across location and MAP

Fresh Storage Root Yield

Fresh storage root yield (FSRY) was significant at $p<0.01$. The highest fresh storage root yield was recorded by genotype IKN120036 with 3.56 t/ha followed by IBA090581 with yield of 3.41t/ha which were above the mean yield value of 2.35 t/ha and above the performance of the checks used in the study. The least was recorded by IBA130818 with 0.72 t/ha which is below the mean yield average (Table 4.14).

Dry Matter

Dry matter content (DMC) was non-significant across location. The check TMEB419 recorded the highest dry matter content value of 39.78 % followed by genotype IBA090525 with dry matter content of 36.89 % above the mean dry matter content of 31.72 %. The least dry matter content was recorded by IBA141092 with dry matter content of 20.82 % (Table 4.14).

Height at Apical Branching

The height at first apical branching was highly significant ($p<0.001$) for all the genotypes. And it was highest for TMEB419 with 3.00 cm while the least was recorded by IKN120036 and IBA130818 with 1.00 cm, respectively (Table 4.14).

Dry Yield

Dry yield was highly significant for all the genotypes ($p<0.001$). And genotype IBA090581 recorded the highest value of 1.09 t/ha while the least value of 0.18 t/ha was recorded by IBA130818 (Table 4.14)

Shoot Weight

Shoot weight (Shtwt) was not significant across location. The highest shoot weight of 4.98 kg was recorded by genotype IKN120016 followed by IBA130896 with 4.89 kg above the mean average of 3.74 kg. The least shoot weight of 2.23 kg was recorded by genotype IBA090525 (Table 4.14).

Number of Plant Harvested

The number of plants harvested was very significant ($p<0.001$) for the genotypes and the check IBA980581 recorded the highest number of plants harvested of 2.50 followed by genotype IBA090525 and IBA090581 with 2.33 above the average performance of 2.05. Genotype IKN120036 recorded the least number of roots harvested with 1.67 (Table 4.14).

Root Number

Root number was very significant for all the genotypes ($p<0.01$) and all the checks had higher harvested root numbers compare to other genotypes. The check IBA980581 had the highest root number of 12.00, followed by the check TMEB419 and the yellow check IBA070593 recorded 10.83 which were above the mean of 10.12. Also, among the

genotypes, genotype IBA090525 and IBA141092 each recorded 10.50 respectively. The least root number was recorded by IBA130818 with 7.67 (Table 4.14).

Root Size

There was no statistically significant difference among the genotypes for root size traits. However, the highest root size was recorded by genotype IKN120036 (Table 4.14).

Root Weight

Root weight (Rtwt) was not significant across location and genotype IKN120036 recorded the highest root weight of 3.28 kg followed by IBA141092 with 2.94 above the average mean of 2.30 kg. The least root weight was recorded by genotype IBA130818 with 0.55 kg (Table 4.14).

Beta Carotene Content

The highest beta carotenoid content of 10.02 µg/g was recorded by genotype IBA141092, followed by genotype IBA130896 with beta carotenoid content of 9.20 µg/g while the least was recorded by check genotype IBA980581 with beta carotenoid content of 1.83 µg/g (Table 4.14).

Harvest Index

Harvest Index (HI) was significant at $p<0.005$. Genotype IBA141092 had highest harvest index of 0.60 followed by IKN120036 with harvest index value of 0.54 above the mean value of 0.39. The least harvest index was recorded by IBA130818 with 0.11 (Table 4.14).

Table 4.14: Mean Squares from Combined Analysis of Variance for Evaluated Traits at different Months and Location.

Source of Variation	DF	FSRY	DMC	Brnht	Dyld	Shtwt	NoHav	RtNo	RtSz	RtWt	B-carot	HI
Genotype	9.00	4.03***	27.49**	0.59***	0.004***	13.59ns	4ns	19.75ns	4.30***	8.40ns	0.20*	2.00*
MAP	2.00	0.58**	1.0***	2.09ns	2.19***	3.60ns	3.54ns	20.07ns	0.61***	8.56ns	0.26*	0.30**
GenxMAP	27.00	0.86***	29.85**	0.00ns	1.00***	42.24*	0.00ns	41.55ns	0.61***	26.89*	0.00ns	0.37***
Location	1.00	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0ns	0.00ns	0.00ns
Rep (Location)	2.00	0.14ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.09ns	0ns	0.00ns	0.00ns
LocationxGenotype	9.00	0.04ns	2.30ns	0.00ns	0.00ns	0.54ns	0.00ns	6.79ns	0.00ns	0ns	0.00ns	0.00ns
LocationxMAP	3.00	3.26ns	65.94ns	0.00ns	0.55ns	392.29ns	11.34ns	387.78ns	0.84ns	167.71ns	0.00ns	0.00ns
LocationxGenxMAP	27.00	0.24*	3.96ns	0.00ns	0.05ns	56.7*	2.03***	71.80**	0.00ns	41.33***	000ns	0.00ns
Pooled error	54.00	0.57	13.9	0.10	0.06	46.84	1.2	52.54	0.40	13.77	0.01	0.00

*, **, ***=Significant at P< 0.05, 0.01 and 0. 001respectively.Sprt=Sprout. ns=non-Significant, DF-Degree of freedom, FSRY- Fresh storage root yield, DMC-Dry matter content, Brnht-Height at first apical branching, Dyld-Dried root yield, Shtwt-Shoot weight, NoHav-Number of plants harvested, RtNo-Root number, RtSz-Root size, RtWt-Root weight, B-Carot-Beta carotene, HI-Harvest index.

4.28. Best Linear Unbiased Estimate (BLUE) of evaluated traits across the months and location.

The best linear unbiased estimates for the traits at Mokwa and Ubiaja shows that sprout, vigour, Brnht, HI and DM were highly significant ($p<0.001$) and very significant for Fyld, Nohav, Rtno($p<0.01$) and was significant for Rtwt ($p<0.05$) and was non-significant for shoot weight (Table 4.15).

Table 4.15: Best linear unbiased estimates (BLUE) for traits evaluated across the months and year

Traits	BLUE	Pvalue
FSRY	3.14**	0.01
SPROUT	1.00***	0.00
VIGOR	6.33***	0.00
BRNHT	3.00***	0.00
SHTWT	14.56ns	0.10
NoHAV	4.17**	0.01
RTNO	28.04**	0.01
RTWT	12.14*	0.05
HI	0.42***	0.00
DM	36.67***	0.00

*, **, ***=Significant at P< 0.05, 0.01 and 0. 001respectively, ns=non-Significant, FSRY-Fresh root yield, BRNHT- First apical branch height, SHTWT- Shoot weight, NoHAV- Number of plant harvested, RTNO-Root number, RTWT-Root weight, HI-Harvest Index, DM-Dry matter

4.29. Variability in the Best Linear Unbiased Estimates (BLUE) Values Based on Different Evaluated Traits for Cassava Accessions Across the Months and Locations.

Genotypes IBA070593(c), IBA090525, IBA141092, IBA980581 (c) and TMEB419 (c) recorded the highest BLUE values for first apical branch height (BRNHT) above the mean of 2.07 as they have similar mean values as shown in table 4.16.

Genotypes IBA090525, IBA130896, IBA980581 (c), IKN120016 and TMEB419 (c) recorded the highest value for dry matter with their values above the mean value of 31.82 % (Table 4.17). Genotypes IBA090525, IBA090581, IBA130896, IBA980581(c), IKN120036 and TMEB419(c) had the highest values for dry yield (DYLD) above the mean values of 0.74 t/ha.

For fresh root yield (FSRY), genotypes IBA090581, IBA141092, IBA980581(c), IKN120036 and TMEB419(c) recorded the highest values as they have similar BLUE values above the mean value of 2.35t/ha. BLUE values were highest for genotypes IBA090525, IBA090581, IBA141092, IKN120036 and TMEB419 (c) in terms of harvest index (HI) as they have similar means above the mean values of 0.39.

In terms of number of plants harvested (NOHAV), genotypes IBA090525, IBA090581, IBA130818, IBA141092, IBA980581(c) and TMEB419(c) had the highest BLUE values above the mean values of 2.05. The highest BLUE values were recorded by genotypes IBA070593(c). IBA090525, IBA090581, IBA141092, IBA980581(c), and TMEB419(c) for root number (RTNO) with their mean above the mean values of 10.12.

For root size (RTSZ), genotype IKN120036 had the highest BLUE values of 4.33 cm above the mean value of 3.13cm. Genotypes IBA090581, IBA141092, IKN120016 and

IKN120036 recorded the highest BLUE values for root weight (RTWT)with their values above the mean value of 2.30.

There was no significant difference among the genotypes for shoot weight and genotypes IBA090525, IBA090581 and IBA130818, IBA141092, IBA980581 (c), IKN120016 and TMEB419(c) recorded the highest BLUE values for sprout above the mean values of 0.79.

BLUE values for storage root diameter (SRD) were highest for genotypes IBA090525, IBA090581, IBA130896, IBA141092, IBA980581 (c), IKN120036 and TMEB419(c) with values above the mean values of 10.87 cm.

Genotypes IBA090525, IBA980581(c) and TMEB419(c) had the highest BLUE values for starch with values above the mean value of 18.07 %. Total carotenoid chart (Tchart) for genotypes IBA130818, IBA130896, IBA141092, IKN120016 and IKN120036 recorded the highest BLUE values above the mean values of 2.70.

Genotypes IBA090525, IBA090581, IBA130818, IBA130896, IBA980581(c) and TMEB419(C) had the highest BLUE values for Vigour with their values above the mean value of 4.93. Genotypes IBA141092 and IBA130896 had the highest BLUE values of 10.02 µg/g and 9.20 µg/g respectively above the mean values of 6.29 µg/g (Table 4.16).

Table 4.16: Genotypes and their Best Linear Unbiased Estimates (BLUE) based on different Evaluated Traits and their Beta carotenoids Contents across Locations.

GEN	BRNHT(cm)	DM(%)	DYLD(t/ha)	FSRY(t/ha)	HI	NOHAV	RTNO	RTSZ(cm)	RTWT(kg)	SHTWT(kg)	SPROUT	SRD(cm)	STARCH	TCHART	VIGOR	β-Carot(µg/g)
IBA070593(C)	3.00a	30.16ab	0.61ab	2.04b	0.33b	1.83b	10.83a	3.00ab	1.73ab	3.83ns	0.47ab	9.83ab	15.6bc	3.00ab	3.00c	8.82ab
IBA090525	2.67a	36.89a	0.86a	2.34b	0.51a	2.33a	10.5a	3.00ab	2.26ab	2.23ns	1.00a	11.33a	23.95a	1.00c	6.33a	4.91bc
IBA090581	2.00ab	32.03ab	1.09a	3.41a	0.48a	2.33a	10.83a	3.00ab	3.51a	3.61ns	0.90a	11.5a	18.43ab	2.00ab	5.67a	6.47ab
IBA130818	1.00ab	24.62c	0.18c	0.72c	0.11c	2.00a	7.67b	3.00ab	0.55bc	4.20ns	1.00a	8.33ab	9.98c	3.67a	5.00a	3.96bc
IBA130896	1.33ab	35.06a	0.82a	2.39b	0.31b	1.83b	9.83ab	3.00ab	2.32ab	4.89ns	0.57ab	10.83a	21.93ab	3.67a	5.00a	9.20a
IBA141092	2.33a	20.82c	0.55b	2.70a	0.60a	2.00a	10.50a	3.00ab	2.94a	3.18ns	0.90a	12.83a	5.86c	4.00a	3.67c	10.02a
IBA980581(C)	2.67a	36.26a	0.88a	2.44a	0.39b	2.50a	12.00a	3.00ab	2.72ab	4.23ns	0.87a	13.83a	23.17a	1.00c	5.67a	1.83c
IKN120016	1.67ab	34.55a	0.49b	1.42bc	0.21bc	1.83b	9.17ab	3.00ab	1.24a	4.98ns	0.73a	7.5ab	21.3ab	4.00a	4.33ab	5.94ab
IKN120036	1.00ab	28.00ab	0.98a	3.56a	0.54a	1.67b	9.00ab	4.33a	3.28a	2.73ns	0.43ab	12.00a	13.19bc	3.67a	4.33ab	7.97ab
TMEB419(C)	3.00a	39.78a	0.97a	2.45a	0.41a	2.17a	10.83a	3.00ab	2.46ab	3.50ns	1.00a	10.67a	27.3a	1.00c	6.33a	3.8bc
Mean	2.07	31.82	0.74	2.35	0.39	2.05	10.12	3.13	2.30	3.74	0.79	10.87	18.07	2.70	4.93	6.29
SE±	0.15	2.82	0.18	0.42	0.04	0.70	1.51	0.13	0.50	0.77	0.07	0.75	3.27	0.12	0.48	0.85
CV	0.99	0.12	0.32	0.20	0.12	0.19	0.21	0.60	0.26	0.29	0.12	0.08	0.24	0.06	0.13	0.42

Mean with same letters are not different from each other, SE=standard error, CV=coefficient of variation, Mean separated with Tukey HSD.

4.30. Performance of Storage Root Diameter (SRD), Harvest Index (HI), Fresh Storage Root Yield (FSRY), Dry Matter Content (DMC) and their Beta Carotenoid Content at Mokwa and Ubiaja.

There was no significant difference for traits evaluated among genotypes across locations (Table 4.17). Storage root Diameter was highest for IBA980581 (20.17 cm) followed by IKN120036 (18.58 cm) and the least was recorded by IBA070593 (11.50 cm) at Mokwa while at Ubiaja, IBA980581 (21.58 cm) had the highest SRD followed by IBA090581(17.23) while the least was recorded by IBA130818 (10.83 cm).

At Mokwa, harvest Index was highest for IBA141092 (0.56) and genotype IBA130818 (0.12) recorded the least while genotypes IBA141092 and IBA130818 had 0.54 and 0.12 respectively at Ubiaja.

Fresh Storage Root Yield was highest for the genotype IKN120036 (4.23 t/ha) and genotype IBA130818 recorded the lowest fresh yield at Mokwa while at Ubiaja, same genotype IKN120036 (4.81) and IBA130818 (1.03) recorded the highest and lowest yield respectively.

Genotype IBA090525 and TMEB419 had the highest dry matter content percentage of 35.89 % at Mokwa followed by genotype IBA130896 with 32.12 % and the least was recorded by IBA141092 (24.43 %) at Mokwa while at Ubiaja, TMEB419 had the highest dry matter content percentage of 37.47 % followed by genotype IBA090581 (34.69 %) and the least Dry matter content percentage was recorded by IBA141092 (20.74 %).

Beta Carotenoid content was highest for IBA130896 with 8.65 µg/g followed by IBA141092 with 7.75 µg/g at Mokwa while genotype IBA141092 recorded the highest beta carotenoid content of 12.29 µg/g at Ubiaja followed by genotype IBA130896 with

beta carotenoid content of 9.76 µg/g Storage root diameter across locations for all the genotypes correspondingly increases with dry matter content. And Dry matter content (DMC) increased with fresh storage root yield (Table 4.17).

Table 4.17: Performance of Genotypes Based on Storage Root Diameter, Harvest Index, Fresh storage root yield, Dry matter, and Beta-Carotenoid at Mokwa and Ubiaja.

C=check, β-carot=beta-carotene, SRD-storage root diameter, HI-Harvest index, FYLD-fresh storage root yield, DM- dry matter

Location	Mokwa	Ubiaja	Mokwa	Ubiaja	Mokwa	Ubiaja	Mokwa	Ubiaja	Mokwa	Ubiaja
Traits Genotypes	SRD(cm)	SRD(cm)	HI	HI	FYLD(t/ha)	FYLD(t/ha)	DM(%)	DM(%)	β-Carot(µg/g)	β-Carot(µg/g)
IBA070593(C)	11.5	12.33	0.36	0.28	1.89	1.83	29.86	27.27	7.85	9.8
IBA090525	15.88	16.44	0.47	0.43	2.96	2.79	35.89	32.54	5.11	4.72
IBA090581	16.75	17.25	0.45	0.39	4.13	4.57	28.61	34.69	6.43	6.51
IBA130818	11.58	10.83	0.12	0.12	1.21	1.03	25.17	23.96	4.02	3.89
IBA130896	17.33	16.42	0.33	0.33	3.74	4.03	32.12	30.57	8.65	9.76
IBA141092	14.55	14.17	0.56	0.54	3.04	2.35	24.43	20.74	7.75	12.29
IBA980581(C)	20.17	21.58	0.35	0.33	3.86	4.04	31.85	32.27	0	3.65
IKN120016	13.25	12.08	0.29	0.25	1.83	3.14	31.69	30.31	7.87	4
IKN120036	18.58	16.17	0.54	0.46	4.23	4.81	26.31	28.84	8	7.94
TMEB419(C)	16.75	16.67	0.42	0.41	2.99	3.3	35.89	37.47	0	3.79

4.31. Trends of Fresh Storage Root Yield Performance at Different Months of Evaluation Across Locations.

Genotypes were significant for fresh storage root yield traits at different months and across the months. Genotype IKN120036 was the highest in terms of FSRY at 3 months after planting (MAP) followed by IBA141092 while genotype IBA130818 had the lowest FSRY at the same month as shown in figure 19. At 6 MAP, genotype IKN120036 still maintained having the highest yield at 3 MAP followed by IBA 090581 while genotype IBA130818 still had the lowest FSRY, at 9 MAP, TMEB419 had the highest yield followed by IKN120036 and IBA980581 while the least was recorded by genotype IBA130818 and at 12 MAP, genotype IBA090581 recorded the highest yield followed by IBA130896 while the least was recorded by IBA130818 (Figure 19).

Fresh storage root yield of genotype IBA130818 and IKN120036 increased after 3 MAP. Genotype IBA130818 among other genotypes increased from 3MAP to 12 MAP across the months while genotype IKN120036 unlike IBA130818 decreased at 9 MAP and increased at 12 MAP as presented in the table 4.19. For all genotypes, it is either FSRY decreases after 3MAP or there was little or no increase until 12 MAP.

Across the months, IKN120036 was the highest performing genotype in terms of yield (4.52t/ha), followed by IBA090581(4.35 t/ha). And the least performing genotype is IBA130818 (1.12 t/ha). The breeding value was also highest for IKN120036 (3.36) followed by IBA090581 (3.23).

At 12^{th} month, genotype IBA090581 (9.0t/ha) recorded the highest, followed by IBA130896 and IBA980581 with 8.4 t/ha respectively (Figure 19).

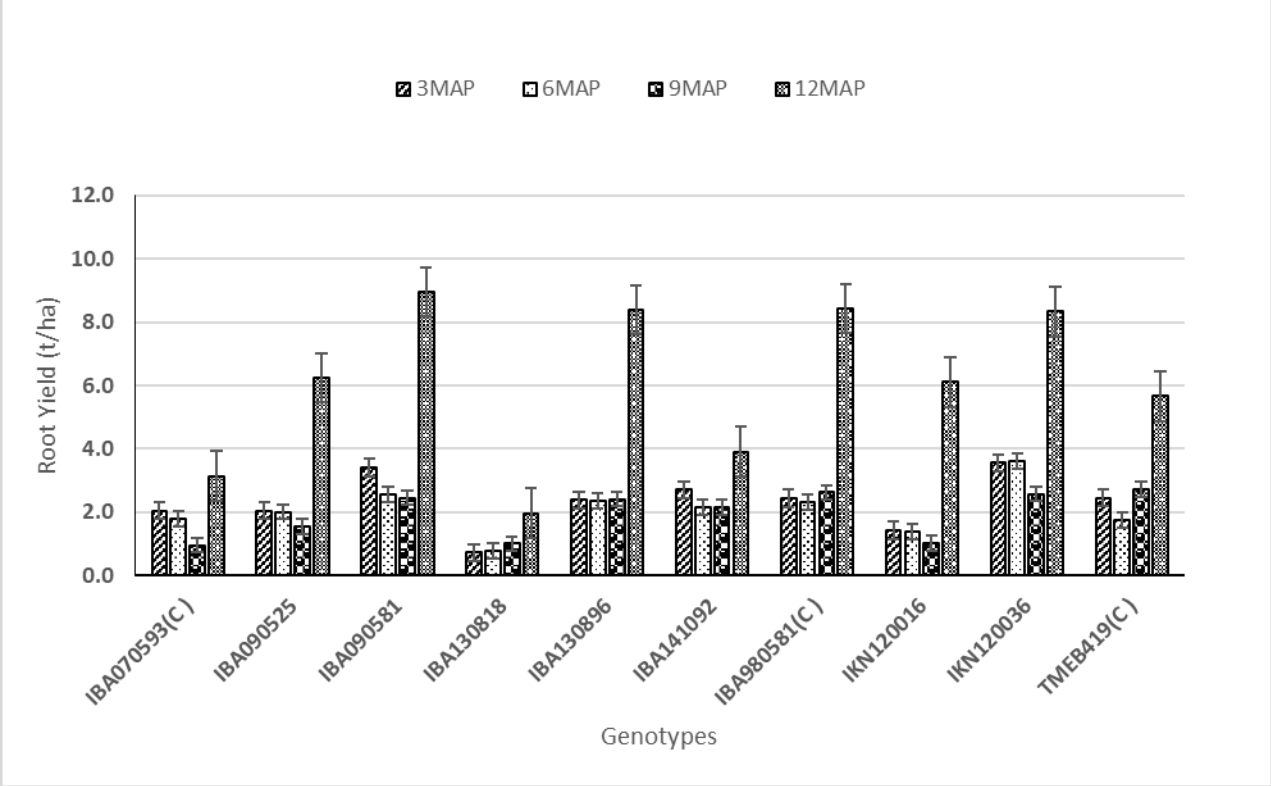


Figure 19: Performance of different Genotypes Evaluated at different Months and Locations

4.32. Best Performing Genotypes in Terms of Fresh Root Yield and β-carotenoids Across Months and Locations.

Genotypes were statistically significant for root yield and their β-carotenoid contents. The best performing genotype in terms of root yield is the genotype IKN120036, followed by IBA090581 and IBA980581(c) while the least performing was genotype IBA130818 as shown in table 4.18. This further revealed that most of the genotypes attained highest yield at 12 months after planting. In terms of beta carotenoids, genotype IBA141092 had the highest beta carotenoid content of 10 µg/g followed by genotype IBA130896 with beta carotenoid content of 9.2 µg/g while the least beta carotenoid content was recorded by the white checks TMEB419 and IBA980581. The top three beta carotenoid genotypes were early and mid-bulking while the least was mid bulking (Table 4.18).

Table 4.18: Fresh storage root yield of genotypes at different evaluated months and their Beta-carotene content.

MAP	FSRY(t/ha) 3	6	9	12	mean	Breeding Value	β-Carotene	Bulkiness
Genotype								
IBA070593(C)	2.00^{bc}	1.80^{bc}	1.00bc	3.10^{cd}	1.98^{bc}	2.09	8.80^{a}	EB
IBA090525	2.00^{bc}	2.00^{bc}	1.50a	6.20^{ab}	2.96b	2.34	4.90^{bc}	LB
IBA090581	3.40^{a}	2.60^{a}	2.50a	9.00^{a}	4.35^{a}	3.23	6.50^{b}	MB
IBA130818	0.70^{c}	0.80^{c}	1.00bc	2.00^{d}	1.12^{c}	1	4.00^{bc}	MB
IBA130896	2.40^{bc}	2.30^{bc}	2.40a	8.40^{a}	3.88^{ab}	2.38	9.20^{a}	LB
IBA141092	2.70^{a}	2.20^{bc}	2.10a	3.90^{cd}	2.73^{b}	2.64	10.00^{a}	EB
IBA980581(C)	2.40^{b}	2.30^{bc}	2.60a	8.40^{a}	3.95^{a}	2.42	0.00^{c}	LB
IKN120016	1.40^{bc}	1.40^{bc}	1.00bc	6.10^{ab}	2.48^{b}	1.58	5.90^{b}	LB
IKN120036	3.60^{a}	3.60^{a}	2.60a	8.30^{a}	4.52^{a}	3.36	8.00^{a}	MB
TMEB419(C)	2.40^{b}	1.70^{bc}	2.70a	5.70^{ab}	3.14^{ab}	2.43	0.00^{c}	MB
Mean	2.2	1.75	1.94	6.11	3.11	2.35	6.29	
SE±	0.27	0.24	0.23	0.78	0.34	0.22	0.85	
CV	0.39	0.43	0.38	0.4	0.34	0.29	0.42	

Mean with the same letters are not significantly different from each other, t/ha=tonnes per hectare, EB=Early bulking, MB=Mid-bulking, LB=Late bulking, mean separated with TukeyHSD

4.33. Fresh Root Yield and Beta Carotenoid Content.

Genotype was significant ($p<0.05$) for beta carotenoid content and was highest for genotype IBA141092 (10µg/g) followed by IBA130896 (9.20 µg/g) and IBA070593 (8.80 µg/g) while the least of 4.0 µg/g was recorded by IBA130818. For all the genotypes, beta carotenoid increases with reduction in root yield. For the white checks genotype, IBA980581 and TMEB419, the fresh storage root yield increases with reduction in their beta-carotenoid content (Figure 20-20a).

