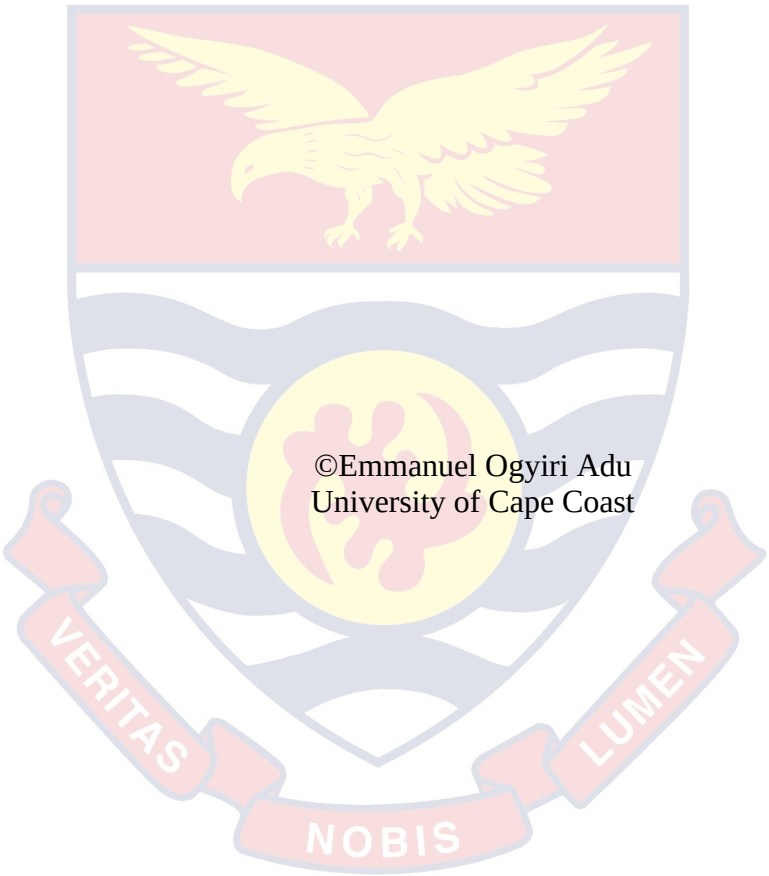
UNIVERSITY OF CAPE COAST

EVALUATION OF YELLOW FLESH CASSAVA (*Manihot esculenta* Crantz) GENOTYPES FOR YIELD, DRY MATTER CONTENT, CYANOGENIC POTENTIAL, TOTAL CAROTENOID CONTENT AND STABILITY

EMMANUEL OGYIRI ADU

2020



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EVALUATION OF YELLOW FLESH CASSAVA (*Manihot esculenta* Crantz) GENOTYPES FOR YIELD, DRY MATTER CONTENT, CYANOGENIC POTENTIAL TOTAL CAROTENOID CONTENT AND STABILITY

BY

EMMANUEL OGYIRI ADU

Thesis submitted to the Department of Crop Science, of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Crop Science.

OCTOBER 2020

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Signature: ……. Date: ……

Name: Emmanuel Ogyiri Adu

Supervisors' Declaration

We hereby declare that the preparation and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor

Signature: ……. Date: ……

Name: Dr. Kingsley Joseph Taah

Co-Supervisor's Signature: ……. Date: ……

Name: Dr. Godwin Amenorpe

Co-Supervisor's Signature:…… Date: ……

Name: Dr. Paul Agu Asare

ABSTRACT

Vitamin A deficiency related diseases are major problem in Sub-Sahara Africa. Yellow flesh cassava (YFC) mutants were developed to combat these challenges but there is a need to evaluate for yield related traits, safety, perceptions and preferences before release. The survey showed that farmers had heard of YFC and 72 % are willing to cultivate and consumed it as *fufu* or *gari*. The yield and yield related traits evaluation under RCBD with 10 treatments in 2018/2019 cropping season indicated that Total Carotenoids (TC) ranged from 1.77-10.38 µg/g and top four genotypes were 6A (10.38), 12B (10.10), 14B (9.83) and 11A (9.57) while IITA control and 6F checks had 7.97 and 1.77 µg/g, respectively. The Dry Matter and Fresh Root Yield ranged from 15.53-38.12% and 21.53-55.97 t ha^{-1}, respectively. The Cyanogenic Potential range (25.9-37.3 mgHN/kg) of all genotypes was lower than innocuous value of 50mgHCN/kg and therefore safe for consumption. The eight YFC genotypes with one white and one yellow flesh checks planted in three environments in 2019/2020 growing season under RCBD, showed that Asuansi (15.87 %), Wamaso (14.71 %) and UCC (14.51 %) location had similar starch yields. There were substantial differences ($p<0.05$) for cassava root yield across locations with Wamaso leading with 33.69 t ha^{-1} and UCC (33.23 t ha^{-1}) significantly higher than Asuansi (28.03 t ha^{-1}). The dry matter ranged from 21.67 - 43.33 % for genotypes 14B and 6F respectively. Also, significant differences among all the genotypes ($p<0.05$) for total carotenoid retention when YFC was processed into gari were observed. All genotypes had total carotenoid retention between 98.23±12.21 % - 59.35±7.09 and above 50 % of initial level. The yellow flesh genotypes 12B, 11B, 5B and 9A were the top four performers recommended for release.

KEY WORDS

Cassava

Cyanogenic potential

Dry matter content

Genotype

Total carotenoid

Yield

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DEDICATION

To my Dad, Mr. Francis Kwame Adu; Mum, Mad. Naomi Ayikai Quaye and my late mentor, Prof. Alexender Gyandoh Carson (Renowned Weed Scientist)

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ACMV	African Cassava Mosaic Virus
AGDP	Agriculture Gross Domestic Product
BNARI	Biotechnology and Nuclear Agriculture Research Institut
CIAT	Centro Internacional de Agricultura Tropical
CMD	Cassava Mosaic Disease
CNP	Cyanide potential
CoSCA	Collaboration Study of Cassava in Africa
CRI	Crop Research Institute
CSIR	Council for Scientific and Industrial Research
DAP	Days after planting
DMC	Dry matter content
EACMV	East African Cassava Mosaic Virus
ESCaPP	Ecological Sustainable Cassava Plant Protection Project
FAO	Food and Agriculture Organizations
FAOSTAT	Food and Agriculture Organization Statistics
FSRY	Fresh storage root yield
GAEC	Ghana Atomic Energy Commission
GCA	General combining ability
GGE	Genotype and Genotype Environment
GxE	Genotype by Environment interaction
ha	hectare
HCN	Hydrogen cyanide
HI	Harvest index
IFAD	International Fund for Agricultural Development

IITA	International Institute of Tropical Agriculture
kg	Kilogram
MAP	Months after planting
MoFA	Ministry of Food and Agriculture
NRCRI	National Root Crops Research Institute
NRTCIP	National Root and Tuber Crop Improvement Project
PCA	Principal component analysis
PCR	Polymerase Chain Reaction
ppm	part per million
RTIMP	Root and Tuber Improvement and Marketing Programme
SCA	Specific combing ability
SRID	Statistics Research and Information Directorate
StC	Starch content
t ha^{-1}	tons/hectare
TC	Total carotenoid
UN	United Nation
WAP	Weeks after planting
YFC	Yellow flesh cassava
µg/g	microgram/gram

CHAPTER ONE

INTRODUCTION

Background to the Study

Cassava (*Manihot esculenta* Crantz) was introduced into Africa in the 16th century by the Portuguese from Latin America (Nweke, Dixon & Falayan, 1994). Ever since the late 19th and early 20th centuries, cassava has been a staple food for many people (Hillocks, 2002) and according to FAOSTAT (2010) cassava is a major constituent of the diet of over 800 million people in tropical countries. In terms of global annual production, cassava is the third most important source of calories in the tropics and the second most important food crop after maize (FAOSTAT, 2010). Cassava has an estimated worldwide production of 257 million tonnes, of which about 146 million tonnes and 17 million tonnes come from Africa and Ghana respectively (FAOSTAT, 2016).

In Ghana, cassava plays an important role in the agricultural economy and accounts for about 46 % of the gross domestic agricultural product (Parkes, Allotey, Lotsu & Akuffo, 2012). They further observe that cassava accounts for a daily caloric intake of 30 % in Ghana and is grown by most farm families. Yields of over 45 tons/ha are achievable in Ghana if appropriate technologies for the crop are fully adopted (FAOSTAT, 2016). Cassava today covers about 21.68 % of the total land area grown to food crops. The area cropped to cassava has increased from an average of 801,000 ha in 2007 to 938,725 ha in 2016 (MoFA, 2017). Cassava is also classified as a classic food security crop for many reasons. First of all, the time for planting and harvesting is flexible, allowing it to be harvested when really needed (DeVries & Toenniessen, 2001).

It also adapts to low soil fertility and water availability. Lastly, the plant is multiplied by vegetative propagation. This makes it possible for farmers to continue growing the crop without any financial input to planting materials (Hillocks, 2002). The post-harvest physiological degradation of the storage root that creates inedible blue and black pigments is a major disadvantage of cassava (Alves, 2002). Another disadvantage is that, depending on the cultivar, environmental condition, cultural practices and plant age, cassava contains toxic cyanogenic glucosides in variable concentrations (McMahon, White & Sayre, 1995). The recommended level of hydrogen cyanide (HCN) concentrations in cassava diet is 10 ppm of HCN/kg body weight (WHO, 2013). Even though, on the average, the roots of 'bitter' cassava contain about 650 ppm cyanide in the peels and 310 ppm in pulps, the corresponding 'sweet' cassava peels and pulps contain less than 200 ppm and 38 ppm total cyanide respectively (Mkumbira, 2003). Due to the toxicity of HCN to man, it is important that the level of HCN be determined before the introduction of new cassava varieties.

Vitamin A deficiency has been described as a common public health issue in 37 countries worldwide, affecting a greater percentage of the population in North-East Brazil and Sub-Saharan Africa, where cassava is a staple crop, according to Shrimpton (1993). Vitamin A deficiency results in xerophthalmia leading to night blindness and total blindness (Nassar, Vizzotto, da Silva, Schwartz & Junior, 2005). As they are abundantly present in plants, pro-vitamin A carotenoids are cheaper sources of vitamin A (Nassar, *et al*, 2005). Among the carotenoids, β-carotene and α-carotene have a high provitamin A activity (Carvalho, 2012) consequently, the most potent pro-vitamin A is ß-carotene and it is also the most widespread (Rodriguez-Amaya, 1999).

In poor countries where cassava is a staple crop, the selection of yellow flesh cassava varieties with high ß-carotene content can significantly contribute to solving the problem of vitamin A deficiency. Studies have shown that the total concentration of carotenoids in the root of yellow flesh cassava ranges from 1 to 100 µg/g (fresh weight), primarily as trans-β-carotene, and is located in the root storage cells of the parenchyma cells (Iglesias, Mayer, Chavez & Calle, 1997). The average WHO requirement of ß-carotene in diet for adults is 2.4 µg/g to 3.5 µg/g (Nassar *et al*, 2005). A valid strategy to reducing vitamin A deficiency is to breed cassava for high vitamin A to enhance the nutritional value of cassava consumers.

Problem Statement

In West Africa and specifically Ghana, cassava breeders are developing staple yellow flesh cassava varieties with improved levels of pro-vitamin A (ß-carotene) to help combat dietary health challenges among poorly resourced people in Ghana and other developing countries. ß-carotene is a pre-cursor for vitamin A, with anti-oxidant properties responsible for reduction of cancer, miscarriages in pregnant women and blindness among children under five years (Vimala, Nambisan, Thushara & Unnikrishnan, 2008). However, there is little or no information on preference among Ghanaians for the new yellow flesh cassava, with respect to taste, yield and mealiness of the new genotypes in different agro-ecological zones in Ghana. In addition, the cyanogenic potential and stability of the ß-carotene in the genotypes during processing are not yet known (Britton & Khachik, 2009).

Consequently, to improve the potential of these yellow flesh cassava genotypes, there is a need to select and evaluate these cassava genotypes for good organoleptic attributes, and genotypic stability in different agro-ecological zones in Ghana. This should go a long way in helping combat vitamin A deficiency among the urban poor and resource poor farmers in rural areas of the country with the cultivation and consumption of yellow flesh cassava.

General Objective

The major objective of this research was to evaluate yellow flesh cassava genotypes for yield, dry matter, cyanogenic potential and ß-carotene stability as means to improve human nutrition.

Specific Objectives

Specifically, this research seeks to:

1. assess the knowledge and preference of farmers and consumers for the new yellow flesh cassava variety.
2. evaluate the yellow flesh cassava genotypes for yield, total carotenoids, cyanogenic potential and dry matter in the coastal savannah zone.
3. evaluate the performance of ten different genotypes in three agro-ecological zones in Ghana.
4. determine the mealiness and starch content of the yellow flesh cassava genotypes in three agro-ecological zones of Ghana.
5. estimate the total carotenoid retention in “gari” and to conduct sensory evaluation of the yellow flesh gari.

Hypothesis

The study will be based on the following null (Ho) and alternate (H_1) hypotheses

Ho Cassava farmers and consumers do not prefer cassava varieties with high ß-carotene content.

Ho There is no effect on the yield, total carotenoids, cyanogenic potential and dry matter of yellow flesh cassava genotypes in coastal savannah zone.

Ho Different agro-ecological zones have no effect on the performance of the ten yellow flesh cassava genotypes.

Ho Different agro-ecological zones have no effect on the mealiness and starch content of yellow flesh cassava genotypes.

Ho Processing of the new yellow flesh cassava genotypes into "gari" have no effect on the retention of total carotenoid levels.

H_1 Cassava farmers and consumers prefer cassava varieties with high ß-carotene content

H_1 There is effect on the yield, total carotenoids, cyanogenic potential and dry matter of yellow flesh cassava genotypes in coastal savannah zone.

H_1 Different agro-ecological zones have effect on the performance of the ten yellow flesh cassava genotypes.

H_1 Different agro-ecological zones have effect on the mealiness and starch content of yellow flesh cassava genotypes.

H_1 Processing of the new yellow flesh cassava genotypes "gari" have effect on the stability or retention of total carotenoid levels.

CHAPTER TWO

LITERATURE REVIEW

Cassava (*Manihot esculenta* Crantz) was grown before 1600 BC in Brazil, Colombia, Venezuela, Paraguay, Mexico and other nations of South America (Figure 2.1). However, where it was first domesticated is not known, but the present consensus is that domestication took place somewhere in Central or Southern America, perhaps along the southern border of Brazil, where there are presently wild cassava relatives (Oslen & Schaal, 1999). Cassava is also believed to have originated from Latin America, where it has been cultivated for at least 4000 years by the native Indian inhabitants (Akinpelu, Amamgbo, Olojede & Oyekale, 2011).

According to Okogbenin, Egesi and Fregene (2006), the crop was brought by the Portuguese to the tropical regions of Africa, the Far East and the Caribbean Islands from Brazil, its centre of origin. The Portuguese introduced cassava from Latin America to in West Africa. In the seventeenth century, cassava was later taken to India and in the eighteenth century to East Africa (Okogbenin *et al*., 2006). The French who colonized the Guyanas and Réunion were primarily responsible for the transfer of cassava to the countries of East Africa and Madagascar and later to Ceylon (Sri Lanka) in 1786. The European movement from Brazil to São Tomé and Fernando Po continued to spread cassava until it reached the central parts of the African continent. According to Oslen and Schaal (1999), cassava's spread continued through the Gulf of Benin to West Africa and then through Reunion Island, Madagascar and Zanzibar, to East Africa in the 18th century.

Cassava was grown around the trading ports, castles and forts in Ghana by the Portuguese which was the major food that the Portuguese and their slaves were eating. The spread of cassava was feasible owing to its tolerance to drought, its ability to strive in low soil fertility, and the fact that it also served as a hunger-reserve crop as populations continued to rise. Cassava was commonly cultivated in Western African nations including Ghana (Eke-okoro & Njoku, 2012) in the twentieth century to meet the growing food requirement.

In Ghana, cassava was very slow to spread from the shoreline to the hinterland (MoFA, 1997). The crop arrived at Ashanti, Brong-Ahafo and Northern Ghana, specifically Tamale in 1930. During the early years of 1980s, the forest belt Akans preferred plantain and cocoyam, while in the North, they preferred sorghum and millet. According to Korang-Amoakoh, Cudjoe and Adams (1987), after the severe drought of 1982/83, cassava became strongly established in most fields when all other plants failed. Cassava and its different preparations, which includes; *konkonte*, *fufu*, *ampesi*, and *gari* are now very common dishes in Ghana (MoFA, 1997).

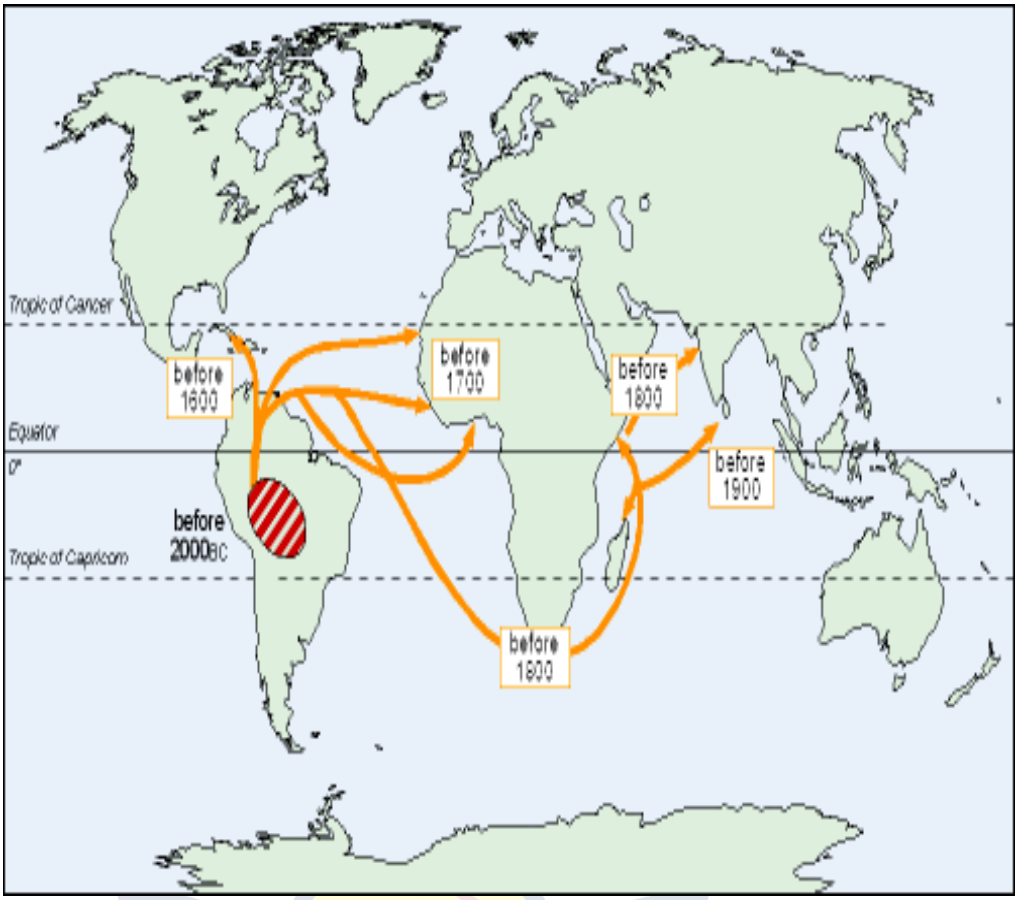

Figure 2.1: The spread of cassava to Ghana and other regions of the world

Source: London Natural History Museum (UK)

Production of Cassava

For several individuals, cassava is a staple food in tropical and subtropical regions and a raw material for various sectors around the globe. It serves as a source of livelihood throughout the globe for up to 800 million families, including processors and traders (Sesrtcic, 2014). Global cassava production rose from 93.1 million tonnes in 1968 to 291 million tonnes in 2017, growing at an average annual rate of 2.39 % (FAO, 2019). The FAO (2012) estimated that more than 280 million tonnes of cassava was produced worldwide, representing a 60 % rise since 2000, with increased annual growth over the past two decades.

The area of cassava harvested in the world increased from 11.2 million ha in 1968 to 26.3 million ha in 2017 increasing at an average annual rate of 1.82 %. Cassava food products of the world grew substantially to 10.1 million tonnes in 2013.

In sub-Saharan Africa, cassava production was 140.9 million tonnes in 2010 and it increased to 177 million tonnes in 2017 (FAO, 2019). The land area for cassava harvested in sub-Saharan Africa increased from 6.16 million ha in 1968 to 20.2 million ha in 2017, growing at an average annual rate of 2.59 % (FAO, 2019). Production of cassava in Africa comes primarily from Nigeria. As of 2017, the production of cassava in Nigeria was 59.5 million tonnes that accounts for 20.37 % of the world's production of cassava.

After the year 2000, the largest production of cassava was in West Africa, where production increased from 47 million tonnes to 76 million tonnes, due to the reality that nations in the sub-region saw the potential of cassava as an industrial crop that could help farmers earn income, gain foreign exchange and create employments (Sanni *et al*., 2009). The production of cassava in West Africa has grown substantially to 96.2 million tonnes in 2017.

Ghana is the sixth world producer of cassava in terms of value. Production of cassava in Ghana increased from 1.45 million tonnes in 1968 to 18.5 million tonnes in 2017 growing at an average annual rate of 6.33 % (FAO, 2019).

Cassava growth cycle

The propagation of cassava is mostly by planting the cuttings from the chosen mature tough stems, although it can also be grown by the seeds (Figure 2.2). At the vegetative stage, the stems branch at one-third to two-third of the total stem height depending on the varieties (Doku, 1999). Stem branching at the apex is more prevalent with short internodes. Branching minimizes as plant maturity approaches. As the plant matures, yellowing and defoliation of leaves increases (RTIMP, 2009).

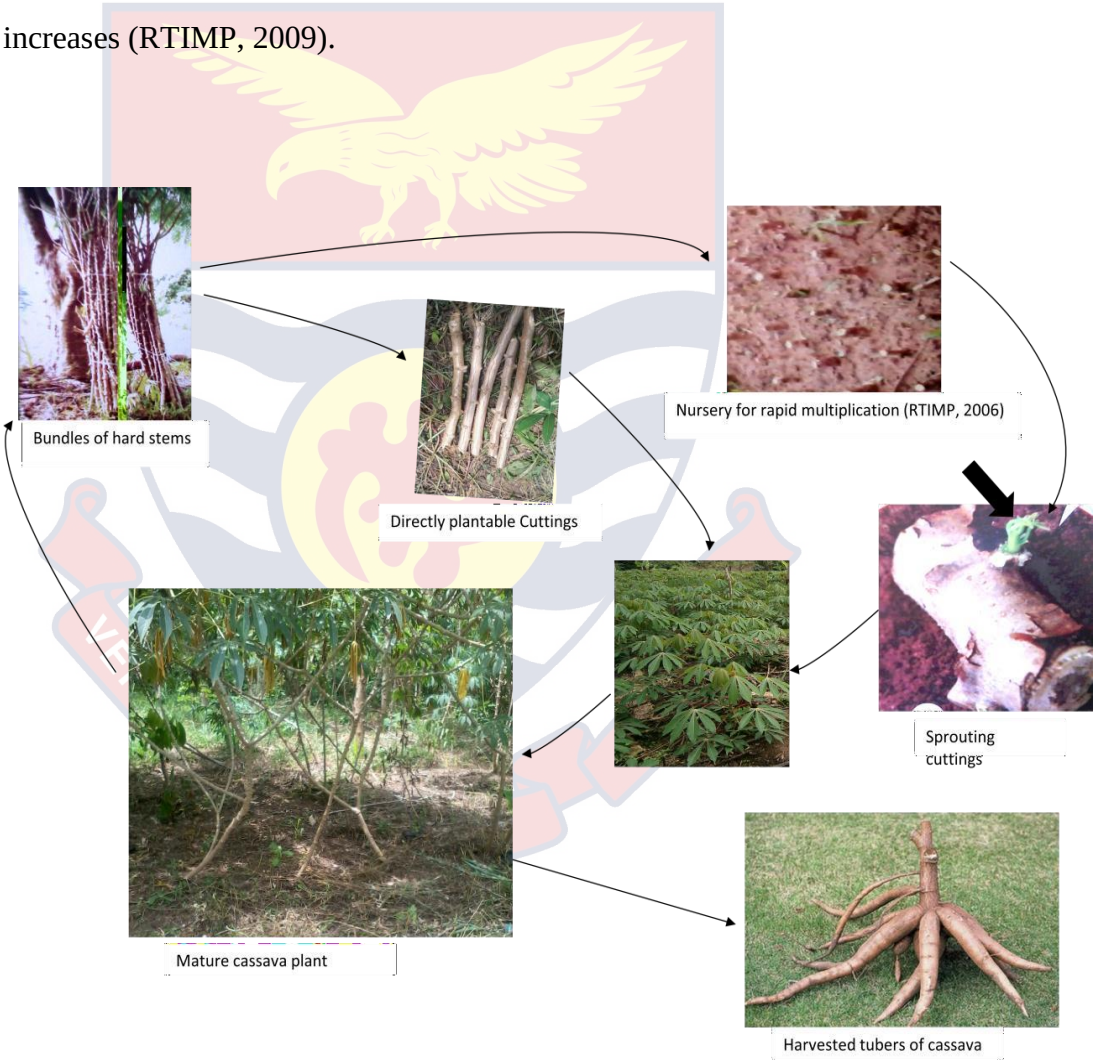

Figure 2.2: Two major ways of generating planting materials for cassava production. Source: RTIMP (2006)

Botany of Cassava

Cassava is a perennial woody shrub in the class of dicotyledoneae, Archichlamydeae subclass, Euphorbiales order and the family of Euphorbiaceae, consisting of 7200 species. Cassava belongs to the Manihotae sub-family, *Manihot* genius, and *Manihot esculenta* Crantz is the name of the species. There are two edible species in the genius, M. *utilissima* Phol (bitter cassava) and M. *palmate var. aipi* Phol (sweet cassava) based respectively on high and low cyanogenic potential.

The stem

In cassava, stems are particularly essential as it is the main part used for propagation. Lignified stem sections, frequently referred to as cangers is used for commercial production of the cassava. The stem is cylindrical and has diameter ranging from 2 to 6 cm and a colouring that can be yellow, violet and silvery grey. According to CIAT (2012) the colour and stem diameter may differ with plant variety and age. The node is the location where the stem is joined by a leaf. In the node of the stem is inserted two lateral stipulations, leaf petiole and an axillary bud protected by a scale. The stem offers permanent record of the development of the plant's history, allowing one to deduce the circumstances and occurrences that might had affected the plant (CIAT, 2012).

The leaf

The most frequently occurring organs where radiant energy is transferred into chemical energy (photosynthesis) are the leaves. The leaves senesce with age, and drop from the cassava plant. According to CIAT (2012), varietal characteristics which is affected by environmental conditions

determines the photosynthetic capacity, the total number of leaves produced by the plant and their longevity.

The leaf's blade is palmate with a varying number of lobes ranging from 3 to 9. Lobes measure 1 to 6 cm in width and 4 to 20 cm in length. The centre of the lobes is bigger than the laterals. There are three types of lobes in a simple classification: linear or straight, obovate, and pandurate. The size of the leaf is a typical characteristic and it differs with conditions of the environment. According to CIAT (2012), the first three to four months leaves produced during the plant's life are mostly larger than leaves produced after the fourth month.

Flowers

Cassava varieties are graded in non-flowering, poor flowering, moderate flowering, profuse flowering with poor fruit setting, and high fruit settings of profuse flowering (Aesidasha & Idana, 2008). It is monoecious, that is, on the same plant, there are male and female flowers. The inflorescence is formed on the stem's terminal bud. Sometimes the inflorescence can be formed in the leaf axil on the upper part of the plant. The female flower is at the lower part of the inflorescence and usually opens on the same branch 10-14 days before the male flower (Aesidasha & Idana, 2008).

The time from planting to flowering depends on the unique conditions of the genotype and the climate and can range from 1 to more than 24 months. On a single branched panicle, the female flowers are borne at the base and male flowers at the tip of the flowers (Alfredo & Setter, 2000). Usually, the flowers are tiny, with a diameter of about 0.5 cm for the male flower and slightly bigger than the female flower.

According to Ceballos *et al*. (2002), it is generally shown in flowers that male and female flowers start to open around midday and stay opened for about a day. Female flowers open first on a specified branch, and the flowering also depends on the habit of the plant. The apical branching, which is a prominent incipient flowering visual sign, precedes the development of flowers and can be used to distinguish crops in the pre-flowering phase. One or two weeks later, male flowers follow, a feature called protogyny. Before the male flowers open, the female flower on the same branch will be aborted or fertilized. On the same branch, female flowers will either be fertilized or aborted by the time the male flowers open. However, because flowering may last more than two months on a single plant, self-and sib-fertilization may occur, depending on the genotype, climate, and presence of pollinating insects for each proportion (Parry *et al*., 2007).

Environmental factors can heavily influence flowering. In one environment, a particular clone may not produce flowers or may only produce flowers that abort or even fail to produce viable seed in another environment, but flower abundantly and seed in a third environment. For breeding purposes, clones are grouped into various growing regions (environments, ecotypes) so that breeders can take the flowering habits of the plants they want to cross into account (Ceballos *et al*., 2002).

Pollen

The pollen grains of cassava are sticky and fairly large in size. Pollen is usually yellow or orange and its size shows dimorphism, the larger grains have a diameter ranging from 130 to 150 microns, while the smaller grains range from 90 to 110 microns (Plazas, 1991).

In certain types, the bigger grains are more abundant and have better germination percentages (60 %) than the smaller ones. Smaller grains are more common in other cultivars (Pearce, 2007). Smaller grains typically germinate less efficiently than larger ones and may have a viability of less than 20 %. Cassava pollen easily loses viability following shedding. Research by Leyton (1993) showed that 97 % seed set with newly collected pollen, 56 % seed set with pollen stored for 24 hours, and 0.9 % seed set after 48 hours of storage. Because of the pollen grain's sticky nature, wind pollination seems to have little effect. Several species of wasps, primarily *Polistes spp* and honeybees are the major pollinators in Colombia and Africa respectively.

The fruit

The fruit starts to develop from the ovary following the pollination of the female flower. According to Ceballos *et al*., (2002) complete fruit maturation takes about three months. The fruit is a dehiscent capsule and it is trilocular and ovoid to globate and has a diameter of 1.0 and 1.5 cm. It has six longitudinal, narrow and prominent ridges. Cross-section of the developing fruit show a series of clearly discernible tissues; epicarp, mesocarp, and endocarp. The epicarp and mesocarp dries up as the seed matures. When fruits are ripe and dried, the ligneous endocarp suddenly opens and releases seeds at a certain distance and disperses them. During the drying process, fruits dehisce and the seed initially falls near the mother plant, but some may be further dispersed by ants that carry to their nests, an uncertain percentage of the seed in the soil (Elias & Mckey, 2000).

The seed

Depending on the quality of the female parent, seed production and viability are variable (Kawano, 2003). Newly harvested seeds are dormant and need to be stored for 3 to 6 months before they germinate (Andrade & Abbate 2005). Cassava seeds are not important for reproduction and commercial multiplication but they have unmatched value for plant breeding, only through sexual reproduction can they be produced as new, genetically superior cultivars. The seed is formally ellipsoid-ovoid and is about 1 cm long, 6 mm wide and 4 mm thick. Coffee-coloured, and mottled grey are the main seed coat colour. Within the new seed, the caruncle is found at the upper part. Once the seed falls to the ground, this structure is lost (CIAT, 2012).

The endosperm is within the seed coat, with the polyhedral parenchymal cells protecting and nourishing the embryo. The cotyledons and the embryonic axis that give rise to the new plant after germination are located inside the endosperm. Also, the embryo consists of two cotyledonous leaves, hypocotyl, plumule, and radicle. (CIAT, 2012).

The seed's interior is nearly occupied by the cotyledonous leaves and endosperm of which they are white, elliptical, and carnose. Seeds can remain viable for up to 1 year, while germination percentages can drop dramatically after six months. Seeds have been recorded to survive without loss of germination for up to seven years under storage conditions (40 ^{o}C and 70-80 % relative humidity) (Plazas, 2007). The persistence of natural seed banks has not been well established, but may last for several years.

Storage root yield

The yield of a plant refers to the mass of the produce harvested from a single plant or the harvested quantity obtained per unit of the area of the land. By the terms of marketable storage roots, cassava yield is often specified (Hershey, 2012), whereas seeds, stem or even leaves might be additional economic products. By Lahai and Ekanayake (2009), dry mass production and partitioning are significant factors for root yield of cassava storage and may be necessary selection criteria for enhanced yield breeding.

Storage root development and bulking

By Izumi *et al*. (1999), root bulking is called the formation and development of storage roots showing secondary thickening. The bulking of root results from the rise in cell numbers as a result of cell division and proliferation, as well as their starch accumulation. Research findings by El-Sharkawy (2003); Ravi, Aked and Balagopalan (2009) showed that root size improves by increasing the number of cells and the size of cells while the weight of the storage root rises by accumulating photosynthates. Storage root bulking and development therefore rely on sink intensity, capability of leaves to export photosynthates and photosynthetic efficiency of leaves (Keutgen, Kubota & Saitou, 2001).

Storage root bulking process

By developing a circular primary vascular cambium and several anomalous circular cambia in the subapical root section, storage root bulking involves secondary growth (El-Sharkawy, 2003). The initials of the primary vascular cambium are first formed within the parenchymatic region between protoxylem and protophloem at the onset of secondary thickening and are linked

by dividing the single-layered pericycle to form a continuous and irregular cylinder (Ravi *et al*., 2009). This is followed by a cork cambium being formed in the outer layers of the pericycle. Subsequent vascular cambium being formed in the centripetal manufacturing of thin-walled storage parenchyma, secondary vascular tissue and a regular cylinder of vascular cambium.

Anomalous circular secondary cambia also originate around secondary xylem elements obtained from the vascular cambium, according to Ravi *et al*. (2009). Unassociated with vascular tissues, the interstitial cambial strips often grow in the secondary parenchyma resulting in the growth of roots in storage. In these cambia, active cell division results in the formation of thin-walled, starch-storing parenchyma cells that cause thickening and lignification's of storage roots. The bulk of starch grains is stored in the xylem parenchyma cells. Accumulation of starch happens in the first generated parenchyma cells, 25 days after being planted. The starting time of secondary thickening and deposition of starch is likely delayed by excising buds or accelerated by adding glucose or sucrose, implying that storage root differentiation can be initiated by sugar alone (Yang *et al*., 2011).

Several trials differed when thickened roots appear during growth and development in cassava (Okogbenin & Fregene, 2002). Izumi *et al*. (1999), for instance, showed that root bulking begins around three months after planting (MAP), and maintained that before 6 MAP, there is no rapid deposition of starch. Doku (1999) revealed that a lot of genotypes began root bulking at the second month and developed 6 MAP new storage root yields based upon sequential harvesting studies amongst multiple Ghanaian cassava cultivars.

However, to explore variations in the onset of root bulking and the rate of bulking, and that root bulking increased over time, but the rate of bulking differed between cultivars, Wholey and Cock (1974) identified that thickened roots were present in their studies after 2 MAP. Amenorpe, Amoatey, Darkwa, Banni and Elloh (2007) found that early bulking, rapid bulking, or combinations of both factors were correlated with early bulking of cassava tubers based on fresh storage root mass (FSRM) accumulated by different genotypes at different times. Similar findings have been recorded on the accumulation of different amount of FSRM by different cultivars at different harvest times, showing the presence of early bulking genotypes (Kamau, 2006; Amenorpe *et al*., 2007; Mtunda, 2009).

Dynamics of storage root bulking

The rate of root bulking of cassava fluctuates over a long period of time owing to the modifications in agro-climatic conditions (Ekanayake, Osiru & Porto, 1998). The cassava storage root unlike the cereal grains can undergo times of arrested development during unfavourable conditions and then continue to grow as condition are enhanced. High bulking rates associate high yielding cultivars over a long period of time, whereas intermediate and low root yielding cultivars have a low bulking rate over a brief period of time or a low bulking rate over a longer period of time (Hershey, 2011). Suja, John, Sreekumari and Srinivas (2009) indicated that high and low yield cassava cultivars differ in their bulking rate and also vary in the period they exhibit the highest bulking rate. During their early development phase, they discovered that short-lived cultivars display a peak bulking rate.

Cassava dry matter content

Based on the plant age plus the genotype and environmental conditions (Bakayoko *et al*., 2009; Ojulong, Labuschangne, Fregene & Herselman, 2008), the concentration of dry matter in cassava roots can differ from 15 to 45 %. On average, carbohydrate is about 90 % of dry root matter, with 4% crude fiber, 3 % ash, 2 % crude protein and 1 % fat. This makes dry matter a significant trait for cassava producers as it is a crop mainly cultivated for its carbohydrate content. High content of root dry matter is particularly crucial when roots are used as raw materials for food, feed and industry (Tan & Mak, 1995).

Iglesias, Hershey, Calle and Bolanos (1994) noted that the content of root dry matter segregate either independently or positively correlate with root yield, suggesting that both traits could be improved at the same time. However, the content of dry matter is not associated with fresh root yield, as progress in one may require sacrifice in the other. Dry matter content heritability has been noted to be intermediate to high and the traits can be improved by easy breeding methods such as phenotypic mass selection, just to exploit additive genetic variance.

Partitioning of dry matter into cassava storage root

The division of dry matter into various parts of the plant varies in cassava during the growth cycle. The distribution of dry matter to the storage roots ranges from almost zero during the early growth phases to approximately 80 % of the daily production of dry matter during the late growth phases (Ekanayake, Osiru & Porto, 1997). Cassava accumulates dry matter more in the leaves than in the stems and in storage roots between 60-75 days after planting (Alves, 2002).

Depending on growing conditions, genotypes vary in the length of maximum dry matter accumulation rates (Alves, 2002). Suggesting that breeders can select maximum accumulation of dry matter for different number of days, based on the environment in which varieties are to be deployed. A maximum accumulation of dry matter achieved 3-5 months after planting (MAP) has been recorded under tropical conditions with the highest growth rate (Howeler & Cadavid, 1983).

Kawano (1987) and other employees noted that root dry matter content tended to be greater at 8 MAP rather than 12 MAP and higher during the start of the dry season than the start of the wet season because starch material is hydrolysed as a source of energy for growing leaves during this period, leaving roots with less starch. In determining the maximum rates for dry matter accumulation, the significance of growing conditions indicates that the germplasm should be evaluated in different environments to estimate the potential of GxE during selection.

The accumulation of dry matter relies on the accessibility of photo-assimilates and the storage roots sink ability (Alves, 2002). It is suggested that vigorous genotypes produce large amounts of stems and leaves but root production is slow, while less vigorous genotypes produce relatively few stems and leave but translocate most of their dry matter to the roots, which after the third month become the dominant sink (Howeler & Cadavid, 1983).

Inheritance of dry matter content in cassava

Although some progress has been made in identifying the inheritance of agronomic qualities in cassava (Jaramillo *et al*., 2005; Ceballos, Perez & Dixon, 2004), few genetic analysis studies indicate that polygenic additive factors

control the inheritance of root dry matter content (Jaramillo *et al*., 2005). Perez *et al*., (2005) working on the cassava plant revealed that, the dry matter content is regulated by additive genes and the overall yield of root storage by dominant gene effects. In an effort to produce quantitative data in relation to the inheritance in cassava, Jaramillo *et al*. (2005), using diallel analysis, observed that the specific combining ability (SCA) is comparatively more essential to root yield than the general combining ability (GCA).

Also, for harvest index, plant architecture and dry matter content, the GCA was revealed to be high and significant. Therefore, the content of dry matter has been additively controlled. SCA accounted for about 35 % of the F1 sum of squares of the crosses for harvest index and dry matter content (Perez *et al*., 2005).

Estimation of dry matter content

Essentially, specific gravity and oven drying methods are two techniques for determining dry matter in cassava (Jennings & Iglesias, 2002). For specific gravity method, unpeeled fresh roots are weighed in air and then in water and the values are inserted in the specific gravity formula to calculate the dry matter of samples of 5 kg and above (Jennings & Iglesias, 2002). By calculating a regression model, Bainbridge *et al*. (1996), noted a linear relationship between specific gravity and dry matter content. The storage root-specific gravity regression of DMC offers a linear regression model that determines estimates of DMC and starch content (Bainbridge *et al*., 1996).

Growth Requirements

Cassava is grown between 30 ^{o}N and 30 ^{o}S latitude in a broad spectrum of edaphic and climatic conditions, growing in areas from sea level to 2000-2300 m altitude. The crop needs a warm, humid environment in general. Temperature is essential because all development stops at about 10 ^{o}C. The crop is typically cultivated in fields that are free from frost throughout the year. The greatest root output can be achieved in the tropical lowlands which are below 150 m altitude and have average temperatures between 25-27 °C. However, some varieties grow at altitudes of up to 1500 m and the crop can tolerate a temperature of 16 ^{o}C – 36 ^{o}C.

According to Akinpelu *et al*. (2011), the plant produces best when rainfall is fairly abundant and can be cultivated where annual rainfall is as low as 500 mm in semi-arid tropics and as high as 5,000 mm in sub-humid and humid tropics, but the crop needs a warm humid climate with a well-distributed rainfall of 1000 mm to 2000 mm per year for best performance. The crop may endure prolonged drought periods in which most other food crops would perish. This makes it useful in areas where there is low annual rainfall or where there is uneven seasonal distribution. The dry season in tropical environments has about the same impact on cassava as the low temperature in other areas of the globe has on deciduous perennials (Manu-Aduening, Lamboll, Dankyi & Gibson, 2005). The dormancy period lasts between two to three months, and development resumes when the rains start again (Manu-Aduening *et al*., 2005).

Cassava grows well in many kinds of soil, varying from light to heavy, but preferred well-drained, friable sandy loam to loamy soils are perfect for improved root growth. Measures should be taken when planted in sandy soils to

minimize soil erosion. The soil should also contain some organic matter with a depth of 30-40 cm, well-drained soil with a clay content of less than 18 % as the crop does not tolerate saline conditions with a pH range of 4-9 (Manu-Aduening *et al*., 2005).

Cassava Production and Research in Ghana

Research institutions have been accountable for cassava research under the CSIR and universities since 1962. Where systematic breeding and selection began in 1930 and primarily aimed at improving the resistance of local varieties to pests and diseases and yields, including; cassava mosaic virus infection, cassava bacterial blight, cassava mealybug and cassava green spider mite (FAO / IFAD, 2005).

As part of the Ghana Smallholder Rehabilitation and Development Program (SRDP) funded by IFAD, the National Root and Tuber Crops Improvement Project (NRTCIP) was launched in 1988 and three improved cassava varieties were issued to farmers in 1993 in cooperation with IITA (NARP, 1996). These efforts were accompanied by the implementation of various activities under the National Agricultural Research Project (NARP) by research institutions and universities in the field of cassava, which included crop improvement, agronomy, integrated pest management, post-harvest management, processing and socio-economic studies.

The National Agricultural Research Plan and other selected research projects were funded by the National Root and Tuber Crops Improvement Project (NRTCIP) in 1988 and the National Agricultural Research Project (NARP) in 1991.

The Crops Research Institute (CRI) was to coordinate the NARP's Root and Tuber Crops Research Program and carry out the following cassava activities: crop improvement, agronomy, integrated pest management, product creation and socio-economic research (FAO, 1994). With the NARP Root and Tuber Crops Research Program, collaborating organizations were: CRI, Soil Research Institute, Savannah Agricultural Research Institute, Plant Genetic Resources Centre, Food Research Institute, Biotechnology and Nuclear Research Institute, Kwame Nkrumah University of Science and Technology, University of Ghana, University of Cape Coast and University for Developmental Studies to exchange germplasm and train research and technical staff.

Ghana cassava breeders have worked effortlessly to breed new varieties of cassava that have high yields with high starch content, high dry matter content, resistant to CMV and suitable to most of the agro-ecologies in Ghana. According to Ghana variety released catalogue (2019), twenty-four (24) white flesh cassava varieties were released and registered in 2015 whilst four (4) white flesh cassava varieties were released in 2019. These varieties were mostly developed by CSIR-Crop Research, KNUST, UCC and GAEC-BINARI. The country's cassava study has currently concentrated on developing yellow flesh cassava varieties with high ß-carotene to fight vitamin A deficiency. CSIR-Crops Research Institute was the first institution in Ghana to have developed and registered a yellow flesh cassava variety named CRI-Lamesese with β-carotene, high yield (40-50 t ha^{-1}) and a good agronomic performance under different agro-ecological zone (Ghana variety released catalogue, 2019).

The University of Cape Coast in collaboration with BNARI-GAEC recently released and registered three (3) yellow flesh cassava varieties namely; *Tetteh bankye*, *Kpomu agbeli* and *Nyonku agbeli* with high pro-Vitamin A, high yielding and mostly used for *gari* and flour (Amenorpe *et al.*, 2019).

Yellow flesh cassava (YFC)

As an instrument to address vitamin A deficiency within countries lacking vitamin A rich food content, the yellow flesh cassava was developed (NRCRI, 2008). The total carotenoid concentration in yellow fresh cassava ranges from 1-100 µg/g (fresh weight), mainly as trans-β-carotene, according to Chávez *et al.* (2005), and is found in the storage root of the parenchyma cells (Iglesias, Mayer, Chavez & Calle, 1997). The first set of released varieties had a β-carotene content of 6-8 µg/g on fresh-weight basis while the second set of varieties had an average β-carotene content of approximately 10 µg/g fresh-weight basis. To select the most suitable traits for release, several clones of yellow-flesh varieties have been under investigation. In South America, cassava varieties with a total carotenoid content of almost 25 µg/g has been achieved (Ceballos *et al*., 2013).

Nigeria released a yellow flesh cassava in 2011 containing a total β-carotene of 6 µg/g (fresh weight) (Saltzman *et al*., 2013). The total root carotenoids of three Nigerian yellow flesh cassava varieties ranged from 2.6 to 7.3 µg/g (average 4.9 µg/g) and varied considerably depending on the varieties (Maziya-Dixon, Awoyale & Dixon, 2015). These values are like those reported by Omodamiro *et al*. (2000) for other varieties of yellow-flesh cassava (6.26–7.76 µg/g), but slightly higher than those reported for white flesh varieties (0.35 µg/g).

There is a wide variation in root pigmentation, ranging from pale yellow to orange or purple (Nassar *et al*., 2007). This variation in root pigmentation is connected with broad variability within the germplasm of carotenoid content (Sanchez *et al*., 2006). Maroya, Kulakow, Dicon, and Maziya-Dixon (2012) indicated that a stable trait of carotenoid concentration is more affected by genotype than by its environment. Although yellow flesh cassava is an excellent source of β-carotene and energy, other nutrients such as iron and zinc are usually considered to be poor in it (Maziya-Dixon, Kling, Menkir & Dixon, 2000).

A number of agronomic characteristics, such as yield and pest resistance, may also be different for yellow cassava, although yellow flesh varieties indicated a delay in the onset of post-harvest deterioration, which may be helpful for both farmers and consumers to accept the crop (Chávez *et al*., 2005). Studies have shown that carotenoid retention differs not only for a variety, but also for processing and storage methods (Chávez *et al*., 2007), and this may be due to the varying distribution of dry weight material within a root (Ceballos *et al*., 2012). The significant limitation to breeding cassava for high β-carotene content is negative association between β-carotene and dry matter under conventional breeding (Vimala *et al*., 2008; Akinwale, Akinyele, Dixon & Odiyi, 2010).

Carotenoids influence on root flesh colour appearance

The white or cream cassava flesh is the majority in Africa, however, enhanced provitamin A varieties with a yellow flesh colour have recently been introduced. The content of carotenoids was found to be strongly associated with cassava flesh colour (Chavez *et al*., 2007; Ceballos *et al*., 2013): white, cream,

purple, deep yellow, orange root corresponded to 1; 4; 6; 8 and more than 12 µg/g respectively.

Total carotenoid content and colour intensity are closely and positively related, according to Sanchez *et al*. (2006), meaning that cassava clones with comparatively high overall carotenoid content could easily be calculated based on visual colour scoring. Sanchez *et al.* (2014) also showed that there was a linear correlation between colour measured using near-infrared spectroscopy (NIRS) or visible colour chromatometer and carotenoids concentrations.

The majority of varieties with provitamin A are presently acquired through traditional breeding. While some attempts have been made and are still ongoing to generate high carotenoid content genetically modified cassava, these have not been implemented due to the epistatic association between different genes (i.e. low content of dry matter associated with high capacity of carotenoids (Failla *et al.*, 2012).

Correlation between carotenoids and dry matter content

The introduced yellow flesh varieties, mostly recorded a low dry matter content with its associated problems, such as taste, drying difficulties and cooking quality. The low dry matter content was reported for the varieties tested in Uganda, where another study showed that carotenoids content correlated negatively (R^2 = -0.46) with the dry matter content (Esuma *et al*., 2012). This was also in correlation with the study in Nigeria, where Akinwale *et al*. (2010) reported that the deeper the yellow colouration of the cassava flesh, the lower the dry matter content. Genotypes with the highest carotene levels contain less dry matter, which affects cooking quality (Akinwale *et al*., 2010; Esuma *et al*., 2012).

This assertion is also supported by Moorthy, Jos, Nair and Screekumari (1990) who observed a lower dry matter of cassava varieties with higher total carotenoid contents in yellow flesh cassava. However, in study recently published, Ceballos *et al*. (2013), found a parallel gain of dry matter content (DMC) and carotenoids content in Latin American cassava, suggesting that simultaneous improvement of both traits is feasible using the right/appropriate germplasm. This finding will therefore serve as an imperative input in possible future initiatives aimed at improving with carotenoids content of landraces and dry matter which will reflect in the cooking quality and increase the adoption rate of the developed varieties. Also, there is an interesting finding that demonstrates that selective breeding could possibly overcome the genetic connection between high carotenoid and low dry matter in cassava.

Yellow flesh cassava stores better after harvest than their white flesh counterparts, considering the comparatively higher amount of moisture in the cassava roots, possibly due to the additional anti-oxidative effect of carotenoids present (Chavez *et al*., 2000). This beneficial property could be exploited by farmers, thus encouraging sustainable post-harvest practices and processing.

Cyanogenic glycosides in cassava

In crops, cyanides in the form of cyanogenic glycosides are generally bound to sugar molecules and protect the plant against herbivores (Jones, 1998; Vetter, 2000). The genetic mapping of cyanide-related genes has been examined in several research works (Balyejusa-Kizito *et al*., 2007; Whankaew *et al*., 2011). Balyejusa-Kizito *et al*. (2007) emphasized that a trait such as cyanide level is heavily affected by environmental factors.

Notwithstanding, it has been demonstrated that the cyanide trait is inbred. Quantitative trait loci (QTL) have been recognized on two distinct linkage groups controlling cyanogenic potential (CNP) (Whankaew *et al*., 2011). In all components of the mature cassava plant, except seeds, cyanogenic glucosides linamarin (95 percent) and lotaustralin (5 percent) are present, according to Conn (1994). However, the concentrations of linamarin and linamarase differ extensively between cultivars of cassava, between crops of the same species, between different tissues of the same plant, between the roots of the same plant and even within the root parenchyma.

Lotaustralin (ethyl linamarin) is present in the vacuole of plant cells and is present in the cell wall of the linamarase enzyme (Mkpong, Yang, Chism & Sayre, 1990). Linamarin is synthesized in the leaves and then transferred to the roots, possibly through the phloem, and some additional synthesis occurs in the root periderm (Jorgensen *et al.,* 2005). The cyanogenic glycosides and the related hydrolytic enzyme (β-glycosidase) are combined when a predator disrupts the cell structure of the plant, leading to a subsequent breakdown of sugar and cyanohydrin, the volatile cyanohydrin rapidly decomposes into cyanide water (HCN) and an aldehyde or ketone under neutral conditions (Moller & Seigler, 1999). Cardoso *et al.* (2005) noted that linamarin is present in big quantities in leaves and root peelings, and a second enzyme called hydroxy nitrile lyase (HNL), which catalyzes the hydrolysis of acetone cyanohydrin to produce HCN and acetone, is also present in the leaves (900-2000 mgHCN / kg fresh weight). In order to avoid the development of toxic cyanide in undamaged cells, linamarin in the vacuole, linamarase and Hydroxy Nitrile Lyase (HNL) in the cell wall are compartmentalized.

The breakdown of the physical barriers between substrates and enzymes after tissue damage initiates cyanogenesis (Poulton, 1990). The potential toxicity of Cassava is linked to the ability of all plant components to release cyanide hydrogen from stored cyanogenic glucosides, and this process is known as cyanogenesis (Nahrstedt, 1993). Cyanogens, linamarin and cyanohydrin acetone are the obvious cause of animal and human cyanide toxicity when converted into cyanide within the body. There are big quantities of cyanogenic glycoside in the fresh leaves and fresh root peel (900-2000 mgHCN/kg) (Cardoso *et al*., 2005).

The leaves comprise the HNL enzyme that catalyzes acetone cyanohydrin's hydrolysis to generate HCN and acetone (Siritunga and Sayre, 2004). Compared to the leaves, the root has about 20-fold reduced linamarin concentrations. The root tubers have significantly decreased leaf-related concentrations of HNL (< 6 percent). There are variations in root cyanogen concentrations depending on the cultivar. For low and high cyanogenic cultivars, total root linamarin concentrations range from 100 to 500 mg linamarin/kg fresh weight. From the exterior peel to the internal parenchyma tissue, there is a marked radial gradient in linamarin content (Bradbury & Egan, 1992). The exterior peel has been shown to contain 7-16 times the linamarin of the same variety's parenchyma tissue (Bradbury & Egan, 1992).

Cyanide and bitter taste of cassava

Depending on the content of cyanide, different cassava cultivars can be differentiated as "sweet" or "bitter" (Nweke *et al*., 1999). Cultivars with < 100 mg/kg fresh weight of cyanide are called' sweet' cultivars while those with 100-500 mg/kg fresh weight of cyanide are classified as ‘bitter' cassava cultivars

(Wheatley, Orrego, Sanchez & Granados, 1993). Cassava roots comprise the glycoside linamarin that is transformed by the enzyme linamarinase into hydrogen cyanide (HCN).

Traditionally, high levels of cyanide in cassava are highly correlated with some bitterness in its taste (Bokanga, 1994). Chiwona-Karltun *et al.* (2004) showed that when farmers tasted raw cassava, the bitter taste was associated with cyanide concentration. Saleh, Mohammed, Khamis and Taib (2004) also recorded an important correlation between the farmers' perceived flavour and the content of cyanide in the roots. However, the discussion on whether the amount of cyanide could be straightaway related to the bitterness conceived is ongoing. King and Bradbury (1995) remarked that the bitter taste was not directly related to the content of linamarin but to some other compound called isopropyl-b-D-apiofuranosyl-(16)-b-D-glucopyranoside (IAG, structure I).

Most studies demonstrate that bitterness is associated with cyanogenic potential. In contrast to "sweet" cassava, the word "bitter" cassava relates to the root parenchyma taste. Higher concentrations of cyanogenic glucosides are connected with bitterness. However, some ecological stressors, such as pest attacks, extended drought and low soil concentrations of phosphorus and potassium, may cause roots to develop bitter taste, and this coincides with a rise in cyanogenic glucoside concentrations. The peel of the "bitter" cassava plant contains an average of 650 ppm while the parenchyma has 310 ppm of complete cyanide; the respective "sweet" variety values were 200 ppm and 38 ppm of total cyanide (Anom, 2005).

Cyanogenic potential in cassava and its implications on health

The use of high levels of cyanogen's of cassava products can lead to disease or death (Tylleskär *et al*., 1991). While many plants are cyanogenic, unlike cassava, the toxic component usually occurs in the inedible components of the plant such as apple seeds and wheat leaves or in tiny quantities in almonds (Jones, 1998).

Consumption of 50 to 100 mg or 2 mmol of HCN within 24 hours can totally block cellular breathing leading to death for an adult person (Rosling, 1994). During digestion, β-glycosidase will be released upon intake of unprocessed cassava and will stay active until deactivated by the low pH of the belly. This enzyme hydrolyzes the cyanogenic glycoside and releases at least portion of the plant's potential content of hydrogen cyanide (WHO, 1993). In several fields of Africa, ingestion of big amounts of cassava or prolonged exposure to improperly processed cassava food has been correlated with chronic cyanide poisoning (Mlingi, Poulter & Rosling, 1992). However, intake of insufficiently processed bitter roots with variable concentrations of glucosides and cyanohydrins may lead in nutritional cyanide exposure involving acute poisoning and other toxic-nutritional diseases (Mlingi *et al*., 1992).

By binding to iron in haemoglobin, HCN is readily absorbed into the blood, whether directly ingested or released from cyanogens in the body, and is quickly transmitted to organs such as the liver, kidney, brain, and blood tissue (Carlsson, Mlingi, Juma, Ronquist & Rosling, 1999). Acute poisoning results in death, exacerbation of goitre and cretinism in iodine-deficient areas causing konzo and involving the incidence of tropical ataxic neuropathy (TAN) and infant stunting (Oluwole *et al.*, 2003; Stephenson *et al.*, 2010).

Genetic improvement in cassava

Genetic improvement starts in cassava when broad-based germplasm is assembled and evaluated (Ceballos, Iglesias, Perez & Dixon, 2004). Source populations with high gene frequencies connected with desirable characters are obtained and fresh recombinant genotypes obtained from chosen elite clones are produced (Ceballos *et al*., 2004). Selected genotypes from the initial evaluation of germplasm typically join the hybridization scheme, followed by the choice of superior clones in the segregating population (Kawano, 2003).

Cassava breeding

The most common practice of multiplication is to use the stem of the plant to breed fresh crops (Sayre *et al*., 2011). Due to the differences in the crops' flowering times, crossing through sexual reproduction of the plant to produce crops with combined parent characteristics becomes difficult (Ceballos *et al*., 2004). Compared to other crops, scientific cassava breeding in a few decades ago has only lately started and thus there are not as many inherited variations amongst wild and improved germplasms likened to other plants with a longer breeding record.

Over the past 30–40 years, excellent progress has been made despite these limitations. The cassava genome has experienced some improvements in traits such as: improved yield, low cyanogenic content, increased resistance / tolerance to major diseases and pests, and high dry matter, and high pro Vitamin A resulting in improved varieties released to farmers (Ceballos *et al*. 2004).

Genetic variation

By Acquaah (2009), genetic or heritable variation is the variation that is attributed to genes that carry particular traits and can be passed from generation to generation. The mixture of its genetic structure called the genotype (G) environment (E) and a portion attributed to the genetic-environment (GxE) interaction results in a phenotype (P), known as the observed trait. Phenotype = Genotype + Environment + G x E (Brown & Caligari, 2009). Usually expressed as: deducing the equation of phenotypic expression, any variation observed in the phenotype is due to variation within the variables of the phenotype. As in equation 1, it is then possible to present the relationship:

$$VP = VG + VE + V (G \times E) \quad (2.1)$$

VP = Phenotypic variation

VG = Genotypic variation

VE = Environmental variations

V (G x E) = Variation due to genotype x environment interaction effects

In general, variation from genotype is split into two parts namely additive and non-additive (Sleper & Poehlman, 2006; Brown & Caligari, 2009). The combined effect of alleles on all trait-influencing gene loci is due to additive variation and is typically most important in the enhancement program of a crop (Falconer & Mackay, 1996). Non-additive variation is divided into dominance variation induced by particular interaction of the allele gene locus and epistatic variation induced by interaction of gene loci (Falconer & Mackay, 1996). The non-additive variation is generally given little consideration due to the fact that the additive portion of genetic difference is inherited (Brown & Caligari, 2009).

The result of gene recombination, chromosome number changes, and mutations is normal genetic or heritable variation (Falconer & Mackay, 1996). Plant breeders use varied techniques and methods to manipulate these three phenomena more extensively, instead of waiting for them to occur naturally as they produce genetic variation for their breeding programs (Acquaah, 2009).

Environmental variation

Variables of plant growth like humidity, nutrients, light and temperature are often heterogeneous for an environment (Ceccarelli & Grando, 1991). Due to its non-heritable nature, environmental variation is usually hard to regulate. Environmental variation is generally connected with the prevailing environmental conditions at the cultivation site (Ceccarelli & Grando, 1991).

Genotype x Environment (GxE) interactions

An interaction between the genotype x environment can be described as a shift in the comparative performance of two or more genotypes in two or more environments. Genotype x environment interaction differs with the genotypes which are tested and have their testing environments selected (Lebot, 2009). Environmental effects affect, particularly quantitative traits that are complexly inherited. For a quantitative trait such as yield, a significant genotype by environmental interaction (GxE) is able to lessen the usefulness of subsequent studies, limit the significance of otherwise valid inferences, and severely restrict the feasibility of selecting superior genotypes (Flores, Moreno & Cubero, 1998). Given the complexity of quantitative traits, in order to unravel significant parts of gene interaction, many different lines or crosses must be closely analysed over different years and environments (Baiyeri *et al*., 2008).

Theoretically, the absence of important interaction of genotypes with locations, years, or locations x year show that it would be adequate to define genotypes with higher genetic capacity at one location during one year (Okoro, 2015). The similarity in the comparative performance of genotypes can be determined by the magnitude of the interaction between the genotype x location calculated by normal variance assessment. Wide changes in the rank performance of genotypes at test locations indicate that the development of genotypes for separate locations may be desirable through autonomous selection and testing programs (Okoro, 2015).

Tan and Mak (1995) noted that the impacts of GxE were important for the root number, harvest index (HI), fresh storage root yield (FSRY), starch and cyanide content of fresh storage root yield. Although significant, their impacts were lower than the impacts of the genotype, except for the number of root storage and fresh root yield. Studies in contrasting environments with different cassava genotypes have also shown that fresh storage root yield (FSRY) is subject to strong GxE (Ssemakula & Dixon, 2007; Aina *et al*., 2009). Tan and Mak (1995) detected significant GxE effects for the content of FSRY, HI, starch, and cyanide. Although significant, their effects were lower compared to the effects of the genotype, except for root number of commercial storage and FRY. They discovered that a linear GxE interaction with the surroundings displayed only cyanide content. Differences between genotypic values can improve or reduce from one environment to the other, resulting in different rankings of genotypes between environments.

In a broad spectrum of different environments, genotypes are typically studied and agricultural studies may involve a large number of genotypes to assess the magnitude and nature of GxE (Egesi, Ilona, Ogbe, Akoroda & Dixon, 2007; Aina *et al.*, 2009). The phenomenon of differential genotypic reactions is referred to as GxE under different environments. Abiotic and biotic stresses have an impact on gene expression that controls important agronomic traits, resulting in GxE (Kang, 2002). For instance, cassava may face overlapping and contrasting environmental stresses during a typical 12-month period, thereby exacerbating the magnitude of GxE (Kang, 2002). As such, in most plant breeding programs, GxE remains of concern. Thereafter, systematic assessment of GxE impacts for a specified trait is helpful for understanding varietal stability and therefore strategic variety implementation (Acquaah, 2012). For the purposes of stability analyses and GxE knowledge, several univariate and multivariate statistical models were established (Gauch, 2013).

It is common for cassava breeders to evaluate advanced breeding lines (as many as 30) in multiple environments (as many as 10) to account for GxE when determining genotypes of high and stable performance (Maroya *et al*. 2012). Studies conducted by Akinwale *et al. (2011);* Tumuhimbise, Shanaham, Melis and Kawuki (2014); Agyeman, Parkes and Peprah (2015) have shown substantial variations through various environmental conditions in fresh root yields. Based on assessment of 28 genotypes in five environments evaluated over two growing years, Ssemakula and Dixon (2007) observed low GxE impact on carotenoid content in cassava roots at harvest.

A recent research on the performance of 18 provitamin A clones across five Nigerian environments showed important relationship between genotypes and carotenoid content in the different environments (Maroya *et al*. 2012). Advancing enhanced on-farm cassava clones would involve systematic assessment of such clones in various environments to define better adapted genotypes (Fukuda, Silva & Iglesias, 2002; Nassar & Ortiz, 2006). The yield is the most prevalent trait for crops that are regularly targeted using the GxE strategy, but other instances have been recorded for other traits including quality (Aucamp, Labuschangne & Deventer, 2006) and of biomass (Bradbury, Potts & Beadle, 2011).

G×E Data analysis

In agricultural research, the existence between GxE shows that phenotypic expression of a trait is influenced by both environmental variables and genotypes, a variety of statistical methods for analysing the relationship between GxE have been published. Examples include variance analysis, regression, non-parametric techniques (Fox, Skoumand, Thompson, Btaun & Cromier, 1990) and pattern assessment of multivariate analytical methods such as additive primary impacts and multiplicative interaction (AMMI) and genotype plus GxE interaction (GGE) biplot (Yan, Hunt, Sheng & Szlavnics, 2000). AMMI enables comprehensive data analysis by conducting periodic variance analysis (ANOVA) and estimating interaction impacts through principal component analysis (PCA), which somewhat improves the accuracy of trait estimates and allows accurate selection (Gauch, Piepho & Annicchiarico, 2008).

The genotype plus GxE interaction (GGE) biplot (Yan & Tinker 2006) is a supplementary analytical instrument for visualizing GxE. A GGE biplot's polygon perspective is the best way to evaluate the patterns of interaction between genotypes and environments and to interpret a biplot efficiently (Yan & Kang 2002). Genotypes that occupy polygon vertices are the highest performers in a particular environment for a specified trait (Yan & Kang 2002). The GGE biplot enables the identification in test environments of stable and best performing genotypes, which is an important decision-making tool for identifying crop varieties for subsequent release (Farshadfar, Rashida, Mahdi & Zali, 2013).

There are many approaches to data transformation, such as environment-centric or standardized, which result in a family of pattern analyzes (Kroonenburg, 1995). Reasonable transformation is dependent on the intent of the study as examined by DeLacy, Basford, Cooper, Bull and Mclaren (1996). For example, when a correlation matrix is used, a structured transformation of the environment is implied and suggested for plant breeding. In addition, when genotype ordination is performed using the covariance matrix, an environmental model is performed and suggested for adaptation study.

Pests of Cassava

Whiteflies, cassava mealybugs, cassava green mite, variegated grasshopper and vertebrate pests (rodents) are the main cassava pests in sub-Saharan Africa. Some of the pests feed on the stems and leaves while others feed on the stems and roots (Olugbenga *et al*., 2011).

Whiteflies

The young cassava leaves of the plant are directly fed on by Whiteflies and which are a virus vector also, making them the most destructive insect pest in all areas of cassava production (FAO, 2013). Two whiteflies species (Spiraling whiteflies and *Bemisia* whiteflies) predominantly cause damage. The Spiraling whiteflies (*Aleurodicus dispersus*) suck sap from the leaves to damage the cassava (Alvarez, Llano & Mejia, 2012). They excrete great quantities of honeydew as they feed, which promotes the development of black sooty mould on the plant. This causes the older leaves to collapse prematurely (Olugbenga *et al*., 2011). In addition, the Bemisia whiteflies (*Bemisia tabaci*) also suck sap from the leaves, but this does not cause plant damage. These insects inject viruses into the plant as they feed resulting in the cassava mosaic disease.

Diseases of cassava

According to FAO (2013), the greatest number of cassava diseases is located at Latin America and the Caribbean, the centre of origin of the plant. However, several of them have now been found in sub-Saharan Africa and Asia. Miskito *et al.* (2000) reported that many diseases are caused by pathogens whose symptoms of damage occur on leaves, stems and roots of storage. According to Miskito *et al*. (2000) some of these diseases attack the cassava plants' leaves and stems, while others attack the storage roots. Common diseases of cassava comprise cassava mosaic disease, bacterial blight of cassava, cassava anthracnose disease, necrosis of cassava buds, and root rot. The cassava mosaic disease (CMD) constitutes the most endemic disease in the country.

Cassava mosaic disease (CMD)

CMD is caused by a virus from the genus Begomovirus and the Geminiviridae family (Busogoro *et al*., 2008). The majority of geminivirus genomes are bipartite, with DNA-A and DNA-B. (Busogoro *et al*., 2008). Although the whitefly, *Bemisia tabaci*, is a vector for CMD-causing viruses (Fargette & Vie, 1995), the use of cuttings from previously grown plants infected with the viruses contributes to the disease's spread (Alvarez *et al*., 2012). A study conducted by Mabasa (2007) found that a higher percentage (27.1 %) of CMD infection was due to the use of infected planting materials compared to whitefly borne-infections (10.4 %).

A variety of factors affect the expression of CMD symptoms, including the genotype of the host, the growing season, the virus species that causes the disease, and the stage of crop growth (Adjata *et al*., 2011). Multiple CMD begomovirus infections have been reported to cause severe symptoms in plants (Ogbe, Thottappilly, Dixon, & Mignouna, 2003). The leaves would be discoloured by patches of ordinary green combined with light green, yellow and white (chlorosis). The cassava plant becomes stunted as a result of a serious cassava mosaic attack, which causes the leaves to become tiny and distorted (Kumar & Legg, 2009). Plants that are less than six months old have more pronounced symptoms than those that are older. CMD decreases photosynthetic area, reducing shoot and root development and growth. It can infect cassava plants as early as one month after planting (MAP), causing leaf size reduction (El-Sharkawy, 1993). Root yields are reduced as a result, and yield losses of up to 90 % have been recorded (IITA, 2008).

According to Zhang, Vanderschuren, Fütterer & Gruissenm (2005), cassava losses in Africa due to CMD are projected to be 19.6-27.8% of total production. Crop yield losses were estimated to be in the range of US$ 1200-2400 million per year (Thresh *et al*., 1998). CMD was said to be the most widespread of the virus diseases limiting cassava production in Sub-Saharan Africa (Ogbe *et al*., 2003; FAO, 2013). Crop hygiene, the use of virus-free stem cuttings as planting material, and the roguing of diseased plants from within stands are the three basic strategies to controlling CMD, according to Thresh *et al*. (1998). Crop hygiene aids in the management of CMD by removing debris and surviving plants from previous crops to reduce the risk of inoculum spreading to new plantings site (Fargette, Fauquet, Grenier, & Thresh, 1990).

According to Legg and Fauquet (2004), using virus-free cuttings as planting materials increases productivity while also reducing the extent of infection in the area and the risk of vector transmission. Roguing, or the removal of CMD-infected plants from a crop stand, is a popular disease control method. However, farmers are often opposed to rouging because the loss of the plants removed is thought to outweigh the potential benefits of reduced virus spread (Legg & Fauquet, 2004). Currently, resistance breeding is being used in Africa to control CMD, and several advances have been made to develop CMD resistant varieties and distribute them to farmers.

Weed Control

Weeds are herbaceous crops that grow where they are not desired (Melifonwu *et al*., 2000). There are many different kinds of weeds growing in cassava farms, causing the farmer significant losses.

Weeds can lower cassava yields by competing with the cassava plant for moisture, nutrients and light (African Organic Agriculture Training Manual, 2011). From the FAO's perspective (2013), initial development of cassava in the first 3 to 4 months, combined with comparatively broad spacing between crops, provides weeds the opportunity to compete favourably for sunshine, water and nutrients after emergence. Weeds can also harbour pests and diseases or physically damage cassava plants and root tubers. Narrow-leaf feathery Pennisetum (*Pennisetum polystachion*), spear grass (*Imperata cylindrica*) and guinea grass (*Panicum maximum*), *Cyperus rotundus* and broadleaf weeds such as (*Chromolaena odorata*) and goat weed (*Ageratum conyzoides*) (Melifonwu *et al*., 2000) are common weeds influencing cassava production in Africa. Weed competition may lead to yield decreases of roughly 50 % in the first four months after planting (Leihner, 2002). Farmers spend more time in weeding in most African nations than in any other aspect in the production of the crop (Olorunmaiye, 2010). Once the canopy of cassava is shut, most weeds will be shaded and the field will be nearly weed-free (FAO, 2013). Weeds may reappear six to eight months after planting, but this usually does not impact returns seriously, but rather makes harvesting difficult.

Cultural practices can provide efficient weed control. Although cultural controls may not be 100% efficient, they contribute to decreasing weed competition and thus the need for mechanical or chemical weeding (Leihner, 2002). High plant density and the recommended fertilizer type and rate can boost early plant growth and fast canopy closure (FAO, 2012).

By removing weeds with hoes about 15 days after planting, many sub-Saharan African cassava farmers use mechanical control measures. Leihner's (2002) research in Colombia found that cassava root yields were 18 t / ha with hand weeding at 15, 30, 60- and 120-days after planting. Just 8 percent lower than those acquired when weeds were treated with herbicides. When weeds were not at all handled, yields dropped to just 1.4 t / ha. On commercial farms, weeds are often treated with herbicides when labour is scarce or too expensive. Pre-emergence herbicides prevent weed seeds from growing or decreasing their growth rate when applied (Melifonwu *et al.*, 2000). Pre-emergence herbicides can be used for 6 to 8 weeks after planting to maintain an almost weed-free cassava field (FAO, 2013). It is also possible to apply a selective post-emergence herbicide. When some lower leaves begin to fall off, weeds can be tracked around 4 to 5 months after planting.

Uses of cassava

Cassava has become one of the continent's most significant crops since its introduction in Africa in the 16th century. Over the past four centuries, production has more than tripled (Hillocks, 2002). It can be used in Africa as food, feed and industrial raw materials (FAO, 2004).

Food

Globally, the use of cassava was estimated at 102 million tonnes in 2000, according to the FAO (2004), with Africa consuming the majority of fresh roots and processed products. Dishes based on cassava are commonly eaten wherever the plant is grown; some are of regional, national or ethnic significance (Frederick, Hog & Hominy, 2008).

In Ghana cassava root is used to prepare *ampesi, kokonte, akyeke, garifoto, akple, gari, tapioca, starch, yakayake, agbelikaklo* and *fufu*. The Ewes in Ghana have named the cassava crop "agbeli" in communities in Ghana, meaning “there is life”. This, undoubtedly, depicts its significance to the nation as a whole and especially to the Ewes who are found in almost every part of the nation. In Nigeria, *abacha, elubon, lafun* and *kpokpogari* are some of the most prevalent cassava-based products apart from those in Ghana. In Cameroon, *baton du manioc, chickwangue, kouron-kouron* and *kumkum* are some of the dishes. Other dishes include *attieke* in Cote d'lvoire, *foofoo* in Sierra Leone, *njambo* in Gambia and *ugali* in Tanzania (IITA, 1990). In many African countries, including Cameroon, the Democratic Republic of Congo, Liberia and Tanzania, young cassava leaves are frequently picked and cooked for human consumption. Based on dry matter, tender leaves contain up to 25 % protein and are a valuable source of iron, calcium and vitamins A and C (Balagoplan, 2004). High quality cassava flour is a non-fermented cassava product that can be used in bread and confectionery as an alternative to wheat flour and starch (Westby & Adebayo, 2012).

Animal feed

The cassava plant's roots and leaves can be used either as animal feed or feed ingredients (Ravindran, 1993). However, because of their high cyanide content in fresh roots or leaves, high cyanide clones can only be eaten fresh by livestock in very small quantities. Cassava roots, though small pieces of leaves are cut, are chipped or sliced. The chopped roots and leaves can be sun-dried in plastic bags or air-tight containers, or tightly packed and fermented to make silage (Ravindran, 1993).