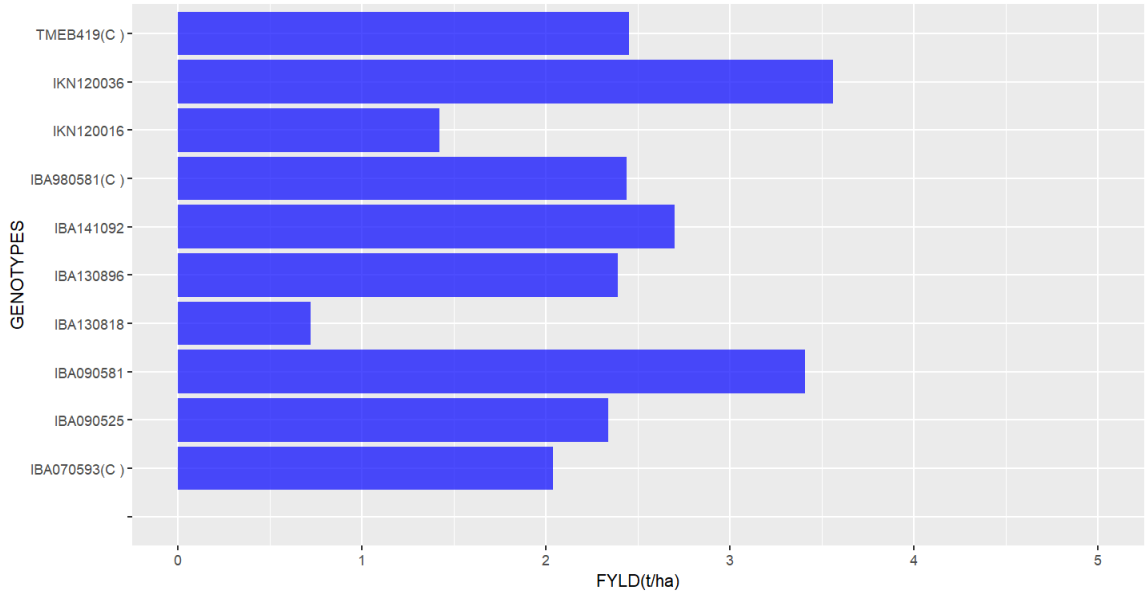


Figure 20: Fresh root yield of genotypes across the months and locations.

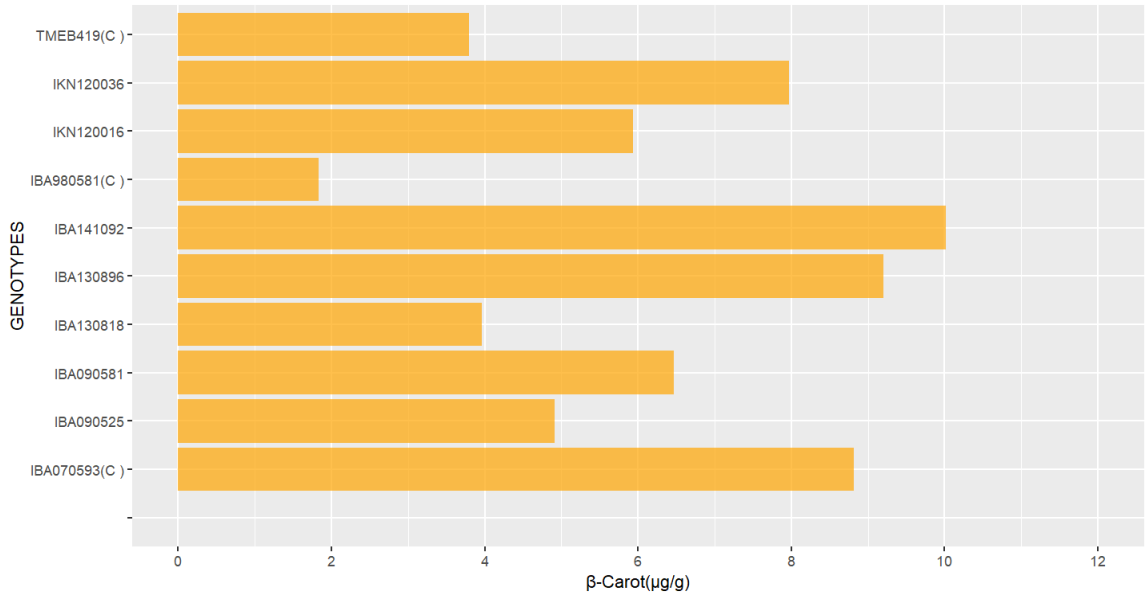


Figure 20a: Beta-carotenoid contents of genotypes across the months and locations.

4.34. Bulking Rate Percentage and Performance of Different Genotypes Across Locations

Bulkiness at 3 MAP shows that IBA141092 and IBA070593 were the only early bulking genotypes among the studied cassava genotypes as shown in table 4.19. Cassava IKN120036, TMEB419, IBA130818 were middle bulking while low bulking genotypes comprises IBA980581, IBA130896, IBA090581, IKN120016 and IBA090525.

Although, genotype IBA141092, IBA070593 may not be the highest yielding at 12 MAP relative to other genotypes in the study but these genotypes were effective in partitioning dry matter production into storage root yield. Genotypes that bulks over 60 % of their final yield at 6 MAP can partition dry matter production into their storage root earlier. The early bulking genotypes in this study were able to bulk over 60 % of DMC into their roots at 3 MAP.

At 3 months, genotype IKN120036 rapidly bulked relative to other genotypes and had the highest yield of 3.6 t/ha followed by genotype IBA141092 with 2.7 t/ha while the least of 0.7t/ha was recorded by IBA130818.

At 6 months, genotype IKN120036 still maintained the highest yield of 3.6 t/ha followed by IBA090581 with 2.6t/ha while the least yield was recorded by IBA130818 with yield of 0.8 t/ha.

At 9 months, virtually all the genotypes reduced in their yield except genotype IBA130818 which had pattern of increases from the 3rd month. The highest yield was recorded by TMEB419 with 2.7 t/ha followed by IBA120036, IBA980581 with 2.5 t/ha each.

At 12 months, genotype IBA090581 had the highest yield of 9.0t/ha followed by IBA980581 and IBA130896 with 8.4t/ha while the least remained IBA130818 with yield value of 2.0 t/ha.

Average yield across the months revealed that genotype IKN120036 with yield of 4.5 t/ha, IBA090581 with yield of 4.3 t/ha, IBA130896 with yield of 3.9t/ha and IBA980581 with yield of 3.9 t/ha are the early bulkers. Mid bulking genotypes are TMEB419 with 3.1 t/ha, IBA090525 with 3.0t/ha, IKN120016 with 2.5 t/ha and IBA141092 with 2.7 t/ha, IBA90581 with 3.4 t/ha While late bulking genotypes are IBA070593 with 2.0 t/ha and IBA130818 with 1.1 t/ha (Table 4.19).

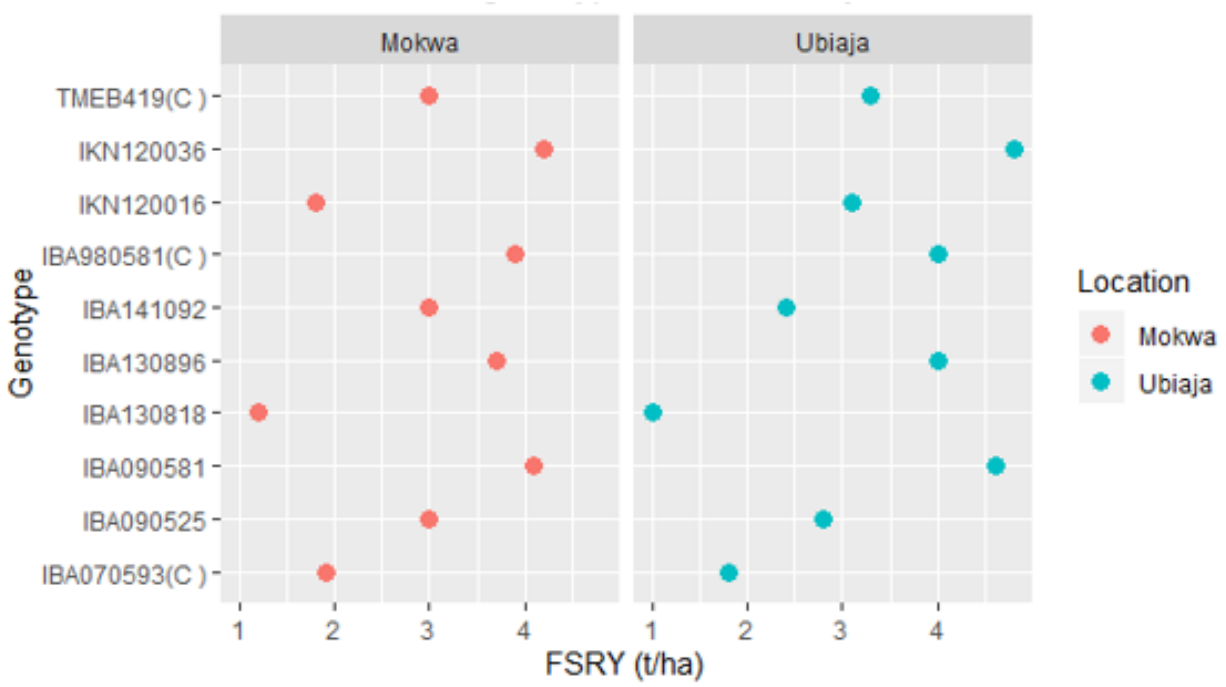
Table 4.19: Early bulking performance of genotypes at 3rd, 6th, 9th and 12th months after planting

	3 MAP		6 MAP		9 MAP		12 MAP	Across MAP	
	FSRY	EB%	FSRY	EB%	FSRY	EB%	FSRY	FSRY	Bulkiness
Genotype									
IBA070593(C)	2	64	1.8	58	1	32	3.1	1.98	Early Bulking
IBA090525	2	32	2	32	1.5	24	6.2	2.93	Late Bulking
IBA090581	3.4	37	2.6	28	2.5	27	9	4.38	Mid Bulking
IBA130818	0.7	35	0.8	40	1	50	2	1.13	Mid-Bulking
IBA130896	2.4	28	2.3	27	2.4	28	8.4	3.88	Late Bulking
IBA141092	2.7	69	2.2	56	2.1	53	3.9	2.73	Early Bulking
IBA980581(C)	2.4	28	2.3	27	2.6	30	8.4	3.93	Late Bulking
IKN120016	1.4	22	1.4	22	1	16	6.1	2.48	Late Bulking
IKN120036	3.6	43	3.6	43	2.6	31	8.3	4.53	Mid-Bulking
TMEB419(C)	2.4	42	1.7	29	2.7	47	5.7	3.13	Mid-Bulking

EB-60% and above, MB-40% - 59%, LB-0% - 039%, EB-Early bulking, MB-Mid-Bulking, LB-Late bulking.

4.35. Yield and Yield Related Traits Across Evaluated Months and Locations

Locations had no significant effect on the genotypes based on fresh storage root yield (Figure 21). Months after planting were significant ($p<0.01$) for fresh root yield at 3, 6 and 9 MAP while it was significant ($p<0.001$) at 12 MAP. For harvest index and storage root diameter, and dry matter, MAP was highly significant at 3,6 and 12 MAP while it was not significant at 9MAP. For root number, root weight, MAP was not significant. Only 12 MAP was significant for shoot weight ($p<0.05$) (Table 4.20).



FSRY-Fresh Storage Root Yield, C-Check

Figure 21: Performance of genotypes for fresh root yield traits across locations

Table 4.20: Yield related traits performance at different months and across locations.

			Range		3 MAP	6 MAP	9 MAP	12MAP
Character	Mean	CV	Min	Max	df=156	df=156	df=156	df=156
FSRY	2.35	20.94	0.72	3.56	2.35**	2.07**	1.98**	6.32***
HI	0.39	12.07	0.11	0.6	0.39***	0.33***	0.38^{ns}	0.37***
NOHAV	2.05	19.12	1.67	2.5	2.05ns	1.9ns	1.99ns	8.22**
RTNO	10.12	21.08	7.67	12	10.12ns	12.7ns	12.15ns	45.30*
RTWT	2.3	26.86	0.55	3.51	2.3ns	2.5ns	2.43ns	0.013*
SRD	10.87	8.12	7.5	13.83	10.87***	12.38***	13.95***	25.47***
SHTWT	3.74	29.22	2.23	4.58	3.74ns	4.42ns	3.89ns	42.33*
DM	35.28	12.35	20.82	39.78	31.8***	35.48***	16.87***	35.28***

*, **, ***=Significant at P< 0.05, 0.01 and 0.001respectively, CV=coefficient of variation, min=maximum, max=maximum, df=degree of freedom, MAP= Months after planting, FSRY-Fresh storage root yield, HI-Harvest index, NOHAV-Number of plant harvested, RTNO-Root number, RTWT-Root weight, SRD-Storage root diameter, SHTWT-Shoot weight, DM-Dry matter.

4.36. Performance of Genotypes in terms of Fresh Root Yield, Harvest Index and Dry Matter Content Across Locations.

Genotypes was highly significant for harvest index (HI) at $p<0.001$. Genotype IBA141092 was significant for harvest index (HI) at $p<0.05$ and had the highest harvest index of 0.60 above the mean harvest index while the least harvest index of 0.10 which was less than the mean was recorded by IBA130818 as shown in table 4.20. At 6 MAP, genotype IKN120036 and IBA141092 had the highest harvest indices of 0.50 which was above the mean value for HI while IBA130818 had the least harvest index value of 0.10 less than the mean. Genotype IBA141092 had the highest harvest index value of 0.60 above the mean value while the least value of 0.10 which was less than the mean value was recorded by IBA130818. At 12 MAP, genotype IBA090525, had the highest harvest index value of 0.60 above the mean value while the least was recorded by genotype IBA070593 (C) with harvest index value of 0,20 below the mean value.

Genotype was highly significant for root yield (at $p<0.001$). Genotype IKN120036 had the highest root yield (3.60 t/ha) at 3 MAP followed by IBA090581 with 3.40t/ha while the least was recorded by genotype IBA130818 with 0.70 t/ha which was less than the mean. Genotype IKN120036 had the highest root yield of 3.60 t/ha at 6 MAP while the least root yield of 0.80 t/ha was recorded by genotype IBA130818. At 9 MAP, genotype TMEB419 had the highest root yield of 2.70 t/ha followed by genotype IKN120036 with the root yield of 2.60 t/ha above the mean root yield while the least was recorded by IBA070593(C) and IBA130818 with root yield of 1.00 t/ha. At 12 MAP, genotype IBA090581 recorded the highest root yield of 9.00 t/ha followed by IKN120036 with

8.30 t/ha while the least was recorded by IBA130818 with root yield of 2.00 t/ha which is less than the mean.

Genotype was significant for dry matter (DM) content at $p<0.01$. At 3 MAP, dry matter was highest for genotype TMEB419 (C) with dry matter content of 39.8 % followed by genotype IBA090525 with dry matter content value of 39.70 % and above the mean value of 32.10 %. The least DM content was recorded by genotype IBA141092 with DM content of 20.80 % below the mean value. At 6 MAP, genotype IBA090525 had the highest DM content of 45.00 % followed by genotype TMEB419 with DM content of 43.30 % above the mean value while the least DM content was recorded by genotype IBA130818 with DM content of 26.30 % below the mean value of 32.10 %. At 9 MAP, genotype IBA090525 had the highest DM content of 21.20 % followed by genotype TMEB 419 with DM content of 19.60 % above the mean DM content value of 16.91 % while the least DM content value of 11.50 % was recorded by genotype IBA141092 below the mean DM content value of 16.91 %. At 12 MAP, genotype TMEB419 recorded the highest DM content value of 44.00 % followed by genotype IBA090581 with DM content value of 38.50 % above the mean value of 35.35 % while the least DM content value of 25.00 % was recorded by genotype IBA070493 (C) which was below the mean value (Table 4.21).

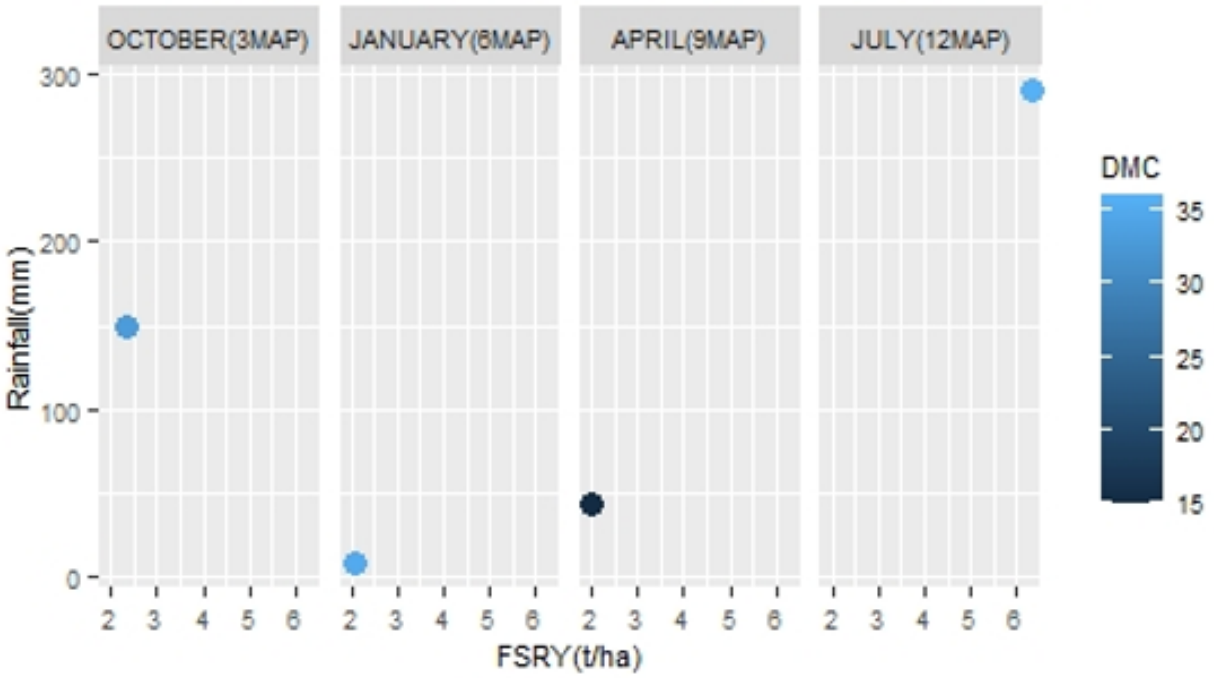
Table 4.21: performance of harvest index, fresh storage root yield and dry matter content at different months after planting and across location.

Traits	HI				FSRY(t/ha)				DM(%)			
MAP	3	6	9	12	3	6	9	12	3	6	9	12
Genotype												
IBA070593(C)	0.30^{b}	0.30^{ab}	0.30^{b}	0.20^{bc}	2.00^{bc}	1.80^{bc}	1.00^{bc}	3.10^{cd}	30.20^{b}	35.80^{ab}	19.10^{a}	25.00^{b}
IBA090525	0.50^{a}	0.40^{a}	0.40^{b}	0.60^{a}	2.00^{bc}	2.00^{bc}	1.50^{a}	6.20^{ab}	39.70^{a}	45.00^{a}	21.20^{a}	33.80^{ab}
IBA090581	0.50^{a}	0.40^{a}	0.40^{b}	0.40^{b}	3.40^{a}	2.60^{a}	2.50^{a}	9.00^{a}	32.00^{b}	37.20^{ab}	18.90^{a}	38.50^{ab}
IBA130818	0.10^{c}	0.10^{c}	0.10^{c}	0.20^{bc}	0.70^{c}	0.80^{c}	1.00^{bc}	2.00^{d}	24.60^{ab}	26.30^{bc}	14.70^{ab}	32.70^{ab}
IBA130896	0.30^{b}	0.30^{ab}	0.30^{b}	0.40^{b}	2.40^{bc}	2.30^{bc}	2.40^{a}	8.40^{a}	35.10^{a}	38.30^{ab}	16.80^{ab}	35.30^{ab}
IBA141092	0.60^{a}	0.50^{a}	0.60^{a}	0.40^{b}	2.70^{a}	2.20^{bc}	2.10^{a}	3.90^{cd}	20.80^{bc}	24.60^{bc}	11.50^{ab}	35.20^{ab}
IBA980581(C)	0.40^{b}	0.30^{ab}	0.30^{b}	0.30^{b}	2.40^{b}	2.30^{bc}	2.60^{a}	8.40^{a}	36.30^{a}	38.30^{ab}	17.90^{ab}	35.80^{ab}
IKN120016	0.20b^{c}	0.20^{c}	0.30^{b}	0.30^{b}	1.40^{bc}	1.40^{bc}	1.00^{bc}	6.10^{ab}	34.50^{a}	37.30^{ab}	15.70^{aab}	36.50^{ab}
IKN120036	0.50^{a}	0.50^{a}	0.50^{a}	0.50^{a}	3.60^{a}	3.60^{a}	2.60^{a}	8.30^{a}	28.00^{ab}	31.90^{b}	13.70^{b}	36.70^{ab}
TMEB419(C)	0.40^{a}	0.30^{ab}	0.50^{a}	0.50^{a}	2.40^{b}	1.70^{bc}	2.70^{a}	5.70^{ab}	39.80^{a}	43.30^{a}	19.60^{a}	44.00^{a}
mean	0.35	0.30	0.40	0.35	2.20	1.75	1.94	6.11	32.10	35.80	16.91	35.35
SE±	0.05	0.04	0.04	0.04	0.27	0.24	0.23	0.78	1.98	2.08	0.95	1.51
SD	0.15	0.13	0.14	0.13	0.86	0.75	0.73	2.46	6.27	6.57	3.01	4.77
CV	0.44	0.42	0.35	0.38	0.39	0.43	0.38	0.40	0.20	0.18	0.18	0.13

Mean with same letters are not significantly different from each other, SE=standard error, SD= standard deviation, CV=coefficient of variation, t/ha=tonnes per hectare,HI- Harvest index, FSRY- Fresh storage root yield, DM- Dry matter, %=percentage, mean separated using Tukey HSD.

4.37. Effect of Rainfall on Fresh Root Yield (FSRY) and Dry Matter (DM)

At 3MAP (October) when rainfall was above 100mm, root yield was 2.35 t/ha while DM was 31.82 as shown in figure 4.21. At 6 MAP (January) when there was no rainfall, fresh root yield was 2.07 t/ha and DM was 35.48 %. At 9 MAP (April) when rainfall was about starting, fresh root yield was 1.98 t/ha and DM was 16.85 % while at 12MAP, fresh root yield was 6.32 t/ha while the DM content was 35.82 % (Figure 22).



DMC-Dry matter content, FSRY-Fresh storage root yield

Figure 22: Fresh Storage Root Yield Performance with Rainfall Relationship at Ubiaja and Mokwa At Different Evaluated Months.

4.38. Correlation Matrix for Different Yield Components at 3 Months after Planting

4.38.1. Harvest index correlation with other yield related traits.

Harvest index (HI) was very significant($P<0.01$) with fresh storage root yield (FSRY) and positively correlated ($R = 0.81$) as shown in figure 4.22. Harvest index was significant ($P<0.05$) with storage root diameter (SRD) and also positively correlated. It had a highly significant relationship($p<0.001$) with Root weight (Rtwt) and also positively correlated ($R=0.87$). Harvest index was also positively correlated with root number (Rtno)($R=0.58$) in a non-significant relationship. It had a significant ($P<0.05$) and negative correlation ($R=-0.73$) with shoot weight (SHTWT) (Figure 23).