A greater quantity of cyanide can be released by either sun-drying or ensiling, making those products safe as feed for pigs, livestock and chickens (Ravindran, 1993). Chips are sold directly or milled into a powder that can be combined with other ingredients, such as soymeal, full-fat soybean, fish meal, or other protein sources, to produce nutritious animal feed that is generally supplemented with methionine, vitamins, and minerals (Ravindran, 1993). The performance of pigs is very similar to that obtained with a diet based on maize or broken rice if the diet is well-balanced in terms of energy and protein (Balagoplan, 2004). Cassava food is easily digestible and contains lactic acid and yeast bacteria naturally, which strengthen the microflora of animals in the digestive tract. Dry cassava leaf meal or cassava hay are typically supplied by cutting plant tops at 2 to 3 months intervals during the cassava growth cycle (Ravindran, 1993). It has a high fibre content and is particularly appropriate for ruminants. Cassava hay is made at a youthful development point of 3-4 months, harvested around 30-45 cm above the ground and sun-dried for 1-2 days until it has a final dry matter of less than 85 percent (Ravindran, 1993).

Medicinal uses

Cassava is not widely used in herbal medicine, but it is used for multiple healing reasons by indigenous people. The leaves can be used as a styptic, while the starch blended with rum, particularly for kids, has been used for skin problems. Cassava can be a helpful source of starch for individuals with coeliac disease (gluten intolerance) because it contains no gluten at all. The cassava roots are transformed into a poultice in herbal remedies and directly applied to the skin as a treatment against sores (Wingertzahn, Teichberg & Wapnir, 1999).

Tapioca starch which is derived from the cassava plant is used in developing nations to help restore bodily fluids. Vitamin C supplements may be obtained from cassava root starch (Chávez *et al*., 2000).

Industrial uses

Starch from cassava is used by the food industry in many preparations, including sauces, gravies, mustard powder, baby foods, tapioca products such as pudding, infant and invalid foods, glucose processing, confectionery and bakery products, as well as jelly or thickening agent in the manufacture of adhesives, dextrin and paste and as filler in the manufacture of paints (IITA, 1990). Most of the indigenous cassava starch in Asia is transformed into a variety of modified starches for use in food products or as feedstock for sweetener, fructose, alcohol and monosodium glutamate production. Modified starch is also used in large quantities in the production of plywood, paper and fabric, along with high quality cassava flour (Balagoplan, 2004).

Cassava is used in the textile field for warp sizing, clothing, felt finishing and printing. The use of explosives, colorants, medicines, chemicals, carpets and linoleum, as well as the manufacture of alcohol and rubber latex coagulation, are minor industrial applications. An important new application of starch is the machine-coating of magazine paper, previously made exclusively with caseins (Ceballos *et al*., 2012).

Cassava is one of Africa, Asia and Latin America's wealthiest fermentable substances for alcohol manufacturing. The fresh roots comprise about 30 % starch and 5 % sugar, and the dried roots contain about 80 % fermentable substances that are equal to rice as an alcohol source.

After grated cassava fermentation, cassava beer and fermented beverages such as ‘Ruut beer’ and ‘Kasili’ are produced in Ghana and Uganda respectively. Although in the tropical climate, barley does not do well, cassava is so simple to grow in Africa. The crop was not used in brewing beer because it begins to degrade within 24 hours of harvesting; however, with SABMiller's latest technology, original root processing in the field enables them to be stored for weeks (Dontoh & Kew, 2013).

CHAPTER THREE

FARMERS' AND CONSUMERS' PERCEPTIONS AND PREFERENCES FOR YELLOW FLESH CASSAVA (YFC) IN THE CENTRAL REGION

Introduction

The adoption by farmers of a new technology is typically motivated by a combination of several considerations. One critical factor is the attitude of farmers to technology. There are differences in the preferences for attributes depending upon economic status of the farmer, geographic locations and his/her farming objective. Variety preference has been shown to be influenced by area of residence (Birol, Smale & Guovai, 2006). According to Birol *et al*. (2006), farmers that have access to markets and developed settlements relied less on their home-produced goods for food whilst farmers residing in the most isolated and economically marginalized settlements value the agricultural biodiversity and food produced in their home gardens.

A new employed intervention called biofortification seeks to improve the content of micronutrient of staple foods consumed by the majority of poor people using conventional plant-breeding techniques in order to make a measurable impact on the magnitude of micronutrient malnutrition. The development of biofortified provitamin A cassava by International Institute of Tropical Agriculture and research partners is a strategy to address the deficiency of vitamin A of white cassava root varieties. Biofortified yellow flesh cassava has a dietary precursor of vitamin A called β-carotene, which is known to be accountable for the yellow to orange colour of flesh storage roots (Rodriguez-Amaya & Kimura, 2004; Njoku, 2012).

Vitamin A is important for immune competence and good vision, as well as, cellular differentiation, growth, and reproduction. The recommended dietary allowance (RDA) of vitamin A for adults and children (4 to 9 years) are 0.75 and 0.3 to 0.4 mg/day retinol respectively (Njoku, 2012). These recommended dietary requirements are not adequately supplied in diets of especially children, pregnant women and the under privileged in most sub-Sahara African countries including Ghana. Therefore, vitamin A deficiency related diseases are major problems in Sub-Sahara Africa and any staple crop that contains high levels of total carotenoids (TC) including β-carotene can be used to combat these challenges. In this research, mutagenesis was used to develop yellow flesh cassava (YFC) varieties and are in the process of being released as YFC varieties in Ghana.

The success of such YFC development depends on whether it is accepted and consumed by the target populations. With cassava as a staple food in Ghana, as in much of Sub-Saharan Africa, the effective introduction of provitamin A cassava could have a substantial impact on reducing the frequency of vitamin A deficiency in Ghana, and elsewhere in Sub-Saharan Africa, where it is a major public health concern. Even though yellow flesh cassava appears to be a successful crop in Ghana, its preference by potential consumers' needs to be assessed, since consumer acceptance is key in marketing strategies and product development in agriculture. Also, there is little study on the preference for yellow flesh cassava by consumers and farmers (Bouis, McClafferty, Meenakshi & Pferiffer, 2011). The present study aimed to solicit information from farmers and consumers in southern Ghana regarding their perception and preferences for yellow flesh cassava. The objectives were to:

i. assess the perceptions of Ghanaian farmers and consumers for yellow flesh cassava varieties.

ii. assess the preferences of Ghanaian farmers and consumers for yellow flesh cassava varieties with pro vitamin A.

Materials and Methods used

Study areas

This study was carried out in Assin South, Abura-Asebu-Kwamankese, Agona East, Asikuma-Odoben-Brakwa and Twifo Ati Morkwa (Figure 3.1).

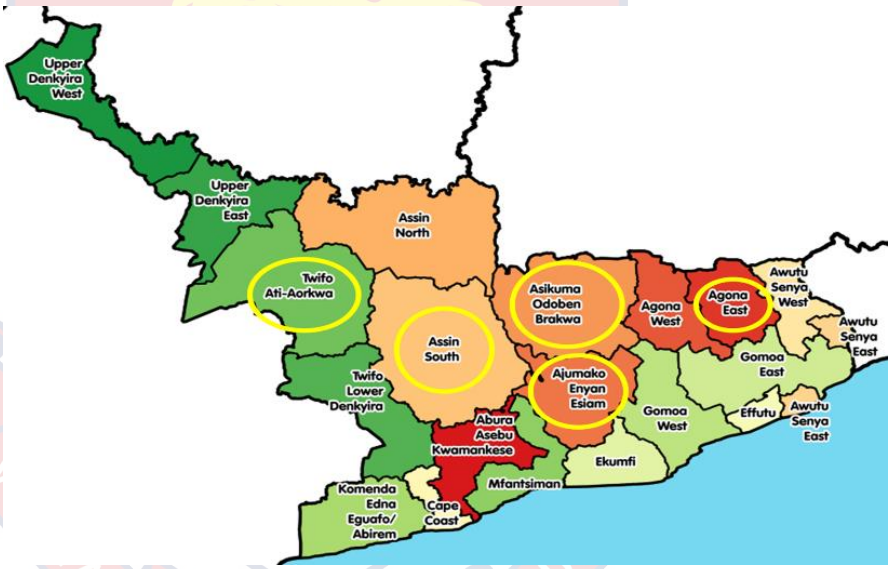

Figure 3.1: Map of Central Region showing the study districts in the yellow circles. Source: *https://en.wikipedia.org/wiki/Central_Region_(Ghana)*

Factors including type of soil, rainfall, and altitude necessitated the selection of these districts (Table 3.1).

Table 3.1: Weather condition of the study area.

Districts	Humidity (%)	Rainfall (mm) min - max	Temp (°C)
Abura-Asebu-Kwamankese	85	1000 - 1900	26 – 29
Agona East	94	1000 - 1400	23 – 29
Assin South	70	1500 - 2000	20 – 30
Asikuma-Odoben-Brakwa	80	1200 - 2000	26 – 34
Twifo Ati-Morkwa	92	1200 - 2000	26 – 30

Source**:** MoFA, (2020)

Sample size determination

The procedure by which a sample is selected from a group of people of certain kind for research purpose is known as sampling. In sampling, the population is divided into a number of parts called sampling units. For this study, a total number of 200 farmers and 400 consumers were sampled in all the five districts (120 per district) with each having 40 farmers and 80 consumers. Anderson's (2007) sampling method was adopted for determining sample sizes using the formula

sampling size (n) $= \frac{z^2pq}{d^2} = 1$ (3.1)

Where n = the sample size, z =1.96, p = proportion of population (the proportion of cassava farmers and consumers in the five districts in the Central Region), q = a weighting variable computed as 1-p and d = the margin of error.

Data Collection

Cassava farmers' and consumers' knowledge about yellow flesh cassava, source of information about YFC, farmers' willingness to cultivate

YFC and apparent usage of YFC were sourced from using pre-tested structured questionnaires for interviews. Also, data were collected on participants age, marital status, educational level and farm size. A total of 600 questionnaires were administered to respondents consisting of 200 cassava farmers and 400 consumers.

Statistical analysis

Data collected were entered into Microsoft Office Excel 2019. Data were then investigated using the Statistical Package for Social Sciences (SPSS) version 25, and reported in percentage, frequency, arithmetic means and standard deviation.

Results

Socio economic characteristics of respondents

Results in Table 3.2 shows the socio-economic characteristics of the respondents (farmers). The proportion of males were higher than female. Males constituted 75 % and female constituted 25 %. Twenty-seven percent (27 %) of the respondents (farmers) were aged between 40-49 years. This was followed by 23 % of farmers who had their ages between 30-39 years while 22 % of the farmers aged between 60-69 years. A total of 44 % of the farmers who cultivated cassava had primary/middle/JHS school education. Thirty-eight percent (38 %) of the farmers had no formal education, 16 % of the farmers had secondary education and 2 % had tertiary education (Table 3.2).

It was observed that 51 % of the respondent (consumers) were females and 49 % males. Most of the consumers aged ranged between 20-59 years. Most of the consumers had primary/middle/JHS education (45 %), followed by no formal education and SHS/SSS with 31 % and 18 % respectively (Table 3.2).

Table 3.2: Socio economic characteristics of respondents

Socio-economic Characteristics	Respondent			
	Farmers (n = 200)		Consumers (n = 400)	
	Freq.	%	Freq.	%
Gender				
Male	150	75	196	49
Female	50	25	204	51
Total	200	100	400	100
Age group				
10-19	6	3	12	3
20-29	32	16	36	9
30-39	46	23	64	16
40-49	54	27	76	19
50-59	40	20	88	22
60-69	22	11	124	31
Total	200	100	400	100
Educational level				
No formal education	76	38	124	31
Primary/middle/JHS	88	44	180	45
SHS/SSS	32	16	72	18
Tertiary	4	2	24	6
Total	200	100	400	100

Source**:** Field data (2019)

Respondents knowledge about yellow flesh cassava (YFC)

Results in Table 3.3 shows that 88 % of respondents are aware of yellow flesh cassava. However, 22 % of respondents are not aware of yellow flesh cassava varieties. Majority of the farmers heard of yellow flesh cassava through other farmers (44 %) followed by their family (33 %) and friends (11 %). Seventy-seven percent (77.5 %) of the respondents have eaten yellow flesh cassava whilst 22.5 % have never eaten yellow flesh cassava. The study also revealed that 81.1 % of the farmers and 69.4. % of the consumers do not known the perceived benefits of yellow flesh cassava whilst 18.6 % and 30.6 % of the farmers and consumers, respectively know the perceived benefits of yellow flesh cassava. Also 81.1 % of the farmers and 76.2 % of consumers do not know the advantages of beta carotene in food crops (Table 3.2).

Table 3.3: Knowledge about yellow flesh cassava (YFC)

Knowledge about yellow flesh cassava (YFC)	Farmers Response		Consumers Response	
	Yes	No	Yes	No
Do you know about YFC	88.8	11.2	91.2	8.8
Have you eaten YFC	77.5	22.5	75.4	24.6
Do you know of any perceived benefits from YFC	18.8	81.2	30.6	69.4
Do you know the benefits of beta carotene in food crops	18.8	81.2	23.8	76.2

Source**:** Field data (2019)

Farmers cultivating Yellow Flesh Cassava (YFC) and willingness to cultivate new varieties of YFC

Currently, 64 % of farmers are cultivating YFC and 36 % are not cultivating YFC. Of the total respondents (farmers), 72 % were willing to accept and cultivate new YFC varieties and 28 % are not willing to cultivate new varieties of YFC (Figure 3.2).

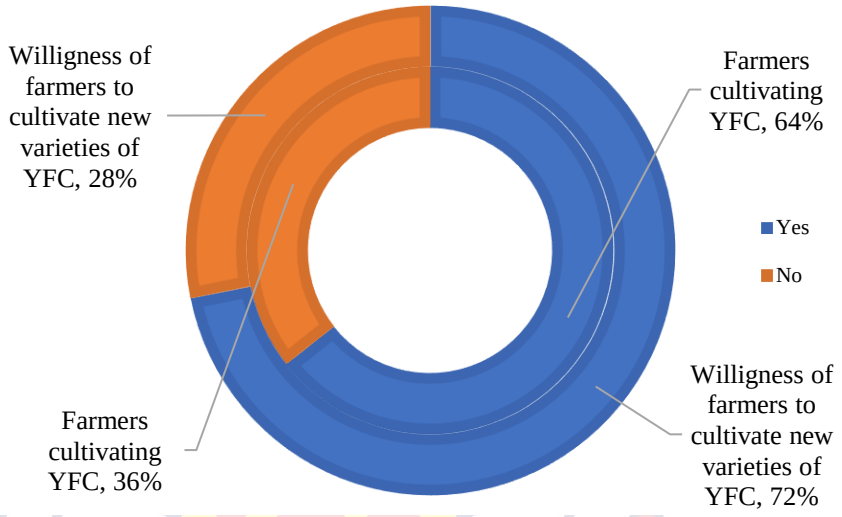

Figure 3.2: Farmers cultivating YFC and willingness to cultivate new YFC varieties

Reason for not cultivating Yellow Flesh Cassava (YFC)

Reasons given for not cultivating YFC included difficulties in getting planting materials and customers not preferring it. One other reason given was that cooked YFC are not poundable (mealiness). The percentages of responses are shown in Figure 3.3.

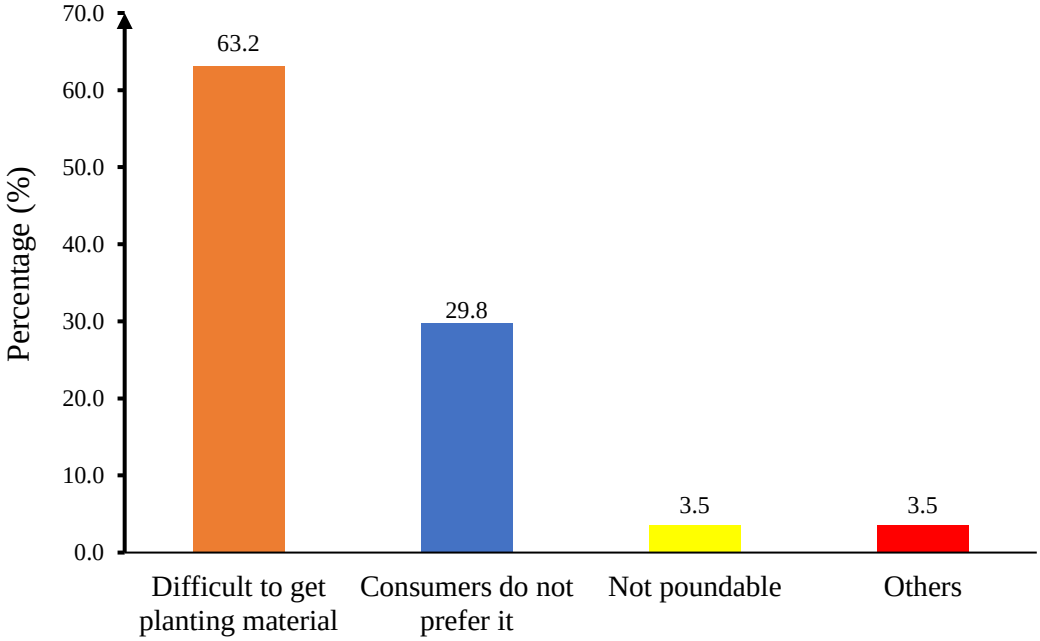

Figure 3.3: Reason for not cultivating YFC

Reason for cultivating YFC

Reasons given for cultivating YFC included high demand by *gari* processors, high yield, not affected by pest and diseases and does not deteriorate fast after harvest. The percentages of responses are shown in Figure 3.4.

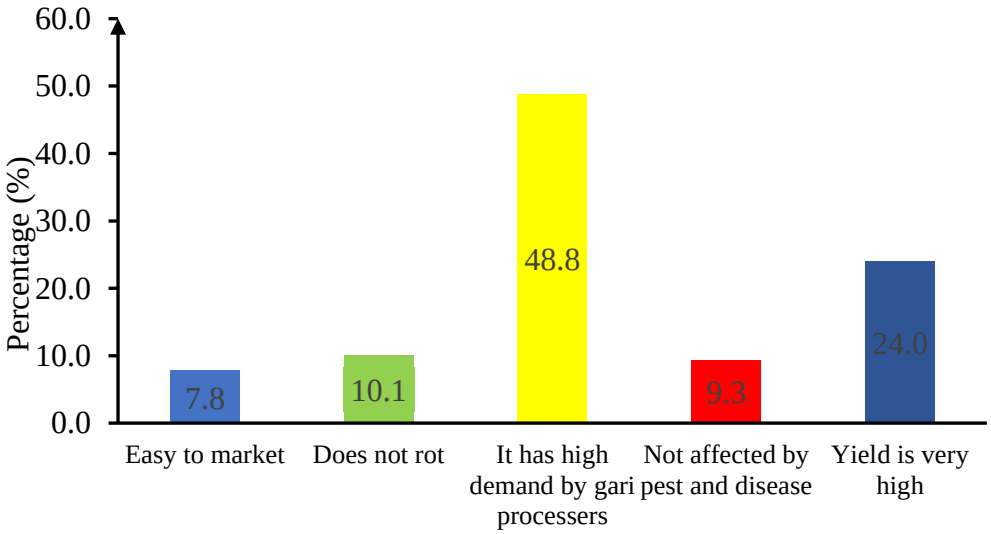

Figure 3.4: Reason for cultivating YFC

Constraints to marketing of YFC

Constraints to the marketing of YFC included no ready market, not poundable (mealiness), difficult to cook and not sweet for *Ampesi*. The percentages of responses are shown in Figure 3.5.

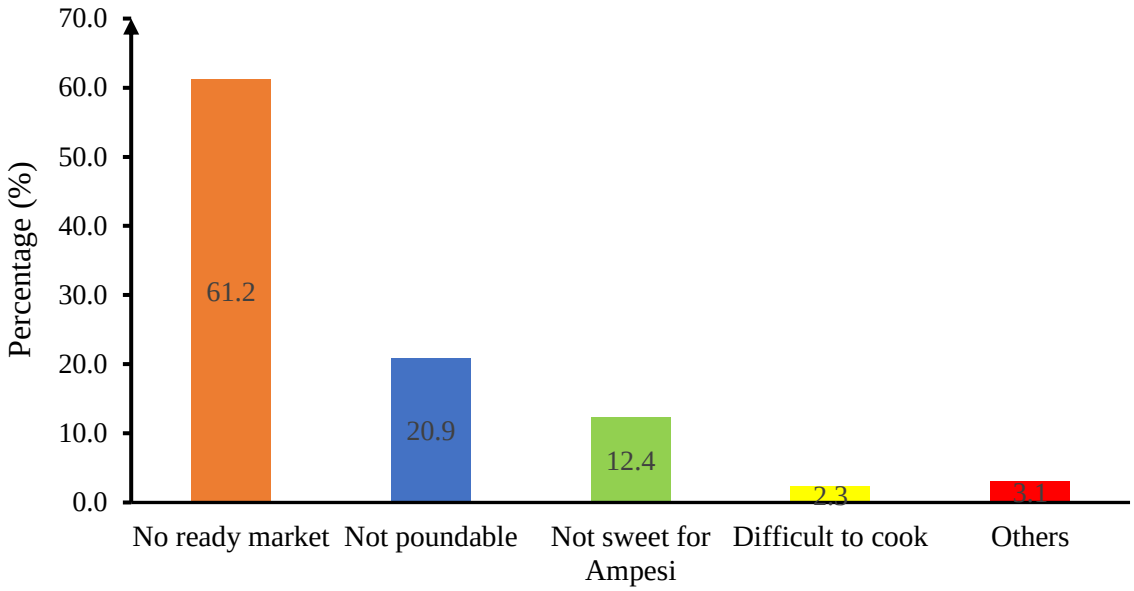

Figure 3.5: Constraints to marketing of YFC

Consumption pattern of YFC by farmers

Cassava products consumption patterns data specified that *fufu* had the maximum frequency of consumption, next was *gari*, *Ampesi* and *Kokonte* (Figure 3.6).

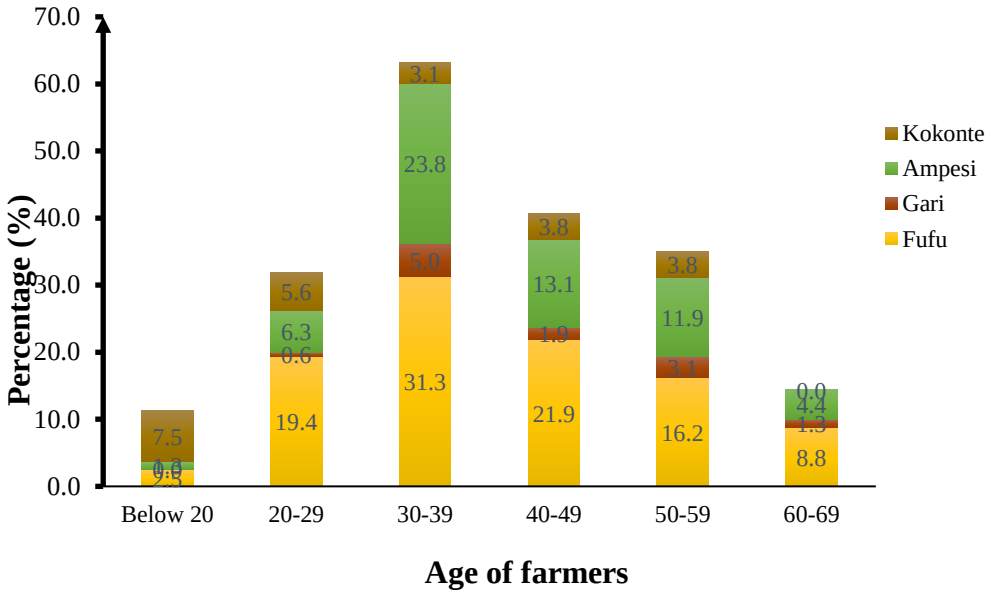

Figure 3.6: Consumption of YFC pattern

Recommended use of YFC by farmers

Most of the respondents (51.3 %) recommended that *fufu* be made from the yellow flesh cassava, followed by 39.4 % and 5.6 % for '*gari*' and '*Ampesi*' respectively. The remaining 3.1 % and 0.6 % recommended yellow flesh cassava to be used for '*Abgelima*' and '*Kokonte*' respectively (Figure 3.7).

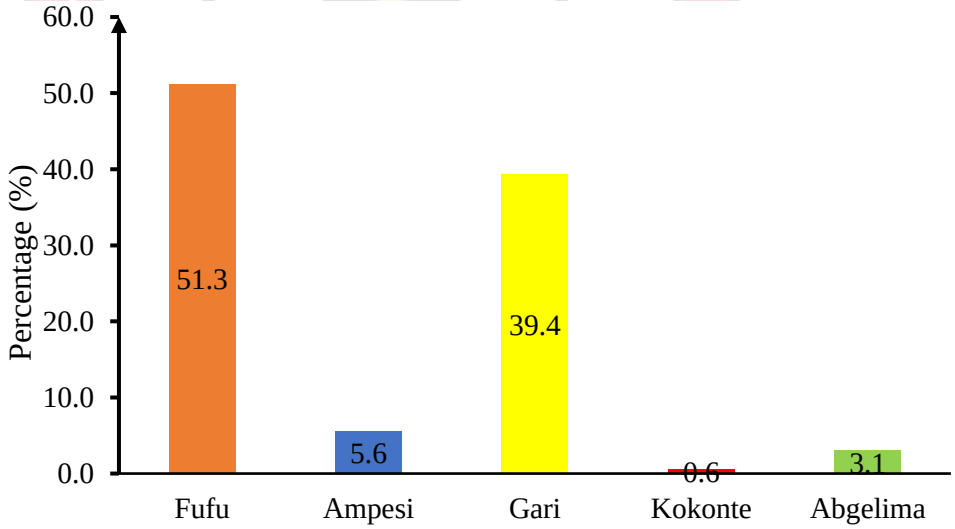

Figure 3.7: Recommended usage of yellow flesh cassava

Frequencies of cassava consumption by consumers

Most of the respondents consume cassava three or more times in a week (44 %), this was followed by those that consume cassava twice in a week (27 %) with 15 % of respondents consuming cassava once a fortnight (Figure 3.8).

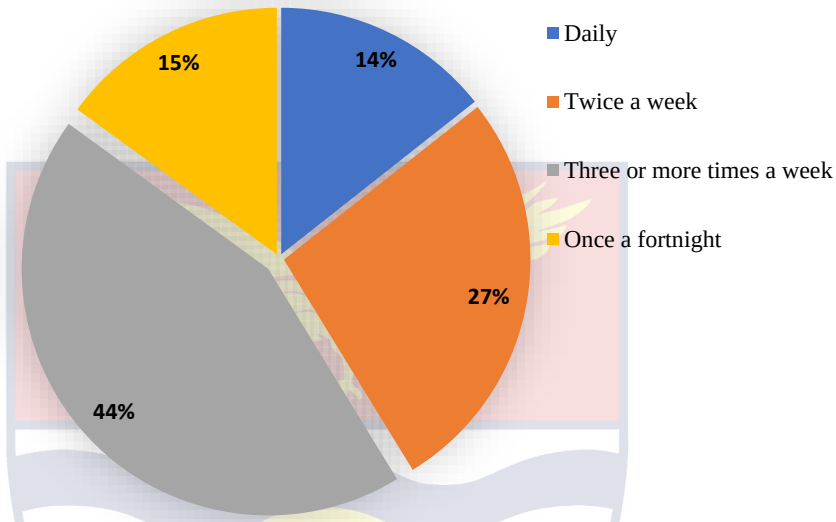

Figure 3.8: Frequencies of cassava consumption

Reasons for cassava consumption by consumers

Respondent ascribed several reasons for consumption of cassava (Figure 3.9). Most of the respondents consume cassava because it gives energy (36 %), its affordable (26 %), staple (22 %) and have lots of uses (16 %).

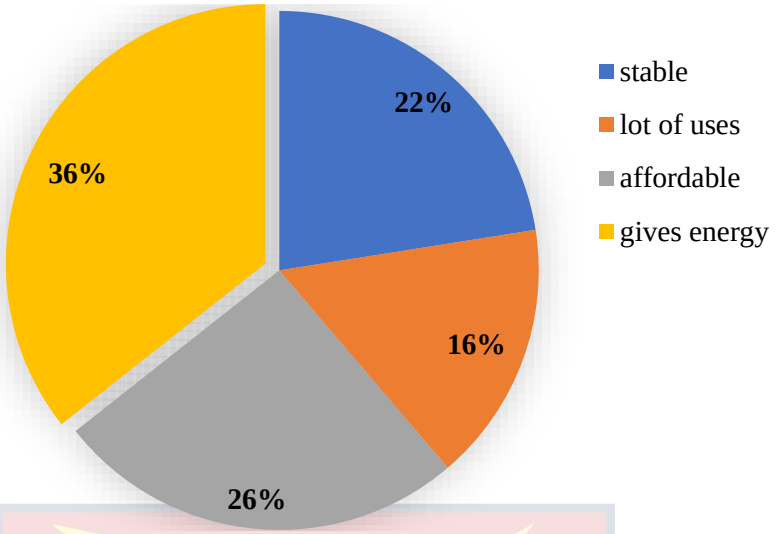

Figure 3.9: Reasons for cassava consumption as food

Consumption of YFC products by consumers

Frequency of consumption of cassava products specified that *fufu* had the largest followed by '*gari'*, '*Ampesi'* and '*Kokonte*' (Fig. 3.10).

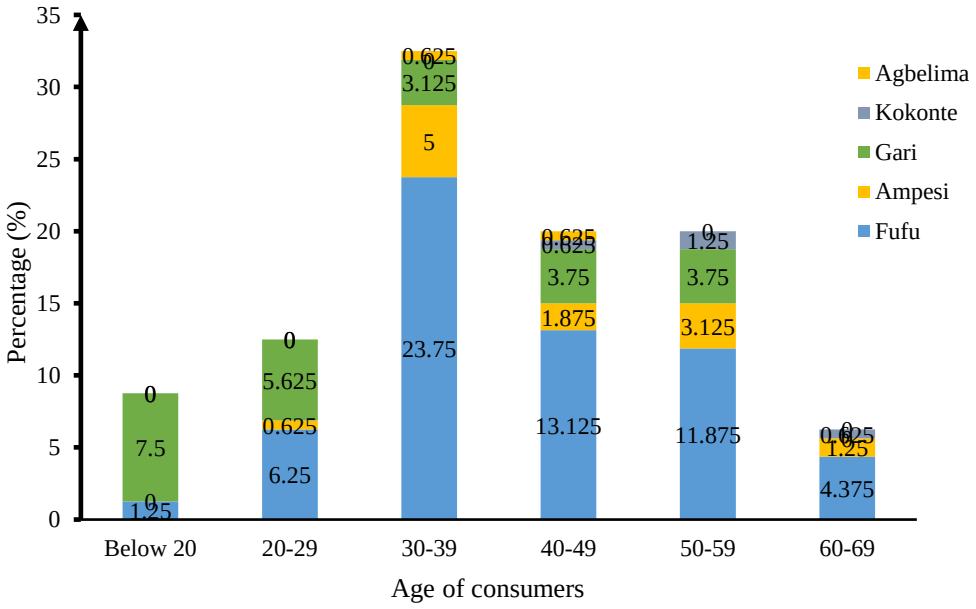

Figure 3.10: Frequency of consumption of YFC products

Recommended use of YFC by consumers

Most of the consumers (55 %) recommended that YFC should be used for *fufu*, followed by 31 % and 6 % for *gari* and *Ampesi* respectively. (Figure 3.11).

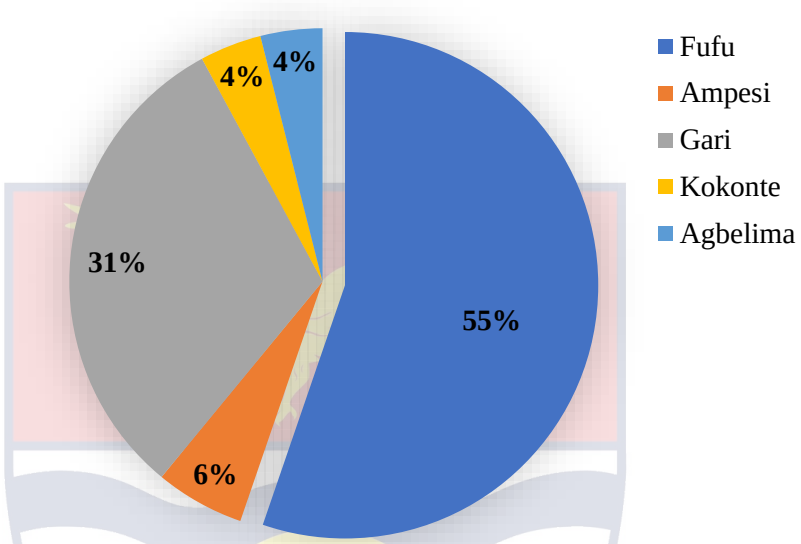

Figure. 3.11: Recommended usage of yellow flesh cassava by consumers

Discussion

It was observed that cassava farming is a male dominated business. This agrees with Kamanda (2017) who reported high percentage of male cassava farmers, indicating the predominance of males in cassava farming. According to Oladeji, Oyedoku and Bankole (2001), It is widely believed that males are often more energetic and could easily be available during harvesting for energy-demanding jobs such as land clearing, planting and removing cassava. Nweke, Spenser and Lyam (2001) also reported that women were found to contribute less than half of the total labour in the cassava production system in five of the six Collaborative Analysis of Cassava in Africa (COSCA). However, it is in a sharp contrast to the findings of Oyegbami *et al.* (2010); Thompson (2013) who stated a higher percentage of female (women) in cassava production, marketing and processing because of the low level of education of the women. Culturally, cassava production is being the primary occupation of women in the communities where the study was carried out.

Majority of the farmers were above 40 years (Table 3.1). This indicates, that the youth are not into farming because they do not see it to be lucrative and therefore, they leave it for the adult population. This is in a sharp contrast with Kamanda (2017) who recorded more than 50 percent of the cassava farmers as youth below 36 years. According to Kamanda (2017), the youth were actively involved in cassava cultivation because when new varieties are released, young people adopt these innovations faster than old people. This is because they are more active, more mobile, more communicating and are also willing to take risk than older people would want to.

Most of the farmers and consumers have high educational background starting from the primary/middle/ JHS level to tertiary certificate (Table 3.1). Education is very important as it helps to refine a person's perceptions of issues and help him/her make reasonable decisions based on available information. The high level of formal education of the farmers in all five districts contributed to the willingness of farmers to accept new varieties of YFC. According to Ajibefun and Aderinola (2004), education facilitates adoption of new varieties; hence, the high level of education among the respondents could have influenced their willingness and acceptance of improved yellow flesh cassava varieties with provitamin A.

On the knowledge about yellow flesh cassava, majority of the farmers and consumers have heard of it through family relatives and other farmers (Table 3.2). This supports the assertion that farmers get to know new information through family and friends. Most of the farmers that have heard of the yellow flesh cassava, have also eaten it in the form of *fufu* or *gari*. However, most of them do not know the perceived benefits of yellow flesh cassava varieties and the importance of ß-carotene in diets. This implies that there must be education to create public awareness on the benefits of ß-carotene in diet and hence the need for the consumption of yellow flesh cassava varieties. If this is done, it will increase the consumption of yellow flesh cassava varieties which will lead to the reduction of vitamin A dietary deficiency in the country. According to Tanumihardjo (2008), nutrition education is an effective instrument for communicating the nutritional and health advantages of bio-fortified foods, and it is also an important factor influencing the acceptability of bio-fortified foods. This was confirmed by Chowdhury *et al*. (2011) who

reported that mothers in Uganda easily accepted bio-fortified foods after receiving nutrition education. Also, Groote *et al*. (2010) have demonstrated the preferences for bio-fortified foods by consumers and this has been influenced by nutritional information provided in Ghana.

Since the yellow flesh cassava varieties currently cultivated by farmers are landrace, they are not easily available. Therefore, farmers are not willing to cultivate it due to the lack of planting materials or non-availability of the planting materials. This agrees with Mtunda (2009) who reported that the major constraints inhibiting cassava production and productivity include poor crop management practices and limited access to quality planting material. Farmers who are currently cultivating yellow flesh cassava noted that it has high demand by *gari* processors (Figure 3.3) since most of the yellow flesh cassava varieties are not mealy.

However, one major constraint that the farmers who cultivate the yellow flesh cassava face was lack of ready market (Figure 3.2). This is because, aside the *gari* processors, most market women and middlemen do not buy the yellow flesh cassava varieties. According to a farmer, at Jakan in the Central Region, when the middlemen and market women come to the farm gate to buy cassava, they only select the white flesh cassava leaving the yellow flesh cassava (Amofah, personnel communication, 2019). Similar reports by Kumanda (2017) indicated that there were no available market outlets for yellow flesh cassava or provitamin A storage roots/products. Mainly cassava is consumed as *fufu*, *Agbelima*, *gari* and *kokonte* in Ghana (Kleih, 2013). The study, revealed that most of the farmers have eaten yellow flesh cassava in the form of *gari*. These were followed by a few who have also eaten YFC in the form of *fufu* (Figure

3.5). This is due to longer shelf life of *gari* which makes it popular quick food preferred by consumers. This agrees with Onyemauwa (2010) who stated that *gari* is the highest consumed cassava product in Ghana and therefore the introduction of yellow flesh cassava will make it more viable for the Ghanaian populace to accept. However, when they were asked to recommend possible YFC products they preferred, majority of them recommended *fufu* made from yellow flesh cassava (Figure 3.6). This is because yellow *fufu* looks very attractive and appealing to the eye and with or without plantain it can still be consumed. Also, others recommended that yellow flesh cassava should be made into *gari* since yellow *gari* is attractive and nutritious when consumed. Since majority of the farmers and consumers prefer yellow flesh cassava varieties processed into *fufu* and *gari*, it's important for breeders to consider breeding more of yellow flesh cassava varieties that are mealy with high starch and dry matter. This will make it easy to pound and prevent a lot of wastage during *gari* processing, since varieties with low dry matter and starch lead to wastage due to high-water content in such varieties.

Majority of the consumers mostly consume cassava products more than three times a week because it gives them a lot of energy (Figure 3.8). According to them, *fufu* contains a lot of energy that helps them to work on the farm. This agrees with the results of Kumanda (2017) who reported fufu as the most consumed cassava product. The addition of cocoyam and plantain to *fufu*, makes it more energy dense when consumed. Also, a section of the respondents consume cassava because it is a staple food in Ghana. Cassava affordability and its several uses were the other reason why people consume it (Duah, 2013).

From the present study, majority of the respondents across the five districts indicated their willingness to accept new varieties of yellow flesh cassava due to its perceived nutritional benefits (Figure 3.1). This agrees with the results of Nkonya and Featherstone (2001) who observed that varieties with farmers' preferred traits were easily adopted. Also, the result is confirmed by Duah *et al.* (2016) who observed that about half of the respondent showed their willingness to accept YFC as food. This is in a sharp contrast with Kamanda (2017) who observed that most of the individual interviewed were not ready to accept YFC due to their lack of knowledge about it.

Conclusion

From the study, it can be concluded that cassava was extensively consumed more than three times in a week in Central Region. *Gari* and *fufu* is the most consumed cassava product according to majority of the respondents. Majority of the respondents have heard of the YFC but don't have any information on its nutritional value. However, a greater number of the respondents were willing to accept and cultivate new varieties of YFC and consume it in the form of *gari* and *fufu*. This is due to its attractive yellow colour and perceived nutritional value. Lack of planting materials and non-availability of ready market were their major constraints. There should be more public awareness on educating the population on the nutritional advantages of YFC to aid in the reduction of vitamin A deficiency in the country. Yellow flesh cassava planting materials should be made readily available by breeders so farmers can easily get access to it.

CHAPTER FOUR

EVALUATION OF YELLOW FLESH CASSAVA GENOTYPES FOR CYANOGENIC POTENTIAL, TOTAL CAROTENOID, DRY MATTER AND YIELD IN THE COASTAL SAVANNAH ZONE

Introduction

The United Nation (UN) World Food Program reports that about 700 million people do not have enough food to lead a healthy, active life. Although less obvious, it is estimated that many more people (more than two billion people) suffer from micronutrient malnutrition (Qaim, Stein & Meenakshi, 2007). Vitamin A deficiency (VAD) is one common form of micronutrient malnutrition. It is prevalent among poor households in developing countries that depend largely on staple food crops for their nutritional needs.

In particular, the populations of underdeveloped and developing countries also suffer from micronutrient deficiencies due to undernourishment and "hidden hunger" (Maroya *et al*., 2010). Areas in Africa, like Ghana, where cassava is widely consumed, are characterized by rampant malnutrition because nutrients such as vitamin A are low in tuberous roots (Ssemakula & Dixon 2007). It is for this reason that in an inexpensive and sustainable manner, the introduction of high ß-carotene cassava varieties should be given much more consideration to reduce malnutrition among the rural and urban poor.

Cassava is important food security and industrial crop in Africa and Asia. It is used as a raw material for industrial use, food and feed. Breeding efforts have led to the development of cassava varieties with desirable characteristics, such as increased root and starch yield, decreased toxicity, decreased susceptibility to pests / diseases and improved nutrient content.

Provitamin A cassava genotypes have been so distinct in biofortification as they have a higher level of micronutrients such as carotenoids (Chávez *et al*., 2005; Ssemakula & Dixon, 2007). The acceptance of biofortified pro vitamin A genotypes, however, largely depends on their agronomic qualities, including the quality of dry matter, fresh root yield, resistance to major pests and diseases and the stability of these traits over time (Ssemakula & Dixon, 2007).

The introduced yellow flesh cassava varieties mostly recorded a low dry matter content (DMC) and associated problems such as drying difficulties, taste and aspects of cooking (Akinwale *et al*., 2010). The low dry matter content (DMC) has also been recorded in Nigeria to be inversely proportion to deepness of yellow colour, where Akinwale *et al*. (2010) reported that the lower the dry matter content, the deeper the yellow colour of the cassava flesh. According to Akinwale *et al*. (2010); Vimala *et al*. (2008), genotypes with the highest levels of ß-carotene produce low dry matter which affects cooking quality.

Nevertheless, in a recent review, Ceballos *et al.* (2013), observed a parallel increase in dry matter content (DMC) and carotenoid content in Latin American cassava varieties, suggesting that if germplasm exchange occurs, both traits may be enhanced simultaneously. According to Ceballos *et al.* (2017), there is no negative association between carotenoids and DMC. It is therefore possible to distinguish varieties with a high content of provitamin A and acceptable level of DMC.

In Ghana, the adoption of yellow flesh cassava varieties will largely depend on their agronomic performance, including fresh root yield, dry matter content (DMC), resistance to major pests and diseases, starch content and the stability of these traits over time.

The IITA and Ghana Atomic Energy Commission – Biotechnology and Nuclear Agricultural Research Institute (GAEC-BNARI) and University of Cape Coast (UCC) in Ghana have initiated new strategies geared towards developing and evaluating yellow flesh cassava mutants that incorporate farmers' preferred traits, especially high dry matter content and mealiness. It is anticipated that this initiative will result in systematic distribution of yellow flesh cassava varieties for the purposes of enhancing the nutritional status of majority of the population that depend on cassava as a major staple food.

Yellow flesh cassava seeds brought from IITA were irradiated at GAEC, grown and evaluated at seedlings stage and developed into clones for preliminary yield trials. These genotypes were transferred to UCC for further research. The objectives of this research were to:

i. determine the genetic diversity of these genotypes based on morphological traits.
ii. determine the levels of total carotenoids in these yellow flesh cassava genotypes.
iii. determine the safety levels of cyanogenic potential in the genotypes.
iv. evaluate the genotypes for yield, high dry matter content and resistance to cassava mosaic disease.

Materials and Methods

Collection of cassava planting materials

Ten cassava genotypes were used in this experiment. The genotypes include 8 yellow flesh mutant; 9A (151036), 6A (150579), 8A (151082), 12B (150306), 1011A (150029), 14B (151110), 5B (151006), 11B (150538), an international yellow flesh check 1A (70593) from IITA and a white flesh check

6F (106F) (*fufuohene*) a newly released variety by UCC (Amenorpe *et al*., 2019).

Experimental site

The field experiment was evaluated on sandy loam soil at the Teaching and Research Farm of the School of Agriculture, University of Cape Coast, Cape Coast, in the coastal savannah ecological zone during 2018/2019 major farming season. The soil has been classified by Asamoa (1973) as Atabadze series, in agreement to Ultisol in the United States Department of Agriculture (USDA Soil Taxanomy) and Haplic Acrisol (FAO/UNESCO soil classification). It belongs to the Edina-Benya-Udu compound association, developed over Sekondian deposits. The rainfall in Cape Coast is bimodal with an annual range of 800 to 1000 mm and an average mean monthly temperature of about 26.5 ^{o}C.

Experimental design and field layout

The ten cassava genotypes were grown under rain fed conditions in a randomized complete block design (RCBD) with four replications. A land size of about 680 m^2 (44 m x 24 m) was ploughed, harrowed and divided into blocks and plots. There was a 2.0 m space between each block and 1.0 m space between plots, each measuring 6.0 m x 4.0 m. Twenty-four (24) cm long cuttings were planted in each plot at a spacing of 1 m within rows and 1m between rows. A total of 960 plants were cultivated.

Cultural practices

Cuttings that did not sprout were replaced two weeks after planting. Weeding was done manually with a hoe on the 1, 4, 8 and 11 months after planting. No fertilizer or insecticide was applied.

Characterization of the cassava genotypes using morphological and agronomic descriptors

The morphological characterization of cassava genotypes was based on the unique features of cassava parts which were taken at specific times during the life cycle of the plant. The standard descriptors by International Institute of Tropical Agriculture was used (Fukuda *et al.*, 2010). The characteristics that featured predominantly during the research work are described below.

Colour of apical leaves

The most frequent occurrence was recorded at three months after planting (MAP) as follows; light green (3), dark green (5), purplish green (7) and purple (9).

Leaf retention

Visual score for leaf retention was done using a scale of 1-5. The most frequent occurrence on all eight central plants/plot were recorded as follows; very poor retention (1), less than average retention (2), average leaf retention (3), better than average retention (4) and outstanding leaf retention (5).

Leaf pubescence

The pubescence on the apical leaf was determined three months after planting (MAP). The most occurrence of the pubescence on the apical leaf was observed and recorded accordingly. The pubescence on the apical leaf was observed and scored as follows: absent (0) and present (1).

Colour of petiole

The colour of petiole was observed and recorded at six months after planting and scored as follows: yellowish green (1), green (2), reddish-green (3), greenish-red (5), red (7) and purple (8).

Shape of the central leaflet

Observation on the shape of the central leaflet was recorded six months after planting. The shapes of central leaflet that frequently occurred were as follows: ovoid (1), elliptic-lanceolate (2), obovate-lanceolate (3), oblong-lanceolate (4), lanceolate (5), linear (6), pandurate (7), linear-piramidal (8), linear-pandurate (9) and linear-hostatilobalate (10).

Flowering

The presence of flowers on the cassava plant was determined at six months after planting (MAP). At least one flower on each of the plant selected in a plot was observed. Scoring was done at every two weeks from time of first flowering until harvest to determine the flowering pattern of the different genotypes. The presence of flowers on the cassava plant was observed and scored as follows: absent (0) and present (1).

Growth habit of stem

The growth habit of the stem of the plant was observed and recorded at exactly nine months after planting. The nature of the stem was categorized as either of the ziz-zag type (1) and the straight type (2).

Prominence of foliar scar

Prominence of foliar scar was observed and recorded accordingly. The observation of true prominence of foliar scar was manifested when the crop plant was more than nine months after planting. Observing the selected plants from the middle ensures that the actual nature of the prominence of the foliar scar is recorded. The prominence of the foliar scar was scored as follows; semi-prominent (3) and prominent (5).

Colour of the stem cortex

The colour of the stem cortex was recorded after careful observation of the plants nine months after planting. A very sharp knife was used in making a shallow cut and peeling the back of the epidermis, thus, revealing the actual colour of the stem cortex. The descriptor scored the colour of the stem cortex in three categories; orange (1), light green (2) and dark green (3).

Colour of stem exterior

Observation and recording of the colour of the stem exterior was done nine months after planting. An observation on the middle part of the selected plant helped in assigning the following scores to the plant; orange (3), grey-yellowish (4), golden (5), light brown (6), silver (7), grey (8) and dark brown (9).

Colour of end branches of adult plant

The predominant colour of the end branches of adult plant was observed and recorded nine months after planting. The observation was taken on top of the 200 cm of the selected plants. The most frequent occurrences were the ones recorded. The colour of the end branches was observed and scored as follows; green (3), green-purple (5) and purple (6).

Height at first branching

The height at first branching was determined by using a tape measure to accurately measure vertically from the base of the stem at the ground level to the first primary branch of the cassava plant. The height at first branching was measured and scored as follows: less than 1 m (1), between 1 m-2 m (2) and more than 2 m (3).

Root constriction

The cassava root was observed twelve months after planting when the roots were harvested. The roots were observed and scored as follows; few (1), several (2) and many (3).

Root shape

The root shape was observed when the crop was harvested twelve months of planting. The root shape was observed and scored as follows; conical (1), conical-cylindrical (2), cylindrical (3) and irregular (4).

External colour of storage root

After harvesting the cassava plant, the unique colour on the storage root was also observed and recorded. The external colours of the storage roots were observed and scored as follows; white/cream (1), yellow (2), light brown (3), and dark brown (4).

Colour of root pulp (parenchyma)

An assessment of the colour of root pulp was done after harvesting the crop. A sharp knife was used to slash the cassava root into two equal parts. The observation of the root pulp (parenchyma) revealed any of the following colours; white (1), cream (2), yellow (3), orange (4) and pink (5).

Texture of root epidermis

The texture of the root epidermis was determined by picking most of the harvested root in a specific plot and touching it with the fingers to find out the most common root epidermis texture. The texture of the root epidermis was observed and recorded as follows; smooth (3), intermediate (5) and rough (7).

Ease of peeling

A knife was used to gently peel the cortex of the cassava root after harvesting. The ease of peeling the root cortex was observed and scored as follows; easy (1) and difficult (2).

Colour of root cortex

About six cassava roots had their epidermis removed with a knife to reveal the most frequent occurrence of a particular colour. The root cortex was observed and scored as follows: white/cream (1), yellow (2), pink (3) and purple (4).

Root taste

The taste of the raw root was determined by chewing a small piece of the root after removing the cortex. The root taste was determined and recorded as follows; sweet (1), intermediate (2), bitter (3).

Cortex thickness

The determination of cortex thickness deals with measuring from three roots, at the proximal end (closet to stem), mid- and distal (furthest from stem). The cortex thickness was determined with vernier callipers and estimated as follows: thin (1), intermediate (2), thick (3).

Root weight per plant

The total root weight per plant was measured and recorded. Eight different stands from a plot had their roots placed in a jute sack, weighed on a hanging scale and the weight recorded. The average weight from the eight plants was used to determine the total root weight for each plot.

Weight of shoot

The above ground weight of each of the plants was measured and recorded. Eight different stands from a plot had their shoot tied up with a rope and weighed on a hanging scale and the weight recorded. The average weight from the eight plants was used to determine shoot weight of each plot.

Fresh root yield (t ha^{-1})

The planting adopted for the experimental field was 1 m × 1 m and so ten thousand plants would be on a hectare of land. Multiplying the number of plants stands by the mean fresh root weight (kg) per plant and dividing by 1000 kg gave the fresh root yield in tonnes per hectare.

Harvest index

The harvest index was determined for cassava following the method of Kamau *et al.* (2011). Eight (8) of the tagged plants selected from each of the genotypes at harvest was used to determine the harvest index**.**

$$\text{Harvest index} = \frac{Root\ weight}{Biomass} \times 100 \qquad (4.1)$$

Dry matter content (%)

The dry matter content (DMC) was expressed as a percentage by selecting three representative storage roots. These were bulked, washed, peeled and sliced using knives. Slices were picked randomly selected and weighed to obtain a 200 g fresh mass sample per genotype before being dried for 48 hours in an oven at 105 °C. To obtain the dry mass the dried samples were then re-weighed. The percentage of DMC was calculated as the ratio of the dry weight multiplied by 100 over the fresh weight as indicated below:

$$\text{DMC} = \frac{Sample\ dry\ weight}{Sample\ fresh\ weight} \times 100 \qquad (4.2)$$

Determination of cassava mosaic disease (CMD)

In order to determine the resistance status of each of the ten genotypes to CMD, the cassava genotypes were evaluated exactly 3, 6, and 9 months after cultivation during the cropping season. Each plant was evaluated for the severity of the entire plant 's symptoms. The severity of CMD was determined on the basis of the standard 1-5 disease rating (IITA, 1990; Ariyo, Dixon & Atiri, 2005), with 1 showing no symptoms of the disease and 5 showing significant symptoms, including chlorosis, leaf distortion and plant stunting (Table 4.1).

Table 4.1: Rating and corresponding symptom expression of cassava mosaic disease (CMD).

Rating	Symptoms
1	No symptoms
2	Mild chlorotic pattern on entire leaflets or mild distortion at the base of the leaflets appearing green and healthy
3	Strong mosaic pattern on leaf, and narrowing and distortion of lower one-thirds of leaflets
4	Severe mosaic distortion of two-thirds of leaflets and general reduction of leaf size
5	Severe mosaic distortion of four-fifths or more of leaflets, twisted and misshapen leaves.

Eight plants from each of the plots were evaluated and their average mean ordinal score determined. Plants with the mean score of “1” were classified as extremely resistant and those with mean score of “5” were classified as highly susceptible, according to Lokko, Danquah, Offei, Dixon & Gedil (2005).

Determination of whitefly population

The vectors of the African cassava mosaic virus (ACMV) disease of cassava plants are whiteflies (*Bemisia tabaci*). In order to evaluate their relationship with the intensity of CMD, the population of whiteflies on the cassava plants was therefore determined. Direct counts of adult whiteflies on each plant on five of the topmost fully extended leaves (Otim-Nape *et al*., 2005). The whiteflies were counted between 6:00 am and 8:00 am in the morning when the climate was cooler and the whiteflies were relatively immobile when they were very active later in the day. The whitefly counts were done 3, 6, and 9 months after planting. Five plants were randomly selected and tagged from each plot. The leaves were carefully turned over and the number of whiteflies on the abaxial leaf surfaces were counted and recorded on each plant. The mean number of whiteflies on the five topmost leaves was then estimated.

Hydrogen cyanide (HCN) potential by titration

A blender was used to ground (20) g of the cassava root (parenchyma). It was then moved and left to stand for 3 hours in a distillation flask. It was then distilled until a distillate of 150 cm^3 was obtained. Approximately 20 cm^3 of 0.02 M sodium hydroxide was applied to the distillate and a volume of up to 250 cm^3 was added using distilled water in a volumetric flask. Three aliquots were collected, two of 100 ml each and one of 50 ml. Subsequently, 8 cm^3 of 6 M ammonium solution and 2 cm^3 of 5 % potassium iodide were applied to the 100 ml aliquots, 4 cm^3 and 1 cm^3 to the 50 ml aliquots. This was titrated using 0.02 M silver nitrate and the 50 ml aliquot was used as the trial. The readings were taken. The equation below was used to calculate HCN in mg.

1 ml of nitrate of 0.02 M silver = 1.08 mg HCN (AOAC, 1990) (4.3)

Determination of total carotenoid using i check device

The portable device consists of two units: the measuring unit (iCheck™ Carotene) and the disposable reagent vial (iEx™), in which the reaction is performed. The disposable reagent vials contain 2 ml of a mixture of reagents which are needed for completion of the reaction. No additional reagents are required. Both the measuring unit and reagent vials are commercially available (www.bioanalyt.com). The iCheck Carotene weighs 250 g and its dimensions (200 mm × 104 mm × 40 mm) make it very portable.

A sample each of the ten cassava genotypes was taken from the field and washed well to prevent soil contamination. The cassava genotypes were sent to the laboratory, peeled and washed. Each sample was then divided into four parts and the opposite parts pooled together. The sample was chopped into 2 cm^3 pieces with a sharp knife. The mixed sample was divided into four equal parts and the two opposite parts were pooled together.

About 5.0 g of each sample was weighed, ground in a mortar and quantitatively transferred to an Eppendorf tube with 20 ml of water. The resultant volume was topped to a final volume of 25 ml. After, 0.5 ml of the mixture was added to a vial containing a solvent in a small bottle, and thoroughly mixed, and allowed to settle. After 10 minutes the starch settled at the bottom of the bottle and the carotenoids remained in suspension. The i check device was used to determine the absorbance in suspension above the settled starch at wavelength of 450 lambda. The absorbance value was multiplied by a dilution factor to calculate the total carotenoid level in the sample. The dilution factor is the total sample volume divided by the actual weight of sample put in the mortar.

Statistical analysis

Microsoft Office Excel 2019 was used to collect and clean the data for analysis. Statistical analysis was done using GenStat (version 14). Analysis of variance for the cassava varieties was conducted, and a Tukey's comparison test at the 5% level was conducted to test for a significant difference among the cassava genotypes.

Results

Whitefly population on the ten genotypes

The mean number of adult whiteflies on cassava genotypes at 3, 6, and 9 months after planting (MAP) is recorded in Table 4.2. The whitefly count for the 3rd month had the high mean values of 19.7, 20.1, 20.1 and 20.3, and recorded for genotypes 6A, 5B, 1A and 12B respectively with least values of 5.4 and 6.5 for genotypes 8A and 14 respectively (Table 4.2).

The whitefly count at the 6th month was significantly different among the genotypes, with a mean range of 5.4 – 21.9. The high whitefly count of 21.9 was recorded for genotype 5B while the low whitefly count of 5.4 was recorded for genotype 8A. The whitefly count at the 9th month, had the high mean values of 21.3 and 21.7 for genotypes 1A and 6A respectively with a low mean value of 5.5 and 7.9 for genotypes 8A and 14B respectively. From Table 4.2, the overall mean for the whitefly count for the 3, 6 and 9 months ranged from 5.5 to 21.0. The high (21.0) mean value of whitefly count was recorded for genotype 5B, followed by genotype 1A with a mean of 20.9. The low overall mean value of 5.5 and 9.9 was recorded for genotypes 8A and 9A, respectively.

Table 4.2: Mean number of adult whiteflies on the ten (10) Genotypes

Genotypes	3 months	6 months	9 months	Mean
9A	9.2^{bc}	11.3^{cd}	9.2^{d}	9.9^{c}
6A	19.7^{a}	19.5^{ab}	21.7^{a}	20.3^{a}
8A	5.4^{c}	5.4^{d}	5.5^{e}	5.5^{d}
1A	20.1^{a}	21.1^{a}	21.3^{ab}	20.9^{a}
12B	20.3^{a}	20.9^{a}	20.7^{ab}	20.7^{a}
14B	6.5^{bc}	17.8^{abc}	7.9^{de}	10.7^{c}
1011A	17.3^{a}	19.2^{ab}	18.2^{b}	18.3^{ab}
5B	20.1^{a}	21.9^{a}	20.9^{ab}	21.0^{a}
11B	9.7^{b}	13.3^{bc}	10.1^{cd}	11.0^{c}
6F	16.7^{a}	20.0^{ab}	12.3^{c}	16.3^{b}
Mean	14.5	17.1	14.8	15.4
Hsd	3.66	6.20	2.87	3.01
% cv	17.5	25.2	13.4	13.5

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Severity for Cassava Mosaic Disease on the ten cassava genotypes

The mean severity scores of Cassava Mosaic Disease (CMD) on cassava genotypes at 3, 6, and 9 MAP is recorded in Table 4.3. The ten genotypes recorded resistance, moderate resistance and susceptibility to CMD. There was significant difference among the ten genotypes for severity scores, however, the scores ranged from 1.0 to 3.8 for the 3 MAP. The high severity scores of 3.1, 3.5 and 3.8 were recorded for genotypes 1011A, 11B and 9A respectively, with the least severity scores of 1.0 and 1.1 recorded for genotypes 1A and 6A

respectively. The severity score recorded for the 6 MAP showed significant difference between the ten genotypes. Genotypes 1011A, 12B, 11B, and 9A, recorded the high severity scores of 1.8, 2.5 and 3.8 respectively.

There was significant difference for severity scores for the 9 MAP which ranged from 1.0 to 3.7. The high severity scores of 2.5 and 3.7 were genotypes by 9A and 11B respectively. The overall mean severity scores (Table 4.3) for the 3, 6 and 9 months ranged from 1.0 to 3.8 with a grand mean of 1.4. There were significant differences in the overall mean severity scores recorded at 3, 6 and 9 months after planting.

Genotypes 11B and 9A recorded a high overall mean severity scores of 2.4 and 3.8 respectively, however, genotypes 6A, 1011A and 14B all recorded a low severity score of 1.1. The lowest severity scores of 1.0 was recorded for most of the genotypes; 6F, 1A, 12B and 5B.

Table 4.3: Mean severity scores of Cassava Mosaic Disease (CMD) by the ten (10) genotypes.

Genotypes	3 months	6 months	9 months	Mean
9A	3.8[a]	3.8[a]	3.7\[a]	3.8[a]
6A	1.1[c]	1.0[d]	1.1[b]	1.1[de]
8A	1.1[c]	3.1[ab]	1.2[b]	1.8[c]
1A	1.0[c]	1.0[d]	1.0 [b]	1.0[e]
12B	1.0[c]	1.0[d]	1.8[b]	1.3[cde]
14B	2.0[b]	1.4[cd]	1.8[b]	1.7[cd]
1011A	1.4[c]	1.1[d]	1.0[b]	1.2[cde]
5B	1.0[c]	1.4[cd]	1.3[b]	1.3[cde]
11B	3.6[a]	2.5[bc]	3.1[a]	3.1[b]
6F	1.0[c]	1.1[d]	1.8[b]	1.3[cde]
Mean	2.1	1.8	1.5	1.7
Hsd	0.52	1.11	1.09	0.60
% cv	5.6	21.3	8.3	9.1

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Total carotenoids content, cyanogenic potential and harvest index

The results for total carotenoid contents and cyanogenic potential of the genotypes are presented in Table 4.4. The results of total carotenoid (TC) recorded among the YFC roots ranged 1.9 ug/g to 10.38 ug/g with a significant difference ($p<0.05$) among the ten genotypes (Table 4.4). The carotenoid for the positive and negative checks; 1A and 6F were 1.77 and 7.97 respectively. These genotypes; 14B, 1011A 12B and 6A recorded the high total carotenoid of 9.57, 9.83, 10.01 and 10.38 ug/g respectively that was above the positive check (Table

4.4). However, these genotypes; 5B, 11B, 9A and 8A also recorded total carotenoids of 5.41, 6.88, 6.07 and 6.64 ug/g respectively which were lower than the positive check value of 7.97 ug/g (Table 4.4). There was a significant difference ($p<0.05$) between genotype 6F that recorded lowest total carotenoids value of 1.77 ug/g and the rest of the genotypes (Table 4.4).

The result of the cyanogenic potential is also presented in Table 4.4. There was a significant difference ($p<0.05$) between the ten genotypes. The concentration of cyanide in genotype 9A, 8A, 12B, 11B and 5B were the high (36.54, 37.16, 38.24, 38.96, and 39.68 mgHCN/kg) respectively, while genotypes 6A and 14B had low cyanide concentrations of 28.52 and 30.32 mgHCN/kg respectively. The concentration of cyanide in cassava genotypes that recorded the high HCN was significantly different ($p<0.05$) from the cassava genotypes 1A, 6F and 1011A, that recorded cyanide concentration of 30.04, 31.71 and 33.92 mgHCN/kg respectively. The cassava genotypes 14B and 6A that recorded low cyanide concentration were significantly different from the rest of the genotypes.

Table 4.4: Mean total carotenoids and cyanogenic potential of the ten (10) genotypes.

Genotypes	Total carotenoid (ug/g)	Cyanogenic potential (mgHCN/kg)
9A	6.07^{c}	37.11^{c}
6A	10.38^{a}	29.15^{f}
8A	6.64^{c}	37.70^{c}
1A	7.97^{abc}	31.36^{e}
12B	10.01^{a}	38.54^{b}
14B	9.57^{ab}	34.41^{d}
1011A	9.83^{a}	30.87^{e}
5B	5.41^{c}	40.13^{a}
11B	6.88^{bc}	39.28^{b}
6F	1.77^{d}	31.15^{e}
Mean	7.45	34.97
Hsd	1.526	0.762
% cv	9.0	1.3

Means in a column with a common letter superscript are not significantly different (P>0.05).

The yield and yield components of ten (10) genotypes of cassava

Results obtained showed that, there were significant differences ($p<0.05$) between the number of roots, root length, fresh root yield and dry matter (Table 4.5). There was a significant difference ($p<0.05$) for the number of roots/plant with a range of 3.0 to 7.0 and percentage coefficient of variation (% cv) of 2.63. Genotypes 8A and 1011A recorded the high mean of 6.75 and 7.0 respectively for the number of roots/plant, followed by genotypes 5B and 11B with the mean number of root/plant of 5.5. Genotypes 9A and 6F recorded

low number of roots/plant of 3.0 and 4.1 respectively (Table 4.5). Most of the cassava genotypes recorded higher mean values greater than 4 roots/plant.

There was a significant difference ($p<0.05$) among the genotypes in relation to the mean root length. There were however no significant differences between genotypes 11B and 6F which recorded the longest mean root length values of 44.92 cm and 55.53 cm respectively. This was followed by genotypes 1A with the mean root length of 41.85 cm (Table 4.5). There was significant difference ($p<0.05$) between genotype 9A and 5B that recorded a shorter mean root length of 19.12 cm and 23.82 cm respectively than the rest of the genotypes.

The fresh root yield ranged from 17.22 to 44.70 with a mean of 30.54 t ha^{-1} (Table 4.5). The yellow fresh root highest yield of 44.70 t ha^{-1} was recorded for genotype 12B. This was not significantly different from the yield of 44.7 t ha^{-1} recorded for the white flesh genotype 6F that was used as a checked. The fresh root yields obtained showed a significant difference ($p<0.05$) among all the genotypes. Genotypes 5B, 1101A and 6A also gave a high yield of 32.92 t ha^{-1}, 32.58 t ha^{-1} and 33.30 t ha^{-1} respectively (Table 4.5). Lower yields of 23.15 t ha^{-1}, 19.95 t ha^{-1} and 17.22 t ha^{-1}, were recorded for genotypes 11B, 9A and 14B, respectively which were about two times lower than the highest root yield recorded. Six genotypes had fresh root yields above the genotype means (30.54 t ha^{-1}) while four of the genotypes yielded less than the genotype means (Table 4.5).

The combined analysis of variance for dry matter content (DMC) of the yellow flesh cassava genotypes showed significant differences ($p<0.05$) among the genotypes. The mean root DMC ranged from 15.53 to 38.12 %. The highest dry mater of 38.12 % was recorded for a white flesh variety 6F and this was

significantly different ($p<0.05$) from the DMC of 36.12 % recorded for a yellow flesh genotype 12B which had the second highest DMC (Table 4.5). DMC of 30.13, 31.93 and 33.52 % which were recorded for yellow flesh genotypes 5B, 9A and 11B respectively were also significantly different from each other. The low DMC of 15.53, 22.33 and 23.52 % were recorded for yellow flesh genotypes 14B, 6A and international check 1A respectively (Table 4.5).

Table 4.5: Yield and yield component of the ten (10) genotypes

Genotypes	Number of roots/plant	Root length (cm)	Fresh root yield (t ha^{-1})	Dry matter %
9A	3.00^{c}	19.12^{f}	19.95^{d}	31.93^{d}
6A	4.62^{bc}	24.84^{e}	33.30^{b}	22.33^{i}
8A	6.75^{a}	26.80^{de}	25.07^{c}	25.33^{g}
1A	4.25^{bc}	41.85^{b}	32.10^{b}	23.52^{h}
12B	6.50^{a}	32.23^{c}	44.70^{a}	36.12^{b}
14B	4.25^{bc}	32.30^{c}	17.22^{e}	15.53^{j}
1011A	7.00^{a}	29.88^{cd}	32.58^{b}	27.13^{f}
5B	5.50^{ab}	23.82^{e}	32.92^{b}	30.13^{e}
11B	5.50^{ab}	44.92^{b}	23.15^{c}	33.52^{c}
6F	4.12^{bc}	55.53^{a}	44.7^{a}	38.12^{a}
Mean	5.11	30.76	30.54	28.37
Hsd	1.002	2.815	2.698	1.703
% cv	19.6	8.5	6.1	1.1

Means in a column with a common letter superscript are not significantly different ($P>0.05$).

Correlation coefficient for whitefly population, Cassava Mosaic Disease (CMD), yield, dry matter and total carotenoids (TC) contents.

The result of combined correlation analysis as shown by their coefficients of correlation (Table 4.6) revealed that Cassava Mosaic Disease showed significant negative correlation with whitefly population and root yield. However, there was a significant positive correlation observed between dry matter content and yield. Correlation between dry matter content and total carotenoids contents was highly significant and positively correlated. The positive correlation observed between dry matter and flesh colour of cassava mutants shows that the deeper the flesh colour (carotene) the higher the dry matter content and this was highly significant. The correlation observed between yield and total carotenoid contents was positive but not significantly correlated.

Table 4.6: Correlation coefficient for whitefly population, Cassava Mosaic Disease (CMD), yield, dry matter and total carotenoid (TC) contents.

Variables	Dry matter	CMD	Yield	TC	Whitefly population
Dry matter	1				
CMD	-0.366	1			
Root yield	0.373	-0.231	1		
TC	0.542*	-0.365	0.420	1	
Whitefly population	0.460*	-0.849**	0.021	0.245	1

Correlation is significant at *$P \leq 0.05$; ** $P \leq 0.01$

Dendrogram of the phylogenetic relationship among the ten cassava genotypes.

A dendrogram (figure 4.2) using 42 agro-morphological traits grouped the 10 Cassava genotypes into three main clusters based on Nei genetic distance (Nei,1983) using Power Maker version 3.25 unweighted pair grouped method with arithmetic average (UPGMA) cluster analysis (Sneath & Sokal, 1973) at a dissimilarity of 24 % (figure 4.2). The 10 cassava genotypes appeared to have emerged from common ancestry and were distinguished into 3 major clusters (A, B and C). Cluster A comprised of 8A and 6F, which show very close relation. Hence, they can be characterized as progenies from a common ancestry. However, cluster B consisted of 70% of the cassava genotypes that were distributed into 3 sub-clusters at 17.5% dissimilarity coefficient. Cluster C was made of 6A, which was an outlier as shown in figure 4.2

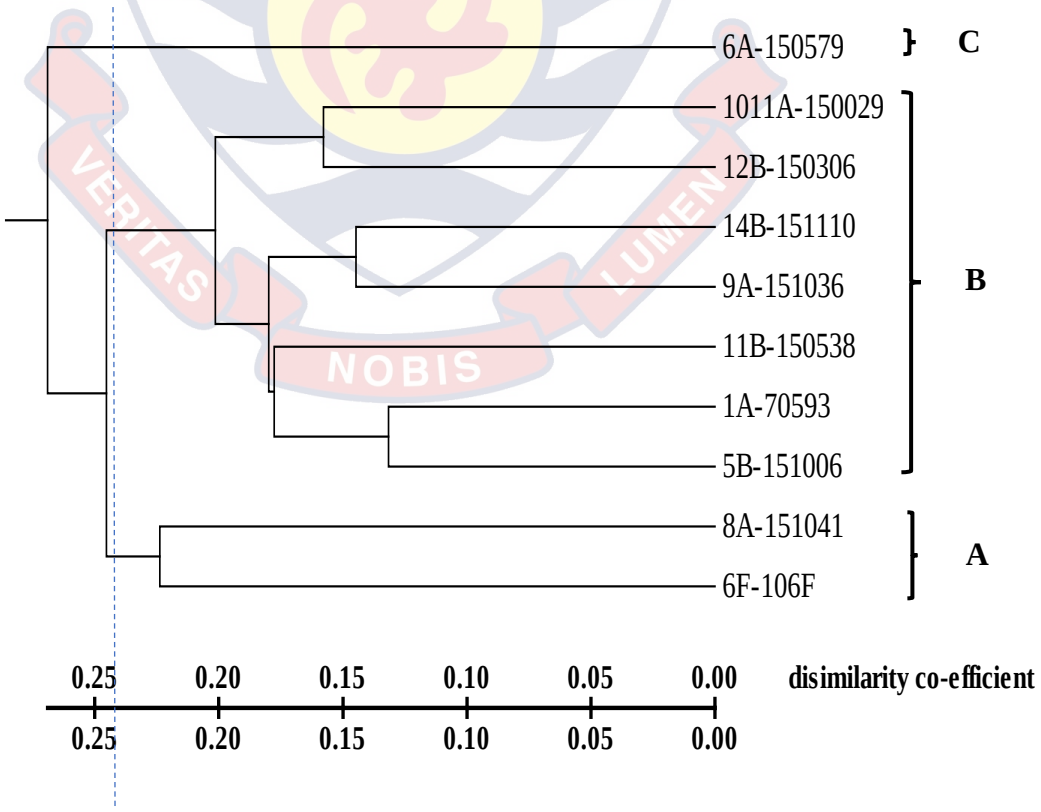

Figure 4.1: A dendrogram illustrating the relatedness of 10 genotypes, which was generated using 42 phenotypic (morphological) descriptors and the sequential clustering algorithm (UPGMA) based on genetic similarity (Nei & Li, 1983).

Discussion

Morphological characterization has been used in analyse the genetic diversity of cassava germplasm (Mezette *et al*., 2013; Asare *et al*., 2011) because it is cheaper, easier, and faster as compared to other techniques like biochemical or molecular. On the other side, morphological characteristic can be correlated to the agronomic traits for preliminary evaluation. The obvious clustering of the mutants with their parent shows how they share similar morphological traits with the parent. Genetic characterization of these mutant will be necessary to ascertain whether there are repetitions of clones. Mutant genotypes that exhibited an entirely different morphological traits from the parent plant (1A) had similar traits with the white flesh cassava used as check and so clustered with it (6F). 6A exhibited no relation with any of the cassava genotypes in the cluster analysis, hence depicting its obvious morphological divergence from all the genotypes (Figure 4.2). Consistent with previous reports, phenotypic variability among the Ghanaian cultivated cassava genotypes considered in this study was low (Rabbi *et al*., 2015). This is not surprising since it is well documented that cassava in general has a narrow genetic base reflecting the vegetative nature and this is an initial bottleneck during domestication and maintained by the low cross-pollination mechanism in the crop.

Whitefly (*Bemisia tabaci*) is one of the most important insects on cassava. It is also the vector of the cassava mosaic begomoviruses (CMVs) that causes cassava mosaic disease (CMD) (Fishpool & Burban 1994). According to Legg *et al*. (2004); Omongo *et al*. (2004), yield loss of more than 50%, for instance, has been recorded in the worst affected cassava varieties. The highest

mean of whiteflies populations recorded (Table 4.2), indicates that the whiteflies populations are mostly high during the six months of growth, because of the vegetative growth of cassava at this stage. This is in a sharp contrast with Tembo, Mataa, Leg, Chikoti and Ntawuruhunga (2017) who said the volume of whitefly was generally high for all cultivars at 2 MAP and reduced gradually in the 4 MAP.