4.38.2. Fresh root yield correlation with other yield related traits.

Fresh root yield (FSRY) had a negative correlation ($R = -0.46$) and a non-significant relationship with shoot weight. It was significant($p<0.05$) with storage root diameter in a positive correlation ($R=0.73$). Fresh storage root yield was highly significant ($p<0.001$) with root weight (Rtwt) and positively correlated ($R=0.97$).

4.38.3. Dry matter content correlation with other yield related traits.

Dry matter was significant ($p<0.05$) and negatively correlated with Total Carotenoid chart ($R = -0.72$). Dry matter was significant ($p<0.05$) and positively correlated with vigour ($R=0.70$).

4.38.4. Branch height correlation with other yield related traits

Branch height was very significant and positively correlated with root number ($p<0.01$) and positively correlated ($R=0.84$) with Total Carotenoid Chart (Tchart), it negatively correlated ($R= - 0.67$) and was significant ($p<0.05$).

4.38.5. Starch correlation with other yield related traits

Starch content positively correlated with vigour ($R=0.71$) and was significant while it significantly and negatively ($p<0.05$) correlated with Total Carotenoid chart ($R= -0.73$).

4.38.6. Root weight correlation with other yield related traits

Root weight was very significant with harvest index ($p<0.001$) and was positively correlated ($R=0.87$). It was not significant with vigour although it positively correlated while it was highly significant with fresh storage root yield ($p<0.001$) and positively correlated ($R = 0.97$) (Figure 23).

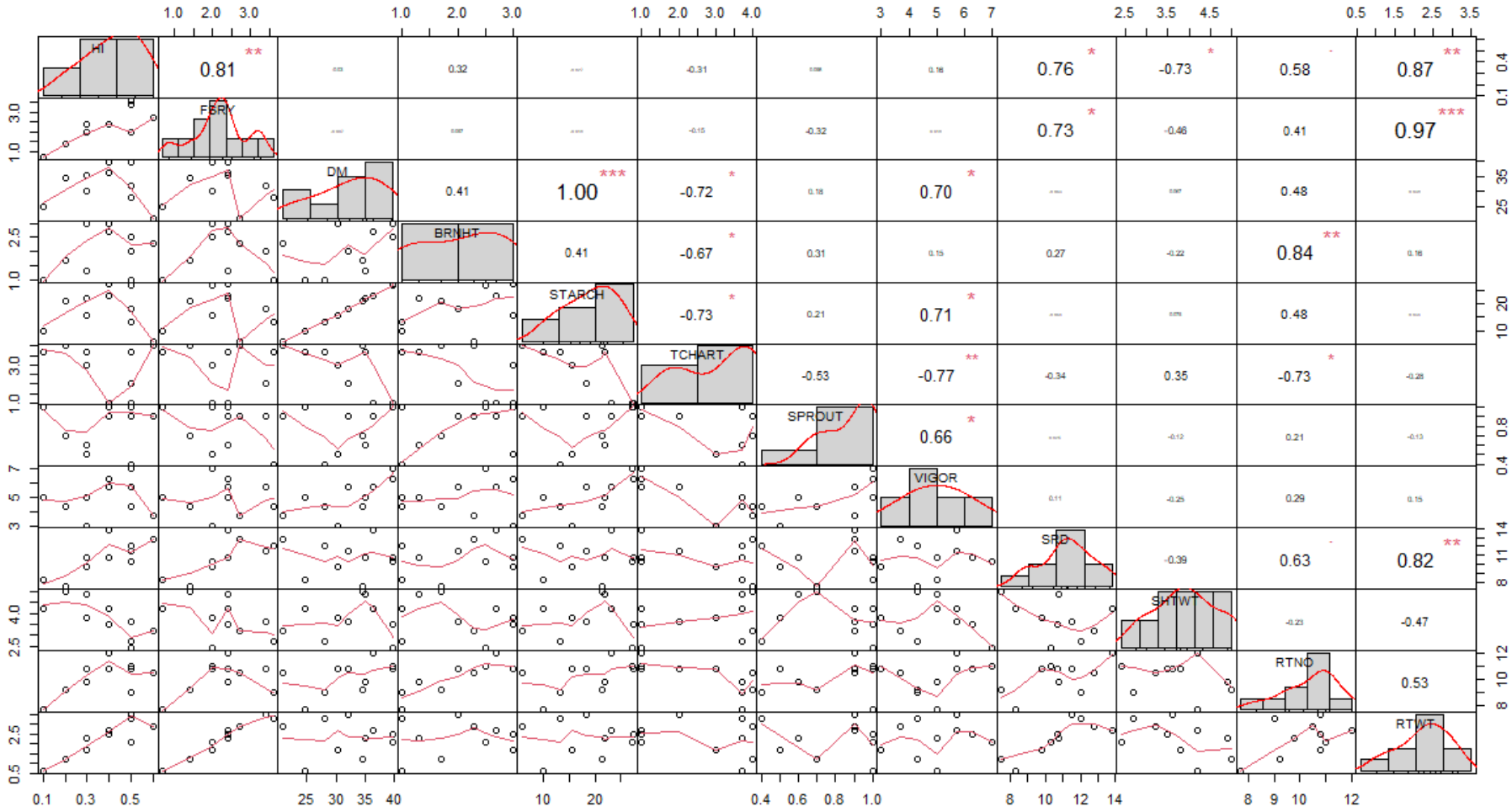


Figure 23: Pearson correlation of different traits evaluated at 3 months after planting

BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, SRD=Storage root diameter, DM=Dry matter content.

4.39. Correlation Matrix for Different Yield Components at 6 Months After Planting

4.39.1. Harvest index correlation with other yield related traits.

Harvest Index (HI) was very significant ($p<0.01$) with fresh storage root yield (FSRY) and positively correlated ($R = 0.83$) as shown in figure 24. Harvest index was not significant with storage root diameter (SRD) and positively correlated. It had a highly significant relationship ($p<0.05$) with Root weight (Rtwt) and positively correlated ($R= 0.75$). Harvest index was not significant with root number. It had a very significant ($p<0.05$) and negative correlation ($R=-0.77$) with shoot weight (Shtwt).

4.39.2. Fresh root yield correlation with other yield related traits.

Fresh root yield (FSRY) had a negative correlation ($R=-0.32$) and a non-significant relationship with shoot weight. It was not significant with storage root diameter. Fresh storage root yield was highly significant ($p<0.001$) with root weight (Rtwt) and positively correlated ($R=0.96$). And was not significant with fresh storage root yield.

4.39.3. Dry matter content correlation with other yield related traits.

Dry matter was significant ($p<0.05$) and negatively correlated with Total Carotenoid chart ($R = -0.73$). Dry matter was significant ($p<0.05$) and positively correlated with vigour ($R=0.65$).

4.39.4. Branch height correlation with other yield related traits

Branch height was not significant with root number and positively correlated(R=0.47). With Total Carotenoid Chart (Tchart), it negatively correlated (R= - 0.67) and was significant ($p<0.05$).

4.39.5. Starch correlation with other yield related traits

Starch content positively correlated with vigour (R=0.64) and was significant while it negatively correlated with Total Carotenoid chart (R= -0.74) and was significant at $p<0.05$.

4.39.6. Root weight correlation with other yield related traits

Root weight was significant with harvest index ($p<0.05$) and was positively correlated(R=0.75). It was not significant with vigour while it was significant with fresh storage root yield ($p<0.001$) and positively correlated (R= 0.96) (Figure 24).

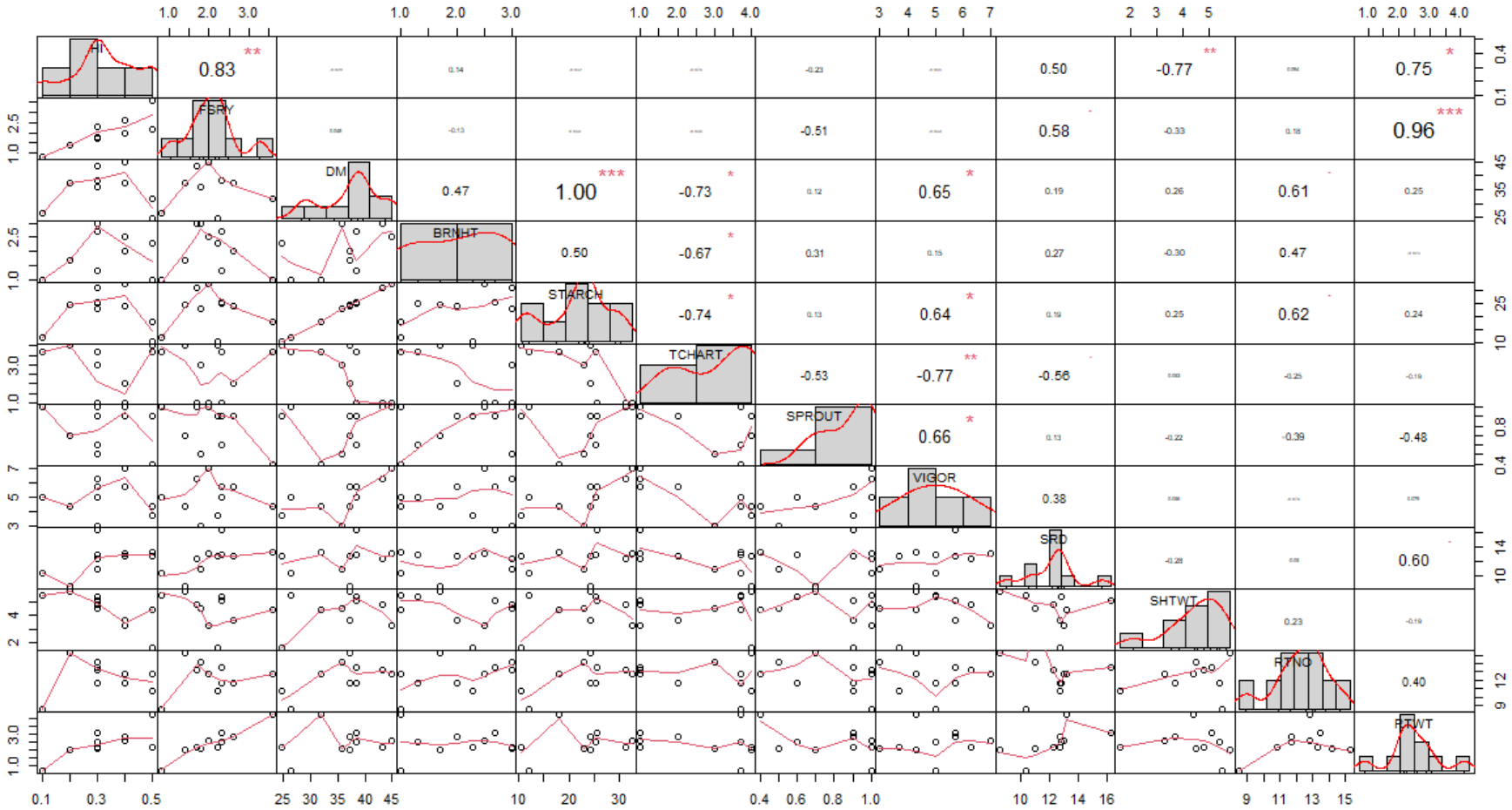


Figure 24: Pearson correlation of different evaluated traits at 6 months after planting

BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, SRD=Storage root diameter, DM=Dry matter content.

4.40. Correlation Matrix for Different Yield Component Evaluated Traits at 9 Months After Planting.

4.40.1. Harvest index correlation with other yield related traits.

Harvest Index (HI) was not significant with fresh storage root yield (FSRY) and positively correlated (R = 0.83) as shown in figure 25. Harvest index was not significant with storage root diameter (SRD) and also positively correlated. It had a non-significant relationship with root weight (Rtwt) and also positively correlated (R= 0.62). Harvest index was significant with root number($p<0.05$) and positively correlated (R=0.64). It had a non-significant and negative relationship (R=-0.39) with shoot weight (shtwt).

4.40.2. Fresh root yield correlation with other yield related traits.

Fresh root yield (FSRY) had a non-significant relationship and positive correlation (R = 0.13) with shoot weight. It was significant ($p<0.01$) with storage root diameter and positively correlated (R=0.8). Fresh storage root yield was significant ($P<0.001$) with root weight (Rtwt) and positively correlated (R=0.94).

4.40.3. Dry matter content correlation with other yield related traits.

Dry matter was significant ($P<0.01$) and negatively correlated with Total Carotenoid chart (R = -0.8). Dry matter was non- significant and positively correlated with vigour (R=0.59).

4.40.4. Branch height correlation with other yield related traits

Branch height was not significant with root number and positively correlated (R=0.86). With Total Carotenoid Chart (Tchart), it negatively correlated (R=-0.68) and was significant ($p<0.05$).

4.40.5. Starch content correlation with other yield related traits

Starch content positively correlated with vigour (R=0.6) and was non-significant while it negatively correlated with Total Carotenoid chart (R= -0.83) and was very significant at $p<0.01$.

4.40.6. Root weight correlation with other yield related traits

Root weight was not significant with harvest index and was positively correlated (R=0.58). It was not significant with vigour but was positively correlated (R=0.38) while it was highly significant with fresh storage root yield ($p<0.001$) and positively correlated (R= 0.94) (Figure 25).

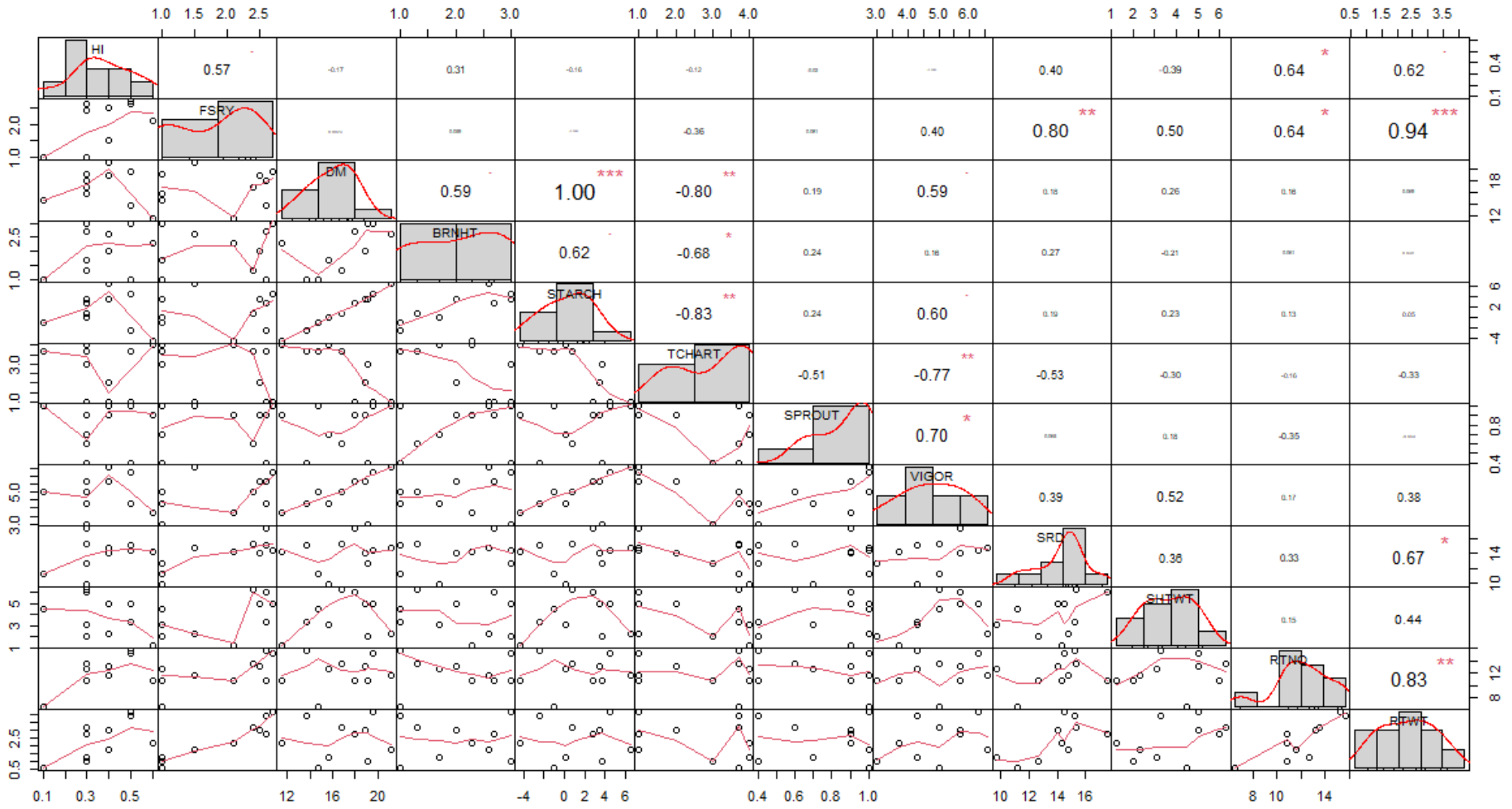


Figure 25: Pearson correlation of different evaluated traits at 9 months after planting

BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, SRD=Storage root diameter, DM=Dry matter content.

4.41. Correlation Matrix for Different Yield Components at 12 Months After Planting

4.41.1. Harvest index correlation with other yield related traits.

Harvest Index (HI) was not significant with fresh storage root yield (FSRY) and positively correlated (R = 0.48) as shown in figure 26. Harvest index was not significant with storage root diameter (SRD) and also positively correlated (R=0.49). It had a significant relationship ($p<0.05$) with Root weight (Rtwt) and also positively correlated (R= 0.68). Harvest index was not significant with root number and positively correlated (R= 0.56). It had a non-significant and negative relationship (R=-0.06) with shoot weight (shtwt).

4.41.2. Fresh root yield correlation with other yield related traits.

Fresh root yield (FSRY) was not significant and positively correlated (R = 0.09) with shoot weight. It was highly significant ($p<0.001$) with storage root diameter and positively correlated (R=0.91). Fresh storage root yield was significant($P<0.05$) with root weight (Rtwt) and positively correlated (R=0.7). It negatively correlated with TCchart (R = -0.39) with non- significant effect.

4.41.3. Dry matter content correlation with other yield related traits.

Dry matter was non-significant and negatively correlated with Total Carotenoid chart (R = -0.32). Dry matter was non- significant and positively correlated with vigour (R=0.57).

4.41.4. Branch height correlation with other yield related traits

Branch height was not significant with root number and positively correlated (R=0.23). With Total Carotenoid Chart (Tchart), it negatively correlated (R= - 0.61) and was non-significant.

4.41.5. Starch content correlation with other yield related traits

Starch content positively correlated with vigour (R=0.59) and was non-significant. It was also non-significant and negatively correlated with Total Carotenoid chart (R= -0.33).

4.41.6. Root weight correlation with other yield related traits

Root weight was significant ($p<0.05$) with harvest index and was positively correlated (R=0.68). It was very significant ($p<0.01$) with vigour and was positively correlated (R=0.87) while it was significant with fresh storage root yield ($p<0.05$) and positively correlated (R= 0.7) (Figure 26).

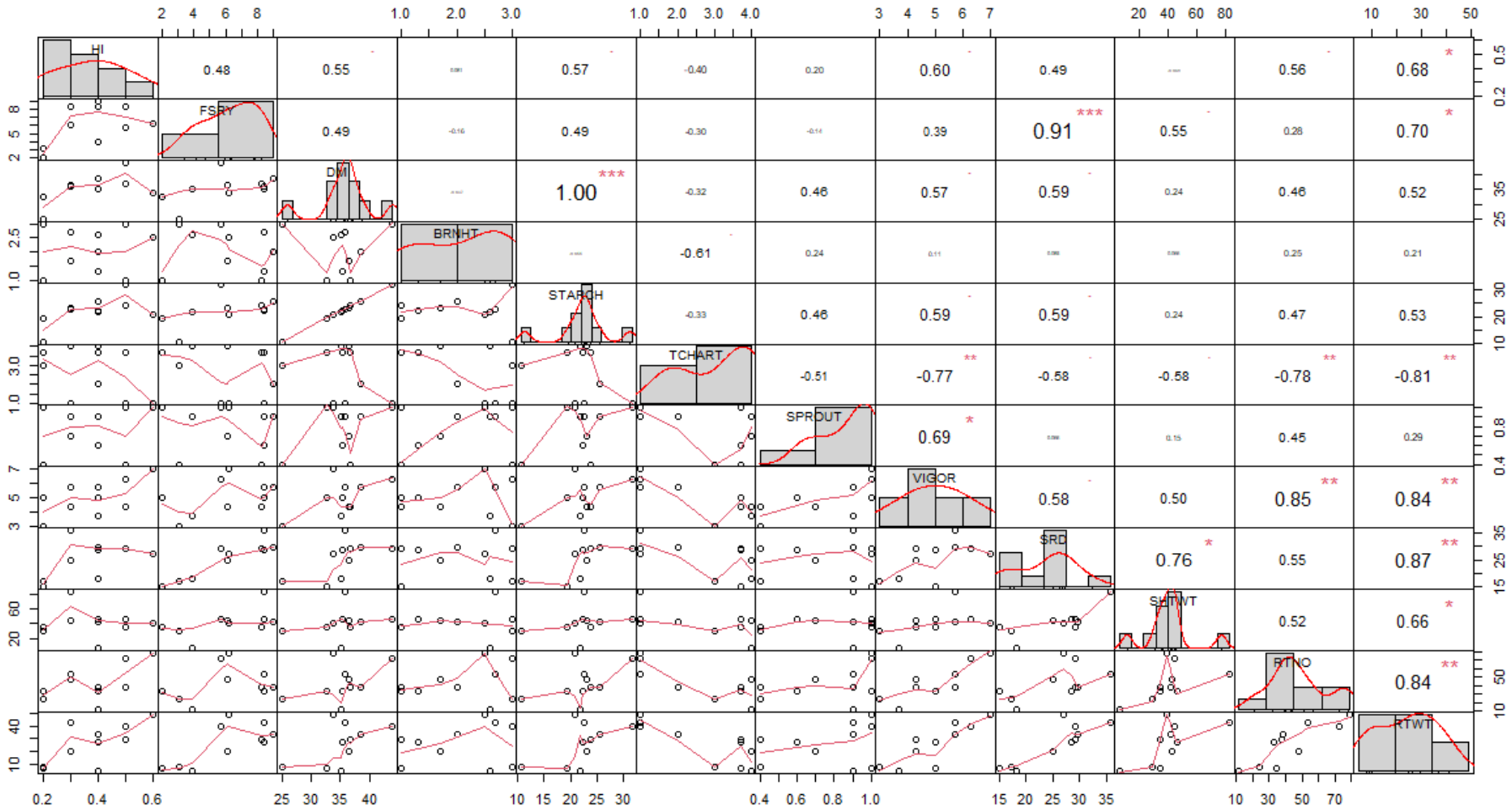


Figure 26: Pearson correlation of different evaluated traits at 12 months after planting

BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, SRD=Storage root diameter, DM=Dry matter content.

4.42. Correlation Matrix Among Different Yield Component Attributes of Cassava Genotypes Across Locations

Fresh storage root yield was very significant ($p<0.01$) with HI and positively correlated ($R=0.85$) as shown in figure 27. Fresh storage root yield was significantly ($p<0.05$) and positively correlated with storage root diameter ($R=0.72$) but was non-significant and negatively correlated with sprout ($R=-0.26$). Fresh storage root yield was not significantly correlated with dry matter ($R=6$)

Branch height and Root number was very significant ($R = 0.82$, $p<0.01$) and positively correlated. It also positively correlated ($R=0.53$) with Number harvested but was not significant. Dry matter significantly ($p<0.001$) and highly correlated with starch ($R= 0.99$) but was significant with vigour ($p<0.05$).

Vigour significantly($p<0.05$) and positively correlated with starch ($R=0.67$) and also significantly ($p<0.05$) correlated with number harvested ($R=0.70$) and sprout ($R=0.65$, $P<0.05$). Beta carotene was very significant($p<0.01$) and correlated with total carotenoid chart ($R=0.73$) and was not significantly correlated with fresh storage root yield ($R=0.21$) (Figure 27).

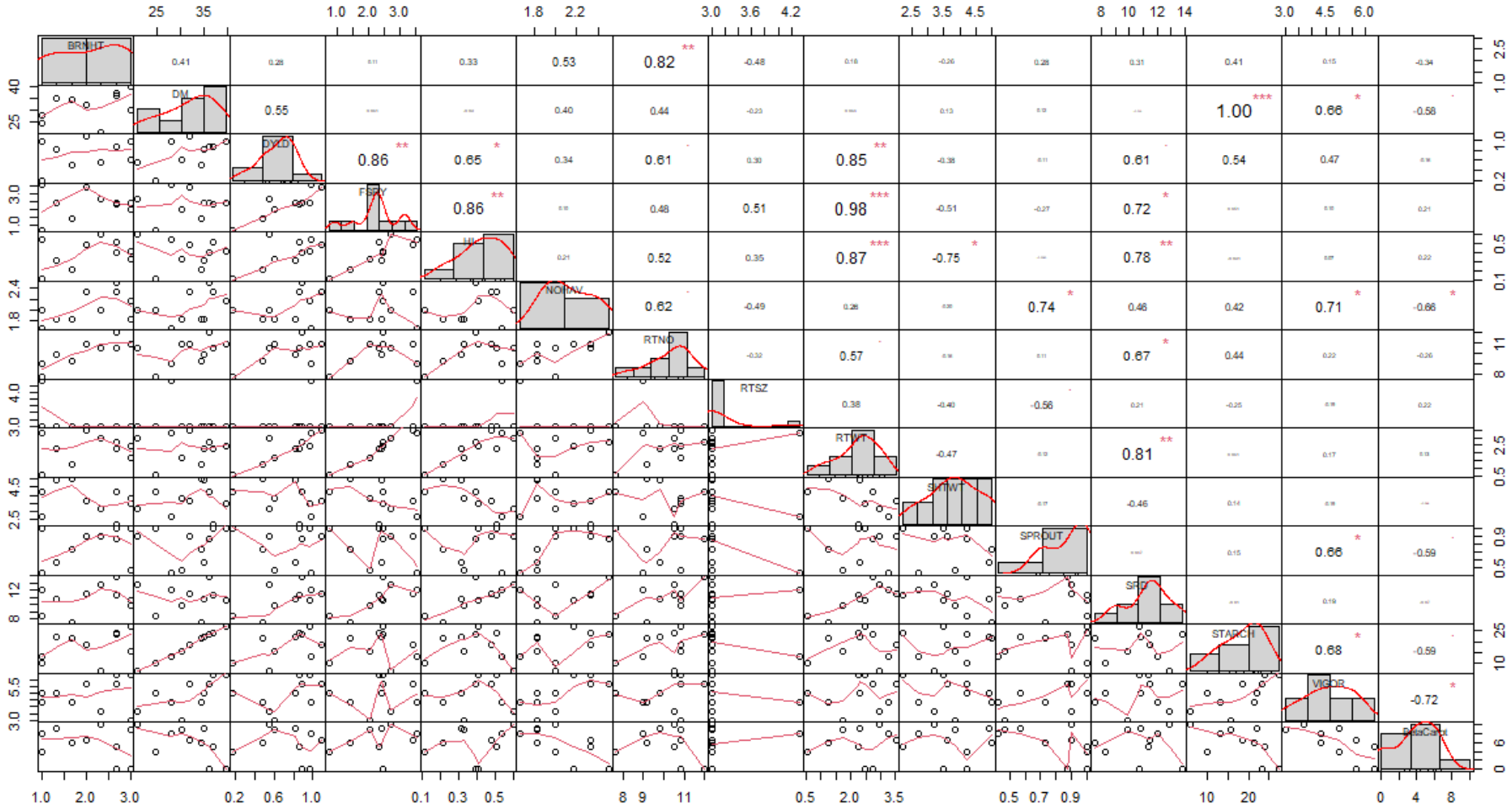


Figure 27: Pearson correlation of different traits evaluated at different months and locations

BRNHT= Apical height at first branching, PLTHT=Plant height, NOHAV=Number of plant harvested, RTNO=Root number, RTWT=Root weight, FYLD=Fresh root yield, HI=Harvest index, SHTWT=Shoot weight, RTSZ=Root size, SRD=Storage root diameter, DM=Dry matter content.

4.43. Discontinuity in Yield Across Evaluated Months

Across locations and across the evaluated months, genotypes IKN120016, IKN120036 and IBA070593 show discontinuity in their yield at 9 MAP as shown in the table 4.21. Genotype IKN120036 was low bulking and the best performing genotype from this study and reduces from 3.61 t/ha (6 MAP) to 2.58 t/ha (9 MAP) with a discontinuity yield value of 1.03 which is greater than the other two genotypes (Table 4.22).

Table 4.22: Root yield discontinuity value

	FSRY(t/ha)			
Genotype	6 MAP	9MAP	Discontinuity Yield Value	Bulking Rate
IKN120036	3.61	2.58	1.03	Middle Bulking
IKN120016	1.38	1.03	0.35	Late Bulking
IBA070593	1.78	0.95	0.83	Early Bulking
IBA090525	2	1.5	0.5	Late Bulking
IBA090581	2.6	2.5	0.1	Late Bulking
IBA141092	2.2	2.1	0.1	Early Bulking

t/ha=tonnes per hectare, FSRY=Fresh storage root yield

4.44. Traits Performance Across Evaluated Months and Locations.

Table 4.22 indicates that location did not have a significant effect on genotypes, and the traits observed at different locations did not show any significant differences among them. Performance of different traits at different evaluated months revealed that not all traits improve over the months. While some traits remained unchanged over the months of evaluation (Sprout, Vigor, CMD, Inncol) other reduced over the months (Plpcol, HI, Tchart, Brnht) and others increased over the months of evaluation. (Table 4.23).

Table 4.23: Performance of different traits at Mokwa and Ubiaja

Location	SPROUT	VIGOR	CMDS	NOHAV	RTNO	RTWT	INNCOL	PLPCOL	RTSZ	SHTWT	SRD	HI	FYLD	DYLD	DM	SPGRV	STARCH	TCHART	BRNHT
Mokwa	0.79	4.97	1.00	4.04	25.21	11.41	1.19	2.00	4.67	17.22	15.89	0.39	3.03	0.95	29.91	1.09	15.99	2.68	2.03
Ubiaja	0.79	4.93	1.00	2.88	14.02	5.35	1.23	2.01	4.60	8.97	15.43	0.36	3.22	1.07	29.98	1.09	16.16	2.70	2.08

CMDS-cassava mosaic disease severity, NoHav=Number harvested, RTNO=Root number, INNCOl=Inner skin colour, PLPCOL=Pulp colour, RTSZ=Root size (cm), SRD=Storage root diameter (cm), HI=Harvest index, FYLD=Fresh root yield (t/ha), SHTWT=Shot weight (kg), DYLD=Dried root yield (t/ha), DM=Dry matter (%), SPGRV=Specific gravity, TCHART=Total carotenoid chart, BRNHT=Height at first apical branch.

4.45. Principal Component Analysis of the Evaluated Traits for Cassava Genotypes

The first principal component accounted for 39.19 % of the total variation observed as shown in table 4.24. Total Carotenoid Chart (-0.357) negatively contributed more to the variation than the others. Other major traits that positively contributed to the variation include number harvested (0.295), Starch (0.291) and Dry matter (0.289). Harvest index (0.150), Sprout (0.150) and FSRY (0.157) contributed least to the variation. The second component contributed 27.60 % of the total variation with the harvest index (0.395) contributing the highest. Other traits that contributed to the variation include FSRY (0.375) and RTWT (0.366) while branch height (0.005) contributed least to the variation and number harvested (-0.056), Shtwt (-0.270), Sprout (-0.143), starch (-0.201) and vigour (-0.132) contributing negatively to the variation.

The third principal component contributed 14.16 %. Sprout (-0.446) negatively contributed more to the variation followed by the Inner skin colour (-0.417). Root size (0.372) positively contributed more followed by DYLD (0.267). Tchart (0.079), Beta carotene (0.083), Rtwt (0.085) and Shtwt (0.099) contributed least to the variation while Brnht (-0.243), HI (-0.067), Inncol (-0.417), Nohav (-0.305), Rtno (-0.124), Sprout (-0.446), SRD (-0.113) and Vigour (-0.003) contributed negatively to the variation. The fourth principal component contributed 8.51 % to the total variation. The major traits that had the highest contribution is the Brnht (0.406) followed by Shtwt (0.333), with Rtwt (0.000), SRD (0.002), Tchart (0.084) with Root weight (0.110) having the least contribution to the variation. Dry yield (-0.003), FSRY (-0.010), Number harvested (-0.119), Harvest index (-0.020), Rtsz (-0.338), Vigour (-0.410) and Sprout (-0.336)

contributed negatively to the variation. The fifth principal component accounted for 4.38 % of the total variation. Shoot weight (0.645) had the highest contribution to the variation followed by Rtwt (0.274) and Nohav (0.201). Beta carotene (0.001) contributed the least to the variation. Those that contributed negatively to the variation include, Harvest Index (-0.129), Brnht (-0.463), DM (-0.041), Root size (-0.188), and starch (-0.015). The entire five principal components accounted for 93.8 % of the total variation observed (Table 4.24).

4.46. Cluster Analysis of Cassava Genotypes Evaluated at Both Locations

The combined result of the two locations had three (3) major clusters (figure 28). The first group (cluster) had 5 genotypes (IKN120036, IBA070593(C), IBA090581, IBA130896 and IKN120036). The second group had 3 genotypes (TMEB419(C), IBA090525 and IBA980581(C)). The third group had 3 genotypes (IBA141092 and IBA130818) as shown in figure 28.

Dice similarity index shows that IKN120016, IBA141092, IBA130896, IBA130818, IBA090581, IBA090525, IBA070593(C), IKN120036 are linked together with 100% level of similarity while IBA980581 (C) and TMEB419(C) are also related with 100% similarity (Figure 28).

Table 4.24: Principal component analysis of traits

Traits	PC1	PC2	PC3	PC4	PC5
BRNHT	0.24	0.00	-0.24	0.4	-0.46
DM	0.28	-0.19	0.25	0.11	-0.04
DYLD	0.28	0.20	0.26	0.00	0.11
FSRY	0.15	0.37	0.18	-0.01	0.14
HI	0.15	0.39	-0.06	-0.02	-0.12
INNCOL	-0.1	0.24	-0.41	0.13	0.12
NOHAV	0.29	-0.05	-0.3	-0.11	0.2
RTNO	0.28	0.12	-0.12	0.42	0.04
RTSZ	-0.07	0.24	0.37	-0.33	-0.18
RTWT	0.18	0.36	0.08	0.00	0.27
SHTWT	-0.11	-0.27	0.09	0.33	0.64
SPGRV	0.29	-0.2	0.22	0.13	-0.03
SPROUT	0.15	-0.14	-0.44	-0.33	0.10
SRD	0.19	0.31	-0.11	0.00	0.25
STARCH	0.29	-0.2	0.23	0.11	-0.01
TCHART	-0.35	0.05	0.07	0.08	0.19
VIGOR	0.28	-0.13	0.00	-0.41	0.18
BetaCarot	-0.23	0.22	0.08	0.26	0.00
Eigenvalue	7.05	4.96	2.54	1.53	0.78
% variance	39.18	27.59	14.15	8.50	4.38
Cummulative	39.18	66.78	80.94	89.44	93.83

BRNHT=Height at first apical branch , DM=Dry matter (%), , DYLD=Dried root yield (t/ha), FSRY=Fresh root yield (t/ha), HI=Harvest index, , INNCOl=Inner skin colour, NoHav=Number harvested, RTNO=Root number, RTSZ=Root size (cm), RTWT-Root weight, SHTWT=Shot weight (kg), SPGRV=Specific gravity, SRD=Storage root diameter (cm), , TCHART=Total carotenoid chart,BetaCarot-Beta carotene, PC=principal component,

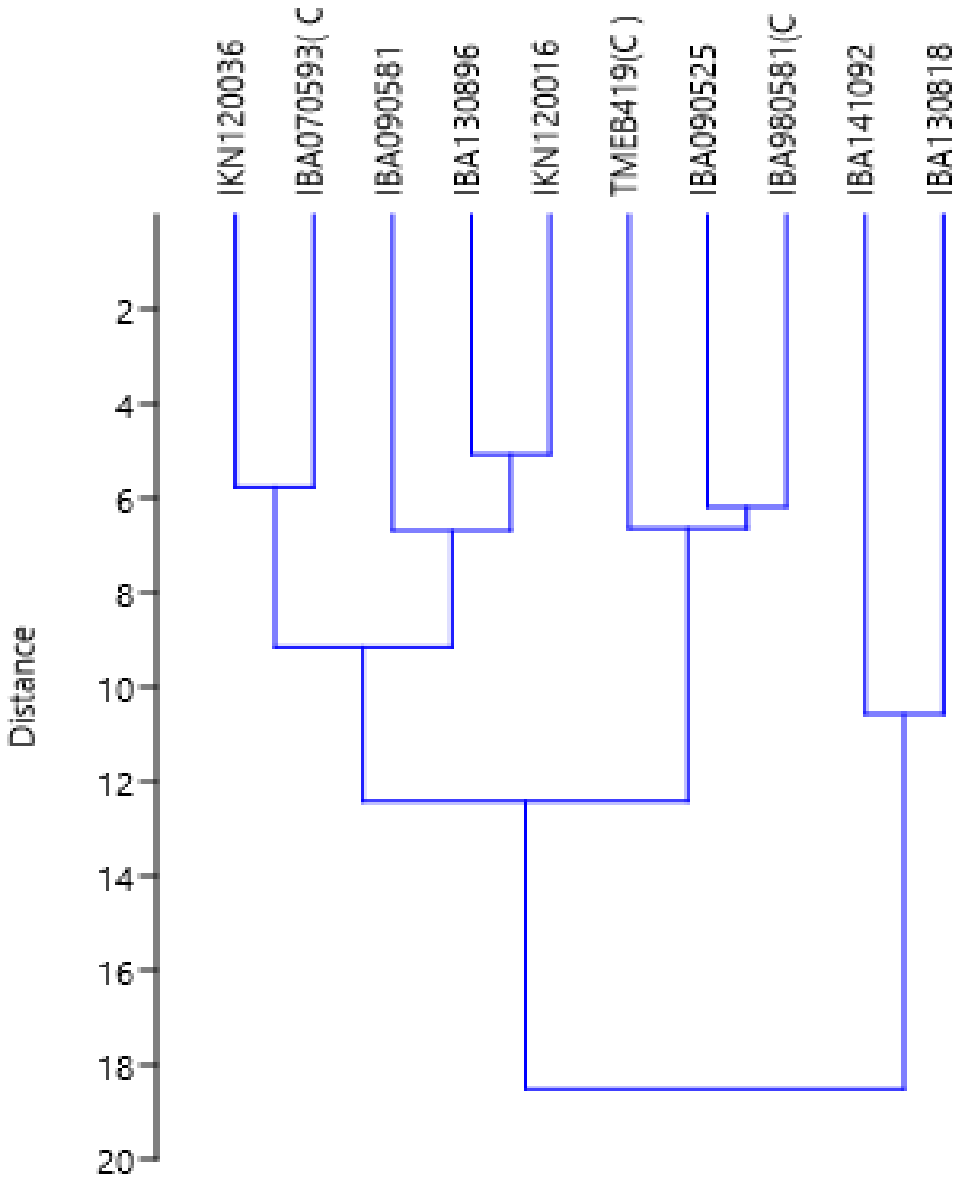


Figure 28: Dendrogram with Average Linkage Cluster Analysis Of Cassava Genotypes

4.47. Genetic Variation of Cassava Genotypes for Different Traits

Genotypic variance ranges from 0.00 to 27.50 for traits studied It was least for SPRGV, while it was highest for DM as shown in table 4.24. Phenotypic variance ranges from 0.00 to 10.08, it was least for BRNHT while it was highest for starch. Heritability ranges from 0.00 to 0.97, it was least for Nohav, RTSZ and PLPCOL recorded the highest. GCV ranges from 0 to 48.31, it was least for Nohav, PLPCOL and RTNO while it was highest for Tchart. PCV ranges from 0 to 48.69, it was least for Plpcol while the highest value was recorded by Tchart. Genetic gain ranges from 0 to 148.4, it was least for Nohav, PLPCOL and RTNO while DM recorded the highest value of 148.4 (Table 4.25)

Table 4.25: Genetic variability estimates of evaluated traits

Trait	Genotypic Variance	Phenotypic Variance	Heritability	GCV	PCV	Genetic Gain
BRNHT	0.59	0.00	0.97	37.20	38.51	0.62
DM	27.50	7.53	0.78	16.48	18.70	148.40
DYLD	0.05	0.04	0.62	29.51	34.32	0.18
FYLD	0.59	0.11	0.83	32.62	36.11	1.69
HI	0.02	0.00	0.95	38.37	40.22	0.03
INNCOL	0.04	0.00	0.90	18.75	20.73	0.13
NOHAV	0.00	0.02	0.00	0.00	17.52	0.00
PLPCOL	0.21	0.00	1.00	0.00	0.00	0.00
RTNO	0.00	0.00	0.00	0.00	20.54	0.00
RTSZ	0.16	0.00	0.90	12.77	14.11	0.77
RTWT	0.65	0.19	0.77	35.00	39.94	1.83
SHTWT	0.18	0.00	0.23	11.44	31.38	1.40
SPGRV	0.00	0.00	0.78	2.60	2.93	0.03
SPROUT	0.04	0.00	0.90	26.94	29.66	0.10
SRD	3.33	0.30	0.90	16.78	17.94	15.03
STARCH	36.22	10.08	0.78	33.31	37.56	95.58
TCHART	1.70	0.00	0.99	48.31	48.69	0.64
VIGOUR	1.00	0.00	0.81	20.25	24.50	3.97

GCV=genotypic coefficient of variation, PCV=Phenotypic coefficient of variation, BRNHT-Height at first apical branching, DM-Dry matter, DYLD-Dried root yield, FYLD-Fresh storage root yield, HI-Harvest index, NOHAV-Number of plant harvested, PLPCOL-Pulp colour, RTNO-Root number, RTSZ-Root size, RTWT-Root weight, RTSZ-Root size, SHTWT-Shoot weight, SPGRV-Specific gravity, SRD-Storage root diameter, TCHART-Total carotenoid chart.

4.50 DISCUSSION

4.51. Fresh Root Yield and Early Bulking

One of the targets of cassava breeding program is cassava root yield which is a complex trait and depends on different factors which directly or indirectly affects it (Tewodros & Ayenew, 2013). Late bulking cultivars occupy land for extended periods of time and therefore rendering the lands to be ineffectively utilized for other crops (Okechukwu & Dixon, 2009; Kamau *et al.,* 2011). Cattle invasion is another reason farmer ultimately need to use early bulking genotypes so that it could be harvested before the period nomads move around with their cattle.

Guinea savannah zone is characterized by short rainfalls periods and long dry periods with bush fires and cattle invasions (Adu-Gyamfi *et al.*,2016). It is therefore essential to identify cassava cultivars that can produce reasonable early storage root yield. Farmers preferred early bulking genotypes to late bulking genotypes (Nweke *et al.*,1994) because this usually averts the problem of bush fires and cattle invasion.

Cassava root yield component in terms of fresh storage root yield (FSRY) was significant in the study at Mokwa and Ubiaja with closer magnitude between GCV (32.62) and PCV (36.11) and shows that the traits is controlled more by genetic variability than the environment and this is also confirmed by study conducted by Adu-Gyamfi (2016) where they noticed significant difference in the root formation at 4, 5, and 6 months after planting (MAP) while fresh root yield was not significant in the bulking rate experiment at Ibadan and this is as a result of higher effect of the environment as shown by the larger

difference between the magnitude of the PCV(144.84) and GCV(48.69). This shows that root yield varies with genotype and environments. High and early storage root bulkiness among genotypes has been linked to genotypic variability (Okogbenin *et al.*, 2008; Joseph *et al.*, 2016).

From the study, at Mokwa and Ubiaja, high yielding genotypes at 12 MAP across locations are not of the early bulking genotypes. The high-yielding genotypes do not exclusively belong to the early bulking (EB) category; rather, some of the middle and low bulking genotype categories also exhibit high yield potential. Contrary to report of Okogbenin *et al* (2013) where they reported that early bulking genotypes are also high yielding. Early bulking genotypes in this study are low yielding relative to other genotypes in the study, although all bulking category increased in yield at 12 MAP. Similar result was obtained in the at Ibadan where the high yielding accessions was from the low bulking category.

In the bulking rate experiment conducted at Mokwa and Ubiaja, it was observed that the bulking percentage of early bulking genotypes decreased from 3 MAP to 9 MAP, which supports the report by Joseph et al. (2016) that storage roots of early bulking genotypes tend to reduce in size during their growth period. However, this trend was not observed in the early bulking category at Ibadan, where only two accessions in the early bulking category either have their bulking percentage increased and decreased later or vice versa. On the other hand, for late bulkers, the bulking rate tended to increase in the middle and later stages of growth (Joseph et al., 2016). Notably, in both experiments, the root yield of the late bulkers either increased, decreased, or remained stable at a later period during the growth cycle. Above-ground canopy architecture cannot be used to measure or

monitor early storage root bulking in cassava except destructive sampling of plants to assess the storage roots (Tumuhimbise *et al.*, 2015). This is because there still no adequate knowledge of source and sink relationships in cassava crop (Joseph *et al.*, 2016). However, ground-penetrating radar presents the exciting potential to monitor storage root bulking in cassava over time without conducting destructive sampling (Zenone *et al*., 2008, Alfredo *et al.*, 2017, Alfredo *et al*., 2019).

Information on the root system development in cassava (*Manihot esculenta* Crantz) is limited (Izumi *et al*., 1999) but destructive bulking rate evaluation at different months after planting could provide a view to source and sink relationship. The highest performing accession (IBA180037) in terms of yield at 6 MAP was the accession with highest bulking rate. The accession had the highest harvest index which is a measure of dry matter production (Alves, 2002). Although, the early bulking progeny was not the highest performing progeny across the months and at the 12 MAP. Early maturing cultivars rapidly develops roots due to more energy for biomass production in order to attain higher yield within short period (Joseph *et al.*,2016).

From the study, there were manifestation of accumulated performance in what Joseph *et al* (2016) termed "Crossover Interaction" in yield performance of genotypes as lower yield performing genotypes at earlier month was high performing at later month. In addition to the crossover interaction, there was also discontinuity in yield performance during the growth period in which genotype performs higher earlier in the month and then reduce in performance at subsequent month of evaluation. The discontinuity might be as a result of reduction in number of newly formed roots (Bararyenya *et al.,* 2020) as a

reduction in dry matter owing to onset of rainfall at this stage. Since carbohydrates demand of different parts varies across the growth cycle, the discontinuity may also be due to remobilization of dry matter from the sink behaving as source. This however do not affect their overall yield performance as the genotypes are either early bulking (EB), mid-bulking (MB) or late bulking (LB) as the best performing genotypes (IKN120036) from the experiment at Mokwa and Ubiaja was from the 6 genotypes that yielded more at 6 months after planting (MAP) than 9 MAP. This means that this genotype had higher partitioning efficiency and this is confirmed by a study by Joseph *et al.* (2016) who indicated that genotypes that partitioned dry matter production into storage root earlier than others were able to bulk 60% of their final storage root yield by 6 MAP and are characterized by high source to sink abilities which translated into early bulkiness (Adu-Gyamfi *et al.*,2016). Another observation with the genotype (IKN120036) was the stability in harvest index values across different months after planting. It could be that higher harvest index at earliest month and stability in the harvest indices across months leads to higher yield as it was observed for genotype IKN120036.

Genotype IKN120036 was shown to have matured earlier than the rest of the genotypes and this could be detected as from 3 MAP when compare with other genotypes under study. Measurement of relative growth rate after 30 days best display differences among genotypes (Kumar *et al.*, 2012). It shows that the genotype was able to allocate higher source to sink capacity as reported by George *et al.* (1998) whose study revealed that cultivars with higher root yields were able to allocate higher proportion of dry matter to storage roots. Genotype IKN120036 possesses superior root characteristics compared to

other genotypes studied. In study conducted by Michael *et al.* (2018), they found that high performing genotypes are characterized by high relative root growth rate. It has also been found that early maturing cultivars rapidly initiated storage root development thereby reaching their maximum yield within a short growing period (Joseph *et al.*, 2016).