The highest mean population of whitefly recorded for the genotypes (Table 4.2) that showed resistance to the cassava mosaic disease, gives an indication that whitefly normally will prefer to shelter under the resistance varieties for survival from predators and the scorchy sun and when the conditions are favourable for feeding, fly to cassava mosaic susceptible plants to feed on and infest them with the disease. Genotypes that were susceptible to the cassava mosaic diseases rather recorded a lower whitefly population. The result is confirmed by Omongo (2003) that improved CMD-resistant genotypes are prone to whitefly invasion. He further indicated that the continuing presence of cassava whitefly populations is that several of the most popular CMD-resistant varieties are highly suitable hosts for whitefly and appear to have whitefly resistance (Omongo, 2003).

In relation to the severity of CMD, the genotypes showed resistance, moderate resistance and susceptibility to the CMD (Table 4.2). According to Kiweesi *et al*. (2014) plants with less virus quantities and less symptom severity expression are regarded as resistant or tolerant. Genotypes resistant to CMD recorded in this study have been described in many studies and used in cassava breeding programs to develop resistant varieties (Okogbenin *et al.*, 2007). The observed differences in CMD severity among the genotypes could be due to

genetic differences. This is because according to Hillocks and Thresh (2000), the variations between cassava genotypes in terms of diseases status are genetically controlled. This suggests that the genetic basis of qualification as resistant or tolerant to CMD is a plus for being used directly for cassava root production or in backcrossing in order to transfer reistance status to other commercial varieties as parents.

Genotypes that expressed the disease at 3 MAP, support previous work showing that among susceptible cultivars, the first viral symptoms can occur within 2 weeks after infection. The result is confirmed by Wagaba *et al*. (2013) who observed CMD symptoms on the 3–5 weeks after infection. Genotypes that showed symptoms of the CMD at the 3 and 6 MAP probably recovered from the CMD didn't show the symptoms during the 9 month by recording low severity scores and the quick recovery of infected plant is good indicator for resistant genotypes. Tembo *et al*. (2017) observed that varieties that were moderately susceptible to CMD, though expressed the symptoms were able to recover as they matured. The cultivars they studied displayed different levels of recovery from CMD symptoms over the course of growth and development during the season (Tembo *et al*., 2017). Genotypes susceptible to the CMD recorded the highest severity scores and yield losses. The results of this study extend previous findings on yield losses caused by CMD, which have been variable and depend on cultivar and other environmental factors (Thresh, Fragette & Otim-Nape, 1994). Yield losses due to CMD have also been reported previously (Otim-Nape, Kintukwonka, Nwesigye & Emokol, 1992; Otim-Nape, Shaw & Thresh, 1994). Reduced tuberization and smaller yields have also been

reported due to decreased photosynthetic activity resulting from CMD-induced chlorosis (Thresh *et al*., 1997; Osiru *et al*., 1999).

There was a negative correlation between CMD and the yield of the cassava genotypes. The genotypes that were susceptible to CMD recorded the lowest yield and those that showed resistance recorded the highest yield (Table 4.6). The negative correlation between CMD and yield confirms the potential storage root yield losses that can be caused by the disease, which was confirmed by Parkes, Fregene, Dixon, Peprah and Labuschangne (2013). The results also agreed with studies by Okechukwu and Dixon (2009) who reported a negative correlation between CMD and yield. On the contrary, Ssemakula and Dixon (2007) reported significant positive correlation between CMD and yield.

The range of total carotenoid (TC) recorded for the genotypes (Table 4.4) was similar to that reported by Ceballos *et al*. (2013) who determined total carotenoid content of six different varieties of yellow flesh cassava from Colombia as 8.32–16.40 µg/g. The high TC recorded compared to the check (released yellow flesh variety) could be due to the mutation breeding that the seeds were subjected to initially that increased the TC in those genotypes. These genotypes could provide more vitamin A in diets and contribute to reducing vitamin A deficiency which is widespread in Ghana. According to Nassar and Ortiz (2010), high TC in yellow flesh cassava provides sufficient opportunity to sustainably address vitamin A malnutrition through deployment of provitamin A cassava varieties in countries where the crop is a major staple (Chavez *et al*., 2007). The high TC recorded agrees with Ceballos *et al*. (2013) who recorded high total carotenoid content of nearly 25 µg/g. Also, Edoh *et al*. (2016) also recorded a high TC between 8.72 - 10.47 µg/g.

Also, the TC obtained for the genotypes in this study was higher than the findings of Maroya *et al*. (2012); Ssemakula and Dixon. (2007), who reported 3.6 µg/g and 5.0 µg/g for yellow flesh cassava breeding populations evaluated at IITA and that of Esuma, Kawuki, Herselman & Labuschangne (2016) where a TC average of 3.8 µg/g was obtained for the varieties in Uganda. The result from the present study is in a sharp contrast with Maziya-Dixon *et al*. (2015) who recorded lower TC of 2.6 µg/g in yellow flesh cassava varieties in Nigeria. Also, lower total carotenoids of 2.3 µg/g and 3.1 µg/g for yellow flesh varieties has also been recorded in a research at Narayanakappa in India (Vimala, Thushara & Nambisan, 2010).

In all, Genotypes used in this experiment recorded TC above the checks (IITA yellow flesh and white flesh varieties) (Table 4.5). The lower levels of TC in the white flesh used as negative checked has been confirmed by Adewusi and Bradburg (1993) who reported similar results in their experiment and Omodamiro *et al*. (2000), who also recorded lower TC of 0.35 µg/g for a white flesh variety.

Although, cassava tubers from the study vary widely in their cyanogenic glycoside content, the range of cyanogenic glycoside for the genotypes was 28.5-39.68 mgHCN/kg fresh weight (Table 4.4). The range of cyanogenic potential of these genotypes were far below the innocuous level of mgHCN/kg fresh weight (Amenorpe *et al*., 2007). The differences in cyanide concentration can be due to the genotypic potential of genotypes among different genotypes (Padmaja, 1995), as all genotypes have been growing in the same ecological zone.

According to Kamara, Menkir, Badu-Apraku and Ibikunle (2003), total dry matter production is a good estimator of the degree of adaptation of a genotype to the environment in which it is grown. Yield of cassava root tubers is related to tuber volume and dry matter content. Yield, therefore, can be improved by increasing dry matter content. In cassava products such as *gari*, recovery largely depends on the dry matter content of the tubers; thus, it important to have high dry matter, since such food products are marketed in dry form.

The average percentage dry matter content is recorded in Table 4.5 with a grand mean of 28.12 %. These results are similar to the range of 25.0 % to 34.7 % with a grand mean of 29.17 % reported by Ssemakula and Dixon (2007). Also, same results between the range of 23.7 % and 33.1 % with a grand mean of 28.82 % is reported by IITA (1987). The concentration of dry matter in cassava roots can vary from 15 to 45 % depending on the genotype and environmental conditions thus providing the potential for selection. Barima *et al*. (2000) stated that cassava varieties with 30 % and above are said to have high dry matter content. In this study four of the nine yellow root cassava genotypes (12B, 5B, 9A and 11B) had high dry matter content. However, the white root cassava genotype used as check (6F) had a dry matter content superior to those of all the nine yellow root cassava genotypes (Table 4.5).

Most of the genotypes that recorded a high DMC had a positive relationship with TC (Table 4.6). This information provided in Table 4.5 is worth emphasizing since it contradicts reports elsewhere by Vimala *et al*. (2008) and Akinwale *et al*. (2010) that recorded an inverse relationship between TC and DMC. Also, it has been occasionally mentioned in different scientific fora

that there is a negative correlation between DMC and TC (Darwin-Ortiz *et al.*, 2010). However, this work clearly demonstrates a positive association between the two variables (TC and DMC) because of mutation effect. This emphasised the fact that what conventional breeding cannot achieve, mutation breeding can achieve far more due to ramification of existing genes sequences. The positive correlation in the current study between DMC and TC is desirable. It is noteworthy that, without much progress, combined selection for both DMC and carotenoid content in Latin America has been ongoing much longer than in Africa. A strong negative association between DMC and TC was confirmed by Esuma *et al*. (2016). The main drivers for variety adoption are usually total carotenoid content (TC) and dry matter content (DMC) in a yellow flesh cassava genotype selection scheme (Abdoulaye *et al.*, 2014; Esuma *et al.*, 2016). For cassava breeding efforts targeting the generation of provitamin A varieties that are appropriate to farmers, high DMC would be an essential feature. Breeding efforts would need to concentrate on developing mutant varieties that combine higher levels of both DMC and TC in high-yielding commercial varieties in order to translate investments in cassava biofortification research into effects on human nutrition.

High fresh root yield was reported for most of the yellow fresh cassava genotypes (Table 4.5). The high yields obtained for most of the YFC genotypes are verified by work done by Edoh *et al*. (2017), who reported a high yield per hectare of all the genotypes of yellow flesh cassava varieties. Also, in agreement with Peprah *et al*. (2020), who reported three of the yellow-flesh varieties with higher fresh root yield as compared with the checks.

Conclusion

From the research, four (4) genotypes had their total carotenoid (TC) content above the released yellow flesh variety used as check with higher yields which was not significantly different from the white flesh also used as check. Also, these genotypes had higher dry matter content and showed resistance to CMD. In addition, the cyanogenic potential (CP), ranged from 28.52-39.68 mgHCN/kg for all genotypes, is safe because it is lower than the innocuous value of 50 mgHCN/kg recommended by FAO. Finally, five (5) genotypes 12B, 5B, 9A, 1011A and 11B have been selected for multi locational trials at three agro-ecological zones in Ghana.

CHAPTER FIVE

GENOTYPE BY ENVIRONMENT INTERACTION OF CASSAVA GENOTYPES IN THREE AGRO-ECOLOGICAL ZONE IN GHANA

Introduction

Cassava has accounted for about 16–46 % of the agricultural GDP over time (Parkes, 2012). It plays a major role in a food security and as income-generating crop for numerous smallholder farmers in developing countries (Tumuhimbise *et al*., 2013). However, cassava as a staple food, is affected by numerous biotic, abiotic and physiological stresses that have impact on its cultivation, consumption and marketability (Bull, Ndunguru, Gruissem, Beeching & Vanderschuren, 2011).

According to Aina *et al*. (2009); Ntawuruhunga, Rubayihayo, Whyte, Dixon & Osiru (2010), the performance of cassava is subject to strong influence of genotype, environment and genotype x environment interaction (GxE). Dixon, Asiedu and Haln (1991) defined GxE as the change in cultivars' relative performance when cultivated in different environments resulting from the differential response of the genotypes to various edaphic, climatic and biotic factors. Individually possessed genes that are important for the expression of traits under investigation is referred to as genotypes. According to Basford and Cooper (1998), the environment is seen as all non-genetic factors that influence expression of traits and may include all biophysical factors such as water, nutrition, temperature, pests and diseases that influence the growth and development of individuals and, thereby, influencing expression of traits.

Abiotic and biotic stresses often affect gene expression that regulates key agronomic characteristics, resulting in genetic and environmental interaction (Kang, 2002). For instance, cassava may experience overlapping and/or contrasting environmental stresses, thus exacerbating the extent of GxE. As a result, in most plant breeding programmes, GxE appears to be of interest (Acquaah, 2012). It should be noted that cassava production differs from genotype to genotype, and, while it grows well in different conditions, it varies from one climate to another. The underlying genotypic properties, environmental factors and GxE interactions are due to this variability (Falconer & Mackay, 1996).

Assessment of GxE effects for a particular trait is therefore useful in understanding varietal stability (Acquaah, 2012). Breeders address the GxE challenge by evaluating genotypes in multiple environments to select better adapted genotypes with high and stable performance in different environments (Nassar & Ortiz, 2006; Esuma *et al*., 2016).

Evaluation of test locations is done by defining three parameters, namely: the ability to discriminate between genotypes (discrimination ability), and the ability to represent the target environment (representativeness) (Xu, Fok, Zhang, Li & Zhou, 2013). The GxE interactions could complicate the selection process (Tumuhimbise *et al*., 2013) therefore, the breeders must conduct multi environment tests to study the effects of GxE interactions. It is common for cassava breeders to evaluate as many as thirty (30) advanced breeding lines in several or as many as ten (10) environments to account for GxE when identifying genotypes with high and stable performance (Akinwale, Akinyele, Odiyi & Dixon, 2011).

Ssemakula and Dixon (2007) noted low influence of GxE on carotenoid content in cassava roots at harvest, based on analysis of 28 genotypes in five environments evaluated over two growing cycles. A much later study on performance of 18 provitamin A clones across five environments in Nigeria indicated significant interaction between genotypes and test environments for carotenoid content (Maroya *et al*., 2012).

Provitamin A cassava genotypes have featured so distinctly in biofortification because they have an increasing level of micronutrients, such as carotenoids (Chávez *et al*., 2005; Esuma *et al*., 2016). However, In Ghana, the acceptance of biofortified cassava varieties will largely rely on their agronomic performances, including root yield, dry matter content (DMC), resistance to major pests and diseases, lower cyanogenic potential, and the stability these traits over time and space. Therefore, breeding programmes that target the development of provitamin A rich cassava varieties should be subjected to multi-locational evaluations where focus shifts to other traits which are highly influenced by environmental effects. This strategy would help to identify high provitamin A genotypes for disease resistance, high root yield and dry matter content that are major indicators of variety adoption in Ghana. These genotypes can therefore be recommended for varietal issue after on-farm evaluation.

The objectives of this study were:

i) to assess the reaction of yellow flesh cassava genotypes to cassava mosaic begomoviruses (CMB) in three agro ecological zones.

ii) to identify and select stable yellow flesh genotypes with high yields and high dry matter in the three agro ecological zones.

Materials and Methods

Experimental materials

Ten (10) genotypes were used for the study as established in Chapter 4.

Experimental site

The field experiments were evaluated during 2019 / 2020 growing season, at three locations in three different agroecological zones namely; University of Cape Coast (Coastal Savannah), Asuansi (Transitional Rain Forest) and Wamaso (Forest Zone).

UCC experimental site

The field experiment was evaluated on sandy loam soil at the Teaching and Research Farm of the School of Agriculture, University of Cape Coast, Cape Coast, a coastal savannah ecological zone during 2019/2020 growing season. The soil has been delineated by Asamoa (1973) as Atabadze series, equivalent to Haplic Acrisol (FAO/UNESCO classification). It belongs to the Edina-Benya-Udu compound association, developed over Sekondian deposits. The rainfall in Cape Coast is bimodal with an annual range of 800 to 1000 mm and a mean monthly temperature of about 26.5 ^{o}C.

Asuansi experimental site

Asuansi Farm Institute is located in the Abura-Asebu-Kwamankese District in the Central Region of Ghana and it is about 30 km North of Cape Coast. The area lies in the southern fringes of the semi deciduous rainforest with two wet seasons in a year. The rainfall pattern follows the traditional double maxima (bimodal) distribution experienced in most parts of southern Ghana with a mean rainfall of about 980 mm. Temperatures are generally warm and uniform throughout the year with a mean monthly temperature of about 26.9 ^{0}C.

The topography of the area consists of low hills and small knolls. The soil type is Acrisols (FAO-UNESCO classification) and belongs to the Asuansi series of the Asuansi-Kumasi/Nta-Ofin compound association. The soils are developed from granite which gives rise to highly porous gravelly sandy loams over gritty sandy clay soils that are often rich in minerals especially potassium if they are not over-cropped or severely leached (Okae-Anti & Ogoe, 2006).

Wamaso experimental site

The School of Agriculture, Commercial, Teaching and Research Station at Twifo Wamaso is located in the south-central portion of Ghana. The topography in general is undulating with gentle slopes at elevations ranging between 950 m and 1000 m above mean sea level. The area is generally hot with a temperature ranging between 26 ºC and 32 ºC with high relative humidity ranging from 65-75%. The highest mean temperatures occur between March and April whereas the lowest is recorded in August. Annual average rainfall is between 900 and 1600 mm with the heaviest occurring in June (MoFA, 2020).

The mean monthly rainfall and mean monthly temperature for the three agro-ecological zones during the 2019/2020 cassava growing season is presented in figure 5.1 and figure 5.2 respectively.

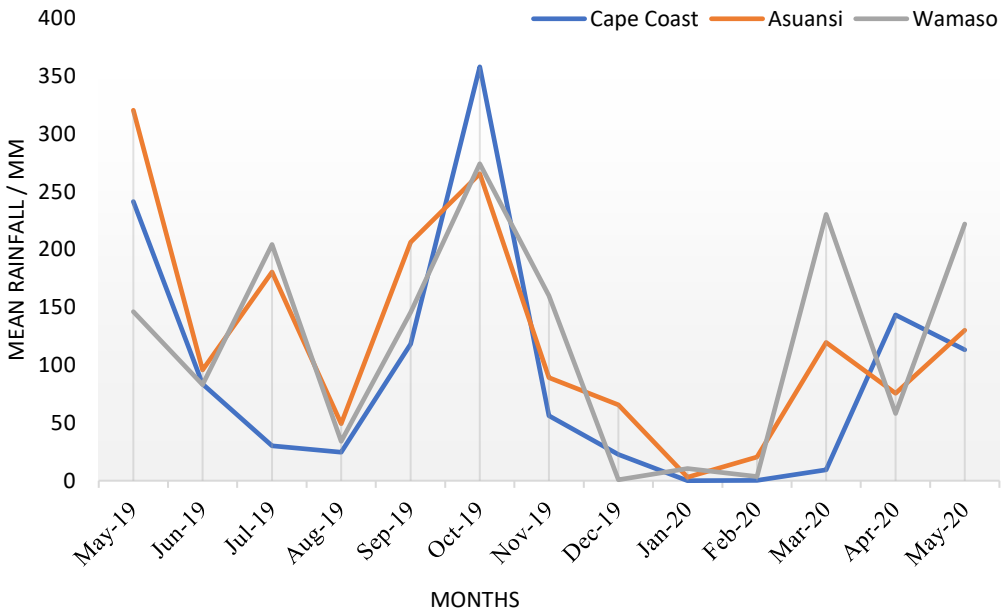

Figure 5.1: Mean monthly average rainfall for the three experimental sites during growing season. Source: Ghana metrological agency, June, 2020

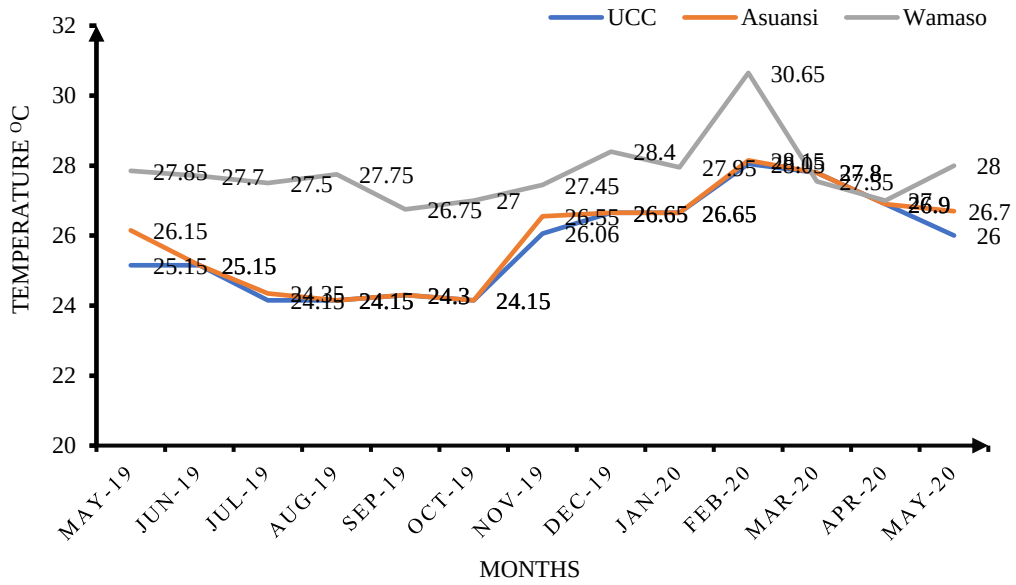

Figure 5.2: Monthly average temperature for the three experimental sites during the growing season. Source: Ghana metrological agency, June, 2020

Soil sampling and analysis

Soil sampling was done prior to planting from the experimental site. The soil samples were taken at depth of 0-30 cm. These samples were taken to the laboratory to determine their physical and chemical properties. The samples were bulked, dried and sieved using a 2 mm mesh sieve.

Soil pH

The hydrogen ion concentration (pH) of soil at the experimental site was determined electrometrically. Ten grams (10 g) of air-dried soil was weighed into 100 ml beaker. Twenty-five millilitres (25 ml) distilled water was added and stirred vigorously for 20 minutes. After allowing suspended clay to settle out from the suspension, a pH meter was calibrated at pH of 4 and 7 respectively. Electrode of pH meter was inserted into the suspension and read and recorded (Motsara & Roy, 2008).

Organic carbon (% C)

Organic carbon was determined by the Walkley-Black oxidation method. Two grams of soil sample were weighed into a 500 ml flask. From a burette, exactly 10 ml of 1.0 N potassium dichromate was added, followed by 20 ml of concentrated H_2SO_4. The mixture was swirled and allowed to cool for 30 minutes. Exactly 200 ml of distilled water and 10 ml of orthophosphoric acid was added and titrated with 1.0 N ferrous sulphate solution to determine organic carbon (Walkley & Black, 1934).

Total nitrogen (N)

About 350 mL of hydrogen peroxide, 0.42 g of selenium powder, 14 g of lithium sulphate and 420 mL of sulphuric acid were used in the digestion mixture. In a 100 mL Kjeldahl flask, about 0.2 g of the oven-dried ground

sample was weighed and 4.4 mL of the digestion reagent was added and the samples were digested for two hours at 360 ^{o}C. In the same way, blank digestions were carried out. The digests were transferred into 50 mL volumetric flasks after digestion and made up for the volume. For about 20 minutes, a steam distillation apparatus was set up and steam passed through it for flushing. A 100 mL conical flask containing 5 mL of boric acid indicator solution was placed under the condenser of the distillation apparatus after flushing out the apparatus. An aliquot was moved via the trap funnel from the sample digest to the reaction chamber. In order to begin distillation immediately, approximately 10 mL of alkali mixture was added and approximately 50 mL of the distillate was collected. To achieve the end point, the distillate was titrated against 1/140 mL HCL. The blank values were subtracted from the titre value of the sample, since the N value was determined as follows:

Calculation

$$N(\%) = \frac{(T-B)\ x\ M\ x\ 14.007\ x\ 100}{Sample\ weight\ (mg)} \times 100 \qquad (5.1)$$

Where;

T = Titre value

M = Molality of Acid

S = Sample titre value

B = Blank titre value

Protein = % N *6.25

Colorimetric determination of P using the ascorbic acid method

Colour forming reagent and P standard solutions were prepared following standard laboratory procedure (IITA, 1985). Reagent A and B was made up from a colour forming reagent. One (1) litter of 2.5M H2SO4, 0.2908g

of potassium antimony tartrate in 100 mL distilled water and twelve (12) gram of ammonium molybdate in 20 ml distilled water was made up of reagent A. The three solutions were mixed together in a 2 L volumetric flask and made up to volume with distilled water (FAO, 2008). By dissolving 1.56 g of ascorbic acid in every 200 mL of reagent A, reagent B was obtained. About 5 μgP/mL solution was prepared from a stock solution of 100 ugP/mL and was used to prepare P standards concentrations of 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0μgP/mL into 25 mL volumetric flasks (IITA, 1985). About 2 mL aliquot of the digested samples were pipetted into 25 mL volumetric flasks. In order to give the samples and the standards the same background solution, about 2 mL aliquot of the blank digest was pipetted into each of the working standards. In addition to the samples after which 4 mL of reagent B was added and their volumes up to 25 mL of distilled water were mixed thoroughly, 10 mL of distilled water was added to the standards. After the flasks were allowed to stand for 15 minutes for colour development and the absorbances of the standards and samples were calculated using a spectrophotometer at a wavelength of 882 nm. Using their concentrations and absorbances, a calibration curve was plotted. The sample solution concentrations were extrapolated from the standard.

Calculation

If C = μgP/mL obtained from the graph,

$$\mu\text{gK/g} = \frac{C\ x\ solution\ volume}{Sample\ weight} \quad (5.2)$$

Determination of potassium and sodium

Potassium and sodium were measured by means of a flame photometer in the digested samples. The following working standards of both K and Na were prepared for the determination: 0, 2,4,6,8 and 10 µg / mL. The working

standard as well as the sample solutions were individually aspirated into the flame photometer and their emissions (readings) recorded. The concentrations and emissions of the working standards were used to plot a calibration curve. The concentrations of the sample solutions were extrapolated using the emissions from the standard curve.

Calculation

$$\mu gK/g = \frac{C\ x\ solution\ volume}{Sample\ weight} \quad (5.3)$$

$$\mu gNa/g = \frac{C\ x\ solution\ volume}{Sample\ weight} \quad (5.4)$$

Table 5.1: Soil status of the three experimental sites during 2019/2020 growing season.

Soil characteristics	Wamaso	UCC	Asuansi
% Nitrogen	0.22	0.07	0.17
Phosphorous (ug/g)	2.52	56.64	11.36
% Organic carbon	2.44	1.04	2.04
Ph	5.34	6.51	6.22
Potassium (K) (cmol/kg)	0.30	0.28	0.54
Sodium (Na) (cmol/kg)	0.43	0.44	0.44
Calcium (cmol/kg)	3.03	1.89	4.52
Texture	Sandy clay	Loamy sand	Sandy clay loam

Source: Field Data (2019)

Experimental design and field layout

The experimental design and field layout for the three experimental sites used for the study were as reported in Chapter 4.

Planting

Planting was done at a spacing of 1 × 1 m, giving a population density of 10,000 plants ha^{-1}. To increase the chances of sprouting and uniform plant establishment, all stakes used for planting were taken from the middle portions of mature stems.

Data collection

Harvesting was done twelve (12) MAP. Data on eight plants was taken from the inner rows of each experimental plot (harvestable plot). Data taken included whitefly count, incidence of diseases, plant height at harvest, root length, number of marketable roots, non-marketable roots, marketable weight, non-marketable weight, fresh root yield (FRYD) and dry matter content (DMC).

Plant height (cm)

Plant height was recorded using the eight tagged plants from the harvestable plot. A meter rule was used to measure plant height from the collar of the stem to the highest point of the plant canopy. The mean height of eight plants was determined and used as the mean plant height for each experimental plot.

Root length (cm)

From the base of the root to the tip, root length was determined. The calculation was performed from the harvestable plot on eight marketable roots and the mean taken to represent the root length.

Fresh root weight (kg)

Root weight was determined by weighing the roots. Eight plant roots were bulked up and packed into a sack. The sack was put on a hanging scale, documenting the weight. To get the fresh root weight per plant, the fresh root weight was divided by eight.

Fresh root yield (t ha^{-1})

The inter-row and intra-row spacing adopted were the same, that is, 1 m apart and therefore the average plant population was 10,000 per hectare. Multiplying the number of plants stand by the mean fresh root tuber weight (kg) and dividing by 1000 kg gave the fresh root yield in tonnes per hectare.

Determination of population of whitefly

The population of the whiteflies on the cassava plants was determined in order to assess their relationship with the severity of cassava mosaic disease (CMD). Direct counts of adult whiteflies on five topmost fully expanded leaves on each plant were made as previously described by Otim-Nape *et al.* (2000) in Chapter 4.

Determination of cassava mosaic disease (CMD)

The five cassava genotypes were evaluated at the 1st, 3rd, 6th and 9th months after planting (MAP) in the three agro-ecological zones during 2019/2020 cropping season to ascertain the resistance status of each of the ten cassava genotypes to CMD. A modified method by Asare *et al.* (2014) was used for this determination.

Determination of dry matter content

Expressing dry matter content (DMC) as a percentage was determine by selecting three representative storage roots. These were bulked, washed, peeled and sliced using knives. Slices were picked randomly selected and weighed to obtain a 200 g fresh mass sample per genotype before being dried for 48 hours in an oven at 105°C. To obtain the dry mass the dried samples were then re-weighed. The percentage of DMC was calculated as the ratio of the dry weight multiplied by 100 over the fresh weight as indicated below:

$$\text{DMC} = \frac{Sample\ dry\ weight}{Sample\ fresh\ weight} \times 100 \quad (5.5)$$

Molecular screening of cassava genotypes against cassava mosaic begomovirus infection

The resistance status of the cassava genotypes based on the field conditions was confirmed with PCR test using degenerate primers for amplifying ACMV and EACMV.

Collection of leaf samples

Two grams each of harvested young leaves from the ten cassava genotypes were collected from the experimental fields of the School of Agriculture Teaching and Research Farm, University of Cape Coast, Cape Coast. The leaves were packed gently into a zipped polythene bag and transported to the laboratory of the Biotechnology Centre of the College of Agriculture and Consumer Sciences, University of Ghana, Legon for analyses.

DNA extraction

Genomic DNA was extracted from the fresh cassava leaf samples with Quick-DNA™ Plant/Seed Miniprep Kit (Zymo Research) according to the manufacturer's instruction. The extracted DNA was stored at -20ºC until needed.

DNA testing using gel electrophoresis

An agarose gel of 0.9 % was prepared by weighing 1.08 g of an agarose powder into a 120 mL 1 X TAE Buffer and stained with ethidium bromide. The DNA samples were then loaded and run for 45 mins at 80 V and visualized using gel documentation system (Gene Flash Syngene Bio-imaging, BIORAD).

Polymerase chain reaction (PCR)

PCR amplification of DNA samples were carried out using species-specific oligonucleotide primers [OjaRep-F/ACMVRep-R and OjaRep-F/EACMVRep-R] (Table 5.2) in a BIO-RAD iCycler™ Thermal cycler (Applied Biosytems). The reaction volume was 25 µl containing 2 µL of genomic DNA, 12.5 µL of 2X Master Mix with standard buffer and 1µL of each primer. PCR amplification was started at an initial denaturation step at 94 ºC for 5 minutes, followed by denaturation at 94 ºC for 1 minutes, annealing at 55 ºC for 1 min, extension at 72 ºC for 1 minutes for 35 cycles, and a final extension at 72 ºC for 10 minutes.

Electrophoresis

The PCR products were run on 1.2% agarose gel stained with ethidium bromide alongside 1 kb plus DNA ladder (New England Biolabs) for 90 mins at 80 V and visualized under UV light by a Gene Flash Syngene Bio-imaging (BIORAD).

Table 5.2: Primer name and sequence (5' to 3')

Virus Strain	Name of Primer	Primer Sequence (5'- 3')	References
EACMV	OjaRep-F	CRTCAATGACGTTGTACCA	Alabi *et al* (2008)
	EACMVRep-R	GGTTTGCAGAGAACTACATC	
ACMV	OjaRep-F	CRTCAATGACGTTGTACCA	Alabi *et al* (2008)
	ACMVRep-R	CAGCGGMAGTAAGTCMGA	

Statistical analysis

Microsoft Office Excel 2019 was used to collect and clean the data for analysis. Statistical analysis was done using GenStat (version 14). Analysis of variance for the cassava varieties was conducted, and a Tukey's comparison test at the 5% level was conducted to test for a significant difference among the cassava genotypes.

Results

Reaction to whitefly population and cassava mosaic disease

Population of whitefly on the genotypes varied significantly ($p<0.05$) at Wamaso. The highest mean number of whitefly population (23.97) was observed on genotype 9A, followed by genotype 6F (21.84) and the lowest on 8A with a mean number of 4.44 (Table 5.3). Reaction of genotypes to CMD was highly significant ($p<0.05$) among the genotypes. The CMD severity scores ranged from 1.0 to 2.75. Considering the severity of CMD, the high mean was recorded for genotypes 1011A, 8A and 14B with the values of 2.38, 2.44 and 2.75 respectively. The lowest mean severity of 1.0 was recorded for genotypes 9A, 6A, 1A,12B and 6F (Table 5.3).

Whitefly population analyzed from UCC, showed that the reaction of genotypes to whitefly was highly significantly ($p<0.05$). Genotype 9A recorded the highest mean value of 22.94, followed by genotype 6F with the mean value of 18.44. The low whitefly population of 8.16 and 3.88 were recorded for genotypes 14B and 8A respectively (Table 5.3). Reaction of genotypes to CMD at UCC showed to vary significantly ($p<0.05$). The CMD severity scores graded from 1.0 to 2.81. Considering the severity of CMD, high severity scores of 2.81, 2.37 and 2.10 were recorded for genotypes 8A, 14B and 1011A respectively. The rest of the genotypes 9A, 6A, 1A, 12B, 5B, 11B and 6F had the least mean severity score of 1.0 (Table 5.3).

Whitefly population at Asuansi was highly significant ($p<0.05$) among the genotypes. The high mean scores of 19.97, 18.97 and 18.75 were recorded for genotypes 9A, 1A and 5B, respectively with lowest mean score of 4.66 recorded for genotype 8A (Table 5.3). There were significant differences ($p< 0.05$) between genotypes and their reaction to CMD severity at Asuansi. Genotypes 8A, 1011A and 14B had high mean number of 3.4, 2.53 and 2.46 respectively. The lowest mean (1.0) of symptomless genotypes was observed for genotypes 9A, 6A, 1A,12B, 5B, 11B and 6F (Table 5.3).

Table 5.3: Mean cassava mosaic disease severity score, and whitefly population on cassava genotypes evaluated at Wamaso, UCC and Asuansi during 2019/2020 growing season.

	Wamaso		UCC		Asuansi	
Genotypes	Whitefly	Mosaic	Whitefly	Mosaic	Whitefly	Mosaic
9A	23.97^{a}	1.00^{c}	22.94^{a}	1.00^{c}	19.97^{a}	1.00^{c}
6A	19.75^{ab}	1.00^{c}	15.91^{c}	1.00^{c}	18.34^{ab}	1.00^{c}
8A	4.44^{f}	2.75^{a}	3.88^{f}	2.81^{a}	4.66^{e}	3.40^{a}
1A	21.34^{ab}	1.00^{c}	16.75^{bc}	1.00^{c}	18.97^{ab}	1.00^{c}
12B	15.16^{d}	1.00^{c}	11.47^{c}	1.00^{c}	13.81^{c}	1.00^{c}
1011A	8.91^{e}	2.38^{b}	8.25^{e}	2.12^{b}	8.56^{d}	2.53^{b}
14B	7.06^{ef}	2.44^{b}	8.16^{e}	2.37^{b}	8.56^{d}	2.46^{b}
5B	17.47^{cd}	1.09^{c}	15.78^{c}	1.00^{c}	18.75^{ab}	1.00^{c}
11B	19.28^{bc}	1.03^{c}	15.12^{c}	1.00^{c}	16.84^{ab}	1.00^{c}
6F	21.84^{ab}	1.00^{c}	18.44^{b}	1.00^{c}	17.19^{ab}	1.00^{c}
Mean	15.92	1.46	13.57	1.42	14.57	1.54
Hsd	2.787	0.298	2.378	0.349	2.554	0.248
% cv	12.1	14.0	12.0	16.8	12.1	11.1

Means in a column with a common letter superscript are not significantly different ($p>0.001$).

PCR screening of the cassava genotypes for ACMV and EACMV

The results for the PCR screening of the genotypes for ACMV and EACMV are presented in Figures 5.3 and 5.4 respectively. The amplification of the ACMV with the species-specific primer pairs (OjaRep/ACMVRep) generated PCR products at 380 bp in all the cassava genotypes 11B, 14B, 12B, 8A, 1A, 6A, 9A, 5B, 1011A, 6F (lanes: 1-10) making all the samples positive

(+ve) to ACMV (Figure 5.3). Unlike the negative control (-ve) which did not produce PCR product, the positive control (+ve) i.e infected plant produced an amplicon at approximately 380 bp (Figure 5.3).

The amplification of the EACMV with the species-specific primer pairs (OjaRep/EACMVRep) did not generate any PCR products at 650 bp in all the tested cassava genotypes, however, the positive control amplified (Figure 5.4).