From the bulking rate experiment at Ibadan, the overall performing progeny at 12 MAP was the accession IBA180210 (followed by IBA180081 and IBA180244) while across the month it was IBA180146 (followed by IBA180181 and the white check IBA090581). This experiment shows that early bulking may not necessarily mean high yielding (at12MAP or during harvesting period) although white check (IBA980581) was one of the LB and was the third performing across the months. Accessions that yield earlier may or may not correspondingly yield higher at 12 MAP. The white check IBA980581 that had an earlier yield at 6 MAP with 9.40 t/ha and 37 t/ha at 12 MAP was considered high yielding, however, it belongs to late-bulking category while accession IBA180098 which had second highest yield at 6 MAP with 7.00 t/ha and 11 t/ha at 12 MAP was of the early-bulking category.

4.52 Fresh Root Yield Discontinuity Among Genotypes and Accessions

The early bulking genotypes have more energy for biomass production and for early remobilization for storage root bulking. Growth pattern of genotype in both studies was continuous and discontinuous for some but increased at 12 MAP. This discontinuity may be due to reduction in number of newly formed roots and other abiotic impacts.

Accessions IBA180047, IBA180064, IBA180259, IBA180238, IBA180294, IBA180146, IBA180070, IBA180256, IBA18065 and IBA180018 show discontinuity in their root yield at 9 MAP and had higher yield at 9 MAP than at 12 MAP. There was reduction in dry matter (DM) at 9 MAP and still, it had higher root yield at this stage. Also, their shoot weight shows that they recorded low shoot weight at 12 MAP than at 9 MAP. This means there shoot weight at 9 MAP was higher. Therefore, at this stage, with lower DM and higher shoot weight, the accessions are effective in partitioning DM to their storage root. It then means these accessions bulks highly only at 9 MAP than others. These accessions had increase in root yield at 9 MAP than at 12 MAP and this may be as a result of their decrease in dry matter at 9 MAP in relation to 12 MAP.

However, the dry matter pattern across different months after planting was similar in that at 6 MAP (December), all accessions had higher DM than other months except for accession IBA180065 which increased progressively in dry matter across the different months in relation to these accessions with discontinuity in root yield. While all accessions had higher DM at 6 MAP, it reduced at 9 MAP (March) at the onset of rains and slightly reduced at 12 MAP (June). This means that at the onset of rain (i.e., 9 MAP, March) in this experiment, the dry matter reduces and yield increased. Also, genotype differs in the response to dry matter accumulation at different months after planting.

The shoot weight of most accessions at 9 MAP shows that they had lower shoot weight at this stage than at 12 MAP and this was because these accessions are effective in directing assimilates towards the root yield. And hence the non-significant effect of root yield in this experiment. Hence, these accessions are effective in assimilate partitioning

(Okogbenin *et al*., 2008; Durand *et al*., 2018) except accessions IBA180031 which had low partitioning efficiency having the least shoot weight and least root yield. However, these can be further improved by crossing with high yielding accession at 12 MAP (IBA180210, IBA180081 and IBA180244).

At 6 and 9 MAP, some accessions increased in shoot weight with no corresponding increase in their FYLD which means these accessions are not directing photosynthate towards root development but rather for shoot growth while at 12 MAP, some accessions increased in FYLD with decrease in shoot weight. This confirms report by Okogbenin *et al* (2008) where they reported genotype varies in their assimilate partitioning.

At Mokwa and Ubiaja, the higher yielding genotypes at earlier months was not the highest yielding at 12 MAP but was the highest yielding across the evaluated months after planting. The highest yielding earlier performed better than the white and yellow checks. The highest yielding genotypes at earlier month is not in the early bulking category. Some genotypes had an early bulking percentage that was higher than the rest of the months. This means that there are genotypes that bulks earlier in the population. At Ibadan, the highest yielding genotype at earlier months was not the highest yielding at 12 MAP but was the third highest across the months. The highest yielding at earlier months was the white check TMEB900581. The highest yielding at earlier month is in the low bulking category while some genotypes at earlier months (6 MAP) had higher early bulking percentage at the other month (9MAP). This means that some accessions bulks later in the population but before 12MAP.

4.53. Bulking Rate in Cassava

Rainfall data shows that the onset of rains at the first 3 months (July to September) during the growth period and this could have enhanced the performance of high yielding genotypes at 3 MAP at Mokwa and Ubiaja. This is because storage root bulking has been shown to be slow under no irrigation as reported by Joseph *et al*. (2016).

Storage root expansion begin to form from cassava fibrous root system from 2 – 3 months after planting. Tuber bulkiness is as a result of secondary thickening due to storage root formation and development (Alves, 2002). Early bulking cassava genotypes is an important farmers' preferred trait, and this is usually so because threat of drought, bushfires and invasion by animals could be averted (Joseph *et al.*,2016).

Root bulking begins about 3 months after planting and this could be observed from genotype IKN 120036 but rapid starch deposition does not occur before 6 MAP (Izumi, 1999, Gonzalez *et al*., 2015). Tuber bulking starts from 2 MAP, but it was observed from 3 MAP (Tsay *et al.,* 1988; Gonzalez *et al*., 2015). And has been reported to be stable after 3 MAP (Izumi, 1999). It has also been reported that root bulking increased with time and it differed among cultivars and varies over a long period due to changes in environmental conditions (Ekanayake *et al.,* 1998). In this study, genotypes recorded higher yields from 3 MAP to 6 MAP and reduces in yield at 9 MAP when DMC was reducing at the onset of rains.

Genotype IKN120016, a low bulking genotype had the highest shoot weight and a very low yield. This is because late bulking genotypes develop sufficient above ground mass before storage root bulking (El-Sharkawy, 2004; Alves, 2002) while early bulking

genotypes begins storage root development and shoot simultaneously and usually due to genetic variability among genotypes (Okogbenin *et al.,* 2008).

Genotype IKN120036, IBA90581, IBA980581 and IBA130896 recorded high bulking rate at 3rd ,6th ,9th month after planting and also at 12MAP. Therefore, earliness in root yield is related to rapid bulking and it varies according to genotypes. For these early bulking genotypes, there is possibility of high source to sink ratio which leads to their high yielding at early months till the 12th month. Early bulkiness genotype has high source and sink capacities which translates into total biomass for the early bulking group (Okogbenin *et al.,* 2008; Adu-Gyamfi *et al.,* 2016).

Slow bulking or late bulking genotypes develops sufficient above ground mass before it starts storage root bulking. Early bulking genotypes on the other hand begins storage root development and shoot at the same time (El-Sharkawy, 2004; Alves, 2002).

Difference in bulking rate among different genotypes and bulking periods are the major determinant for high or low yielding cassava. Early maturing genotypes bulks at early stage (Suja *et al*., 2010).

4.54. Dry Matter Content of Genotypes

Generally, the genotypes recorded high values for dry matter content (DM). Dry matter contents increased for all the genotypes from 3 to 6 MAP and reduces at 9 MAP for all the genotypes while it reduced at 12 MAP for IBA070593, IBA090525, IBA130896, IBA980581 (C), IKN120016, and increased for IBA90581, IBA130818, IBA141092, IKN120036 and TMEB419. At 3 MAP, dry matter percentage was highest for genotype

TMEB419 followed by IBA090525. At 6 MAP, it was highest for genotype IBA090525 followed by TMEB419. At 9 MAP, dry matter was highest for IBA090525 followed by TMEB419 while at 12 MAP, it was highest for TMEB419 followed by IBA090581.

Across the month and location, DM increases at 6 MAP reduces at 9 MAP and increased again at 12 MAP for all the genotypes in the study as noted in the experiment at Mokwa and Ubiaja. The fresh storage root yield (FSRY) followed same pattern by increasing from 3 MAP and reduced at 9 MAP. The DM was highest among other yield component evaluated. The genotypes all had higher DM than other traits followed by FSRY across the evaluated months. This pattern was also similar to what was obtainable among accessions for experiment conducted in Ibadan. Variation in yield may be due to the variation in the rates of DM production. Optimum growth pattern of genotypes differs, and environment may play a part. For first 6 MAP, the DM content increase was proportional to Photosynthetic Active Radiation (PAR) (Veltkamp,1985).

Genotype IBA130818 had the least DMC and incidentally the lowest performing yield. This is because the genotype is not effective in allocating photo assimilates. Similarly, accession IBA180031 in the experiment at Ibadan had the least DM and FYLD. Shoot weight and fresh storage root yield in cassava grows simultaneously and therefore photo assimilates are partitioned into both parts at the same time hence a cultivar-based competition based on the superiority of the crop for dry matter (DM) allocation. Also, upper biomass has preference over root growth (Cock *et al.*, 1979; Tan & Cock, 1979; Tan, 1987). And root growth occur after the upper biomass preference must have been met. Therefore, the superiority of genotypes would play a role in the effectiveness of

photo assimilates partitioning to the roots since shoot and root growth in cassava develop at the same time and DM is diverted into these parts of the crops during their active growth stage.

Genotype TMEB419 had the highest DM contents among all the genotypes and a mid-bulker genotype. In this study, there was positive but no significant correlation between DM and FSRY. However, there was a high positive correlation between root yield and DM accumulation according to Lahai *et al.* (1999). In their study, genotype that produces high DM have also been found to produce high leaf area index and root yield (Osiru & Hahn, 1998; Akparobi *et al.,* 1999).

Dry matter in cassava is partitioned into roots, stems, laminae and the proportion allocated to these various parts of cassava decreases with time (Lahai *et al*., 1999) but increases with time in varieties planted in the upland (George *et al*., 1998). In cassava, photo assimilates are partitioned between leaves and tuberous root growth because of simultaneous shoot and tuberous development (Alves, 2002). Cassava genotypes varies in dry matter production. Dry matter in cassava is not constant but varies across their growth stages depending on the varieties and the environment (Indira, 1996) and at 6 MAP, DM production is slow due to fallen of leaves (Howeller & Cadavid,1983; Howeller, 2011). Across the month and location, in this study, DM increases at 6 MAP reduces at 9 MAP and increased again at 12 MAP for all the genotypes.

Cassava yield and total dry matter production were higher at high temperatures than at lower temperatures (Akparobi *et al*., 1999). Production and distribution of DM to root tubers increases with light intensities but will not increase at higher intensities due to leaf

senescence (Holmes & Wilson, 1977). Partitioning of DM to roots usually increases during summer months and had little seasonal variation (Manrique, 1990) and differences in root yields between seasons may be due to differences in DM partitioning into branches.

In the study at Mokwa and Ubiaja, dry matter (DM) content and fresh storage root yield (FSRY) was the lowest at 9 MAP (January). The FSRY increases at 12 MAP (July) ostensibly due to rainfall onset but reduces at 6 MAP when there was no rain and continue to decline at 9 MAP and this could be due to the onset of rainfall as revealed in the rainfall data but gradually increase from 3 MAP to 6 MAP as a result of decline in rainfall from October to January (3MAP-6MAP).

This means, reduction in rainfall enhances dry matter partitioning into the storage roots. And as suggested by Sagrilo *et al.* (2008) who reported that low vegetation is related to dry matter partitioning. Similarly, low vegetation in this study was synonymous to the period between October and January which is a dry season period and therefore, might have also assisted in the dry matter partitioning to the storage root.

4.55. Yield Component and Nutritional Traits.

There is inverse relationship between yield and β-Carotene content of all the genotypes evaluated in Mokwa and Ubiaja location. As the beta carotene increases, there is reduction in fresh storage root yield. The inverse relationship between the beta carotene and yield means that as beta carotene increases, there is reduction in yield. It has been reported that group of genes is responsible for both yield and carotenoid content (Carvalho *et al.*,2016). So as one increases, the other reduces. In this study, at 12 MAP,

Tchart was negatively correlated with root yield and also typical example could be seen in genotype IBA980581 which is reduced in its beta carotene content as its yield increases. Genotype IBA141092 was the highest genotype with beta carotenoid content among all the genotypes. This was also reported by Olayide *et al.* (2020) in their study where they profiled 13 cassava landraces for starch and carotenoid composition and they reported IBA141092 having highest content of all trans beta carotenoid and its isomers in its root.

Also, there was a negative correlation between dry matter and harvest index meaning that as one increases, the other reduces. Root yield can be determined by the performance of their harvest index. As relationship exist between dry matter content, fresh storage root yield and harvest index. The relationship between carotenoid and bulking rate varies with genotypes and environment. In Ibadan, accessions belonging to the late bulking category had the highest carotenoid content and while in the experiment at Mokwa and Ubiaja, the genotypes with higher carotenoids content were in the early bulking category.

4.56. Genetic Variability

Understanding variability in crop genotypes is the key for a successful plant breeding program as this plays an important role in selection of desirable genotypes (Idahosa *et al.*, 2010; Ndukauba *et al*., 2015). Genetic variations for cassava root yield components have been identified in different studies in Africa (Aina *et al*., 2007, Tumuhimbise *et al*., 2015). The coefficient of variation compares the relative amount of variability between crop plant traits (Sharma, 1988). In the bulking rate experiment at Mokwa and Ubiaja, the highest coefficient of variation based on performance of yield-related traits was recorded

for shoot weight and the least being the storage root diameter. It shows that the shoot weight having the highest coefficient of variation had the higher amount of exploitable genetic variability among the traits of the genotypes studied. It also showed that this trait can be selected compared to others (Eid, 2009, Ndukauba *et al*., 2015). The storage root diameter having the least coefficient of variation shows that the traits have a low exploitable genetic variability and as a result has less potential for favorable advance for selection when compared to other traits (Chikezie *et al*., 2015).

This study revealed that shoot weight had low heritability and a low genotypic coefficient of variation (GCV) with large differences between the magnitude of GCV and phenotypic coefficient of variation (PCV) which implies that its phenotypic expression is not due to its genetic component but as result of the environmental influence. A greater difference between PCV and GCV is an indication of greater degree of environmental control (Chikezie *et al.*, 2015). Conversely, in similar study conducted by Rodrigo de Souza *et al.* (2016), they reported high genotypic coefficient of variation and low heritability for shoot weight. It will be therefore suggested that the traits be studied in multi environmental trial such as to accurately detect if the manifestation of the traits is as a result of genotype or environment. This then revealed that the highest coefficient of variation value exhibited by the traits was influenced the environment. Low heritability may be an effect of high environmental coefficient of variation which shows on low value of genetic gains (Rodrigo de Souza *et al*., 2016; Souza *et al.*, 2016).

Coefficient of variation for fresh storage root yield was 20.94 % and this allow selection as a result of genetic variability. This was similar to the coefficient of variation obtained

for fresh storage root yield in study conducted by Neto *et al.* (2013) when 10 cassava genotypes were evaluated.

Significant difference observed in harvest index (HI) at different harvesting periods across location among genotypes shows effect of genetic variation and possibility of genetic gains for this trait. This was similar to result obtained by Rodrigo de Souza *et al.,* (2016) where significant difference was observed in HI. In this study (at Mokwa and Ubiaja), HI had the highest phenotypic coefficient of variation (PCV) of 40 % among the traits with genotypic coefficient of variation (GCV) of lower value of 38%. The close difference between GCV and PCV shows an indication of little environmental impact on the genotypic expression of the traits. And the higher PCV than the GCV shows that selection is possible for the trait. High PCV indicate the existence of greater scope for selection for the traits under consideration (Khan *et al*., 2010) and GCV shows a measure of genetic variation existing in different traits. The HI thus indicate the presence of exploitable genetic variability which could assist in selection of the particular traits (Yadav *et al*., 2009). The genotypic variance for all the traits is greater than the phenotypic variance. This therefore means that the environmental coefficient of variation for all the traits are very low reflecting genetic variability among the studied traits and that the environment had little or no influence on the traits which implies selection for the trait in any environment. Estimates of PCV were higher than those of GCV but were close, this implies that genotype contributed more than the environment in the expression of these characters and selection based on these phenotypic values is attainable.

There is narrow scope of selection existing for branch height, storage root diameter, total carotenoid chart, dry matter, Harvest index, Inner skin colour and root size due to their low variability as a result of slight difference between their GCV and PCV. On the other hand, high PCV to GCV difference exist for root number, shoot weight, number harvested fresh storage root yield, root weight, starch and vigor indicates the existence of greater scope for selection for these traits (Khan *et al.*, 2010). All traits studied at Mokwa and Ubiaja bulking experiment had higher heritability. The traits with the highest heritability values were total carotenoid content (99%) and branch height (97%). Heritability values ranged from 0% to 99%, with higher values indicating less environmental influence on the observed variation (Eid, 2009).

4.57. Effect of Agroecologies on Cassava Genotypes

Variation in the performance of genotypes in an environment is due to response to various edaphic, climatic and biotic factors (Dixon *et al*.,1991). For the purpose of selecting superior genotypes during breeding program, there is need for such testing over diverse environments. However, the interaction of environments on genotypic expression is a challenge that must be overcome. Most of the traits evaluated at Ibadan had the influence of the environments on the performance of the traits by having higher PCV than the GCV except total carotenoids.

This is not far-fetched because the study revealed that fresh root yield for instance performed best in the first season of the bulking experiment at Ibadan (and in the 9^{th} and 12^{th} month after planting). Root yield performance of provitamin A cassava increased with increase in rainfall (Okoye *et al.,* 2020) and this was confirmed in this study where

cassava performed the most in cropping seasons with highest rainfall. The environments had no effect on traits at Mokwa and Ubiaja as the GCV was closer to the PCV values for most traits. Root yield increased with dry matter at Mokwa and Ubiaja while at Ibadan, root yield was low with high dry matter in the first season while in the second season, root yield was high with low dry matter. Therefore, cassava performance varies with genotypes and environment and the effect of climate, pest and diseases, biotic stresses can be improved upon when genotypes are tested in multilocation. The genotypes evaluated in different locations can be studied for their performance in terms of yield and response to pest or disease in such location such that best genotypes can be selected (Egesi *et al*., 2009, Akinwale *et al.,* 2011).

Phenotypic expression of any genotypes is a function of the environment. In cases where there is no significant interaction between the genotype and the environments, as in the bulking rate experiment at Mokwa and Ubiaja, it means the genotypes have a very high additive genotypic variance and low phenotypic variance with little effect of environmental effect. This is an indication of qualitative nature of the evaluated traits and it means that the traits are controlled by few genes that are less prone to environmental impacts (Ssemakula *et al*., 2007). And may also be due to number of environments in which the study was conducted because according to Tan and Mark (1995), cassava shows high level of GXE interaction when evaluated over diverse environments. The no interaction of GXE at Mokwa and Ubiaja shows that these genotypes were able to express their genotypic performance in single environments due to the low phenotypic variance without subjecting them to multi locations. Therefore, the breeder can select for

the best performing genotypes without testing in many locations due to low GXE. Accessions performance in terms of DM and TC was higher at season one with higher rainfall than the season where the rainfall was less. While root yield was higher at season two with less rainfall.

4.58. Genetic Advance and Improvement in Selection from Parents

The increase in the genetic advance estimates for DM, TC, Rtsz and Shtwt in the bulking experiment at Ibadan is an indication that the inheritance of the said traits is as a result of improvement from selection among the parents. The high heritability of these traits for the parent is an indication that the traits is governed by additive gene action and are highly heritable (Parkes *et al.*,2013). The lower heritability for fresh root yield at parental and progeny level revealed that environment have greater impact on the fresh root yield as revealed by the greater phenotypic coefficient of variation than the genetic coefficient of variation for both progeny and the parents. However, for Fyld and Rtwt and HI, it shows that there is no more selection to be made as their genetic advance (GA) either reduced, stable or same at both parental and progeny level and the BLUE revealed that there is no significant difference in the performance of these traits' progeny level. The reduction in the genetic advance of Fyld noticed at the progeny level may also be as a result active selection via improvement for FYLD which might be the reason for the decrease in the GA for the progeny However, GA of the TC, DM, Rtsz and Shtwt revealed that there was increase and improvement over the selection for these traits and this shows an improvement over selection for these traits.

Parent-offspring regression analysis revealed high heritability (>0.60) for total carotenoids according to Morillo & Herencia, (2009) and Njoku *et al.* (2015). This confirms the heritability in terms of TC for the parents and progeny in this study which was 100% and 82% respectively. The heritability of traits such as fresh storage root yield, root weight, harvest index, total carotenoids, dry matter and root size was higher for the parents than the F_1 progenies this may be because of higher environmental influence as indicated by larger phenotypic variance than the genotypic variance which led to lower heritability for most of the traits. For the parents, the genotypic variance was less than the phenotypic variance among the traits and this implies that the traits have little environmental effect on their performance as confirmed by the close difference between the genotypic variance and phenotypic variance.

And generally, the parental genotypes had higher heritability magnitude for traits studied. The closer values of PCV and GCV shows that environment have little effects on the parental genotypes. The genotypic variance of the progeny was less than the phenotypic variance as in the parents. Their PCV is almost similar to the GCV showing that environment have little or no impacts on the progeny performance. The higher magnitude of heritability estimates in the progeny for TC traits and others (Vigour, Number harvested and root number) is an indication of little environmental effect on the accessions. And this implies that the accessions can perform true to type in any environment. There is improvement in the performance of progenies over the parents. The F_1 progenies have been reported to outperform their parents in relation to traits such as fresh root yield and carotenoids content (Tumuhimbise, 2013; Njenga *et al.*, 2014)

whereas this study showed that the progenies outperformed their parents in total carotenoids, dry matter. Root size and shoot weight.

4.59. Best Linear Unbiased Predictor (BLUP) of Evaluated Traits

Plant breeding involves phenotyping thousands of traits and it takes several years to be able to identify a genotype with desirable traits via selection. Estimates of breeding value determine the heritability of a traits and Best Linear Unbiased Prediction (BLUP) estimate of the random effects of a fixed model provides the unbiased expected predicted and true breeding value estimates (Piepho & Mohring, 2007; Piepho *et al.,* 2008). Heritability is dependent on the breeding value because BLUP determines the proportion of heritable traits for a genotype and therefore selection could be made based on BLUP. The higher BLUP values recorded by some of the accessions implies that the accessions relative to other accessions had the highest predicted breeding value meaning that this accession has the ability to perform without the effect of the environment on its expression compare to other progenies. This is because the prediction error variance is minimized (Piepho *et al.,* 2008).

4.60. Best Linear Unpredicted Estimates (BLUE) of Evaluated Traits

The ultimate objective in breeding program is ability to predict the genotypic value of a population instead of evaluation and selection from a larger set of phenotypes. Best Linear Unbiased Estimates (BLUE), an estimate of a fixed effect of a mixed model allows the estimation of genotypic value by providing the estimates of a genotypic values for a trait through mixed model effect through which genotypic values (BLUE) and breeding values (BLUP) can be obtained.

Most research consist of both fixed and random effect and mixed model provide accurate and correct conclusion unlike other analysis of variance model where all effects are treated as fixed (Yang, 2010). The highest BLUE recorded by different accessions in this study is an indication that the accession can perform true to type independent of the environment while the least BLUE values is an indication of environmental effect on the genotypic expression of the accession performance (Piepho *et al.*,2008).

4.61. Effects of Total Carotenoids on Dry Matter Contents

Dry matter content, Fresh storage root yield, Starch, Cassava Mosaic Disease, Mealiness, Root number are traits that determines end user acceptability and variety adoption (Abdoulaye *et al.*, 2014; Esuma *et al.*, 2016). And dry matter is one of the preferred traits by end users most especially farmers (Tumuhimbise *et al*., 2012, Ceballos *et al.*, 2017). Low dry matter has been associated with total carotenoids (Jos *et al.*,1990; Moorthy *et al*., 1990).

Total Carotenoid contents of some accessions increases as their dry matter content increased as revealed in this study which is a breakthrough in breeding for these traits. Negative correlation between the two traits was reported by Esuma *et al* (2016) in their study and this implication poses a challenge in breeding program for high total carotenoids because genotype with high pVAC and acceptable level of Dry matter could only be selected (Ceballos *et al.*, 2017). The relationship of total carotenoids and dry matter increases at 6 MAP and decreases at 9 MAP and both increase slightly at 12 MAP. This is to confirm that both TC and DM are linked. The dry matter content in cassava is linked with its carotenoids content and research is ongoing to break the linkages such as

to have genotypes with high dry matter and carotenoids (Parkes, E. Pers.comm). Dry matter is linked with carotenoids and this is because two major loci found on chromosome 1 at 24.1 and 30.5 is responsible for carotenoids and a single locus of dry matter occupies same locus that peaks for carotenoids at 24.1 mbp. This linkage is rather physical linkage rather than pleiotropy which is when a gene control multiple traits or characteristics and this is responsible for the negative correlation between these traits. The haplotypes at these loci are responsible for 70 % and 37 % of the phenotypic variability in terms of yellowness and DM of roots (Rabbi *et al.*, 2017). However, while there are some accessions that increased in TC as their DM reduces, for some accessions studied, total carotenoids increased with dry matter (DM) for IBA180022, IBA1800051, IBA180067 and IBA180064 (IBA180022 with 14.89 µg/g for TC and 24.30 % DM; IBA180051 with 17.68 µg/g and DM of 22.45 %; IBA1800067 with 16.99 µg/g and DM of 23.79 % and IBA180064 with 18.05 µg/g and DM of 24.22 %). Accession IBA180058 was the top performing in terms of total carotenoids above the yellow check, accessions IBA180210 was the top performing accessions based on fresh root yield while accession IBA180124 was the top performing accession based on dry matter.

CHAPTER FIVE

5.0. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Parental genotypes were crossed in different crossing combinations to obtain progenies for bulkiness evaluation to select and identify early bulking progeny with high provitamin A carotenoid contents in Ibadan after evaluation for two seasons. Another experiment involving different cassava genotypes were established in a different agroecology of Mokwa and Ubiaja for similar purpose.

The high yielding and higher provitamin A carotenoid genotype IBA141092 were used as one of the parents in the crossing combinations to obtain F_1 progenies at Ibadan. Incidentally, this same cassava genotype was also an early bulking genotype in the Mokwa and Ubiaja bulking rate experiments and had the highest provitamin A carotenoid content and its progenies in the experiment at Ibadan were among the top five performing accessions in terms of root yield.

The three progenies of the pedigree IBA141092 were among the top 5 performing accessions in terms of fresh root yield and were low bulking. This means that early bulking is not necessarily high yielding but can be exploited to obtain high yielding progenies.

Accessions IBA180294 and IBA180098 an early bulking genotype with 95 % and 64 % bulking rate respectively was obtained at Ibadan bulking rate experiment. And genotypes IBA141092 and IBA070593 (C), an early bulking accession with 69 % and 64 % bulking

rate respectively was obtained at Mokwa and Ubiaja bulking rate experiments. These two materials are to be multiplied and to be advanced for next breeding stage.

At Ibadan, accessions IBA180058 and IBA180084 had the highest carotenoid contents of 19.40 µg/g and 19.24 µg/g respectively across the bulking category and belonged to low bulking category while at Mokwa and Ubiaja experiments, genotypes IBA141092 and IBA070593(c) had the highest beta carotenoid contents of 10.00 µg/g and 8.80 µg/g respectively across the bulking category and belonged to the early bulking category.

The bulking rate experiment at the different agroecologies suggests that cassava genotypes and accessions performed differently in terms of their relationship with root yield and carotenoids. The bulking rate experiments at Ibadan revealed that there exists wider variability among accessions evaluated. Although, there exist no correlation between root yield and total carotenoids, some of the accessions' root yield had positive relationship with carotenoids contents while at Ubiaja and Mokwa, genotypes had negative relationship between root yield and total carotenoids. The positive relationship between root yield and carotenoids as exhibited by some accessions as revealed in this study means that accessions with higher carotenoids and root yield could be selected.

Root yield increased with dry matter at Mokwa and Ubiaja location and at Ibadan, root yield was low with high dry matter in the first season while in the second season, root yield was high with low dry matter. Dry matter, root yield and total carotenoids of cassava accessions or genotypes varies with the bulking rate experiments at different agroecologies of Ibadan, Mokwa and Ubiaja.

During the first season (2019/2020) at Ibadan, rainfall was highest with 127.38 mm while root yield was lowest with 9.23 t/ha, dry matter and total carotenoids was highest with 20.93 % and 14.41 µg/g respectively and at second season (2020/2021), where rainfall was lowest, the root yield was highest with 15.50 t/ha with slightly lower dry matter and total carotenoids of 19.66 % and 12.48 µg/g respectively when compared with the first seasons while at Mokwa and Ubiaja, during the 6th month after planting when there was low or no rainfall with 4.58mm precipitation, root yield was lowest (3.63 t/ha) and dry matter and total carotenoids was highest with 25.70 % and 13.76 µg/g respectively. This shows that expression of cassava genotypes or accessions is genotype and environment dependent as low rainfall favours lower dry matter and lower carotenoids with lower root yield as observed at Mokwa and Ubiaja, the cropping seasons with lower rainfall at Ibadan had highest root yield with lower dry matter and total carotenoids while the cropping seasons with higher rainfall had the higher dry matter content and total carotenoids with lower root yield.

Accessions are variable for different evaluated traits. The high PCV and GCV values for all traits in the bulking rate experiments in Ibadan suggest that there is an existence of greater chance for making selection among the accessions for traits of choice while the closer differences between PCV and GCV observed among genotypes for different traits in the bulking rate experiment in Mokwa and Ubiaja shows less impact of the environment.

In the bulking rate experiment at Mokwa and Ubiaja, the location had no effect on the cassava genotypes, meaning that the genotypes have a very high additive genotypic

variance and low phenotypic variance with little effect of environmental effect. These genotypes need not be subjected to multilocation because of the high additive genotypic variance which is not affected by the environments.

5.2. Recommendation

Different crossing combinations should be made among the top 6 accessions that had the highest BLUP in terms of fresh root yield, DM and TC. The accessions that bulks highly at 9MAP can be used to improve the early bulking progeny. To improve any of the progeny based on root yield, dry matter, and carotenoid content, these could be crossed with accessions with highest BLUP values for root yield (IBA180146), Dry mater (IBA180124) and Total carotenoids content (IBA180058). Also, genotype IBA141092, the genotype that bulks the highest at 3MAP can be used to improve the overall best outcome from the improvement for early bulkiness, root yield and total carotenoid. To gain a better understanding of how these accessions perform in different environments, it would be beneficial to conduct this experiment in multiple locations and over several cropping seasons

5.3. Contribution to Knowledge

This study contributes to knowledge by providing new information on the performance and characteristics of different cassava genotypes and accessions in relation to bulking rate, root yield, dry matter, and provitamin A carotenoid content across different agroecologies. The study also highlights the importance of early bulking as a potential strategy for obtaining high yielding cassava varieties with high carotenoid content. The following are the contribution of this study to knowledge:

i. Identification of cassava genotypes with high provitamin A carotenoid contents and early bulking traits, which can be used to develop high-yielding cassava varieties with enhanced nutritional value.

ii. Demonstration that early bulking may not necessarily be high yielding, but can be exploited to obtain high-yielding progenies.

iii. Identification of cassava genotypes with higher carotenoid contents and positive relationship with root yield, which can be selected for breeding programs.

iv. Identification of cassava genotypes with higher carotenoid contents and dry matter, which can be selected for breeding programs.

v. Understanding the variability of cassava genotypes and accessions in terms of their relationship with root yield, carotenoid contents, and bulking rate in different agroecologies.

vi. Recognition of the impact of environment on cassava genotypes, accessions, and traits, and the need to consider the agroecological conditions for breeding and selection.

vii. Evaluation of the phenotypic and genotypic variances of cassava genotypes and accessions for different traits in bulking rate experiments, which can inform breeding strategies.

viii. Demonstration that the location has no effect on some cassava genotypes, indicating high additive genotypic variance and low phenotypic variance with little environmental effect, which can be useful for multi-location trials.

ix. Analysis of the relationship between root yield and dry matter in cassava genotypes and accessions, which can help to optimize cassava production and processing.

x. Establishment of cassava breeding and evaluation trials in different agroecologies, which can facilitate the development and dissemination of high-yielding and nutritious cassava varieties.

xi. Contribution to the literature on cassava breeding, genetics, and agronomy, which can inform future research and development efforts in cassava production and utilization.

5.3.1. Limitation

The study was conducted over a relatively short period of time, and the results may not necessarily be indicative of long-term performance of the studied genotypes and accessions. Conducting same study in many environments will give better understanding of the complex interactions between different traits and environmental factors in cassava breeding.

5.3.2. Areas for future research that build on the current findings

Root yield is at the nexus of rainfall and dry matter accumulation. Therefore, due to complexity in dry matter accumulation and the impact of rainfall on root yield, there is need to study how rainfall affect dry matter accumulation in cassava root yield. The tentative future topic might be “The Impact of Rainfall on Dry Matter Accumulation in Cassava Root Yield: A Case Study of Niger state - A Southern Guinea Savanna

Agroecology". It will be crucial to provide answer to the knowledge gap this study has created in relation to dry matter accumulation and rainfall impact in cassava. And thus, will be important to provide answers to different research questions like; what is the relationship between rainfall and dry matter accumulation in cassava root yield? How does rainfall variability affect dry matter accumulation in cassava root yield? And can we develop a predictive model that links rainfall patterns to dry matter accumulation in cassava root yield? This study will help us fill a critical knowledge gap in our understanding of the relationship between rainfall and dry matter accumulation in cassava root yield. The findings will have significant implications for cassava productivity and food security, particularly in regions where rainfall is limited or variable.

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Accession_name	FYLD(t/ha)	TC(µg/g)	DM(%)	SHTWT(kg)	HI	RTSZ	RTWT(kg)	RTNO	NOHAV	VIGOUR	SPROUT	PLTHT(cm)
IITA-TMS-IBA070593(Ychk)	15.55	10.81	25.64	19.44	0.38	5.25	15.18	30.00	9.08	5.17	3.83	180.58
IITA-TMS-IBA180017	18.03	14.19	20.76	16.18	0.43	4.92	15.16	27.50	8.00	4.33	3.17	174.92
IITA-TMS-IBA180018	5.87	10.48	10.89	4.78	0.12	1.50	1.83	5.25	1.75	3.83	1.51	155.58
IITA-TMS-IBA180022	13.26	14.89	24.30	13.00	0.34	3.92	7.38	19.33	5.08	5.50	2.67	183.92
IITA-TMS-IBA180031	1.33	7.01	10.00	2.79	0.15	1.50	1.49	6.83	2.67	2.67	0.48	59.75
IITA-TMS-IBA180034	11.77	14.81	21.71	18.15	0.31	4.08	8.03	20.17	6.25	3.83	3.00	190.96
IITA-TMS-IBA180037	14.86	16.86	25.04	16.12	0.47	5.17	13.54	32.83	7.67	5.83	3.33	187.75
IITA-TMS-IBA180047	11.09	16.12	20.92	12.47	0.27	3.50	7.50	22.20	7.70	3.80	3.50	147.40
IITA-TMS-IBA180049	17.41	15.64	19.19	19.86	0.28	3.67	9.18	29.75	5.58	5.00	1.89	194.58
IITA-TMS-IBA180051	7.91	17.68	22.45	12.49	0.37	4.42	7.83	20.25	7.83	5.33	3.67	184.50
IITA-TMS-IBA180058	14.48	19.40	19.93	15.22	0.36	3.83	8.56	18.67	6.17	5.00	3.37	186.50
IITA-TMS-IBA180064	11.45	18.05	24.22	14.90	0.34	3.58	10.11	32.17	8.00	4.17	3.67	196.83
IITA-TMS-IBA180065	16.80	13.39	15.11	10.12	0.25	3.08	6.39	15.92	4.67	4.17	1.87	155.42
IITA-TMS-IBA180067	10.19	16.99	23.79	18.41	0.23	3.42	5.86	16.58	7.00	5.83	2.50	186.50
IITA-TMS-IBA180070	10.10	17.27	19.31	7.16	0.27	3.42	3.32	12.00	4.75	3.83	1.68	167.33
IITA-TMS-IBA180071	14.66	14.67	21.51	12.99	0.32	4.75	8.38	15.33	5.17	3.00	1.69	213.75
IITA-TMS-IBA180073	18.66	15.34	19.90	10.13	0.46	4.58	11.39	27.17	7.92	4.17	2.92	199.75
IITA-TMS-IBA180081	22.21	15.33	24.04	15.08	0.46	4.75	22.33	47.42	9.42	5.83	4.00	195.54
IITA-TMS-IBA180084	7.40	19.24	22.83	15.06	0.22	3.08	6.14	22.58	7.17	4.17	3.21	213.08
IITA-TMS-IBA180088	11.69	16.30	24.23	18.41	0.35	4.50	13.27	33.42	9.25	5.00	4.00	180.92
IITA-TMS-IBA180090	9.31	16.36	20.53	10.08	0.33	4.08	5.17	17.50	5.25	3.33	2.70	173.33
IITA-TMS-IBA180098	8.11	12.97	16.40	10.72	0.29	3.08	4.60	14.75	4.25	5.00	3.01	186.17
IITA-TMS-IBA180106	13.98	14.75	22.91	16.71	0.40	4.75	16.76	29.67	8.50	4.67	3.92	163.75
IITA-TMS-IBA180124	12.51	15.21	25.71	26.98	0.25	4.42	12.61	40.75	9.33	4.67	3.88	187.00
IITA-TMS-IBA180146	26.33	14.09	20.61	10.42	0.35	3.33	8.63	18.00	5.08	3.50	2.66	137.50
IITA-TMS-IBA180147	15.20	15.10	21.48	14.41	0.38	4.71	12.56	21.00	7.79	5.00	2.89	157.71
IITA-TMS-IBA180148	13.16	17.86	19.54	9.12	0.49	4.25	8.68	20.83	6.25	4.17	2.12	138.42
IITA-TMS-IBA180158	3.03	12.65	17.20	8.30	0.18	2.67	2.13	6.33	4.75	5.25	0.75	148.00
IITA-TMS-IBA180173	2.93	11.73	17.01	13.62	0.12	2.42	2.78	11.50	8.42	3.00	3.08	143.17
IITA-TMS-IBA180180	10.09	12.06	16.38	13.93	0.27	3.58	6.62	15.67	7.58	4.67	3.00	172.58
IITA-TMS-IBA180182	15.87	11.77	17.78	11.02	0.31	4.08	10.41	21.25	3.83	2.33	2.04	113.17
IITA-TMS-IBA180210	19.83	16.00	20.66	12.96	0.34	3.67	11.69	25.67	6.25	4.17	3.44	167.17

IITA-TMS-IBA180221	13.17	13.22	20.98	17.83	0.31	4.17	8.83	25.00	7.08	5.00	1.75	196.21
IITA-TMS-IBA180231	9.74	10.34	12.79	6.78	0.12	2.08	1.41	4.58	2.00	5.00	0.43	112.33
IITA-TMS-IBA180244	18.37	13.59	21.38	11.16	0.51	4.75	19.18	55.83	9.08	5.00	3.75	195.08
IITA-TMS-IBA180256	11.45	10.88	14.23	7.31	0.30	2.83	4.78	10.25	3.08	2.25	1.54	110.50
IITA-TMS-IBA180259	5.97	13.50	17.81	11.54	0.19	2.92	2.94	9.75	3.45	2.58	1.25	143.50
IITA-TMS-IBA180271	5.46	9.18	16.16	11.73	0.21	2.92	5.68	15.00	6.25	2.58	3.42	124.33
IITA-TMS-IBA180294	5.50	10.27	14.25	5.22	0.18	1.83	3.33	11.50	2.50	3.25	1.17	91.17
IITA-TMS-IBA980581(WChk)	21.42	2.76	26.18	26.18	0.37	5.33	18.38	44.67	8.50	5.50	3.67	225.17
TMEB419(WChk)	9.15	3.22	25.99	11.84	0.36	3.58	6.42	17.67	7.17	6.67	3.17	216.75
TMEB693(WChk)	13.47	2.85	30.52	18.73	0.33	4.25	11.64	28.83	9.08	5.33	3.50	244.42
Mean	12.35	13.45	20.29	13.32	0.31	3.73	8.76	21.94	6.35	4.37	2.69	169.12
SE±	0.84	0.62	0.68	0.79	0.02	0.15	0.78	1.76	0.34	0.17	0.16	5.75
CV	0.44	0.30	0.22	0.38	0.33	0.26	0.58	0.52	0.34	0.25	0.38	0.22
SD	5.45	4.02	4.38	5.12	0.10	0.99	5.06	11.39	2.18	1.07	1.01	37.24

Wchk=white check, Ychk=Yellow check, SE=Standard error, CV=coefficient of variation, SD=standard deviation

Appendix I: Mean summary of 42 accessions evaluated at different months and year

Parental Genotypes	MCMDS	DM	DYLD	FYLD	SHTWT	RTWT	HI	NOHAV	RTNO	RTWT	SPROUT	RTINNCOL	RTOUTCOL	PLPCOL	RTSHP	RTSZ	TCHART	TCiCHK
IITA-TMS-IBA011371(C)	1.52	24.74	3.39	12.77	19.17	16.03	0.44	9.68	36.83	4.27	0.89	1.37	2.29	1.98	2.11	5.19	4.50	8.68
IITA-TMS-IBA061635(C)	1.14	25.28	3.52	13.37	15.70	14.68	0.45	8.06	28.20	4.10	1.13	1.47	2.82	1.99	2.20	4.98	4.44	8.40
IITA-TMS-IBA070539(C)	1.15	26.21	4.88	17.49	21.74	17.93	0.46	10.50	45.29	3.80	0.80	1.46	2.76	1.96	2.11	4.86	3.66	9.28
IITA-TMS-IBA140145(C)	3.00	32.20	2.80	8.80	3.40	2.20	0.40	4.00	18.00	1.97	1.00	2.00	3.00	1.96	2.00	3.00	4.00	11.00
IITA-TMS-IBA141092(C)	1.06	25.46	9.70	30.76	17.01	17.39	0.50	7.22	38.14	5.60	0.78	1.73	1.99	1.98	2.38	4.86	4.49	14.86
IITA-TMS-IBA141096(C)	1.67	22.54	7.09	26.79	16.39	19.11	0.54	6.82	41.88	4.50	0.75	1.47	1.53	2.00	2.35	4.76	4.76	13.28
IITA-TMS-IBA141104(C)	2.56	18.84	1.42	9.06	10.34	4.89	0.35	7.00	20.78	3.23	0.89	1.78	3.00	2.00	2.00	3.44	4.78	14.19
IITA-TMS-IKN130010(C)	1.73	30.09	6.06	18.63	12.55	11.24	0.45	5.96	27.58	2.68	0.87	1.23	2.91	2.00	2.19	4.48	4.09	13.08
IITA-TMS-UBJ120003(C)	1.00	30.58	5.03	15.07	18.78	12.38	0.40	6.60	22.93	4.40	0.74	1.47	3.00	2.00	2.07	4.87	3.60	12.20
IITA-TMS-IBA160011	1.00	17.98	8.45	47.50	42.25	19.00	0.31	5.00	54.50	3.99	1.00	2.00	3.00	2.00	2.00	5.00	3.00	9.13
IITA-TMS-IBA160019	1.13	22.22	8.33	26.10	11.88	14.13	0.55	5.00	35.25	3.73	0.50	1.75	3.00	2.00	2.00	5.00	3.75	14.66
IITA-TMS-IBA160021	1.00	19.03	7.16	28.06	22.25	14.20	0.38	4.50	28.50	4.64	0.75	2.00	2.50	2.00	2.50	4.50	3.25	11.54
IITA-TMS-IBA160027	3.50	17.85	5.24	29.38	25.25	11.75	0.33	4.00	39.00	3.66	0.80	2.00	3.00	2.00	2.00	3.00	3.00	14.07
IITA-TMS-IBA160043	1.00	19.54	7.33	37.50	13.00	15.00	0.54	1.00	23.00	4.40	0.20	2.00	2.00	2.00	2.00	7.00	4.00	11.98
IITA-TMS-IBA160063	1.00	25.21	8.89	26.88	22.95	14.00	0.38	4.50	33.25	4.58	0.70	1.75	2.00	2.00	2.00	5.00	4.00	12.21
IITA-TMS-IBA160075	1.00	22.93	5.35	14.85	17.50	7.38	0.29	5.75	20.00	3.25	0.80	2.00	3.00	2.00	2.75	4.50	4.50	15.43
IITA-TMS-IBA160077	1.00	27.88	5.01	10.31	18.38	5.00	0.22	7.00	18.00	2.10	1.00	2.00	3.00	2.00	2.25	3.00	4.00	14.71
IITA-TMS-IBA160079	1.00	23.82	4.60	19.38	25.25	7.75	0.23	5.00	20.50	3.17	1.00	2.00	3.00	2.00	2.00	3.00	4.50	11.10
IITA-TMS-IBA160089	1.33	19.95	4.31	21.88	7.75	8.75	0.53	2.00	13.00	4.74	0.40	2.00	3.00	2.00	2.00	6.00	3.50	12.29
IITA-TMS-IBA160096	3.50	20.64	2.42	11.88	8.75	4.75	0.36	3.00	9.50	0.98	0.70	2.00	3.00	2.00	2.00	4.00	4.00	11.40
IITA-TMS-IBA160097	3.67	18.67	0.89	3.75	2.50	1.50	0.38	1.00	7.00	0.62	0.20	2.00	3.00	2.00	2.00	3.00	4.00	18.82
IITA-TMS-IBA160099	1.00	22.25	7.18	25.78	27.50	13.63	0.34	5.75	30.25	4.70	1.00	1.50	2.75	2.00	2.00	5.00	3.75	12.75
IITA-TMS-IBA160101	1.00	16.90	6.28	36.88	16.50	14.75	0.48	5.00	31.50	4.52	1.00	2.00	2.00	2.00	2.00	4.00	3.00	10.49
IITA-TMS-IBA160120	2.17	19.16	4.22	20.63	14.75	8.25	0.35	5.00	28.50	4.37	1.00	2.00	3.00	2.00	2.00	3.00	4.00	8.13
IITA-TMS-IBA160132	3.33	21.04	2.14	10.63	12.25	4.25	0.27	3.50	19.00	2.89	0.60	2.00	3.00	2.00	2.00	3.00	5.00	19.32
IITA-TMS-IBA160137	1.13	15.43	2.60	16.25	6.50	6.50	0.50	4.00	21.00	3.16	0.65	2.00	2.00	2.00	2.00	3.00	4.00	21.27
IITA-TMS-IBA160139	3.17	19.41	1.97	11.25	7.25	4.50	0.39	4.00	16.00	2.43	0.90	2.00	3.00	2.00	2.00	4.00	4.50	19.12
IITA-TMS-IBA160141	3.50	15.08	2.21	1.88	4.00	0.75	0.17	1.50	3.50	0.34	0.50	2.00	3.00	2.00	2.00	3.00	4.00	18.85

IITA-TMS-IBA160142	3.33	15.97	2.31	16.88	26.50	6.75	0.20	4.50	22.50	3.11	0.90	2.00	3.00	1.00	2.00	3.00	2.00	7.18
IITA-TMS-IBA160160	3.33										0.20							
IITA-TMS-IBA160167	1.13	24.80	3.30	13.75	7.00	5.50	0.46	1.50	19.50	2.56	0.70	2.00	3.00	2.00	2.00	3.00	4.00	19.60
IITA-TMS-IBA160173	2.67	22.15	1.83	10.00	6.50	4.00	0.32	3.50	14.00	3.33	0.70	2.00	3.00	2.00	2.00	3.00	3.50	16.33
IITA-TMS-IBA160199	2.67	18.36	0.92	3.75	4.50	1.50	0.25	1.50	5.50	0.67	0.40	1.50	2.50	2.00	2.00	3.00	3.50	15.08
IITA-TMS-IBA160201	2.95	20.10	3.29	12.29	15.50	5.33	0.26	5.33	24.67	4.86	0.90	1.67	2.67	2.00	2.00	3.00	4.00	18.16
IITA-TMS-IBA160203	3.25	19.47	5.10	14.79	15.33	8.33	0.34	5.00	26.33	4.03	1.00	2.00	3.00	2.00	2.00	4.33	4.67	14.71
IITA-TMS-IBA160207	1.06	19.97	2.21	7.08	8.63	3.00	0.25	3.33	14.67	1.87	0.51	1.67	3.00	2.00	2.00	3.00	4.33	15.66
IITA-TMS-IBA160575	1.00	20.85	1.89	6.25	13.50	3.50	0.21	7.00	14.00	1.43	0.86	2.00	3.00	2.00	2.00	3.00	4.00	17.87
IITA-TMS-IBA163955	1.00	16.20	2.59	16.00	14.00	5.60	0.29	3.00	13.00	1.29	0.56	1.00	3.00	2.00	2.00	3.00	3.00	13.38
mean	1.91	21.59	4.37	17.68	14.95	9.06	0.37	4.78	23.92	3.24	0.74	1.81	2.75	1.97	2.08	3.97	3.92	13.79
SD	1.01	4.19	2.38	10.12	8.11	5.43	0.11	2.22	11.27	1.35	0.24	0.27	0.41	0.16	0.17	1.04	0.61	3.59
SE±	0.16	0.69	0.39	1.66	1.33	0.89	0.02	0.37	1.85	0.22	0.04	0.04	0.07	0.03	0.03	0.17	0.10	0.59
CV	0.53	0.19	0.54	0.57	0.54	0.60	0.29	0.46	0.47	0.42	0.32	0.15	0.15	0.08	0.08	0.26	0.16	0.26

Wchk=white check, Ychk=Yellow check, SE=Standard error, CV=coefficient of variation, SD=standard deviation

Appendix II: Mean Performance of Parental Genotypes for different evaluated traits

Appendix III: Summary of monthly weather at Ibadan during 2019 and 2020 cropping season

Ibadan

2019		Temp			2020				
Month	Rainfall(mm)	Minimum(°c)	Maximum(°c)	Relative humidity	Month	Rainfall(mm)	Minimum(°c)	Maximum(°c)	Relative humidity
Jan	7.10	21.20	32.80	88.00	Jan	0.00	22.00	33.00	76.00
Feb	42.90	22.00	33.90	97.00	Feb	0.00	22.00	34.00	71.00
Mar	110.30	23.10	34.00	96.00	Mar	27.69	23.00	34.00	75.00
Apr	200.60	23.00	32.90	95.00	Apr	19.80	23.00	32.90	78.00
May	242.20	22.00	31.70	97.00	May	49.31	22.00	31.70	82.00
Jun	212.00	21.80	28.70	97.00	Jun	49.16	21.80	29.00	86.00
Jul	206.20	21.00	27.60	93.00	Jul	4.73	21.50	28.00	88.00
Aug	236.85	21.00	27.00	96.00	Aug	0.47	21.00	27.00	88.00
Sept	305.30	21.80	28.70	96.00	Sept	5.66	21.80	28.60	86.00
Oct	299.95	22.00	30.00	97.00	Oct	10.37	22.00	30.00	84.00
Nov	32.40	22.00	31.80	95.00	Nov	0.00	22.00	32.00	80.00
Dec	9.00	21.00	33.00	92.00	Dec	0.15	21.00	33.40	76.00

Temp=Temperature
Source : IITA weather station, Ibadan, Oyo state, Nigeria.