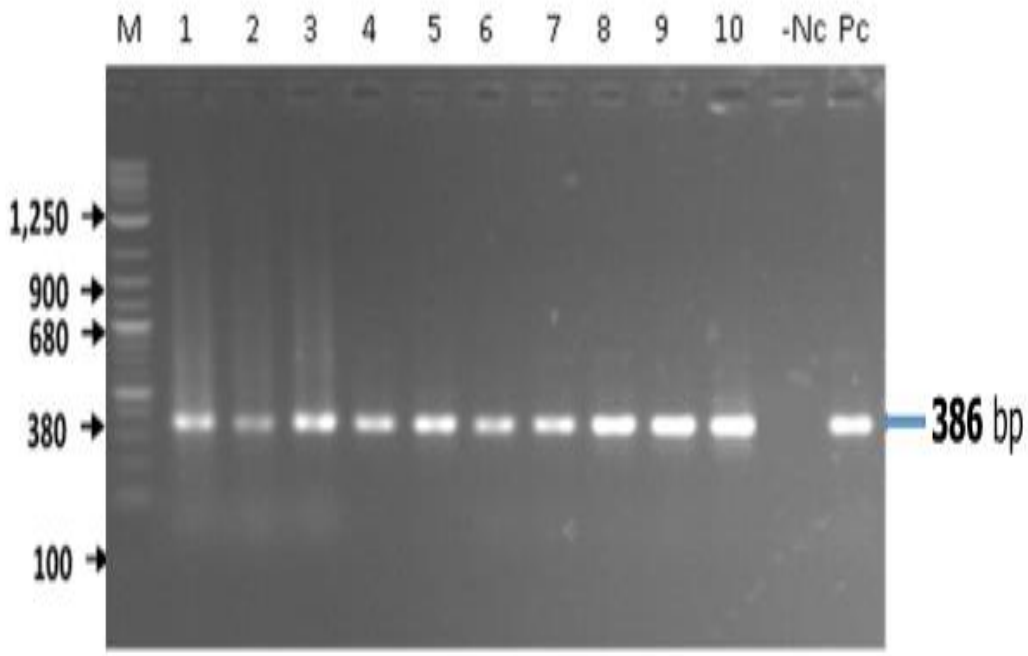

Figure 5.3: Amplified DNA fragments of ACMV from cassava leaves sampled from UCC Farm with species specific primer pairs (OJAREP- ACMVRep)

All genotypes had ACMV DNA bands at 386 bp in lanes 1 to10. Lanes: 1 = 11B; 2= 14B; 3= 12B; 4= 8A; 5= 1A; 6= 6A; 7= 9A; 8 = 5B; 9 = 1011A and 10 = 6F. M = Molecular size marker, Quick-Load Purple 2-Log DNA Ladder (0.1-10.0 kb); -Ve = Negative control (nuclease-free PCR water), and; +Ve = Positive control (Known ACMV sample)

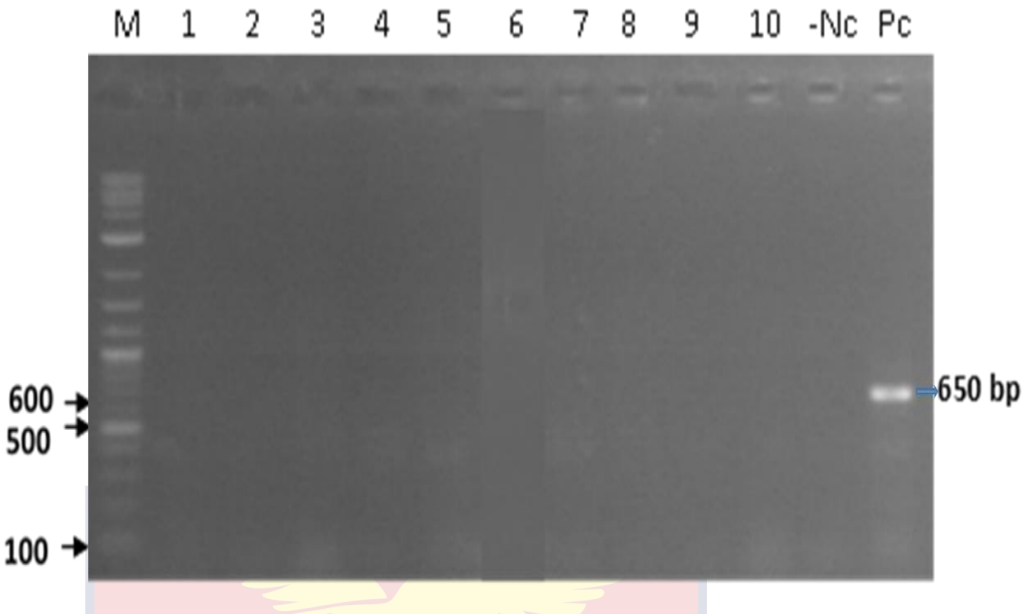

Figure 5.4: Amplified DNA fragments of EACMV from cassava leaves sampled from UCC Farm with species specific primer pairs (OJAREP-F/EACMVREP-R). No genotypes had EACMV DNA bands at 650 bp in lanes 1 to 10. Lanes: 1 = 11B; 2= 14B; 3= 12B; 4= 8A; 5= 1A; 6= 6A; 7= 9A; 8 = 5B; 9 = 1011A; 10 = 6F; M = Molecular size marker, Quick-Load Purple 2-Log DNA Ladder (0.1-10.0 kb); -Ve = Negative control (nuclease-free PCR water), and; +Ve = Positive control (known EACMV sample).

Mean plant height

The genotypes differed significantly ($p<0.05$) in plant height at Wamaso. The height among cassava genotypes varied from 181.2 cm to 231.8 cm. Genotypes 6F and 1A were taller than the other genotypes with values of 231.8 cm and 203.6 cm respectively. However, genotypes 6A and 14B were short with the mean heights of 181.2 and 187.2 cm respectively (Table 5.4). The genotypes were generally tall and highly significant ($p<0.05$) when grown at UCC with mean height of 209 cm. Plant heights of 233.2, 245.5 and 247.2 cm were recorded for 5B, 8A and 6F, respectively and all were considered as tall. The short plant heights of 182.5, 191.9 and 192.9 cm were observed for genotypes 11B, 9A and 6A respectively (Table 5.4).

At Asuansi, the mean plant height recorded for the genotypes varied highly significantly ($p<0.05$). The tall genotypes 1A and 6F recorded plants height of 219.8 and 200.2 cm, respectively and the short mean heights of 176.9 and 181.4 cm were recorded for genotypes 5B and 6A respectively (Table 5.4).

Table 5.4: Mean plant height (cm) on cassava genotypes evaluated at Wamaso, UCC and Asuansi during 2019/2020 growing season.

Genotypes	Wamaso	UCC	Asuansi
9A	189.3^{b}	191.9^{g}	184.4^{bcd}
6A	181.2^{b}	192.9^{g}	176.9^{d}
8A	194.4^{b}	245.4^{b}	186.4^{bcd}
1A	203.6^{b}	200.8^{e}	200.2^{b}
12B	190.9^{b}	207.1^{d}	184.1^{bcd}
1011A	192.6^{b}	182.5^{h}	194.8^{bc}
14B	187.2^{b}	201.5^{e}	195.6^{bc}
5B	202.8^{b}	232.2^{c}	181.4^{cd}
11B	200.2^{b}	198.8^{g}	193.0^{bcd}
6F	231.8^{a}	247.2^{a}	219.8^{a}
Mean	197.4	209.9	191.7
Hsd	20.28	12.96	14.94
% cv	7.1	4.3	5.4

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Yield and Yield Components at Wamaso

Genotypes at Wamaso were highly significantly ($p<0.05$) different for mean root number, root length, marketable roots, root yield and dry matter. There was an average mean of 6.8 for a number of roots that ranged between 4.75 and 10.78 with an average mean of 6.8. High mean number of roots (7.44, 8.00 and 10.78) were recorded for genotypes 6F, 11B and 1011A, respectively. Genotypes 6A and 8A had low mean number of 4.75 and 5.03, respectively (Table 5.5). The longest root length of 41.25 and 49.62 cm were recorded for genotypes 11B and 6F respectively. The shortest root length of 27.62 and 30.06 cm were recorded for genotypes 14B and 1011A. Genotypes 6F, 11B and 1011A had high number of marketable roots of 6.78, 7.28 and 9.75 respectively, but low marketable roots of 4.41 and 4.59 were recorded by genotypes 8A and 12B respectively (Table 5.5).

Dry matter content was observed to be high for genotypes 5B and 11B with the values 35.00 and 37.50 %, respectively whilst the highest dry matter content (41.25 %) was recorded for genotype 6F. Low dry matter contents of 22.50, 25.00 and 28.75 % were recorded for genotypes 14B, 12B and 1011A respectively. Genotypes 1011A, 12B and 6F had high root yields of 41.88, 42.00 and 45.00 t ha^{-1} with an average of 33.23 t ha^{-1}. Low root yields of 21.25 and 23.75 t ha^{-1} were recorded for genotypes 14B and 8A respectively (Table 5.5).

Table 5.5: Mean number of storage roots, root weight per plant, root length, marketable roots, fresh storage roots yield and dry matter performance of YFC genotypes at Wamaso.

Genotypes	Number of roots / plant	Root weight (kg)	Root length (cm)	Number of marketable roots	Yield (t ha^{-1})	Dry matter (%)
9A	6.69^{bc}	3.188^{e}	37.62^{c}	5.72^{bc}	31.88^{d}	33.75^{cd}
6A	4.75^{c}	2.625^{e}	30.94^{de}	4.75^{c}	26.25^{e}	31.25^{de}
8A	5.03^{c}	2.375^{e}	31.88^{d}	4.41^{c}	23.75^{e}	31.25^{de}
1A	$6.81b^{c}$	3.750^{bc}	40.72^{bc}	5.53^{bc}	37.50^{bc}	30.00^{e}
12B	$5.88b^{c}$	4.250^{ab}	37.09^{c}	4.59^{c}	42.00^{ab}	25.00^{f}
1011A	10.78^{a}	4.188^{ab}	30.06^{de}	9.75^{a}	41.88^{ab}	28.75^{e}
14B	6.78^{bc}	2.125^{e}	27.62^{e}	5.78^{bc}	21.25^{e}	22.50^{f}
5B	6.06^{bc}	3.312^{cd}	37.19^{c}	5.06^{bc}	33.12^{cd}	35.00^{bc}
11B	8.00^{b}	3.375^{cd}	41.25^{b}	7.28^{b}	33.75^{cd}	37.50^{b}
6F	7.44^{bc}	4.500^{a}	49.62^{a}	6.78^{bc}	45.00^{a}	41.25^{a}
Mean	6.82	3.36	36.40	5.97	33.69	31.62
Hsd	2.425	0.502	3.389	2.218	5.025	2.507
% cv	24.5	10.3	6.4	25.6	10.3	5.5

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Yield and yield components at UCC

Highly significant ($p<0.05$) differences between genotypes were found for mean root number, root length, marketable roots, root yield and dry matter. Genotypes 5B, 12B and 1011A recorded high number of roots of 6.46, 6.53 and 9.68 respectively (Table 5.6) whilst the fewest numbers of 4.12 and 4.75 were recorded by genotypes 1A and 14B respectively.

The longest mean root length of 48.50 cm recorded for genotype 6F was significantly different from genotype 9A (37.88 cm) followed by genotype 11B (41.75 cm) and the rest of the genotypes. The short mean root lengths of 26.44 and 31.13 cm were recorded for genotypes 14B and 1011A were significantly different from the other genotypes (Table 5.6). Records observed from the marketable roots showed a mean range of 2.75 to 8.00. The high number of marketable roots of 5.25, 5.56 and 8.00 were recorded for genotypes 12B, 6A and 1011A respectively. Genotypes 1A and 14B recorded low marketable roots of 2.75 and 2.87 respectively (Table 5.6). The low marketable root for 1A and 14B at UCC was due to flood that occurred during the planting season leading to the deterioration of most of the root tubers.

Mean dry matter content at UCC range between 23.75 % and 41.25 % with an average mean of 29.75 %. A comparison between the dry matter content shows that genotypes 8A, 11B and 6F had high dry matter content of 31.25, 36.25 and 41.25 % respectively. Low dry matter content of 23.75 and 25.00 % were recorded for genotypes 14B and 1011A respectively (Table 5.6). The high root yields of 38.06, 43.44 and 44.69 t ha^{-1} were recorded for genotypes 5B, 6F and 12B respectively with a mean root yields of 33.23 t ha^{-1}. Low yields of 20.13, 21.79 and 23. t ha^{-1} were recorded for genotypes 14B, 1A and 6A, respectively (Table 5.6).

Table 5.6: Mean number of storage roots, root weight per plant, root length, marketable roots, fresh storage roots yield and dry matter performance of YFC genotypes at UCC.

Genotypes	Number of roots / plant	Root weight (kg)	Root length (cm)	Number of marketable roots	Yield (t ha^{-1})	Dry matter (%)
9A	5.71^{b}	3.50^{ab}	37.88^{c}	4.87^{b}	35.00^{ab}	30.00^{cd}
6A	5.56^{b}	2.31^{c}	30.63^{f}	5.56^{b}	23.13^{c}	26.25^{fg}
8A	5.46^{b}	2.40^{c}	31.50^{ef}	4.68^{bc}	24.06^{c}	27.50^{ef}
1A	4.12^{b}	2.17^{bc}	37.19^{cd}	2.75^{d}	21.79^{bc}	31.25^{c}
12B	6.53^{b}	4.46^{a}	34.31^{de}	5.25^{b}	44.69^{a}	27.50^{ef}
1011A	9.68^{a}	3.87^{a}	31.13^{ef}	8.00^{a}	38.75^{a}	25.00^{gh}
14B	4.75^{b}	2.01^{c}	26.44^{g}	2.87^{cd}	20.13^{c}	23.75^{h}
5B	6.46^{b}	3.90^{a}	37.88^{cd}	5.43^{b}	39.06^{a}	28.75^{de}
11B	4.96^{b}	3.68^{a}	41.75^{b}	4.37^{bcd}	36.88^{a}	36.25^{b}
6F	5.06^{b}	4.34^{a}	48.50^{a}	4.43^{bcd}	43.44^{a}	41.25^{a}
Mean	5.83	3.32	35.67	4.83	33.23	29.75
Hsd	2.163	0.866	3.166	1.690	8.661	1.652
% cv	25.6	18.0	6.1	24.1	18.0	3.8

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Yield and yield components at Asuansi

ANOVA showed highly significant differences ($p<0.05$) among the cassava genotypes in terms of number of roots, root length, marketable roots, root yield and dry matter (Table 5.7). High mean number of roots of 6.71, 7.31 and 7.71 were recorded for genotypes, 5B, 12B and 1011A respectively. Genotypes 9A and 6A had low number of roots, 4.56 and 4.90 respectively.

The results showed highly significant effect ($p<0.05$) for root length which ranged from 28.19 to 50.81 cm with an average of 37.61 cm (Table 5.7). Genotypes 12B, 11B and 6F recorded the highest root length of 40.28, 41.84 and 50.81 cm, respectively whilst the shortest root length of 28.19 and 31.25 cm were recorded for genotypes 14B and 1011A, respectively. The mean number of marketable roots ranged between 4.06 and 7.00 with an average of 5.57. The highest mean number of marketable roots of 7.00 was recorded for genotype 1011A, followed by genotype 8A (6.41) while genotypes 9A and 11B recorded low mean number of marketable roots of 4.06 and 4.69, respectively (Table 5.7).

Fresh root yield obtained from Asuansi varied significantly ($p<0.05$). Genotype 6F had the highest mean root yield (38.44 t ha^{-1}) which was significantly different from genotypes 5B (30.31 t ha^{-1}) and 12B (34.69 t ha^{-1}). However, low root yields of 20.00, 22.50 and 22.81 t ha^{-1} were recorded for genotypes 14B, 8A and 9A respectively. Genotypes 11B and 6F had high dry matter contents of 36.25 % and 47.50 %, respectively. Genotypes 14B and 1011A recorded low dry matter content of 18.75 % and 23.75% respectively (Table 5.7).

Table 5.7: Mean number of storage roots, root weight per plant, root length, marketable roots, fresh storage roots yield and dry matter performance of YFC genotypes at Asuansi.

Genotypes	Number of roots / plant	Root weight (kg)	Root length (cm)	Number of marketable roots	Yield (t ha^{-1})	Dry matter content (%)
9A	4.56^{c}	2.281^{cd}	37.84^{c}	4.06^{c}	22.81^{cd}	31.25^{c}
6A	4.90bc	2.562^{cd}	33.81^{d}	4.90^{bc}	25.62^{cd}	32.50^{c}
8A	6.59^{abc}	2.250^{cd}	32.44^{d}	6.41^{ab}	22.50^{cd}	23.75^{e}
1A	6.31^{abc}	2.875^{bc}	42.53^{b}	5.66^{abc}	28.75^{bc}	32.50^{c}
12B	7.31^{ab}	3.469^{ab}	40.28^{bc}	6.41^{ab}	34.69^{ab}	27.50^{d}
1011A	7.71^{a}	2.781^{cd}	31.25^{de}	7.00^{a}	27.81^{bcd}	23.75^{e}
14B	5.43^{abc}	2.000^{d}	28.19^{e}	5.19^{abc}	20.00^{d}	18.75^{f}
5B	6.71^{abc}	3.031^{bc}	37.09^{c}	5.72^{abc}	30.31^{bc}	27.50^{d}
11B	5.40^{abc}	2.938^{bc}	41.84^{b}	4.69^{bc}	29.38^{bc}	36.25^{b}
6F	6.46^{abc}	3.844^{a}	50.81^{a}	5.69^{abc}	38.44^{a}	47.50^{a}
Means	6.14	2.803	37.61	5.57	28.03	30.12
Lsd	2.158	0.746	3.095	1.686	7.468	1.545
% cv	24.2	18.4	5.7	20.9	18.4	3.5

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Performance of the ten cassava genotypes for whitefly population, mosaic, yield and dry matter content across the three locations.

Combining the data for the three locations, highly significant differences ($p<0.05$) were seen in whitefly population, mosaic, yield and dry matter content among the ten cassava genotypes (Table 5.8). Mean population of whitefly on the genotypes over the three surroundings varied significantly ($p<0.05$).

It graded from 4.33 to 22.9 with an average of 14.72. The highest mean number of whitefly population (22.9) was observed on genotype 9A followed by genotype 6F (19.16) and genotype 6A (18.00). Low mean number of 4.33 and 7.93 were recorded for 8A and 1011A (Table 5.8) respectively. The reaction of the genotypes to cassava mosaic disease across the three environments varied significantly ($p<0.05$). The reaction ranged from 1.0 to 2.98 with a mean of 1.48. Genotypes 1011A, 14B and 8A recorded high CMD reaction of 2.34, 2.42 and 2.98 respectively (Table 5.8). The root yield ranged from 20.46 t ha^{-1} to 42.29 t ha^{-1} with a mean of 31.45 t ha^{-1}. Four of the genotypes had root yields of more than the mean (31.45 t ha^{-1}), while six genotypes yielded less than the mean (Table 5.8).

Genotype 6F had the highest root yield of 42.29 t ha^{-1}. This was followed by genotypes 11B, 5B and 12B with root yield of 33.34, 34.16 and 40.46 t ha^{-1} respectively. Low root yield of 20.46 and 23.44 t ha^{-1} were recorded for genotypes 14B and 12B respectively (Table 5.8). ANOVA showed that dry matter content varied significantly ($p<0.05$) among the genotypes. The overall dry matter content ranged from 21.67 to 43.33 %, with an average of 30.50 %. The highest dry matter of 43.33 % was recorded for genotype 6F while genotype 14B recorded the lowest dry matter of 21.67 % (Table 5.8).

Table 5.8: Mean performance of the ten cassava genotypes evaluated across the three locations (Asuansi, UCC and Wamaso).

Genotypes	Whitefly	Mosaic	Yield (t ha^{-1})	Dry matter content (%)
9A	22.29^{a}	1.00^{c}	29.90^{abc}	31.67^{bc}
6A	18.00^{abc}	1.00^{c}	25.00^{bc}	30.00^{bc}
8A	4.33^{e}	2.99^{a}	23.44^{bc}	27.50^{cd}
1A	19.02^{ab}	1.00^{c}	29.35^{abc}	31.25^{bc}
12B	13.48^{cd}	1.00^{c}	40.46^{a}	26.67^{cd}
1011A	8.57^{de}	2.34^{b}	36.15^{ab}	25.83^{cd}
14B	7.93^{e}	2.43^{b}	20.46^{c}	21.67^{d}
5B	17.33^{abc}	1.03^{c}	34.16^{abc}	30.42^{bc}
11B	17.08^{bc}	1.01^{c}	33.34^{abc}	36.67^{ab}
6F	19.16^{ab}	1.00^{c}	42.29^{a}	43.33^{a}
Means	14.72	1.48	31.45	30.50
Hsd	2.95	0.22	8.22	4.68
% cv	11.8	9.0	15.4	9

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Location effect on mean CMD, whitefly population, plant height, yield and dry matter content.

The effect of location on mean CMD severity scores and whitefly population is presented in Table 5.9. There was no significant difference ($p>0.05$) among genotypes for CMD severity across the three locations even though genotypes from Asuansi recorded the highest severity of 1.54.

For whitefly population, genotypes from Wamaso recorded the highest population of 15.92 and genotypes from UCC recorded the least population of 13.67. Across the three locations, genotypes from UCC recorded the highest mean plant height (210.0 cm), followed by Wamaso (197.39 cm), while genotypes from Asuansi had the lowest mean plant height of (191.65 cm) (Table 5.9). For the yield recorded, there was no significant difference ($p>0.05$) across the three locations for Wamaso (33.64 t ha^{-1}) and UCC (32.69 t ha^{-1}) but there were significant differences between them and the yield recorded for Asuansi (28.03 t ha^{-1}). Records from the dry matter content showed no significant difference ($p>0.05$) across the three locations. Genotypes from UCC recorded the least dry matter content (29.75 %), followed by Asuansi (30.13) while Wamaso recorded the highest dry matter (31.63 %) (Table 5.9).

Table 5.9: Location effect on CMD, whitefly population, plant height, yield and dry matter content.

Location	CMD	Whitefly	Plant height (cm)	Yield (t ha^{-1})	Dry matter content (%)
Asuansi	1.54^{ns}	14.56^{b}	191.65^{b}	28.03^{b}	30.13^{ns}
Wamaso	1.47^{ns}	15.92^{a}	197.39^{b}	33.64^{a}	31.63^{ns}
UCC	1.43^{ns}	13.67^{b}	210.00^{a}	32.69^{a}	29.75^{ns}
Mean	1.48	14.72	199.7	31.45	30.50
Lsd	0.12	1.30	11.36	3.75	2.54
% cv	8.7	9.4	6.1	12.7	8.9

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Correlation coefficient between whitefly population, (CMD), marketable root, yield, and dry matter evaluated on ten genotypes at Asuansi, UCC and Wamaso.

Significant association was seen among plant height, whitefly population, levels of cassava mosaic disease, dry matter content and yield as affected by the three locations (Table 5.10). Correlation between mosaic and whitefly were significantly negatively correlated. The correlation observed between mosaic and yield were significantly negatively correlated. The dry matter content was positively correlated with root yield of cassava but negatively correlated with mosaic disease. Furthermore, plant height had positive relationship with root yield. The results of the relationship between cassava yield and marketable root, root weight per plant and root length were positively correlated ($p<0.05$).

Table 5.10: Correlation coefficient between whitefly population, (CMD), marketable root, yield, and dry matter evaluated on ten genotypes at Asuansi, UCC and Wamaso.

	Dry Matter Content (%)	Marketable Root	CMD	Number of roots	Plant Height (cm)	Root Length (cm)	Root weight/ Plant (g)	Whitefly	Yield (t $ha^{-1)}$
Dry Matter	-								
Marketable Root	-0.015	-							
CMD	-0.5612**	0.1446	-						
Number of root	-0.0681	0.9337**	0.1557	-					
Plant Height (cm)	0.3907**	-0.0279	-0.05	-0.0046	-				
Root Length Root(cm)	0.7897**	-0.0606	-0.5796**	-0.076	0.4069**	-			
weight/ Plant (g)	0.377**	0.2567*	-0.4213**	0.3193**	0.2721*	0.4742**	-		
Whitefly	0.5255**	-0.0924	-0.7913**	-0.1253	-0.0123	0.5684**	0.2974**	-	
Yield (tha^{-1})	0.377**	0.2567*	-0.4213**	0.3193**	0.2721*	0.4742**	1.000	0.2974**	-

p<0.01 ** p<0.05 *

Discussion

Genotypes behave differently when cultivated under different agro-ecological zones. Genotypes that perform better in the rainforest area may perform poorly in the coastal savanna area and vice versa (Gibson *et al*., 1997). According to Obeng-Antwi, Craufurd, Menkir, Ellis, and Sallah (2012), there is the need to evaluate different genotypes in different agro-ecological zones in order to determine their genetic diversity and how they respond to incidence of disease pressure, and biotic / abiotic stresses.

Whitefly population showed variability among different genotypes from the different locations. Resistant CMD genotypes were observed to have high counts of whiteflies (Table 5.1). This indicates that those genotypes were the most liked by the whiteflies because of their broader and tender leaves compared to the curled leaves of the susceptible genotypes. Also, the CMD resistant genotypes provide the whiteflies protection against strong wind and sunshine during rest and during active feeding time and they may fly to feed on the CMD susceptible genotypes. This outcome agrees with that of Otim, Legg, Kyamanywa, Polaszek and Gerling (2006), where high numbers of whiteflies were found on CMD resistant varieties compared to CMD susceptible varieties of cassava. It is also confirmed by Adriko *et al*. (2011) who observed high whitefly populations as a characteristic feature of the CMD resistant cassava cultivars while the susceptible cassava cultivars had the lowest number of whiteflies, as most of the cultivars had a higher protection of whiteflies on healthy plants than on plants that are diseased. This is consistent with the observations made by Legg, Sseruwagi and Brown (2003), and it is attributed to the whitefly preference for safety on the resistant varieties.

From the data collected during the trials (Table 5.6), whitefly population was observed to be mainly high in the rainforest (Wamaso), followed by the transitional zone (Asuansi) as compared to the coastal savannah zone (UCC), indicating that their presence could be influenced by climatic conditions. This is a sharp contrast to the work done by Akumanue (2015) who observed more whitefly population at UCC than Asuansi. She attributed the high whitefly population at UCC to the cultivation of other host plants like vegetables at UCC as also reported by other scientists (Liu, 2012; Wan, Zhang, Liu, Luo & Chu, 2009; Zhang, Lu & Wan, 2007). However, the results of this study, agrees with report by Klein *et al*. (2002); Teodoro, Klein and Tscharntice (2008) who observed differences in diversity and density of pests in tropical regions and attributed it to variation in local environmental factors such as temperature, rainfall and relative humidity. Also, whitefly populations were found to increase in areas with high annual rainfall possibly as a result of the increased vegetative growth (Robertson, 1985). However, Legg (1994) reported that no direct relationship has been found between the whitefly's population and rainfall. There was a negative correlation between whitefly population and CMD severity (Table 5.7). This is in sharp contrast to Mauck (2012); Bokanga (1994) who observed a positive correlation between whitefly population and CMD severity.

The incidence of CMD varied across the three agro-ecological zones and resulted in different levels of severity scores among the genotypes (Table 5.1). Even though three of the genotypes were susceptible to CMD and showed reaction to CMD severity, the rest of the genotypes showed CMD symptomless as observed in Table 5.1. These three genotypes showed high CMD severity across all the three environments (Table 5.6).

This might suggest that virus replication and symptom expression are moderated by distinct genes in cassava than from the environment. This assertion is alluded to by Kiweesi *et al.* (2014) but in sharp contrast to Sing'ombe *et al.* (2015) who observed that the development of cassava mosaic disease is affected by environmental conditions and may vary depending on rainfall, temperature, sunlight and humidity of the field.

Most of the genotypes were also found to exhibit symptomless expression of CMD (Table 5.6). The observation does not agree with the study by Chikoti, Shanahan and Melis (2016), in which severe CMD symptoms was recorded by all genotypes. This may be attributed to the influence of the environment on the cassava mosaic virus, the whitefly population and the growth activities of the plants, according to Fargette, Muniyappa, Fauquet, Nguessan and Thouvenel (1993). Asuansi was found to have a higher mean susceptibility to genotypes relative to UCC and Wamaso (Table 5.7). This finding is consistent with that of Akainwale *et al.*, (2011), where the reaction of the genotypes to cassava mosaic disease infection was affected by the variations between environments and seasons. It must be noted that most farmers in Africa are not worried about the incidence of CMD because, in spite of the disease, cassava varieties still give appreciable yields. Also, according to Okorogri, Adetimirin, Ssemakula, Odu and Dixon (2010), the susceptible CMD varieties sometimes possess farmer preferred qualities or traits which promote their unique interest.

Recent study by Chen *et al.* (2012) have showed that PCR techniques based on DNA sequences have proven valuable in the identification and analysis of disease resistance in CMD because the presence of highly conserved repetitive sequences in the genomes of cassava mosaic begomovirus, vector and host make

them highly useful for strain differentiation. Though a morphological screening of the ten genotypes for CMD resistance was caried out based on the 1-5 disease rating by IITA (1990); Ariyo, Dixon and Atiri (2005), a more advanced resistance screening using PCR techniques based on DNA sequences with ACMV strain-specific primers showed that all the cassava genotypes were susceptible to CMD (Figure 5.3), unlike the morphological screening which recorded only three genotypes being susceptible to CMD (Table 5.1). These results were similar to those of Asare *et al*. (2014) who equally found cassava genotypes to be asymptomatic to CMD during field screening but tested positive to CMD in molecular screening. This finding could partially indicate that, as stated by Ogbe (2001), the field resistance shown by the cassava genotypes is not necessarily an indicator of true resistance to the infection of the virus. This indicates that morphological screening should therefore be complemented with virus detection methods such as PCR in field selection for resistance.

The EACMV strain that was not detected in all the ten (10) genotypes, signifies the resistance status of the genotypes to EACMV (Figure 5.4). This could possibly suggest that either the cassava genotypes possess true resistance to the EACMV or the virus that causes the EACMV infections is absent at the experimental sites. This result is similar to Hayford (2017), who also did not detect any EACMV strains for the cassava genotypes he studied at UCC and Asuansi. However, the result of the present study is in contrast with the finding of Akumanue (2015) who detected the EACMV strains in cassava genotypes studied at UCC. Also, studies by Gibson and Otim-Nape (1997) showed that EACMV occurs over a much wider area in West Africa including Ghana. The CMG strains responsible for the EACMV disease is systemic, therefore, the

EACMV strain that was not detected has the potential to be multiplied for distribution to farmers across Ghana.

Differences in plant height between genotypes were observed, suggesting that it was genotype dependent (Table 5.4). The overall mean plant height was 209 cm. These observations are within the height range of 100 to 400 cm of the cassava plant (Ekanayake *et al.,* 1997). It was observed that the relationship between genotype and environment for height differed significantly. This may be due to the various growing conditions such as rainfall, temperature, solar radiation that support the plant's growth (Yihong, 2009). Compared to Wamaso and Asuansi, the genotypes in UCC were usually taller (Table 5.9). Similar findings were reported by Laban, Baguma, Kizito and Osiru (2013), where genotypes and locations differed significantly in three locations in Uganda for plant height. The tallest plant at UCC and Wamaso could be due to the fact that these locations had good rainfall and optimum temperatures which had favoured plant growth compared to Asuansi. Genotype 8A had a higher plant height but gave a lower yield. This is because taller plants do not guarantee higher yields as plant height dry matter partition is more towards the growth than to the storage roots. Also, this is supported in experiment by Kundy (2013), where low to medium plant heights had high to very high root yields. Also, the results agree with Amarullah, Indradewa, Yudono, and Sunarminto (2017), where cassava growth and yield parameters have a deep influence on the final root yield. They posit that, root yield has been negatively associated with plant height, suggesting that as the plant grows higher, the tuber yield decreases. This may be due to the distribution of assimilates instead of root to vegetative growth.

According to Mba and Dixon (1995) root yield is a trait that is demonstrated by genotype and environmental interaction. It was observed in this study that some cassava genotypes were suited for different agroecological zones. Four of the genotypes were identified as superior yielding genotypes across locations (Table 5.8). This implies that these genotypes can be grown in any of the three locations. This may be due to varietal and climatic superiority especially in their ability to utilize resources more efficiently through appropriate partitioning of assimilates (Mandal, 2006). Also, the superiority for these genotypes existed probably because these four genotypes were not affected by diseases and had consistent high number of roots per plant across the locations. These results agree with previous study by Ntuwurunga *et al*. (2006) who reported that cassava root yield increases as plant root number increases.

The overall average root yield among the ten (10) genotypes across the three locations was 31.45 t ha^{-1}. The mean yields from the study were greater than what has been observed in some other cassava yield studies. For instance, Maroya and Dixon (1992) observed a range of mean genotypes root yields of 11.47 - 25.14 t ha^{-1} with a grand mean of 18.17 t ha^{-1}. Also, Kundy (2013) investigation revealed highest mean root yield of 21.72 t ha^{-1}. The mean yield of the genotypes from the study even though lower than the potential yield was higher than the actual average yield. According to MoFA (2011), cassava has the potential to yield up to 48.7 t ha^{-1} on researchers' field but on farmers field yields are far below average; yielding up to 18.3 t ha^{-1} in 2013 (FAOSTAT, 2014).

Generally, the trend for the root yield was consistent with increase in rainfall, as the yields were higher at Wamaso which is located in a rainforest, followed by the yields at UCC, which is located in a coastal savannah zone and lastly, Asuansi, which is located in a transitional zone. The rainfall at Wamaso and UCC was found to be high compared to that at Asuansi during the growing season of 2019/2020 (Figure 5.1). This may have influenced the relatively better root yield of genotypes at Wamaso and UCC than at Asuansi. These results conform to the optimum conditions for cassava growth and development. According to Nassar and Ortiz (2007) cassava performs better under rainfall between 1000 mm-1500 mm per annum. These results agree with observations by Akumanue (2015), who reported similar trend of root yield at the two locations with Asuansi recording lower yields than UCC. The lower yield observed at Asuansi could also be due to high incidence of CMD at that location. Kiweesi *et al*., (2014) reported that low yield could be attributed to yield cost on the plant due to resistance to disease.

Aside the white flesh (6F) used as check, Genotype 12B and 5B (Table 5.6) were on average, considered as the best for root yield across the three locations and specifically for UCC, while genotype 1011A was more suitable for Wamaso (Table 5.5). Based on these results therefore, Wamaso was the most suitable location for cassava root yield production, as this location had suitable conditions for cassava growth and development (Table 5.9).

The selection and assessment of genotypes with increased yield and stability is very vital in any genetic breeding program to indicate superior materials for marketable use. According to Yan *et al*. (2000), a comprehensive assessment of the significance of G × E is important to confirm higher precision

in the selection and release of high yielding and stable genotypes across locations.

Higher dry matter content was observed for most of the genotypes (Table 5.8). These findings show that yellow-fleshed cassava genotypes can have relatively high dry matter content. The findings agree with those of Gyau (2015), where the amount of dry matter produced varied from 30 % to 40 %. Also, Teye, Asare, Amoah and Tetteh (2011) had similar results when the dry matter values obtained ranged from 31.45 % to 40.74 %. Also, Okechukwu and Dixon (2009) recorded dry matter content ranging between 23-43 %. The grand mean for dry matter content for the three locations was 30.5 % (Table 5.8). The results obtained were similar to results reported in other research of yellow flesh genotypes (Ssenmakula & Dixon, 2007). Also, Maroya *et al*. (2012) observed that high dry matter was associated with yellow flesh cassava genotypes in their study.

Based on the results of this study, it was observed that the mean dry matter content did not varied within and across locations (Table 5.9) but varied significantly among genotypes (Table 5.8). This suggests that dry matter content is not extremely influenced by the environment as by genetic traits and therefore, to distinguish genotypes with high and stable performance, fewer environments may be required. This assertion is revealed in a study by Perez *et al*. (2001) who stated higher genotype than environmental effects on dry matter in cassava. Also, the effect of GxE interaction on dry matter content corroborates with studies by Benesi *et al*., (2003) who reported that dry matter content is not highly controlled by environments and they suggested it was controlled by one, or a few major genes. On the contrary, Ssemakula and Dixon (2007) reported that the

environment has influence on cassava dry matter content as compared to the genotypes.

The fresh root yield, root number and dry matter content can be selected simultaneously as they are positively and significantly correlated (Table 5.10), according to the results of this study. Similar findings were stated by Egesi *et al.* (2007) for the correlation of fresh root yield with root number.

There was, however, a negative correlation between CMD and root yield (Table 5.10), indicating that the higher the frequency of CMD, the lower the root yield. This result is supported by earlier studies by Tumwesigye *et al.* (2006), who found a negative correlation between the incidence of CMD and yield under natural disease infection conditions in several cassava genotypes. A negative correlation coefficient between cassava mosaic disease and yield was also reported by Okechukwu and Dixon (2009).

The damaging effects of CMD, that is, chlorosis and reduction in leaf size, especially at the early and most susceptible stage of plant growth, result in a decrease in photosynthetic activity, thereby affecting the partitioning of photoassimilates from leaves to storage roots (Mariscal, Berganthin & Troyo, 2002). On the contrary, studies by Ssemakula and Dixon (2007) have shown a sifnificant positive correlation between yield and cassava mosaic disease. In cases where there was a weak and positive correlation between cassava mosaic disease and a trait, it was suggested that cassava mosaic disease had no effects on the particular trait (Chikoti *et al*., 2016).

Positive correlations were found between number of roots per plant and root yield (Table 5.10), indicating that any increase in such characters will suffice the boost in root yield. Similar research results were published by

Ntawurunga *et al*. (2001), indicating that those traits were the most important traits contributing to root yield. The marketable root weight was positively correlation with yield (Table 5.10) and this was commonly preferred by farmers to increase their income and enhance their livelihoods. It can also be selected for yield improvement.

Conclusion

This study showed the G x E interactions among the 10 genotypes in relation to CMD infestation, dry matter content and their yield components. High dry matter content and high yielding yellow flesh genotypes with specific adaptation were identified. For example, the overall performance of the genotypes based on the combined ranking showed that for all the traits studied, yellow flesh genotypes 12B, 11B, 5B and 9A were the top four performers. It suffices to note that the improved genotypes evaluated in this study were a set of genotypes derived from an advanced yield trial and multi-locational trial, which means they could have attained stability for important agronomic traits including root yield and DMC. It is therefore recommended that these genotypes be further screened for farmer's field trials and also demonstration plots should be established for the release of these genotypes as varieties for farmers.

CHAPTER SIX

MEALINESS AND STARCH CONTENT OF YELLOW FLESH CASSAVA GENOTYPES IN THREE AGRO ECOLOGICAL ZONES OF GHANA

Introduction

The economic value for cassava products for end users emanates from the dry matter and starch contents. The performance of cassava starch and dry matter in food, feed and other industrial applications vary according to the variety from which the product was obtained (Benesi *et al*., 2003; Singh, Sandhu & Kaur, 2005). In Ghana, several cassava varieties grown are known to farmers as having high dry matter and starch content since most of the cassava produced and consumed are mainly processed as *gari* and *fufu*. Inheritance of dry matter content as an agronomic trait has been done in cassava (Jaramillo *et al*., 2005). However, studies conducted on genetic analyses suggest that inheritance of root dry matter content is controlled by polygenic additive factors (Kawano, 1987).