Appendix IV: Summary of monthly weather at Ubiaja at 2018 and 2019 cropping season

Ubiaja	2018	Temp(^{0}C)			2019		Temp(^{0}C)		
Months	Rainfall	min	max	RH	Months	Rainfall	min	max	RH
Jan	0.19	22	33	76	Jan	14.89	21.6	33	76
Feb	78.75	22.9	33.4	77	Feb	18.22	22	32.9	77
Mar	71.22	22	33	76	Mar	58.32	22	33	76
Apr	51.56	22.9	32.4	87	Apr	35.1	22	32.4	77
May	109.85	23	31.3	96	May	161.15	23	31.3	96
June	412.5	22.5	31	98	June	315.76	22.5	33.3	98
July	340.64	21	27.8	98	July	241.36	21	26.8	98
Aug	295.96	21.4	27	97	Aug	386.17	21.4	27	95
Sept	325.42	22	28.9	98	Sept	384.7	22	29.2	98
Oct	139.97	22	29.8	95	Oct	158.4	22	28.8	95
Nov	76.72	21.6	31.6	97	Nov	29.3	20.6	31.2	77
Dec	0.22	21	32	74	Dec	0	21	31.6	76

Temp=Temperature, RH=Relative humidity, min=Minimum, max=Maximum
Source : IITA weather station, Ubiaja, Edo state, Nigeria.

Appendix V: Summary of monthly weather at Mokwa during 2018 and 2019 cropping season

Mokwa

2018		Temp. (^{0}C)			2019		Temp. (^{0}C)		
Months	Rainfall	min.	max.	RH	Months	Rainfall	min.	max.	RH
Jan	0	19.3	33.7	56	Jan	0	19.3	33.7	55
Feb	26.04	22.1	35.7	41	Feb	1.13	22.1	35.7	39
March	8.24	23.5	35.8	45	Mar	3.15	23.5	35.8	51
April	21.3	23.4	34.5	66	Apr	14.16	23.4	34.5	65
May	86.06	22.6	32.5	73	May	134.29	22.6	32.5	74
June	188.68	21.7	30.7	85	June	88.54	21.7	30.7	82
July	306.61	21.5	29.1	86	July	116.19	21.5	29.1	84
Aug	189.66	21.3	28.7	86	Aug	171.19	21.3	28.7	85
Sept	228.03	21.2	29.6	85	Sept	282.28	21.2	29.6	85
Oct	95.72	21.5	33.3	82	Oct	271.05	21.5	33.3	82
Nov	1.41	20.3	33.4	72	Nov	4.85	20.3	33.4	70
Dec	0	18.8	32.4	61	Dec	0	18.8	32.4	60

Temp=Temperature, , RH=Relative humidity, min=Minimum, max=Maximum
Source : IITA weather station, Mokwa, Niger state.

Appendix VI: Soil physicochemical properties at Ubiaja and Mokwa

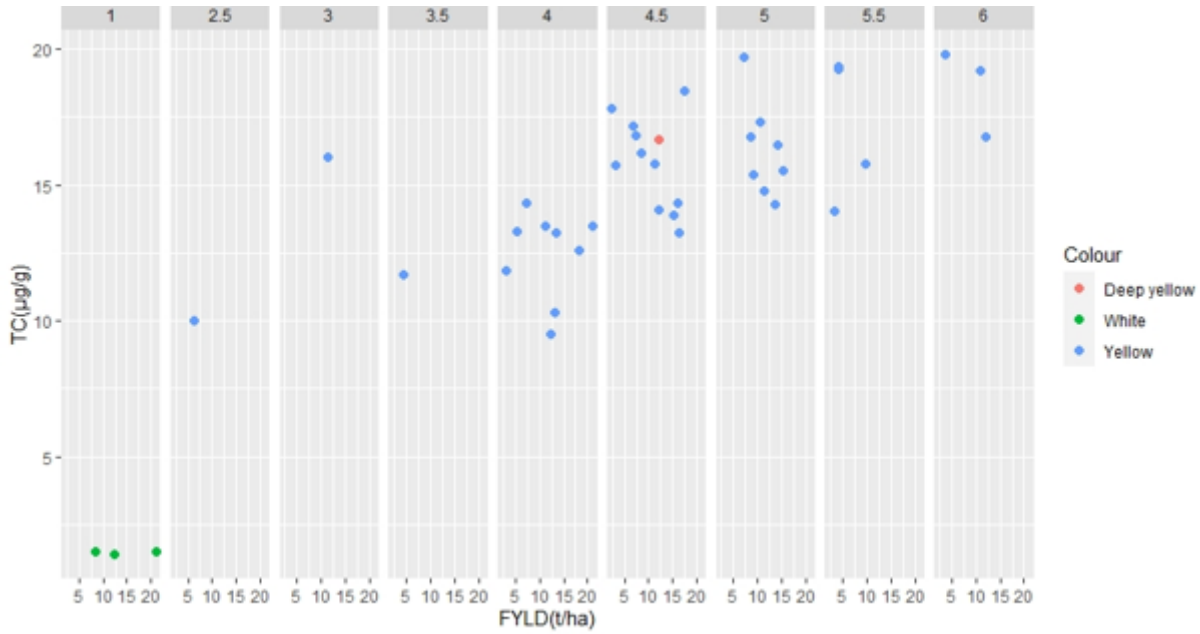
2018/2019 Cropping Season		
Properties	**Mokwa**	**Ubiaja**
PH H_2O	7.1	5.9
Organic C(%)	8.44	1.5
TotalN(g/kg)	0.72	0.68
Avail P(mg/kg)	11.47	5.48
Exch.K(cmol+kg)	0.41	0.39
Sand(g/kg)	721.1	688.4
Silt(g/kg)	70.1	80.45
Clay(g/kg)	240.37	178
Soil Texture	Sandy loam	sandy loam

Appendix VII: Soil physicochemical properties at Ibadan during 2019 and 2020 cropping season

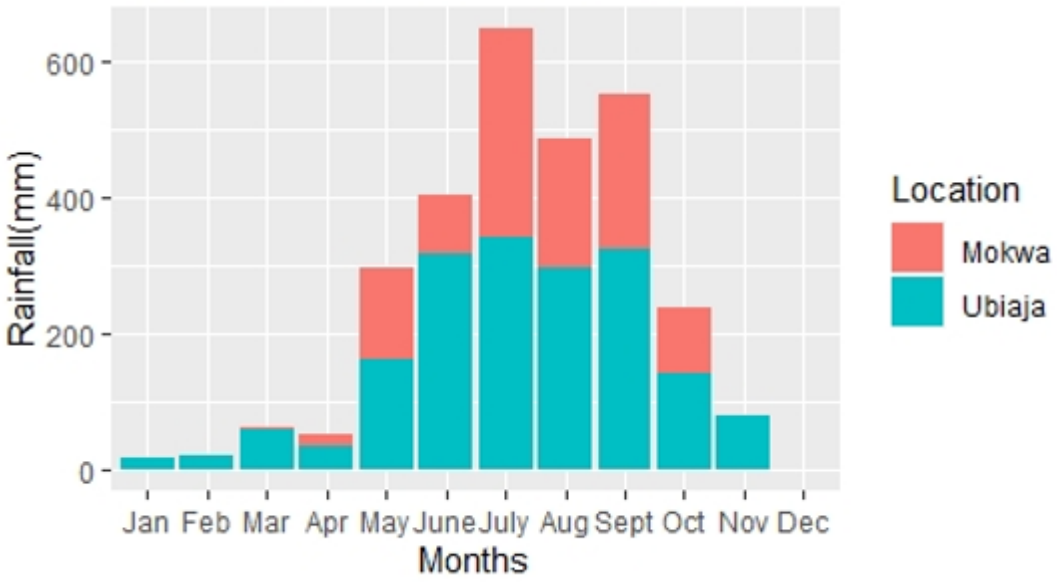
	Cropping Season	
	2019/2020	**2020/2021**
Properties	**Ibadan**	**Ibadan**
PH H_2O	5.7	6.5
Organic C(%)	1.52	5.9
TotalN(%)	0.74	0.68
Avail P(mg/kg)	5.78	7.42
Exch.K(cmol+kg)	0.22	0.26
Sand(g/kg)	629	720
Silt(g/kg)	98	78
Clay(g/kg)	137	129
Soil Texture	Sandy loam	Sandy loam

Appendix IIX: Experimental sites

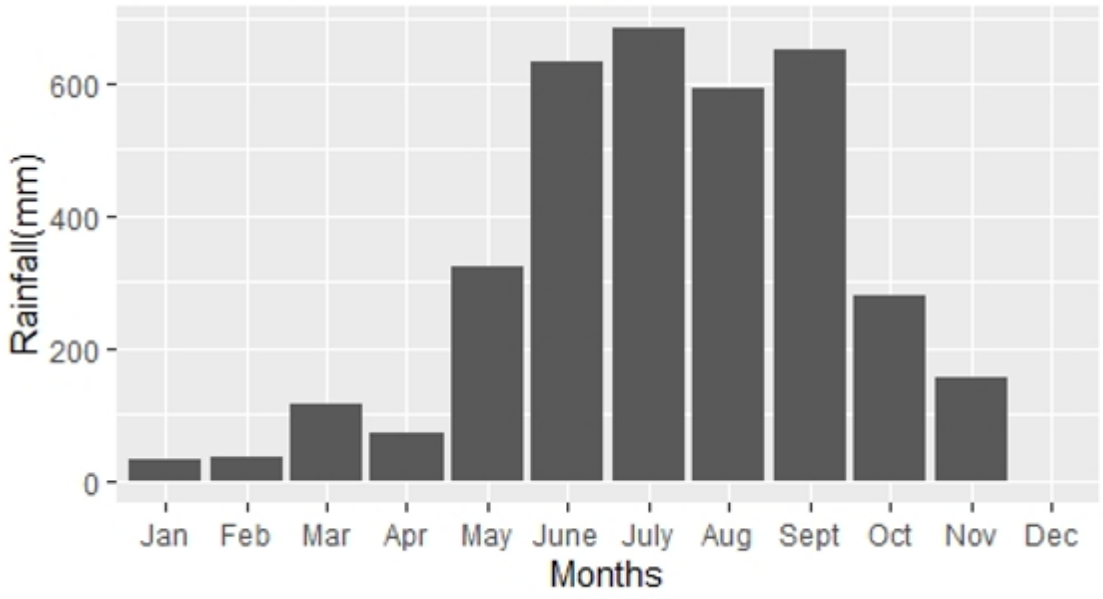
Climatic factors	Ibadan	Mokwa	Ubiaja
Lattitude	07.50278^{o}N	06.32812^{o}N	06.7608^{o}N,
Longitude	003.89459^{o}E	005.63599^{o}E	006.5358 ^{0}E
Altitude	209m	212.7m	202.1m
Mean Annual Rainfall(mm)	158.7	93.27	154.43
Agro ecological zones	Derived Savanna	Southern Guinea Savana	Rainforest
Length of growing periods(days)	211-270	181-201	211-270
Soil type	Ferric Luvisol	Ferric Luvisol	Ferric Luvisol



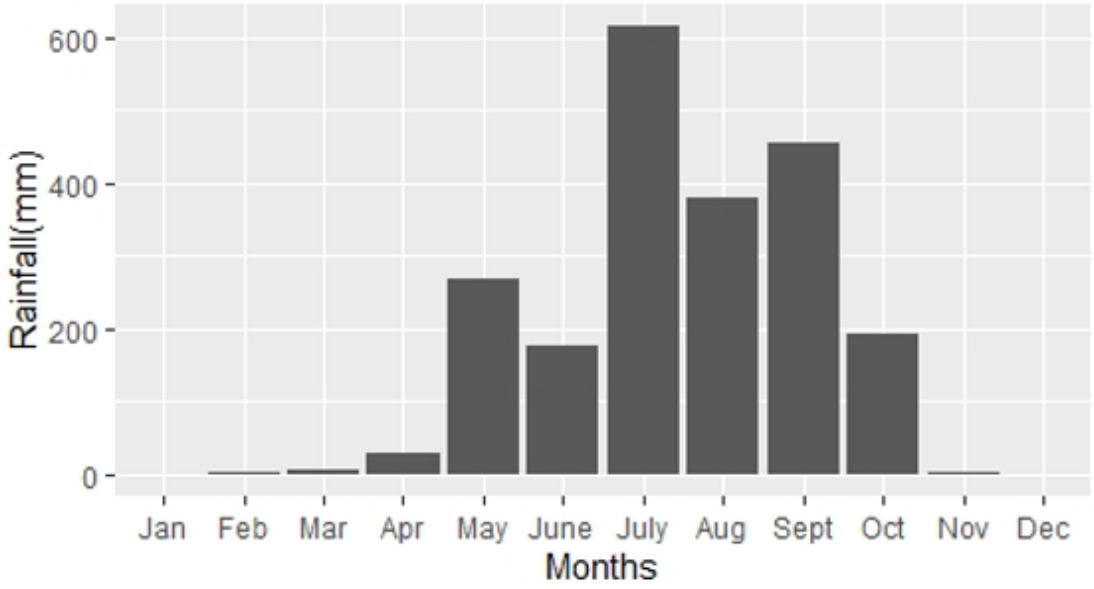
Appendix IX: Total carotenoid relationship and fresh storage root yield relationship of accessions and their colour relationship.



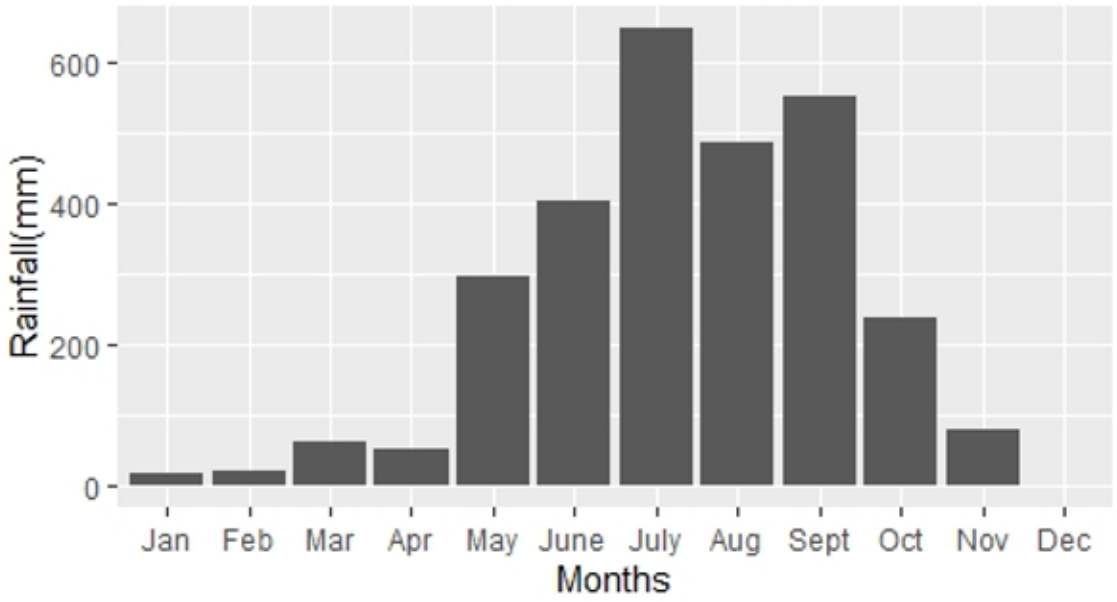
Appendix X: Stacked Bar plots of Mean Rainfall distribution at Mokwa and Ubiaja



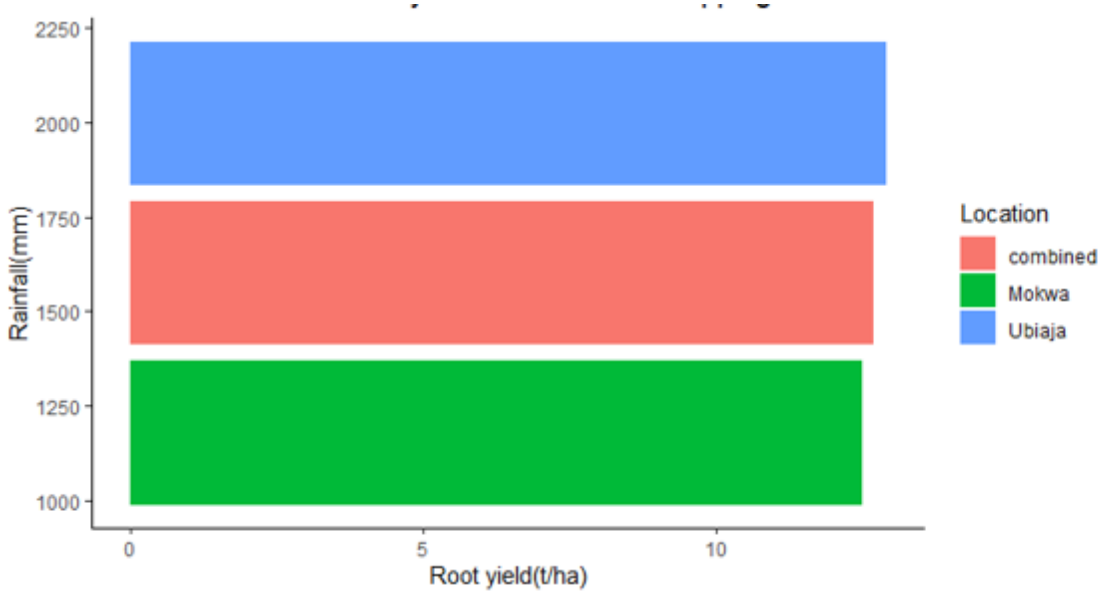
Appendix XI: Mean Rainfall distribution at Ubiaja



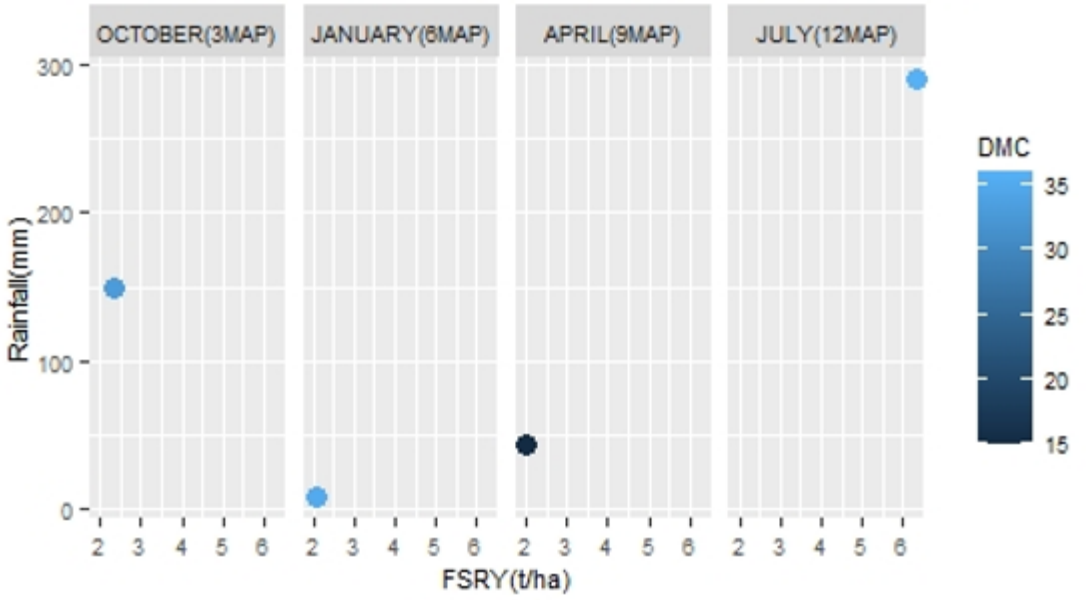
Appendix XII: Mean Rainfall Distribution at Mokwa



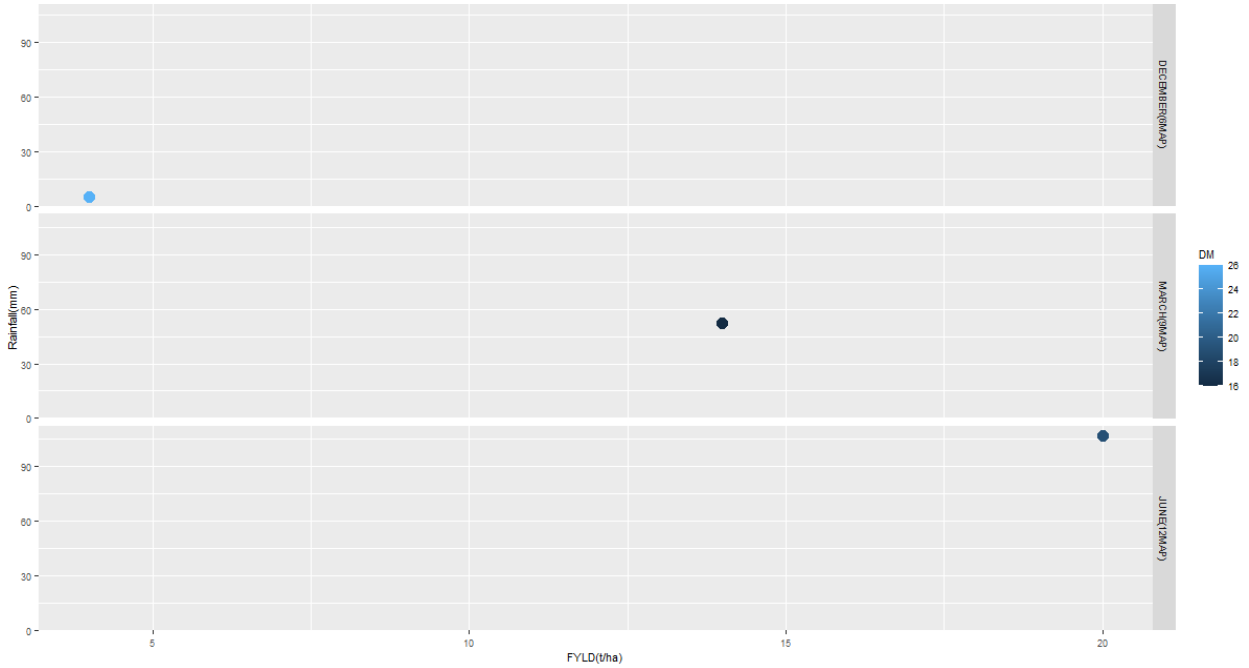
Appendix XIII: Mean Rainfall Distribution across Location