According to Barima *et al.* (2000), cassava dry matter ranges from one genotype to another and ranged from 17 % to 47 %, with the majority between 20 % and 40 %. Values over 30 % are considered high. Dry matter content in cassava roots can also vary from 15 to 45 % depending on the age of the crop, the genotype used and environmental conditions (Bakayoko *et al.*, (2009); Okechuku and Dixon, 2009). The dry matter of the tuberous roots has become an important character for the acceptance of cassava by researchers and consumers who boil as *ampesi* or process them into *fufu*. Cultivars with high dry matter content are preferred by the vast majority of users because increased dry matter content has a positive effect on the extraction efficiency in the processing

of cassava (flour or starch) (Kawano *et al*., 1987). Tan and Mak (1995) reported that, high dry matter content is important especially when roots are used as food, feed and industrial raw materials. However, most literature report lower values of dry matter contents in yellow-flesh varieties due to higher moisture in the roots. Ukenye *et al*. (2013) reported a higher dry matter content for white-flesh varieties as compared to yellow flesh varieties. However, Aniedu and Omodamiro (2012) reported higher dry matter content for yellow flesh cassava varieties compared to those of white fleshed varieties.

There are two methods for determination of dry matter content in cassava. According to Jennings and Iglesias (2002) the specific gravity method is a quick method for determining root dry matter content. Normally, unpeeled fresh roots are weighed in air and then in water. The other method is using the forced oven dry method (Jennings & Iglesias, 2002). To determine the percentage of dry matter content, the fresh tuber is weighed, dried in an oven for 24 hours at 105 ^{o}C and reweighed. This method is more tedious when dealing with large samples and almost impossible in places where there is no source of power or energy. This study used specific gravity as an alternative method for determining the dry matter content of cassava tubers rather than using the dry oven method.

The main component of the cassava root is starch (Ceballos *et al.*, 2006), which therefore plays an important role in the use of cassava as a food, feed and industrial crop. Starch functionality in cassava depends on the variety, environmental conditions and the age of the crop (Asaoka, Blanshard, Rickard, Kurotjanawong & Sriroth, 1992).

Variation in starch quantity with values ranging between 13.6 % and 35.8 % has been reported (Rickard, Asoaka & Blanshard, 1991). The starch yield from cassava roots is dependent but not limited to cultivar, maturity, extraction method and cultivation practices. Starch composition in cassava root rises with an increase in the dry matter accumulation (Henry, Andres & Collinson, 1998). Starch content of cassava can be determined chemically or enzymatically, but starch yield is the amount of starch physically recoverable from cassava roots.

In the production of custard powder, the use of starch derived from yellow flesh cassava roots has gradually found its application in food formulations and composite flour preparations in Nigeria for sustainable strategy (Okoye, Okoriji & Asumugha, 2007). This helps in preventing and minimizing vitamin A deficiency. Custard powder is an edible, sweet and flavoured yellow coloured starch. It gives the desired colour, taste, and aroma when hot milk is added (Okoye *et al*., 2007). According to Maziya-Dixon *et al*. (2005) the total starch content from forty yellow flesh cassava varieties (67.08 - 81.18 %) was similar to that of three white flesh varieties (70.48 - 82.42 %) when they were studied. However, starch yield from four yellow flesh cassava varieties was lower than starch yield from white and cream-flesh varieties (Ukenye *et al*., 2013). Again, starch extracted from six roots of recently released yellow flesh varieties was lower on average in comparison to that from white flesh varieties (Aniedu & Omodamiro, 2012).

There is relationship between specific gravity value, dry matter and starch content which has been developed by several workers (Dale & Mackay, 1994). Specific gravity conversion tables are available in countries to be used to determine dry matter and starch (Teye *et al*., 2011; IITA., 2005).

However, there is a limitation that calibration of the method should be done for yellow flesh cassava roots harvested under diverse conditions of environment, soil type, age at harvest etc. Moreover, conversion charts for specific gravity, dry matter and starch content have not been developed for the yellow flesh cassava varieties in the country. The objectives of this study were;

i. to establish the relationship and prepare conversion chart for specific gravity, dry matter and starch contents for nine yellow flesh cassava genotypes in Ghana.
ii. to determine the relationship between dry matter content and mealiness among the yellow flesh genotypes.

Materials and Methods

Study area

The study was conducted at the Alexander Gyandoh Carson Technology Laboratory, University of Cape Coast, Cape Coast in May, 2020. The area has a temperature and relative humidity of 30-36 ^{o}C and 60 -70 %, respectively.

Experimental materials

The cassava tubers were obtained from the Teaching and Research Farm - UCC, Commercial, Teaching and Research Station at Wamaso, and Asuansi Research Farm in Abura-Asebu-Kwamankese District in the Central Region of Ghana. In all, ten genotypes were collected, nine (9) yellow flesh genotypes and a white flesh genotype as recorded in Chapter 4.

Determination of specific gravity

To get rid of all the soil particles on the roots, the freshly harvested roots were peeled and thoroughly washed with water. To get a uniform shape, the ends of the roots were nicely trimmed. With a thin thread, the roots were tied. This

was done to prevent the roots from reaching the beaker walls during weighing and to increase the removal of the roots from the beaker.

Determination of dry matter content (DMC)

The dry matter content (DMC) was expressed as a percentage by selecting three representative storage roots. These were bulked, washed, peeled and sliced using knives. Slices were picked randomly selected and weighed to obtain a 200 g fresh mass sample per genotype before being dried for 48 hours in an oven at 105 °C. To obtain the dry mass the dried samples were then re-weighed. The percentage of DMC was calculated as the ratio of the dry weight multiplied by 100 over the fresh weight as indicated below:

$$\text{DMC} = \frac{\text{Sample dry weight}}{\text{Sample fresh weight}} \times 100 \qquad (6.1)$$

Determination of starch content

Two hundred grams (200 g) cassava samples were sliced and blended in 500 ml of water for five minutes in a blender. The pulp was washed on a sieve with an additional 500 ml of water, and the fibrous material retained on the sieve was thrown away. The starch slurry was then filtered through a cheese cloth into a plastic container. The distillate was allowed to stand for about four hours to settle after which the supernatant was drained away. The pure white starch in the plastic container was dried to constant weight using analytical weighing scale. The percentage was calculated as

$$\% \text{ Starch} = \frac{\text{Starch weight}}{\text{Fresh weight}} \text{x } 100 \qquad (6.2)$$

Using equation to confirm dry matter (DM) and starch content

Heritability for DM in cassava is relatively high. They were 0.87 broad sense heritability and 0.51 – 0.67 narrow sense heritability (Kawano *et al*., 1987). Estimation of DM and starch content in cassava was based on the principle of a linear relationship between specific gravity with DM and or starch content. Percentage DM = 158.3x – 142, while starch content = 112.1x – 106.4; where x = specific gravity.

Mealiness

Mealiness is an important trait in breeding for quality assessment. It is a method used in assessing the cooking quality of cassava genotypes. Samples were prepared by washing each root with clean water to remove all soil. Each root was sliced into four equal parts. The sliced samples were placed into a pot and were cooked for 25 min on a gas cooker. Mealiness was measured by taking and pressing a small portion of the boiled sample between the thumb and the index finger. It is called mealy if it is soft and can form a sticky paste and suitable for '*ampesi*' or for '*fufu*'. On the other hand, the hard and difficult to press will not form a sticky paste and is called non-mealy. However, for *agbelima*, non-mealy genotypes can be used, or dried for *konkonte* or processed into *gari*. Components include: mealiness on a scale 1-4 (1 = non-mealy 2 = mealy, 3 = very mealy, and 4 = excellent) (Parkes, 2011).

Statistical analysis

Microsoft Office Excel 2019 was used to collect and clean the data for analysis. Statistical analysis was done using GenStat (version 14). Analysis of variance for the cassava varieties was conducted, and a Tukey's comparison test at the 5 % level was conducted to test for a significant difference among the cassava varieties.

Linear regression analysis was used to establish the relationship among specific gravity, dry matter and starch content of which specific gravity was considered as independent variable and other two traits as dependent (response) variables. The specific gravity conversion for each location is presented in a table and the computed regression is presented in graph for each location.

Results

Mean specific gravity, dry matter content and starch contents at UCC

The results for cassava starch percentage vary significantly ($p<0.05$) among the genotypes at UCC (Table 6.1). The highest starch content was 19.42 % and the lowest was 11.83 %. Genotype 6F recorded the highest starch content whereas the lowest starch content was recorded for genotype 14B (Table 6.1). Also, the dry matter content varied significantly ($p<0.05$) among the genotypes. The dry matter values obtained ranged between 24.95 - 35.67 %. Genotypes 6F, 11B and 9A recorded high dry matter content of 35.67, 35.50 and 30.64 % respectively. The lowest dry matter of 24.95 % was recorded for genotype 14B. Also, the specific gravity values for all the accessions were greater than 1.0 and ranged from 1.05 to 1.12.

Table 6.1: Mean specific gravity, dry matter content (DMC) and starch contents at UCC.

Genotypes	Specific Gravity	DMC %	Starch %
9A	1.09^{ab}	30.64^{ab}	15.86^{ab}
8A	1.05^{bc}	25.21^{b}	12.01^{b}
6A	1.06^{b}	28.14^{b}	14.17$_{b}$
1A	1.07^{b}	35.60^{a}	19.40^{a}
12B	1.06^{b}	26.92^{b}	12.96^{b}
1011A	1.06^{b}	26.92^{b}	13.22^{b}
14B	1.05^{bc}	24.95^{b}	11.83^{b}
5B	1.06^{b}	26.72^{b}	13.08^{b}
11B	1.06^{b}	27.23^{b}	13.44^{b}
6F	1.12^{a}	35.67^{a}	19.42^{a}
Mean	1.08	28.75	14.51
Hsd	0.021	3.33	2.36
% cv	1.3	8.4	11.9

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Mean specific gravity, dry matter content and starch contents at Wamaso

The highest starch content (19.46 %) at Wamaso was obtained from genotype 6F. Genotypes 11B, 1011A, 5B and 8A were statistically the same mean with starch content of 13.60 %, 13.40 %, 13.34 % and 12.02 % respectively. Similarly, genotypes 9A (17.23 %) and 1A (17.81 %) recorded high starch values which were significantly different from the other genotypes. Genotype 14B gave low starch content value of 10.55 % (Table 6.2). Also, for the dry matter content, significant ($p<0.05$) differences were recorded between the genotypes.

The highest dry matter content of 35.74 % was recorded for genotype 6F, followed by genotype 1A with 33.40 %. The lowest dry matter content of 23.15 % was recorded for genotype 14B (Table 6.2). The specific gravity values for all the genotypes ranged from 1.04 to 1.12 with genotype 6F recording the highest value (1.12) and lowest value (1.04) for genotype 14B (Table 6.2).

Table 6.2: Mean specific gravity, dry matter content (DMC) and starch contents of 10 genotypes at Wamaso.

Genotypes	Specific Gravity	DMC %	Starch %
9A	1.09^{abc}	32.60^{abc}	17.20^{a}
8A	1.05^{cd}	25.23^{d}	12.02^{bc}
6A	1.10^{abc}	32.16^{abc}	16.93^{a}
1A	1.10^{abc}	33.40^{abc}	17.85^{a}
12B	1.05^{cd}	26.44^{bcd}	12.91^{bc}
1011A	1.06^{bcd}	27.14^{bcd}	13.40^{b}
14B	1.04^{d}	23.15^{d}	10.55^{c}
5B	1.06^{bcd}	27.18^{bcd}	13.30^{bc}
11B	1.06^{bcd}	27.44^{bcd}	13.65^{b}
6F	1.12^{a}	35.74^{a}	19.46^{a}
Mean	1.08	29.03	14.71
Hsd	0.025	3.98	2.82
% cv	1.6	9.4	13.1

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Mean specific gravity, dry matter and starch contents at Asuansi

There was highly significant ($p<0.05$) difference among the genotypes for starch and dry matter content at Asuansi. Genotype 6F recorded the highest dry matter content (36.51 %), which did not differ significantly from genotypes

1A (34.79 %) and 9A (32.00 %). The lowest dry matter content (16.50 %) was recorded for genotype 14B. The highest starch content (20.01 %) was recorded for genotype 6F, followed by genotype 1A (18.79 %), while the lowest starch content (5.84 %) was recorded for genotype 14B (Table 6.3). Also, the specific gravity values for all the genotypes were greater than 1.0 and ranged from 1.00 to 1.13. Genotype 14B recorded the lowest value while genotype 6F recorded the highest value (Table 6.3).

Table 6.3: Mean specific gravity, dry matter content (DMC) and starch contents at Asuansi

Genotypes	Specific Gravity	DMC (%)	Starch (%)
9A	1.09^{bc}	32.00^{ab}	16.82^{ab}
8A	1.07^{d}	28.25^{d}	14.82^{d}
6A	1.09^{bc}	31.91^{bc}	16.75^{bc}
1A	1.11^{ab}	34.79^{ab}	18.79^{ab}
12B	1.08^{cd}	29.27^{cd}	14.89^{cd}
1011A	1.09^{bc}	31.35^{bcd}	16.36^{bcd}
14B	1.02^{e}	20.60^{e}	8.70^{e}
5B	1.08^{cd}	30.40^{cd}	15.69^{cd}
11B	1.09^{bc}	31.62^{bcd}	16.55^{bcd}
6F	1.13^{a}	36.51^{a}	20.01^{a}
Mean	1.09	30.9	15.87
Hsd	0.014	2.205	1.561
% cv	0.9	5.0	6.8

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Relationship between specific gravity, dry matter and starch content

The regression equations for each location and their means are presented in Table 6.4. The highest coefficient of determination ($R^2 \geq 0.98$) and correlation ($r > 0.98$) were computed for the regression of specific gravity, starch and dry matter contents for all locations. From the close relationship between dry matter content and specific gravity at Asuansi, a regression equation was derived (Y = - 142.2 + 158.4 X) and from a close relationship between starch and specific gravity at Asuansi, a regression equation of Y = - 107.1 + 112.8 X was derived. Similarly, from the close relationship between dry matter content and specific gravity at UCC, the regression equation derived was Y = - 142.6 + 158.9 X while the close relationship between starch and specific gravity gives a regression equation of Y = - 106.7 + 112.4 X (Table 6.4). At Wamaso, a regression equation of Y = - 142.5 + 158.7 X was derived for close relationship between dry matter content and specific gravity while a regression equation of Y = - 106.7 + 112.3 X was derived for close relationship between starch and specific gravity (Table 6.4). The graphic presentation of regression computed on the basis of means for the genotypes at Asuansi, UCC and Wamaso are presented in Figures 6.1, 6.2 and 6.3 respectively.

Table 6.4: Regression equation, coefficient of determination (R^2) and correlation of the genotypes mean.

Location	Regression Equation	R^2	Correlation (r)
Auansi	DM = - 142.20 + 158.4 x	0.99	0.99
	Starch = - 107.10 + 112.8 x	0.98	0.98
UCC	DM = - 142.6 + 158.9 x	0.98	0.98
	Starch = - 106.7 + 112.4 x	0.98	0.98
Wamaso	DM = - 142.5 + 158.7 x	0.98	0.98
	Starch = - 106.7 + 112.3 x	0.98	0.98

x = Specific gravity

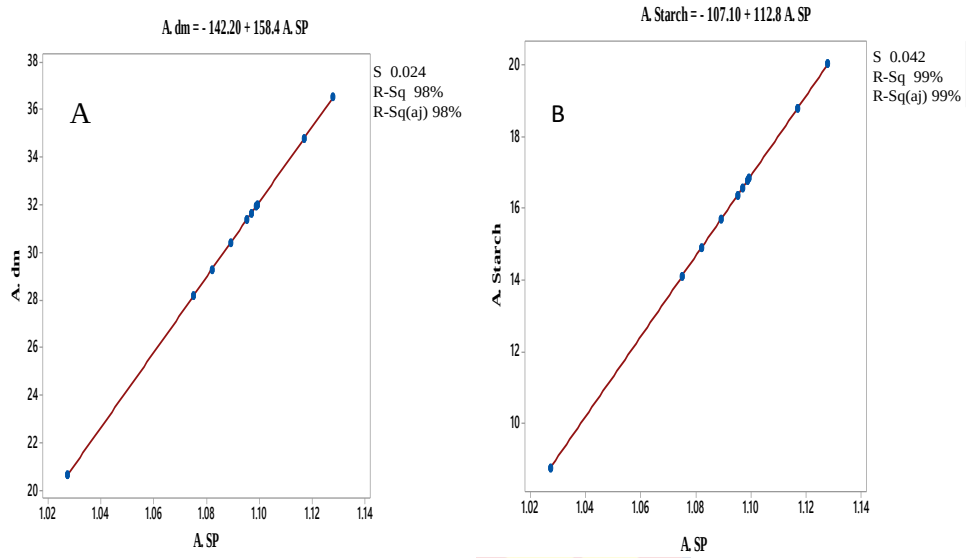

Figure 6.1: Linear regression of specific gravity on A). Dry matter content (DMC) on B). Starch contents of 10 genotypes with equation of best-fit line on the mean values at Asuansi.

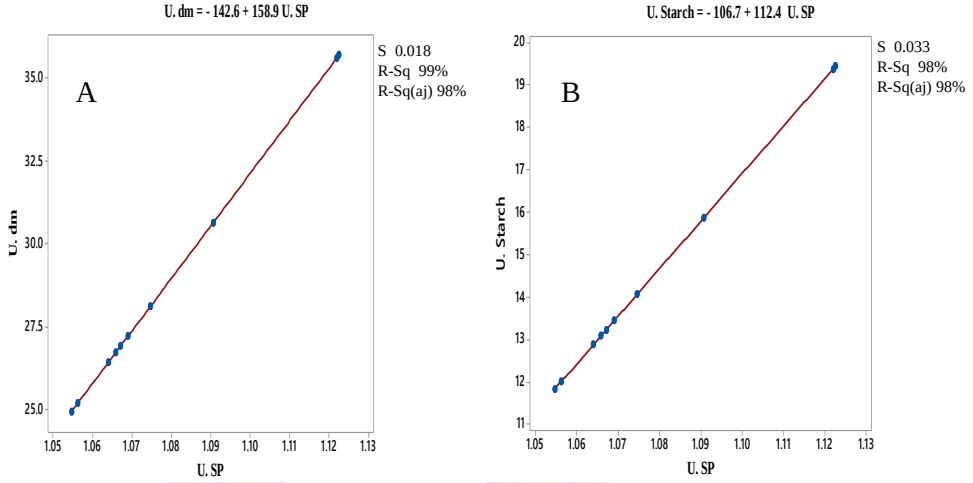

Figure 6.2: Linear regression of specific gravity on A). Dry matter content (DMC) on B). Starch contents of 10 genotypes with equation of best-fit line on the mean values at UCC.

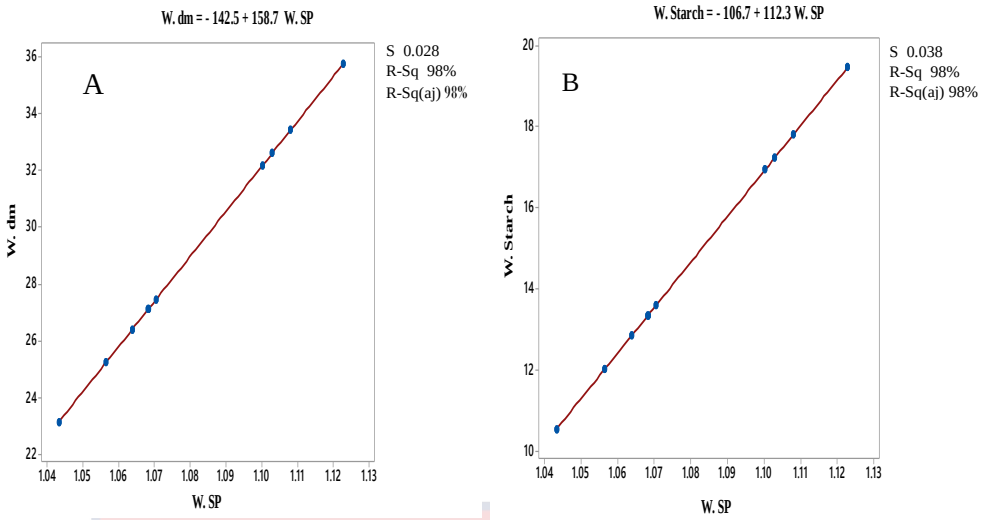

Figure 6.3: Linear regression of specific gravity on A). Dry matter content (DMC) on B). Starch contents of 10 genotypes with equation of best-fit line on the mean values at Wamaso

Mean dry matter and starch contents for the genotypes at the three locations and their mealiness

The combined analysis of variance revealed that dry matter and starch content were significantly influenced by genotype (Table 6.5). Genotype 6F recorded the highest dry matter and starch contents of 35.97 % and 19.63 % respectively. This was followed by genotype 11B which also recorded high values of 33.12 % and 17.61 % for dry matter and starch respectively. The lowest dry matter and starch contents of 22.10 % and 10.37 % were recorded for genotype 14B. Four of the genotypes 8A, 6A, 1011A and 14B were non-mealy and recorded a score of 1.0 (Table 6.5). Two of the yellow flesh cassava genotypes 9A and 11B recorded a value of 3.5 making them very mealy. The white flesh (genotype 6F) was excellent in relation to it mealiness and recorded a score of 4.0 (Table 6.5).

Table 6.5: Mean dry matter content (DMC) and starch contents for the genotypes at the three locations and their mealiness.

Genotypes	DMC (%)	Starch (%)	Mealiness
9A	29.91^{cd}	15.33^{cd}	3.5^{b}
8A	27.87^{de}	13.89^{de}	1.0^{f}
6A	26.19^{e}	12.70^{e}	1.0^{f}
1A	29.76^{cd}	15.23^{cd}	1.5^{e}
12B	29.89^{cd}	15.32^{cd}	2.5^{d}
1011A	30.65^{c}	15.34^{c}	1.0^{f}
14B	22.10^{f}	10.37^{f}	1.0^{f}
5B	28.48^{d}	14.32^{d}	3.0^{c}
11B	33.12^{b}	17.61^{b}	3.5^{b}
6F	35.97^{a}	19.63^{a}	4.0^{a}
Mean	29.48	15.03	2.217
Hsd	2.13	1.51	0.14
% cv	5.0	7.0	3.60

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Location effect on mean dry matter and starch contents

The effect of location on mean dry matter and starch content is presented in Table 6.6. There was no significant difference ($p>0.05$) between dry matter content at the three locations even though Asuansi recorded the highest dry matter of 30.66 %. Wamaso recorded dry matter content of 29.03 % while UCC had the lowest dry matter of 28.75 % (Table 6.6). Also, across the three locations, there was no significant differences ($p>0.05$) for the starch recorded for Asuansi (15.87 %), UCC (14.71 %) and Wamaso (14.51 %) (Table 6.6).

Table 6.6: Location effect on dry matter and starch contents

Location	DMC (%)	Starch (%)
Asuansi	30.66^{ns}	15.87 ^{ns}
Wamaso	29.03^{ns}	14.51^{ns}
UCC	28.75^{ns}	14.71^{ns}
Mean	29.48	15.03
Hsd	1.07	1.39
% cv	15.10	20.90

ns = not significant

Discussion

The specific gravity values for all the genotypes across all the three locations were greater than 1.0 (Tables 6.1, 6.2 and 6.3). This shows that the various roots used were all denser than water and the values obtained agree with NRI (1996). Also, similar results of specific gravity greater than one were obtained by Teye *et al*. (2011) in their findings. Also, Wassu (2016) suggested that potato tubers should have a specific gravity value of more than 1.0 since those with less than 1.0 are generally unacceptable for processing. This shows that the evaluated genotypes were suitable for processing into starch and other products.

The dry matter values obtained by genotypes at UCC, Wamaso and Asuansi are presented in Tables 6.1, 6.2 and 6.3. These values confirmed to the findings of Barima *et al*. (2000). It was also not different from cassava varieties used by Teye *et al.* (2011) and varieties grown in India (Vimala *et al*., 2008). The results showed that the dry matter content of cassava roots depends on the specific gravity and vice versa. A similar trend was observed from the study conducted by Asare (2004). From the positive relationship between dry matter content and specific gravity, a positive regression equation was derived (Table 6.4). These were similar to Teye *et al*. (2011) who derived similar regression equation of Y = - 175.46 + 188.61 X.

There was a perfect correlation (r = 0.99) from this present study of the equation. Woolfe (1992) has had a similar correlation equation (r = 0.998) and Teye *et al.* (2011) have confirmed this with a perfect correlation of r = 0.9979. This means that in laboratories of tropical developing countries which are not equipped to carry out standard analysis, using the equation, the dry matter

content of cassava roots can be calculated easily and rapidly. Specific gravity can also be used in the absence of drying facilities to provide an accurate estimation of the dry matter content (Figures 6.1, 6.2 and 6.3). The relationship developed in this work for the genotypes is similar to that reported by Wholey and Booth (1987) for two Malaysian cultivars. The close agreement in the linear regressions developed for different cultivars from different sources indicates that the use of a standard conversion equation may be possible in cases where an approximate conversion from specific gravity to dry matter is required (Teye *et al*., 2011; Kumar *et al*., 2005). The results from this study, support this suggestion, particularly over the mid-range of specific gravities and dry matter percentages, and the data reported here will be useful in developing such a relationship.

There was variation in dry matter content among the genotypes at the various locations. Studies have shown dry matter ranging between 15-45 % (Kawano *et al*., 1987) depending on the genotype and environmental conditions. For the vast majority of cassava uses, varieties with high dry matter content are preferred because increased dry matter content has a positive effect on the process of extracting cassava into flour or starch (Kawano *et al*., 1987).

From the results, percentage starch was also estimated using the specific gravity values for both locations (Tables 6.1, 6.2 and 6.3). The results presented also support the findings of Wholey and Booth (1987) in that specific gravity can be used to estimate starch level of fresh cassava storage roots. The relationship of specific gravity with starch content was linear with high coefficient of determination, which was not statistically different from the different locations (Figures 6.1, 6.2 and 6.3).

The measured specific gravity showed perfect correlations with the estimated starch contents from positive regression equations from the three different locations (Table 6.4). The presence of wide variations among genotypes for specific gravity and starch contents (Tables 6.1, 6.2, 6.3) indicated that a genetic factor influences the starch content. The variations observed are a good opportunity for producers to select varieties that meet market demand. Several other researchers have documented major differences in the quality of these tuber traits (dry matter and starch content) among potato varieties (Kaur & Aggarwal, 2014; Ismail, Abu & Wael, 2015). The starch content was not significantly influenced by location. This is in contrast to Kaur and Aggarwal (2014) who reported the influence of growing location on starch content. The specific gravity and starch content are genetically controlled but can be influenced by environmental conditions (Dorota & Kew, 2011; Kaur & Aggarwal, 2014). The outcome indicated the importance of testing cassava varieties across locations to identify widely adaptable varieties that in all environments could produce roots with uniform specific gravity and starch content. There was variation in starch content among the genotypes across the three locations. Variation in starch content has been reported (Rickard *et al*., 1991). The starch percentage recorded were all below 20 %. This is in a sharp contrast to Abera and Rakshit (2003) who reported a starch content ranging from 21.2 to 27.8 % of the fresh root weight. Similarly, Santisopasri *et al*. (1998), studying cassava varieties in Thailand, also observed a high starch content between 26-28 % in improved varieties.

The total starch content observed for all the yellow flesh genotypes at the various locations were lower than the white flesh variety used as check (Tables 6.1, 6.2 and 6.3). These reports suggest that the starch content of the genotype of white flesh cassava was higher than that of the genotype of yellow flesh, while genotypic differences and age can also cause differences in starch content between genotypes. Similarly, the starch content of the four varieties of yellow-flesh cassava was lower than that of the white and cream-flesh starch (Ukenye *et al*., 2013). In comparison to that of white-flesh varieties, starch derived from six roots of enhanced yellow-flesh varieties was also lower on the average (Aniedu & Omodamiro, 2012). However, Maziya-Dixon, Adebowale, Onabanyo and Dixon (2005) reported higher total starch content from 40 yellow flesh cassava varieties and this was similar to that of three white flesh varieties from Nigeria. The lowest starch quantity was obtained from 14B across all the locations (Tables 6.5). The results agreed with studies by Sriroth, Piyachomkwan, Wanlpatit and Oates (2000) who found differences in starch content among yellow flesh genotypes.

There were no significant differences in starch content between the locations (Tables 6.6). The locations made the smallest contribution to variation in starch content. This implies that it is not important to consider where to grow cassava to optimize the starch content from the storage roots. This is in sharp contrast with Sriroth *et al*. (2000) who observed that starch the harvest quantity is influenced by environmental factors such as rainfall and crop age. The results obtained from this study does not corroborate what Corbishley and Miller (1984) reported that aside from the age of the plant, cassava root starch yield depends on several variables, such as variety, type of soil and environment.

According to CIAT Annual Report (1995), dry matter content is closely related to starch content in cassava since 70–90 % of it on dry basis is starch (Oyewole & Obieze 1995). Also, the fresh root of cassava contains 30 % to 40 % dry matter of which 85 % is starch on dry weight basis. As the crop is mainly grown for its carbohydrate content, this makes dry matter an important trait for cassava farmers. Literature indicates that dry matter content and starch are highly correlated; therefore, there is a possibility of employing indirect selection to improve starch content (Oyewole & Obieze 1995).

For the Ghanaian cassava consumers, the mealiness (suitability for 'fufu') of the cooked roots, the elasticity and smoothness or freedom from lumps of the pounded paste are important cooking quality parameters. Some high yielding and improved yellow flesh varieties, developed by IITA, were found to lack the cooking quality preferred by the Ghanaian consumer due to low dry matter content. However, this study observed yellow flesh genotypes with high dry matter and good cooking quality (Table 6.5). This in sharp contrast to Ngeve (2003), who found a negative correlation between dry matter content and mealiness. According to Ngeve (2003), dry matter content does not always correlate with mealiness, due to the fact that cassava mealiness is controlled by large size starch granules.

However, the result of this study is in line with Safo-Kantanka and Owusu-Nipah (1992) who reported that mealier varieties had higher contents of dry matter and larger starch granules (Amenorpe, 2007). Similarly, Kawano *et al*. (1987) also indicated that dry matter content was positively correlated with the eating quality especially when roots are consumed after boiling.

A study by Asaoka *et al*. (1992) also indicated considerable variation in hardness of the texture of cooked roots between varieties. According to them, hardness of texture in cooked roots reflects the dry matter content and starch contents.

Conclusion

This study showed that starch content on fresh root basis and root dry matter content can be determined using specific gravity. Most importantly, perfect correlations of the measured specific gravity with the estimated dry matter and starch contents using regression equation were determined. These allow recommending the importance of measuring specific gravity and using the prepared specific gravity conversion chart as reliable indicator for starch and dry matter content.

Genotype greatly contributed to the variation in specific gravity, starch content, and dry matter content. Generally, yellow flesh genotypes which gave high dry matter, starch contents and were very mealy were 11B, 9A, 5B and 12B. Those improved genotypes that have all these attributes will be readily acceptable to consumers in Ghana where *ampesi* and *fufu* varieties are preferred.

CHAPTER SEVEN

DETERMINATION OF TOTAL CAROTENOID RETENTION IN "GARI" AND CONDUCT SENSORY EVALUATION OF THE YELLOW FLESH "GARI"

Introduction

Cassava is the first crop in terms of energy intake and per capita consumption in Ghana among roots and tubers (Angelucci, 2013) and it is used to prepare products that include *fufu*, *kokonte*, *gari*, *agbelima*, starch, and bio-ethanol in Ghana (Ugwu & Ay, 1992).

According to WHO (2009) high carotenoids will have impact on the nutrition and health of people in countries where the prevalence of vitamin A deficiency is high. ß-carotene is a precursor of vitamin A, a well-known nutrient in the human diet, carotenoid has received a lot of attention from previous researchers. A class of hydrocarbons (carotenes) and their oxygen derivatives (xanthophylls) constitute the carotenoids. The main sources of Vitamin A in diet is carotenoid. There are about 600 carotenoids in nature, but significantly only three of them are essential precursors of vitamin A for humans. These are α-carotene, β–cryptoxanthin and β-carotene. β-carotene is the major provitamin A component of most carotenoid-containing foods (Parker, 1996).

The Agriculture for Nutrition and Health (A4NH) a program by HarvestPlus uses traditional plant breeding techniques to grow staple food crop varieties rich in micronutrients, a food-based strategy to minimize micronutrient malnutrition. With the release of yellow flesh cassava varieties to combat VAD in burdened populations, these achievements have spread to neighbouring countries in sub-Saharan Africa (SSA).

These varieties are currently processed into various foods such as *agbelima*, *fufu* and *gari* that are common food products made from cassava in Western Africa, and their production represents two thirds of the cassava grown (Westby, 2002). However, because of the sensitive nature of carotenoids to light, heat and physical handling, retention of carotenoids is still a challenge. (Rodriguez-Amaya, 1997). According to Wright *et al*. (1994) carotenoids are often subject to destruction by oxidation, light, minerals, heat, moisture and length of storage, among other factors. Measurement of the retention of provitamin A during processing is important to guarantee that the bio-fortified food holds sufficient pro-vitamin A (pVAC) and thus enhances health benefits for the people who eat it. Finding its retention is crucial because it considers changes in food weight during cooking (e.g. loss of water and soluble solids) and offers a fairer estimation of the actual carotenoid retention during the cooking process.

Mechanisms of carotenoid degradation may involve the reaction of carotenoids to atmospheric oxygen (autooxidation), light (photodegradation) and heat (thermal degradation), as well as the degradation of singlet oxygen, acid, metals and free radicals by the reactions of carotenoids. However, in food systems, the mechanisms for degradation are more complex (Boon *et al*., 2010). According to Borsarelli and Mercadante (2009) differences in sequestration and intracellular location of carotenoids in the tissue may be a crucial factor in the susceptibility of these pigments to trans-cis isomerisation and oxidation.

β-carotene has also been reported to be sensitive to heat and oxidation during blanching and drying (Negi & Roy, 2000). Excessive processing methods such as roasting, prolonged boiling at high temperatures and frying can cause

huge losses of provitamin A (Thakkar, Maziya-Dixon & Filla, 2009). According to La Frano *et al*. (2013), low heat processing methods such as boiling for a few minutes, soaking, and chopping can improve bioavailability, with little carotenoid loss.

Greater losses in total carotenoid content have been reported for cassava flour stored at the same temperature in a dark place (Oliveira, Carvalho, Nutt, de Carvalho & Gonclaves, 2010). According to La Frano (2013), Other processes, including oven-drying, boiling, and sun-drying, all reduced retention of β-carotene at different levels, ranging from 20 to 90 %. Retention varies between 10 % for cassava products that have been processed to a greater extent and for products like *gari* and 87 % for boiling (Maziya-Dixon *et al*., 2000). Also, during *gari* processing from biofortified yellow cassava, there is higher reduction of pVACs as compared to most other methods such as boiling, frying and oven drying (De Moura, Miloff, & Boy, 2015; Failla, 2012). The justification for this research is that although there is a study on retention of biofortified cassava in fermented dough, *fufu* and *gari* (Eyinla, Sanusi, Alamu, & Maziya-Dixon, 2018), no study has evaluated the retention of total carotenoid (TC) in these genotypes with high carotenoid content. These genotypes were used in this study, particularly when processed into commonly consumed products such as *gari* and *agbelima*. Therefore, the aims of this research were:

i. to determine total carotenoid content in raw and processed yellow flesh cassava roots
ii. to evaluate TC retention after processing of the selected yellow flesh genotypes into *agbelima* and *gari* using traditional processing methods.

Materials and Methods

This research was in two parts; the first section was a laboratory analysis done to determine the total carotenoids retention in cassava after processing into *gari* and *agbelima*. The second section was a sensory analysis to identify the consumption patterns of the yellow flesh *gari* among Ghanaians.

Sample collection and preparation

Newly developed cassava genotypes (9A, 8A, 1A, 12B, 1011A, 5B, 11B and 6F) were cultivated and harvested from the School of Agriculture Teaching and Research Farm - UCC. All the genotypes are yellow fleshed except 6F (106F) which is a white flesh cassava. The cassava roots were processed at the Alex Gyandoh Carson Technology Village of the School of Agriculture, University of Cape Coast.

Processing of cassava into Gari

The cassava roots were peeled and all discoloured part were removed. They were washed twice to remove dirt and other impurities after which water was drained out. The peeled roots were grated into a mash and placed in nylon bags for onward dewatering and fermentation. The mash was screw pressed for two days to allow for fermentation, dewatering and starch removal at the same time. Fermentation for about two days has been recommended which allows for tissue breakdown and release of carotenoid in the fermented dough. This was done in three replicates for all genotypes. After fermentation, each dough was sieved and roasted in a large stainless-steel pan and fitted to a fireplace on a mud stove. The dough was roasted at a temperature of 100 °C to dry the mash to a very low moisture content to allow for gelatinization of the residual starch. The roasted gari was transfered into a clean bowl to cool after which they were

poured into air-tight polyethene bags and kept at a temperature of -18°C prior to laboratory analysis and sensory evaluation.