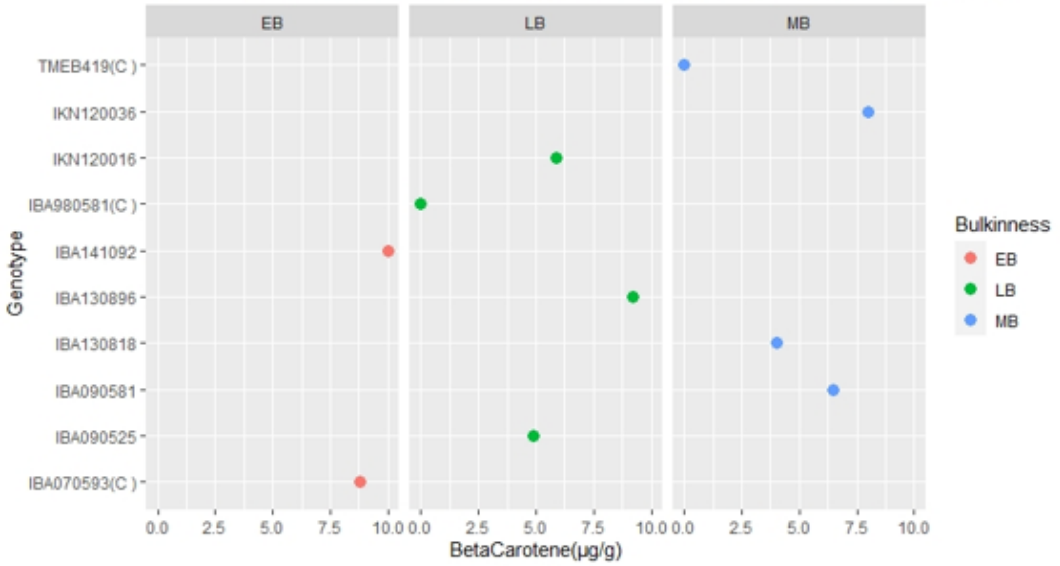
Appendix XIV: Mean Rainfall Distribution with Corresponding Root Yield performance at Mokwa, Ubiaja and Combined



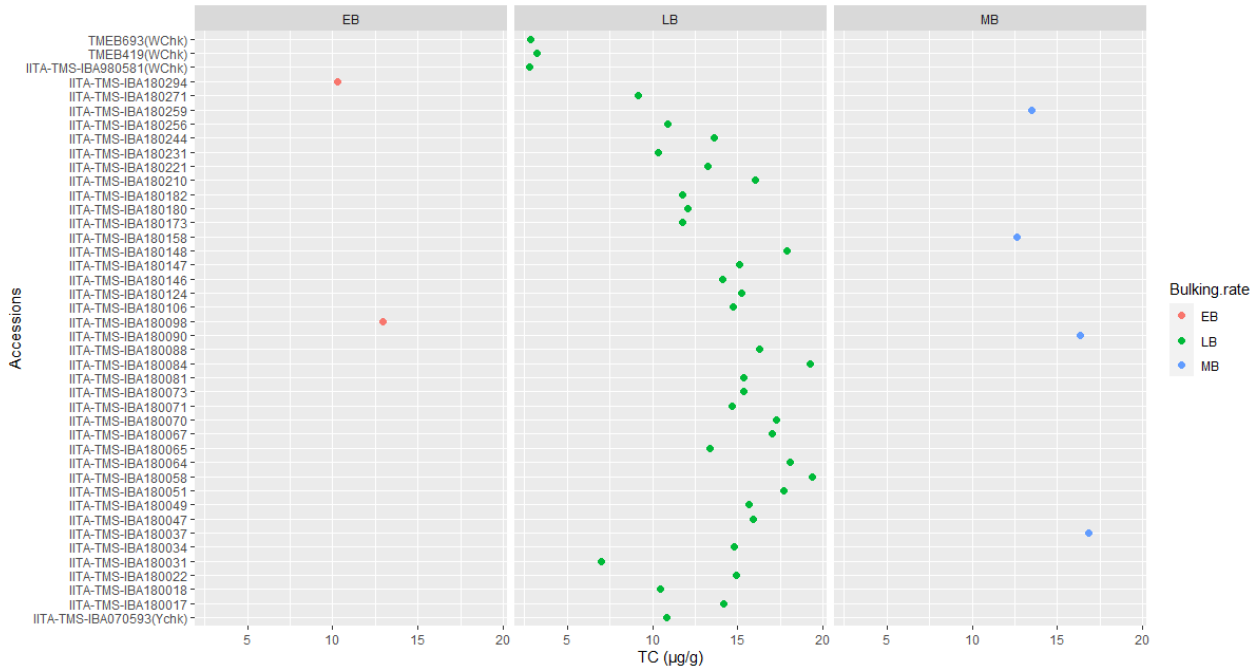
Appendix XV: Fresh storage root yield performance at Ubiaja and Mokwa at different evaluated months and rainfall



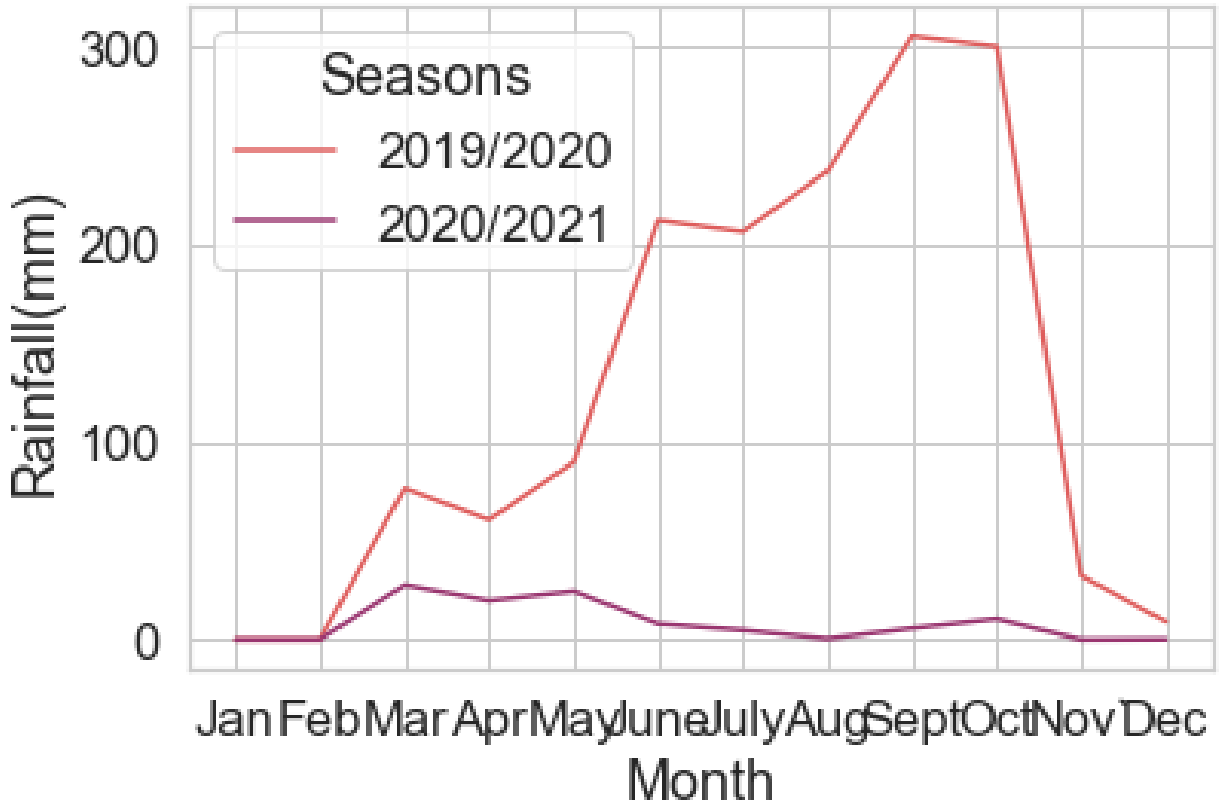
Appendix XVI: Performance of accessions in terms fresh storage root yield with respect to rainfall at different months in Ibadan



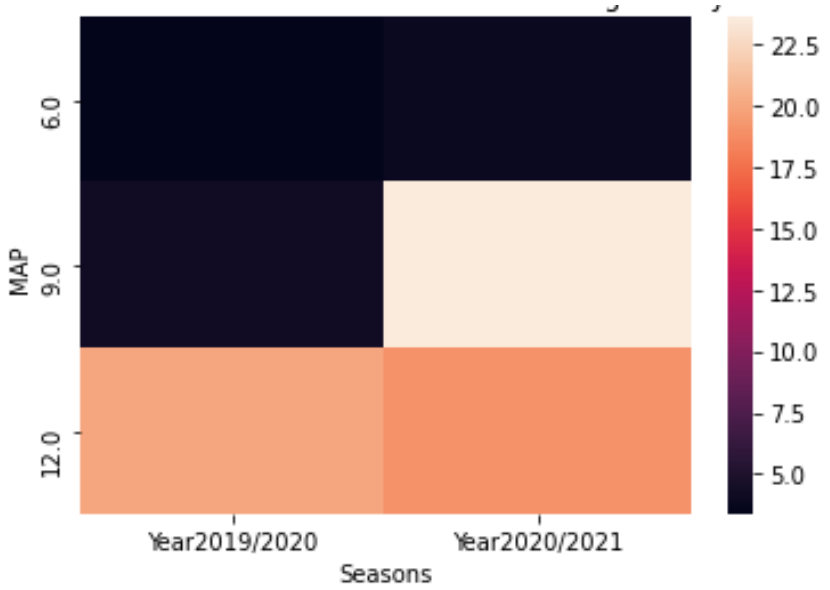
Appendix XVII: Relationship between Beta carotene content and Early bulkiness in Cassava genotypes at Mokwa and Ubiaja



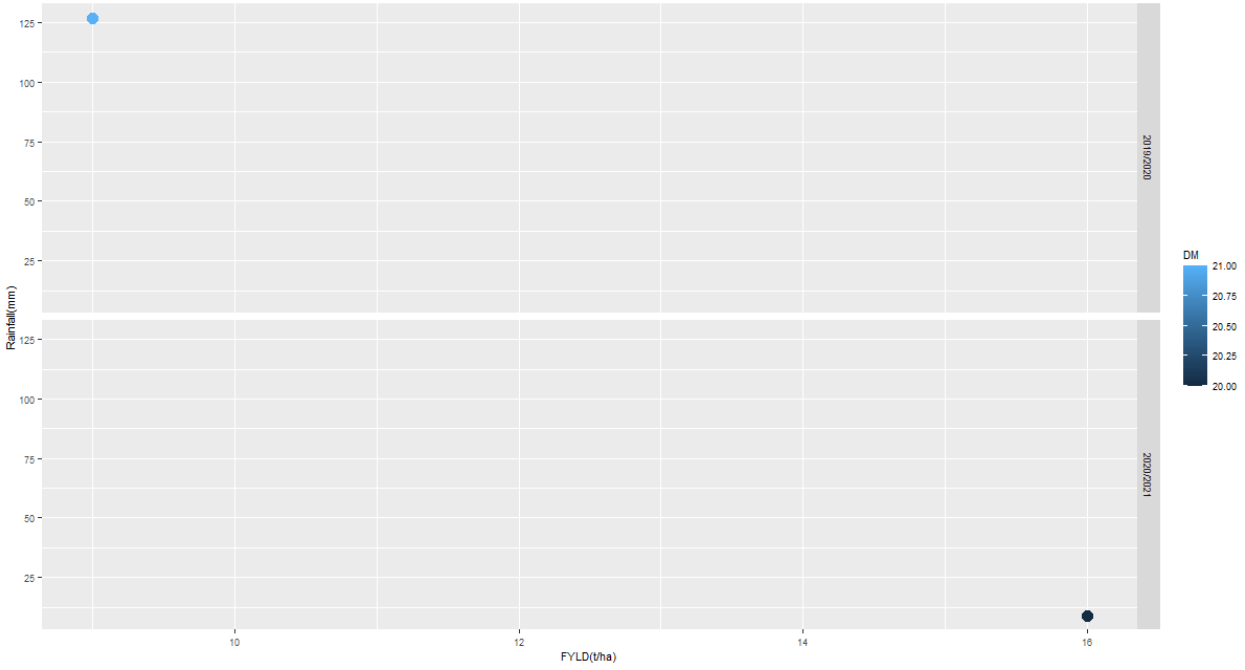
Appendix XVIII: Relationship between Beta carotene content and Early bulkiness in Cassava accessions at bulking rate experiments in Ibadan



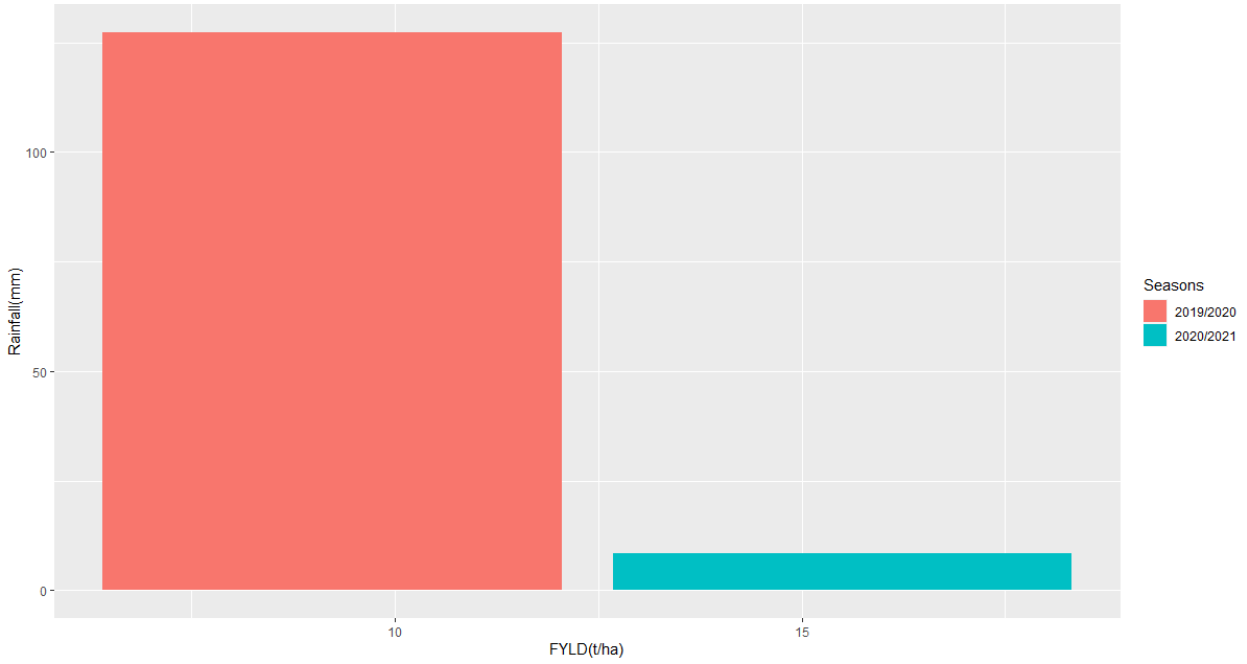
Appendix IXX: Trend of rainfall across cropping seasons



Appendix XX: Heatmap of the effect of cropping seasons on fresh root yield



Appendix XXI: Rainfall and Cropping seasons effect on dry matter and fresh root yield



Appendix XXII: Effect of cropping seasons on fresh root yield

Appendix XXIII: Rainfall relationship with yield-related data at different months and location in Mokwa/Ubiaja

MAP	Rainfall(mm)	FYLD(t/ha)	DM(%)	β-carotene(µg/g)
3MAP (October)	149	2.3	33	
6MAP (January)	8	2	35	
9MAP (April)	43	1.9	15	
12MAP (July)	291	6.3	36	6.11
Location	Rainfall(mm)	FYLD(t/ha)	DM(%)	β-carotene(µg/g)
Mokwa	1178.89	12.48	28.57	5.57
Ubiaja	2023.73	12.9	29.98	6.64

Appendix XXIV: Rainfall relationship with yield-related and quality traits at different months and cropping seasons in Ibadan

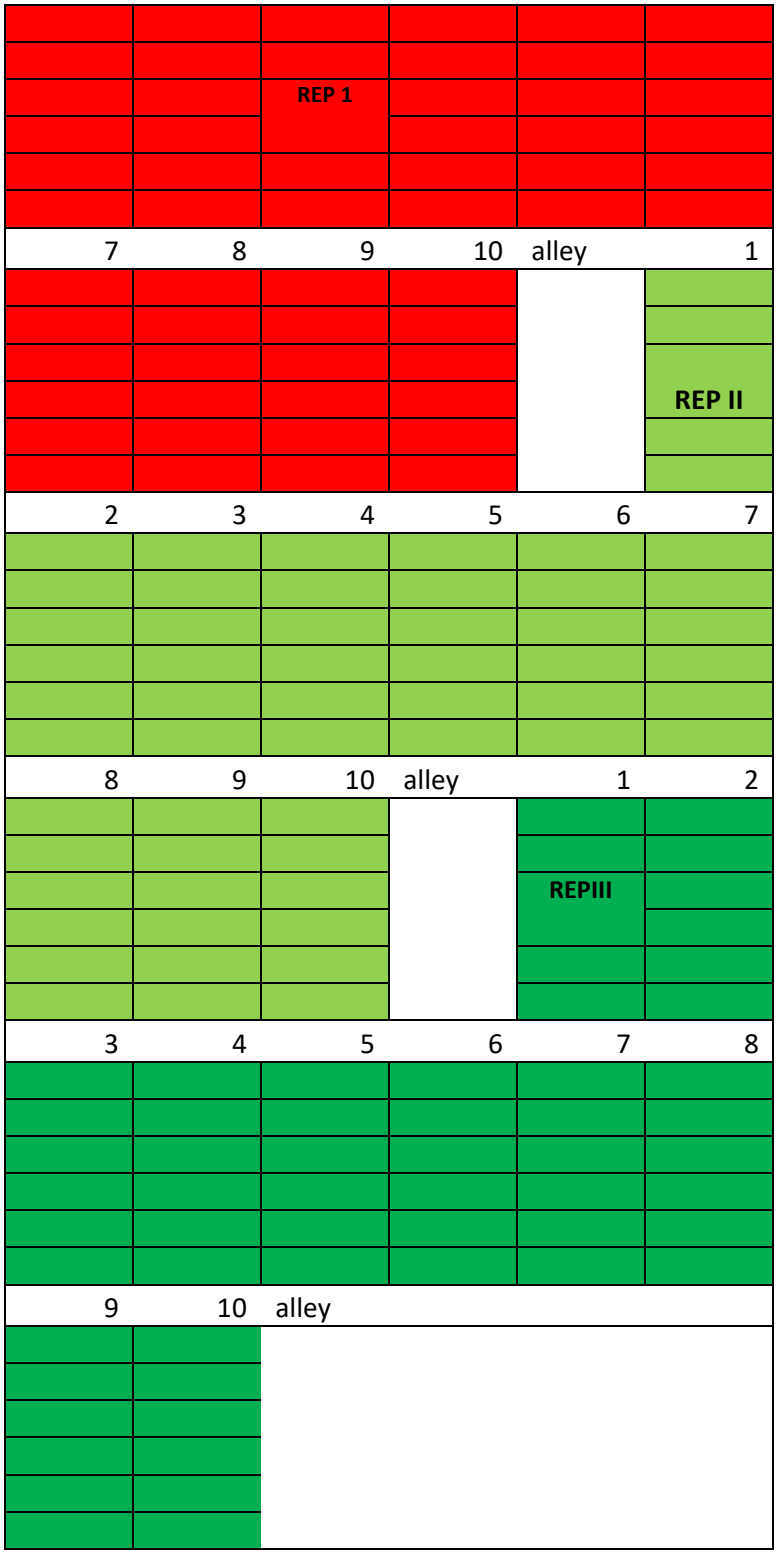
MAP	Rainfall(mm)	FYLD(t/ha)	DM(%)	TC(µg/g)
6MAP (December)	4.58	3.63	25.70	13.76
9MAP(March)	52.09	13.92	16.40	13.51
12(June)	107.05	19.54	18.76	13.04
Season	Rainfall(mm)	FYLD(t/ha)	DM(%)	TC(µg/g)
2019/2020	127.38	9.23	20.93	14.41
2020/2021	8.45	15.50	19.66	12.48

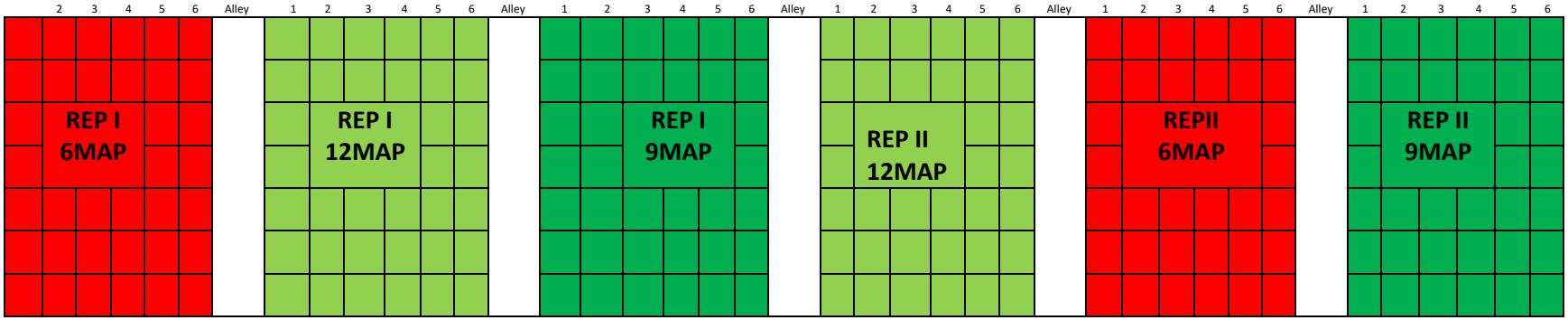
Appendix XXV: Schedule of experimental activity

Experiment I			
Crossing Block to raise Progenies			
Activities	**Date**	**Duties**	**Location**
Crossing block establishment	12th April, 2018	To obtain seeds and progenies to be evaluated with their parents in a biparental crossing.	Ibadan
Crosses	18th Oct.,2018	Crosses were made in a biparental crossing among parents	Ibadan
Seedling nursery	9th Dec.,2018	Seeds obtained were planted into seedling nursery	Ibadan
selection of mature plants stem for 2019/2020 establishment	20th June, 2019	Mature Progenies in seedling nursery were selected for 2019/2020 establishment	Ibadan
Experiment II			
Planting/Establishment of F1 progenies for evaluation at 2019/2020 season			
2019/2020 establishment of Progenies	25th June,2019	F_1 progenies for evaluation at different harvesting periods of 6,9,12 months after planting.	Ibadan
First Harvesting	25 Dec.,2020	6 months after planting	Ibadan
Second Harvesting	25 Mar,2020	9 months after planting	Ibadan
Third Harvesting	25 June,2020	12 months after planting	Ibadan
Planting/Establishment of F1 progenies for evaluation at 2020/2021 season			
2020/2021 establishment of Progenies	7th June,2020	Second year planting was harvested at 3 different harvesting periods.	Ibadan
First Harvesting	7th Dec.,2020	6 months after planting	Ibadan
Second Harvesting	7th Mar.,2020	9 months after planting	Ibadan
Third Harvesting	7th June,2021	12 months after planting	Ibadan
Experiment III			
Field establishment	18th July,2018	Planting was evaluated at 3,6,9, and 12 month after planting	Mokwa&Ubiaja
3 MAP Harvesting	18th Oct.,2018	3 Months after planting	Mokwa&Ubiaja
6 MAP Harvesting	18th Jan.,2018	6 Months after planting	Mokwa&Ubiaja
9 MAP Harvesting	18th Apr.,2019	9 Months after planting	Mokwa&Ubiaja
12 MAP Harvesting	18th Jul.,2019	12 Months after planting	Mokwa&Ubiaja

APPENDIX XXVI: Experimental Field Layout

Experiment one:





Experiment two