Determination of total carotenoid and its retention in yellow cassava products after processing

Total carotene of the grated cassava mash, fermented dough and roasted *gari* were determined following the method reported by Abano, Quayson, Bosompem and Quarm (2020). One gram each of grated cassava mash and fermented dough was weighed into a volumetric flask and 10 cm^3 of absolute ethanol was added to it. The mixture was allowed to stay for 20 minutes to allow for the extraction of the carotenoid. It was periodically shaken. To facilitate the extraction of carotenoids in the roasted *gari*, mortar and pestle were used to grind the *gari* to extract the carotenoids after adding absolute ethanol. This was repeated till the *gari* showed no colour of carotenoid. The resulting solution was filtered and 15 ml of petroleum ether (40 - 60°C) was added to it. This separated the solution into two layers with the carotenoid part staying on top. The carotenoid layer was pipetted for absorbance which read at the wave length of 450 nm. The Total Carotenoids (TC) was then calculated from equation 7.1.

$$Total\ carotenoids\ (g/ml) = \frac{ABS\ X\ V\ (ml) X 10{,}000}{2592 * W(g)} \quad (7.1)$$

Where absorbance is ABS; V(ml) is the volume of solvent used for extraction; W(g) is the original weight / volume of the sample; while the β-carotene extinction coefficient in petroleum ether is 2592

The apparent retention of beta-carotene after processing the cassava into roasted gari was determined as defined by De Moura *et al*. (2015) using equation 7.2.

$$\text{Retention} = \frac{Total\ carotenoid\ content\ of\ the\ final\ product}{Total\ carotenoid\ content\ from\ peeled\ raw\ cassava\ root}\ 100 \qquad (7.2)$$

Determination of functional properties of *Gari*

Bulk Density

To determine the bulk density of the processed *gari*, an empty container was weighed and its volume determined. The *gari* samples were then poured into the container and weighed again. The bulk density was then calculated using Equation 7.3

$$\text{Bulk Density (g/cm}^3) = \frac{Weight\ of\ gari\ and\ container - Weight\ of\ empty\ container}{Volume\ of\ gari} \qquad (7.3)$$

Swelling Capacity

The capacity of swelling was set according to the method of Iwuoha (2004) and Abano *et al*. (2020). Six grams (6 g) of each sample of *gari* prepared from the various genotypes were transferred into clean and dry 100 cm^3 graduated cylinders. The samples were gently levelled and its volume recorded before the addition of 60 cm^3 distilled water. The cylinder was whirled and allowed to settle for 1 hour and the final volume of *gari* in the distilled water recorded. The swelling capacity of each *gari* sample was calculated as a multiple of the original volume using equation 7.4.

$$\text{Swelling Capacity} = \frac{Final\ volume\ of\ gari\ in\ distilled\ water - Initial\ volume\ of\ gari\ before\ addition\ of\ water}{Initial\ volume\ of\ gari\ before\ addition\ of\ water} \qquad (7.4)$$

Sensory analysis

A trained sensory panel of 48 members was selected from among the staff and students of the University of Cape Coast, Ghana. The panellists were familiar with the scoring scale and the assessment method during the preliminary training session. They were trained to recognize and score distinct quality attributes of the *gari* samples including appearance (which includes colour), flavour, taste, texture and overall acceptability. The *gari* samples were served to the panellists at room temperature conditions at 11: 00 am in the morning. The samples were served in transparent plastic cups in separate booths in a well-lit sensory evaluation room at Conference Room of School of Agriculture, University of Cape Coast with a temperature of 20 °C. This was to allow for candid observation of the colour. The panellists were also served with water in-between sample testing to rinse their mouth. For the evaluation of the *gari*, a 9-point hedonic scale denoted as dislike extremely 1; dislike very much 2; dislike moderately 3; dislike slightly 4; neither like nor dislike 5; like slightly 6; like moderately 7; like very much 8; like extremely 9; was used by the panellists.

Statistical analysis

Microsoft Office Excel 2019 was used to collect and clean the data for analysis. Statistical analysis was done using GenStat (version 14). Analysis of variance for the cassava varieties was conducted, and a Tukey's comparison test at the 5% level was conducted to test for a significant difference among the cassava genotypes.

Results

Total carotenoid content and its retention after processing into *gari*

The yellow flesh cassava genotypes recorded significant higher total carotenoid content than the white flesh cassava 6F after they were grated to mash (Table 7.1). This confirms the availability of total carotene in the newly developed cassava genotype which impacts on the yellow colour. After fermentation of the grated mash, there was an increase in the total carotene content with the yellow cassava genotypes being significantly different from the white cassava (Table 7.1). The 8A had the highest carotene of 5.324µg/g after fermentation while 11B recorded the lowest carotene of 2.314µg/g. *Gari* had retention between 98.23 % and 59.35 % for 8A and 5B respectively. There was significant difference among all samples ($p<0.05$).

Table 7.1: Total carotenoid content (ug/g) and its retention after processing

Genotypes	Fermented Dough	Gari	Retention (%)
9A	4.06^{ab}	2.88^{bc}	88.2^{abc}
8A	5.32^{a}	4.39^{a}	98.23^{a}
1A	4.78^{ab}	4.93^{a}	95.36^{abc}
12B	4.98^{a}	4.30^{ab}	92.05^{abc}
1011A	5.16^{a}	3.50^{ab}	90.20^{abc}
5B	4.14^{ab}	1.81^{c}	59.35^{cd}
11B	2.31^{bc}	1.71^{c}	63.94^{bc}
6F	0.15^{c}	0.15^{d}	16.37^{d}
Mean	3.86	2.96	80.59
Hsd	1.56	0.90	26.69
% cv	23.30	17.40	19.50

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Functional properties of *gari* from yellow flesh cassava

The bulk densities and swelling capacities of *gari* produced from the newly developed genotypes of cassava are presented in Table 7.2. There was a significant difference in the bulk density of all the genotypes of the cassava used in this study. The genotype 11B recorded the highest bulk density of 0.5634 g/cm^3 and the lowest bulk density of 0.3744 g/cm^3 was recorded by the genotype 12B. The genotypes can be grouped into two with regards to their swelling capacity. Genotypes 8A, 1011A, 5B, 11B can be placed in one group with swelling capacity ranging from 3.28 – 3.54. The other group of genotypes including 12B, 1A, 9A and 6F on the other hand had swelling capacity range of 2.41 – 2.79.

Table 7.2: Functional properties of yellow flesh cassava

Genotypes	Bulk Density (g/cm^3)	Swelling Capacity
9A	0.4881^{c}	2.79^{b}
8A	0.4677^{d}	3.46^{a}
1A	0.4174^{e}	2.64^{b}
12B	0.3744^{f}	2.41^{b}
1011A	0.4703^{cd}	3.28^{a}
5B	0.4732^{cd}	3.54^{a}
11B	0.5634^{a}	3.30^{a}
6F	0.5404^{b}	2.44^{b}
Mean	0.4744	2.98
Hsd	0.01	0.29
% cv	1.40	5.70

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Sensory evaluation of *gari* from yellow flesh cassava genotypes

From the statistical analysis carried out, the gari samples differed significantly in terms of appearance, taste, flavour and overall acceptability (Table 7.3). The appearance of the processed *gari* samples were judged to have significant differences ($p<0.05$). The average mean score of 7.77 ("liked moderately'') was recorded for genotypes 9A and 1A. The appearance of 5B, 11B and 6F were not different and were judged "liked slightly''. Genotype 1011A was "disliked moderately" in terms of the appearance (Table 7.3). Genotypes 1A was judged to be the tastiest and was "liked moderately" (7.0) by the respondent. Also, the taste of 5B and 9A did not differ with scores of 6.9 and 6.75 ("liked slightly'') respectively. Genotypes 8A and 6F were disliked moderately (Table 7.3). In all the sensory attributes evaluated, the least rated in all attributes was 8A, with mean scores of 4.625 ("disliked moderately") in overall acceptability. Genotypes 1A, 9A and 5B shared the highest mean score above (7.0) in overall acceptability and this corresponds to "liked moderately" on the hedonic scale of preference (Iwe, 2003).

Table 7.3: Sensory evaluation of *gari* from improved cassava genotypes

Genotypes	Appearance	Taste	Texture	Flavour	Overall Acceptability
9A	7.479^{ab}	6.750^{ab}	7.021^{ab}	6.646^{a}	7.563^{a}
8A	6.479^{bc}	3.938^{d}	4.625^{cde}	4.792^{b}	4.625^{d}
1A	7.771^{a}	7.083^{a}	7.563^{a}	6.625^{a}	7.313^{ab}
12B	5.563^{cd}	4.833^{cd}	5.375^{cd}	5.250^{b}	5.500^{cd}
1011A	4.979^{d}	4.167^{d}	3.745^{e}	4.854^{b}	4.625^{d}
5B	6.542^{abc}	6.938^{ab}	7.000^{ab}	6.813^{a}	7.146^{ab}
11B	6.750^{abc}	5.750^{bc}	5.833^{bc}	5.771^{ab}	6.229^{bc}
6F	4.188^{d}	3.854^{d}	4.500^{de}	4.750^{b}	3.625^{d}
Mean	6.34	5.41	5.71	5.69	5.95
Hsd	0.81	0.82	0.79	0.78	0.76
% cv	31.70	37.80	34.80	34.30	32.10

Means in a column with a common letter superscript are not significantly different ($p>0.05$).

Discussion

Fermentation rather increased the carotenoid content in the genotypes (Table 7.1). This assertion is supported by Abano *et al*. (2020) that fermentation increases the carotene content of cassava mash. There are numerous factors that may contribute to an increase in β-carotene due to increased fermentation time. According to Maziya-Dixon *et al*. (2008), loss of solid matter as well as unacounted moisture at fermentation time increased may be one reason. Also, increased carotene extraction efficiency due to fermentation may be another possible reason (Rodriguez-Amaya, 1997). The increase in the carotene after fermentation could be due to breakdown of tissues of the cassava making the carotene available. Oboh and Akindahunsi (2003) also reported an increase in protein and fat content but a decrease in carbohydrate after cassava mash was fermented. However, fermentation could be ruled out because no carotenoid was added during fermentation process. During pressing some carotenoids leached out because it was highly water soluble. So detatering process reduced total carotenoids but increased the residual carotenoid to dry matter ratio which was measured to have the marginal increase over grated cassava with a lot of water.

Nutrient retention is defined as the measure of the amount of nutrients left in the processed food in relation to the nutrients originally present in the raw food (USDA, 2009). Smolin, Grosvener and Burns (2003) report that the time, method and temperature for the cooking are some of the factors that affect nutrient retention. According to Rodriguez- Amaya (2002), a higher processing temperature and a longer processing time decreases the retention of carotenoids.

Degeneration of the β-carotene content in the fermented dough was influenced by the roasting of the *gari* (Table 7.1). Carotenoids are endangered by heat as expected, and therefore the *gari*'s relatively high roasting temperature conditions will lead to some β-carotene degradation. Essentially, the application of heat results in the isomerization of all trans-β-carotene to cis-trans-β-carotene, which has a lower activity of vitamin A, thereby making the contribution of all-trans-β-carotene higher than that of cis-trans-β-carotene, as stated by Nzamwita, Gyebi and Minnar (2017). Even though roasting led to degradation of the β-carotenoid, its retention in the *gari* samples were high (Table 7.1). This means that the carotenoid loss during *gari* processing was much lower in yellow *gari*.

The differences in bulk density of *gari* samples could be due to differences in their starch structure. Bulk density of food materials depends on the arrangement and form of the starch present in them (Plaami, 1997). The samples differ in terms of relative bulk density (Table 7.2). The bulk density of 11B and 6F genotypes were similar to the bulk density (0.57%) of *gari* produced in Bendel (Okolie, Brai, & Atoyebi, 2012). Genotypes which recorded a lower bulk density could be attributed to the structure of starch polymers and the loose structure of starch polymers (Plaami, 1997). According to Sanni, Adebowale, Awoyale and Fetuga, (2008), the lower the bulk density, the higher the floatation on the water of the *gari* samples and, as a result, may not properly soak in water, which may lead to consumers' rejection. However, *gari* with high bulk density is heavier and can make one satiable and thereby would be easily preferred by consumers.

The swelling index the ability of the *gari* to swell and is influenced by the quantity and starch component present in the *gari* (amylose and amylopectin). The swelling index has been shown to give consumers' a greater volume and a more feeling of satiety per unit weight of *gari*, according to Almazan, (1992), and a swelling index of at least 3.0 has been regarded as preferred by consumers. The range of swelling capacity for four of the genotypes were within the range 3.01 - 4.30 reported by Ojo and Akande (2013) and above the swelling index of 3.0 recommended by Akingbala *et al*. (2005); Almazan (1992). Moreover, this range is above that of Teye, Amoah, Adu, and Darko (2017) who determined the swelling capacity of *gari* from seven regions of Ghana to be between 3.0 - 3.2. According to Ukpabi & Ndimele (1990) a good quality *gari* has been described as being capable of swelling to at least 3 times its original volume. Sanni *et al*. (2005) stated that the swelling index of the granules represents the magnitude of the associative forces within the granules, thus, the higher the swelling index, the lower the associative forces.

The overall acceptability of *gari* based on likeness (Table 7.3) was largely influenced by the varietal difference as these significantly influenced the appearance, flavour, taste and texture for which the panellists based their scores. These sensory attributes impacted on the overall acceptability of *gari*. That is, consumers' satisfaction of *gari* based on the attributes may vary with variation in cassava varieties as these largely affect the quality of the product.

Results of the sensory attributes (Table 7.3) showed that the taste of *gari* from the genotypes varied significantly among the genotypes. This variability was also recorded in Nigeria (Makanjuola, Ogunmodede, Makanjuola, & Awonorin, 2012) and Ghana (Oduro, Ellis, Dziedzoave, & Nimako-Yeboah,

2000). In Cameroon, Laya, Koubala, Kouninki, and Nukenine (2018) reported that *gari*'s physicochemical and sensory properties varied significantly with the variety. The taste of *gari* for four of the genotypes were "disliked slightly" and "disliked moderately". The direct manifestations of various biochemical reactions that occur during fermentation can be attributed to this. During cassava fermentation, the acid formation was due to the action of microbial flora on the root carbohydrates (Ogunnaike, Adepoju, Longe, Elemo & Oke, 2015). The rate of biochemical reactions such as cyanide hydrolysis, reducing sugar and acid production during fermentation bring about the degree of soundness in the taste of cassava foods (Brimer, 2015). *Gari*'s acceptability is affected by its sourness, which is related to the amount of lactic acid or length of fermentation (Karim, Balogun, Akintayo & Awoyale, 2016). This finding is consistent with the Abass, Dziedzoave, Alenkhe and James (2012) study that *gari* should not be too acidic.

The appearance of *gari* is an important indicator for *gari* buyers because it measures its purity on the Ghanaian market. Although, white *gari* is considered pure, highly priced *gari* in Ghana is the yellow *gari* because of the perception that it has added nutrients.

In this research, the acceptance of *gari* from yellow flesh cassava genotypes was higher than that of the local white varieties and this was consistent with an earlier study that targeted school children (Talsma *et al*., 2013). This result was also confirmed in a recent study on the acceptance of biofortified foods (Talsma, Melse-Boonstra & Brouwer, 2017). Previous market awareness of bio-fortified cassava may have improved acceptance scores. In a study on *gari* and *eba* from biofortified cassava an Oyo and Imo State, stated that when nutrition information was given to consumers, acceptability increased

significantly (Oparindeet, 2012). However, study by Oparinde, Murekezi, Birol and Katsuairo (2017) on high-iron bean showed that the dearth of information provided to consumers did not affect the acceptability of the beans. In addition, too much knowledge may also reduce the acceptability of biofortified crops addition (Lagerrkvist, 2016).

This sensory study is good because taste, appearance and texture the most important attributes of *gari* on the Ghanaian market. According to Abass *et al*. (2012), before buying, aggregators and customers most frequently do not taste *gari*. Similarly, the grittiness, grit uniformity, and brightness of the colour of *gari* are considered very important to producers and consumers. These features encourage consumers to buy *gari* in order to enable them derive the needed intrinsic nutritional benefits.

Conclusion

The sensory analysis of gari collected from eight (8) different genotypes are well documented here for the first time. Yellow gari made from two mutant genotypes 9A and 5B recently developed by GAEC in collaboration with IITA and now evaluated by UCC were perceived by the panellists as being different from the white flesh used as a check, mainly in appearance, taste, flavour and overall acceptability. Also, all the genotypes except the white flesh genotype studied had a ß-carotenoid retention above 50 %. This is good news, since *gari* consumers will prefer yellow *gari* with high total carotenoid content.

CHAPTER EIGHT

SUMMARY, GENERAL CONCLUSIONS AND RECOMMENDATIONS

Summary

The first aim of this research was to determine perception and preference for yellow flesh cassava, taking into consideration the five major cassava growing districts (Assin South, Abura-Asebu-Kwemekese, Agona East, Twifo Ati morkwa and Odoben-Asikuma-Brakwa) in the Central Region of Ghana. A structured questionnaire was employed. Some farmers and consumers prefer YFC to white flesh ones because of its potential health benefits and varieties of food products that YFC could be used for. However, it is difficult getting planting materials for farmers.

The second aim of this research was to evaluate yellow flesh genotypes and checks for yield, dry matter content, cyanogenic potentials and total carotenoid content in the Central Region of Ghana. The total carotenoid values observed ranged from 1.9 ug/g to 10.38 ug/g among the ten genotypes. Genotype 6A recorded 10.38 ug/g which is significantly higher than the IITA check (7.97). All genotypes were safe for human consumption because their cyanogenic potential was lower than the innocuous threshold of 50 mgHCN/kg required to poison a 64 kg man. The fresh cassava root yield ranged from 21.62 to 55.46 t ha^{-1} with a mean average of 38.15 t ha^{-1}. Seven (7) genotypes out of ten had fresh root yields more than the mean. The highest yellow fresh root yield of 55.46 t ha^{-1} was recorded for genotype 12B. The mean root DMC ranged from 15.53 to 38.12 %. Most of the genotypes which recorded a high DMC had a positive relationship with TC and this profound observation was due to mutagenic effect

of gamma irradiation. Five (5) genotypes (12B, 5B, 9A, 1011A and 11B were adjudged the best.

The best genotypes were further evaluated at three agro-ecological zones for CMD, dry matter content, starch content and stable yield. It was observed that there were significant differences ($P<0.05$) for the yield recorded across the three locations. Wamaso recorded a yield of 33.69 t ha^{-1}, followed by UCC with a yield of 33.23 t ha^{-1} and Asuansi with yield of 28.03 t ha^{-1}. On the other hand, starch and dry matter were stable across locations.

Finally, last aim of this research was to quantify the total carotenoids in cassava products (*agbelima*, *gari*) and to conduct a sensory analysis for taste, appearace, smell and the overall acceptability of the YFC *gari*. *Gari* had total carotenoid retention between 98.23 % and 59.35 % for 8A and 5B respectively. Even though roasting led to degradation of the total carotenoid, its retention by the YFC *gari* samples was above 50 %. Also, *gari* samples were observed to differ significantly on the basis of appearance, taste, flavour and overall acceptability. Genotypes 1A, 9A and 5B shared the highest mean score (7.0) which corresponds to "like moderately" in overall acceptability. This shows that these genotypes can be processed into *gari* and used by the Ghanaian populace as food.

General conclusions

The main findings from the research are summarised below:

1. In examining the perception and preference of farmers and consumers on YFC cassava, it was revealed that majority of the respondents had heard of the yellow flesh cassava but did not have any knowledge on its nutritional value. Also, a greater number of the respondents were willing

to accept and cultivate new varieties of YFC and consume it in the form of *gari* and *fufu*. This is due to its attractive yellow colour and perceived nutritional value. The hypothesis that cassava growers and consumers do not prefer cassava varieties with high β-carotene content was rejected based on the results obtained.

2. The evaluation of the genotypes revealed that four of the genotypes 12B, 5B, 9A, 1011A and 11B had high total carotenoid content that was above the international yellow flesh and the white flesh used as checks. These genotypes had a high yield, high dry matter and were resistant to CMD. It was also observed that all genotype studied were safe for human consumption because their cyanogenic potential range (29.15 – 40.13 mgHN/kg) was far below the innocuous threshold of 50 mgHCN/kg.
3. The study also showed the GxE interactions among the 10 genotypes in relation to CMD infestation, dry matter content and their yield components. High dry matter content and high yielding yellow flesh genotypes with specific adaptation were identified. For example, overall performance of the genotypes based on combined ranking indicated that yellow flesh genotypes 12B, 11B, 5B and 9A were the top four performers for all the traits studied. These genotypes could be of immediate importance for further evaluation and/or used in breeding.
4. Yellow flesh genotypes which gave high dry matter, starch contents and considered very mealy were 11B, 9A, 5B and 12B. Those improved genotypes that had all these attributes will be readily acceptable to consumers in Ghana where *ampesi* and *fufu* varieties are preferred.

5. The sensory analysis of *gari*, collected from of 8 different genotypes are well documented here for the first time. Yellow gari made from two mutant genotypes 9A and 5B recently developed by GAEC in collaboration with IITA and now evaluated by UCC were perceived by the panellists as being different from the white flesh used as a check, mainly in appearance, taste, flavour and overall acceptability. Also, all the genotypes except the white flesh genotype studied had a beta carotenoid retention above 50 %. This is good news since *gari* consumers will prefer yellow *gari* with high ß-carotenoid content.

Recommendations

1. Though 72% of farmers are willing to cultivate new varieties of YFC varieties, it would not be prudent to generalize it for the entire farmers in Ghana. Therefore, further research should be done across the country on the perception and preference of cassava farmers and consumers on YFC, their willingness to cultivate it and the recommended product that they will prefer. Also, nutrition educators and plant breeders should educate the general public on the nutritional benefits of consuming yellow flesh cassava thus increasing its awareness and willingness to consume and accept.
2. It is necessary to evaluate these YFC genotypes at different harvesting period (4, 6, 9 and 12 MAP) to determine the best time for harvesting and also ascertain if the total carotenoid level increases or decreases as the plant matures. Also, total carotenoid analysis across multi-locations should be done to determine the environmental effect on total carotenoid.

3. It was established that some YFC genotypes contained high starch content due to mutagenesis. It is however, recommended that further research be done to evaluate this in natural hybridization populations.
4. Though, the experiment revealed that more than 50 % of the total carotenoid was retained, when processed into *ga*ri, it is recommended that the total carotenoid retention be analyzed in other processed food such as *fufu*, *ampesi* and *kokonte*, since these are the major foods that consumers preferred their processed cassava.
5. The four best genotypes (12B, 11B, 5B and 9A) should be further screened for farmers field trails and setting up demonstration plots for the release of these genotypes as varieties for farmers.
6. Finally, the Department of Crop Science-UCC and MoFA should passionately multiply these planting materials and release to farmers for cultivations since most of the farmers complained that the major challenge of not growing YFC varieties is due to lack of planting materials.

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APPENDICES

APPENDIX A: FARMERS' AND CONSUMERS' PERCEPTIONS AND PREFERENCES FOR YFC IN THE CENTRAL REGION

A. Questionnaire for YFC Farmers

Farmers Perception and Preference for Yellow Flesh Cassava

Dear participant, I am a graduate student of the School of Agriculture, University of Cape Coast. I am conducting this research in partial fulfilment of the requirements for the award of PhD in crop science. I assure you that the responses you give will be treated with strict confidentiality. I would be grateful if you would agree to answer the questions below as objectively as you can.

Section A - Background Information

1. Age at last birthday……years

2. Sex. a. Male [ ] b. Female [ ]

3. Marital status. a. Single [] b. Married [] c. Divorced [] d. Widow/widower []

4. Educational level. a. No formal education [ ] b. Primary/JSS [] c. SHS/SSS [] d. Tertiary [ ]

5. Main occupation. a. Student [ ] b. Government employee [ ] c. Private employee [ ] d. Unemployed [ ] e. Farmer [ ] f. Other [ ] please specify ……

6. How many persons are in your household? .....

SECTION B FARM RELATED CHARACTERISTICS

6. Do you cultivate cassava a. Yes[ ] b. No[ ]

7. If yes, since when……

8. What is the area under cultivation?.....acres / hectares

9. Have you heard of yellow flesh cassava? A. Yes[ ] b. No[ ]

10. If yes, where did you hear about it? a. Media [ ] b. Friends [ ] c. Family [ ] d. Farmers [ ] e. Others [ ]……..

11. Do you cultivated yellow flesh cassava?. A. Yes[ ] b. No[ ]

12. What are the benefits, of cultivating yellow flesh cassava? a. Easy to market [ ] b. Does not rot [ ] c. It has high demand by gari processers [ ] d. Not affected by pest and disease [ ] e. Yield is very high [ ]

13. What are the constraints in its cultivation? a. Difficult to get planting material [ ] b. Too many diseases [ ] c. Deteriorates / rots very fast after harvesting [ ] d. Difficult to harvest [ ] e. Others [ ]

14. What are the constraints in the marketing of the yellow flesh cassava? a. No ready market [ ] b. Not poundable [ ] c. Not sweet for Ampesi [ ] d. Difficult to cook [ ] e. Others [ ]

15. If No (Question 11), what are your reasons. a. Difficult to get planting material [ ] b. Consumers do not prefer it [ ] c. Not poundable [ ] d. Difficult to cook [ ] e. Others[ ]……..

16. What is the best way of preparing the yellow flesh cassava? a. Fufu [ ] b. Ampesi [ ] c. Gari [ ] d. Kokonte [ ] e. Others [ ]……

17. Will you be willing to cultivate new varieties of yellow flesh cassava? a.Yes[ ] b.No[ ]

18. If yes, state your reasons……

19. If no, state your reasons……..

SECTION C - Knowledge about yellow flesh cassava

22. Have you eaten yellow flesh cassava before? a. Yes [ ] b. No [ ]

23. If yes, which form? a. Fufu [ ], b. Ampesi [ ], c. Gari [ ], d. Kokonte [ ], e. Agbelima [ ], f. Other [ ] please specify ……

24. Did you enjoy it? a. Yes [ ] b. No [ ]

25. When given the option, would you eat it again? a. Yes [ ] b. No [ ]

26. If yes, why? ……

27. If no, why not? ……

28. Do you know of any perceived benefits from yellow flesh cassava? a.Yes[ ] b.No[ ]

29. If yes, please list a.……

b.…….

c……..

30. Do you know the benefits of beta carotene in food crops? a. Yes [ ] b.No[ ]

31. If yes, please state…….

32. Which food type would you recommend yellow flesh cassava to be used for? a. Fufu [ ], b. Ampesi [ ], c. Gari [ ], d. Kokonte [ ], e. Agbelima [ ], f. Other [ ] please specify ……

33. Please state your reasons……

B. Questionnaire for YFC Consumers

Consumers Perception and Preference for Yellow Flesh Cassava

Dear participant, I am a graduate student of the School of Agriculture, University of Cape Coast. I am conducting this research in partial fulfilment of the requirements for the award of PhD in crop science. I assure you that the responses you give will be treated with strict confidentiality. I would be grateful if you would agree to answer the questions below as objectively as you can.

Section A - Background Information

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4. Educational level. a. No formal education [ ] b. Primary/JSS [] c. SHS/SSS [] d. Tertiary

5. Main occupation. a. Student [ ] b. Government employee [ ] c. Private employee [ ] d. Unemployed [ ] e. Farmer [ ] f. Other [ ] please specify ……

6. How many persons are in your household? .....

Section B - Consumption and Usage of Cassava

7. How often do you eat cassava? a. Daily [ ] b. Twice a week [ ] c. Three or more times a week [ ] d. Once a forth night [ ] e. Not at all [ ]

8. Which way do you like your cassava prepared? a. Fufu [ ], b. Ampesi [ ], c. Gari [ ], d. Kokonte [ ], e. Agbelima [ ], f. Other [ ] please specify ……

9. Why do you consume cassava?.....

SECTION C - Knowledge about yellow flesh cassava

10. Do you know or have you heard about yellow flesh cassava? a. Yes [ ] b. No [ ]

11. If yes, how did you know/hear about it? a. Media [ ] b. Family [ ] c. Friends [ ] d. Workshop [ ] e. FBO [ ] f. Farmers [ ] g. Other, please specify……

12. Have you eaten yellow flesh cassava before? a. Yes [ ] b. No [ ]

13. If yes, which form? a. Fufu [ ], b. Ampesi [ ], c. Gari [ ], d. Kokonte [ ], e. Agbelima [ ], f. Other [ ] please specify ……

14. Did you enjoy it? a. Yes [ ] b. No [ ]

15. When given the option, would you eat it again? a. Yes [ ] b. No [ ]

16. If yes, why? ……

17. If no, why not? ……

18. Do you know of any perceived benefits from yellow flesh cassava? a.Yes[ ] b.No[ ]

19. If yes, please list a.……

b.…….

c……..

20. Do you know the benefits of beta carotene in food crops? a. Yes[ ] b.No[ ]

21. If yes, please state…….

22. Which food type would you recommend yellow flesh cassava to be used for? a. Fufu [ ], b. Ampesi [ ], c. Gari [ ], d. Kokonte [ ], e. Agbelima [ ], f. Other [ ] please specify ……

23. Please state your reasons……

APPENDIX B: EVALUATION OF YELLOW FLESH CASSAVA GENOTYPES FOR TOTAL CAROTENOIDS, DRY MATTER, YIELD AND CYANOGENIC POTENTIAL IN THE COASTAL SAVANNAH ZONE

A. Effect of YFC Genotypes on Whitefly Population, Cassava Mosaic Diseases

Variate: Whitefly population on 3rd Month

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	982.147	109.127	6.92	<.001
Residual	27	174.188	6.451		
Total	39	1175.319			

Variate: Whitefly population on 6th Month

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	829.22	92.14	4.68	<.001
Residual	27	531.94	19.70		
Total	39	1381.81			

Variate: Whitefly population on 9th Month

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1137.858	126.429	38.77	<.001
Residual	27	88.052	3.261		
Total	39	1256.030			

Variate: Cassava Mosaic Diseases on 3rd Month

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	44.4000	4.9333	38.37	<.001
Residual	27	3.4719	0.1286		
Total	39	48.1422			

Variate: Cassava Mosaic Diseases on 6th Month

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	36.2848	4.0316	6.90	<.001
Residual	27	15.7855	0.5846		
Total	39	56.3590			

Variate: Cassava Mosaic Diseases on 9th Month

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	30.6754	3.4084	6.00	<.001
Residual	27	15.3480	0.5684		
Total	39	46.6871			

B. Effect of YFC Genotypes on Total carotenoids content, Cyanogenic potential and Harvest index

Variate: Total Carotenoids content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Genotypes	9	129.7046	14.4116	31.66	<.001
Residual	9	4.0964	0.4552		
Total	19	135.0113			

Variate: Cyanogenic potential

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Genotypes	9	445.6236	49.5137	247.58	<.001
Residual	20	3.9999	0.2000		
Total	29	449.6235			

Variate: Harvest index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Genotypes	9	0.612747	0.068083	55.81	<.001
Residual	20	0.024400	0.001220		
Total	29	0.637147			

C. Effect of YFC Genotypes on Growth, Yield and Yield Components

Variate: Number of roots/plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	131.3625	14.5958	15.50	<.001
Residual	63	59.3375	0.9419		
Total	79	201.9875			

Variate: Root length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	8962.855	995.873	128.48	<.001
Residual	63	488.338	7.751		
Total	79	9520.764			

Variate: Fresh root yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	3151.354	350.150	100.32	<.001
Residual	30	104.705	3.490		
Total	39	3256.059			

Variate: Dry matter content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	1733.514	192.613	123.19	<.001
Residual	30	46.908	1.564		
Total	39	1780.421			

APPENDIX C: GENOTYPE BY ENVIRONMENT INTERACTION ANALYSIS OF MOSAIC DISEASE, YIELD AND DRY MATTER CONTENT OF NINE (9) YELLOW FLESH CASSAVA IN THREE AGRO-ECOLOGICAL ZONE IN GHANA

A. Effect of YFC Genotypes on Disease Severity, Growth, Yield and Yield Components at Wamaso

Variate: Whitefly population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1670.939	185.660	50.30	<.001
Residual	27	99.650	3.691		
Total	39	1816.771			

Variate: Mosaic

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	19.32812	2.14757	50.70	<.001
Residual	27	1.14375	0.04236		
Total	39	20.61719			

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	7054.4	783.8	4.01	0.002
Residual	27	5277.5	195.5		
Total	39	14180.9			

Variate: Number of storage roots

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	105.743	11.749	4.20	0.002
Residual	27	75.456	2.795		
Total	39	190.278			

Variate: Root weight per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	23.9828	2.6648	22.21	<.001
Residual	27	3.2391	0.1200		
Total	39	27.6547			

Variate: Root length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1548.623	172.069	31.53	<.001
Residual	27	147.330	5.457		
Total	39	1820.225			

Variate: Number of marketable roots

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	94.433	10.493	4.49	0.001
Residual	27	63.100	2.337		
Total	39	169.656			

Variate: Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	2398.28	266.48	22.21	<.001
Residual	27	323.91	12.00		
Total	39	2765.47			

Variate: Dry matter content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1125.625	125.069	41.88	<.001
Residual	27	80.625	2.986		
Total	39	1431.875			

B. Effect of YFC Genotypes on Disease Severity, Growth, Yield and Yield Components at UCC

Variate: Whitefly population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1160.970	128.997	48.02	<.001
Residual	27	72.527	2.686		
Total	39	1322.548			

Variate: Mosaic

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	18.32656	2.03628	5.15	<.001
Residual	27	1.56406	.05793		
Total	39	20.12344			

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	19256.0375	2139.5597	4057.46	<.001
Residual	27	14.2375	0.5273		
Total	39	19416.6547			

Variate: Number of storage roots

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	85.594	9.510	4.28	0.002
Residual	27	60.036	2.224		
Total	39	164.075			

Variate: Root weight per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	28.4219	3.1580	8.86	<.001
Residual	27	9.6215	0.3564		
Total	39	38.4469			

Variate: Root length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1448.908	160.990	33.81	<.001
Residual	27	128.545	4.761		
Total	39	1778.830			

Variate: Number of marketable roots

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	78.650	8.739	6.44	<.001
Residual	27	36.612	1.356		
Total	39	137.025			

Variate: Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	2842.19	315.80	8.86	<.001
Residual	27	962.15	35.64		
Total	39	3844.69			

Variate: Dry matter content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1035.000	115.000	88.71	<.001
Residual	27	35.000	1.296		
Total	39	1072.500			

C. Effect of YFC Genotypes on Disease Severity, Growth, Yield and Yield Components at Asuansi

Variate: Whitefly population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1053.066	117.007	37.76	<.001
Residual	27	83.664	3.099		
Total	39	1153.250			

Variate: Mosaic

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	29.47695	3.27522	111.90	<.001
Residual	27	0.79023	0.02927		
Total	39	30.32461			

Variate: Plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	5406.8	600.8	5.66	<.001
Residual	27	2863.5	106.1		
Total	39	8605.1			

Variate: Number of storage roots

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	38.353	4.261	1.93	0.091
Residual	27	59.737	2.212		
Total	39	108.611			

Root weight per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	11.5316	1.2813	4.84	<.001
Residual	27	7.1543	0.2650		
Total	39	20.6215			

Variate: Root length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1577.260	175.251	38.52	<.001
Residual	27	122.832	4.549		
Total	39	1712.443			

Variate: Number of marketable roots

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	28.500	3.167	2.34	0.042
Residual	27	36.470	1.351		
Total	39	78.965			

Variate: Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	1153.16	128.13	4.84	<.001
Residual	27	715.43	26.50		
Total	39	2062.15			

Variate: Dry matter content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	2305.625	256.181	25.86	<.001
Residual	27	30.625	1.134		
Total	39	2336.875			

APPENDIX D: RELATIONSHIPS AMONG DRY MATTER, MEALINESS AND STARCH CONTENT OF YELLOW FLESH CASSAVA GENOTYPES IN THREE AGRO ECOLOGICAL ZONES OF GHANA

A. Effect of YFC Genotypes on Mean Specific Gravity, Dry matter, Starch content at Wamaso

Variate: Mean specific gravity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	0.0243317	0.0027035	8.98	<.001
Residual	27	0.0081269	0.0003010		
Total	39	0.0332492			

Variate: Dry matter content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	609.725	67.747	8.98	<.001
Residual	27	203.652	7.543		
Total	39	833.189			

Variate: Starch content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	305.762	33.974	8.98	<.001
Residual	27	102.126	3.782		
Total	39	417.824			

B. Effect of YFC Genotypes on Mean Specific Gravity, Dry matter, Starch content at UCC

Variate: Mean specific gravity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	0.0225113	0.0025013	11.87	<.001
Residual	27	0.0056897	0.0002107		
Total	39	0.0295740			

Variate: Dry matter content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	564.109	62.679	11.87	<.001
Residual	27	142.578	5.281		
Total	39	741.093			

Variate: Starch content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	282.886	31.432	11.87	<.001
Residual	27	71.499	2.648		
Total	39	371.640			

C. Effect of YFC Genotypes on Mean Specific Gravity, Dry matter, Starch content at Asuansi

Variate: Mean specific gravity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	0.02634900	0.00292767	31.77	<.001
Residual	27	0.00248832	0.00009216		
Total	39	0.02911320			

Variate: Dry matter content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	660.277	73.364	31.77	<.001
Residual	27	62.355	2.309		
Total	39	729.544			

Variate: Starch content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatments	9	331.112	36.790	31.77	<.001
Residual	27	31.269	1.158		
Total	39	365.848			

APPENDIX E: DETERMINATION OF TOTAL CAROTENOID RETENTION IN THE YELLOW FLESH CASSAVA GENOTYPES AFTER PROCESSING INTO SOME COMMON FOODS IN GHANA

A. Total Carotenoid Content, Retention and Functional Properties

Variate: Grated cassava

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPE	7	24.3220	3.4746	31.76	<.05
Residual	16	1.7504	0.1094		
Total	23	26.0724			

Variate: Fermented dough

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPE	7	66.4993	9.4999	11.70	<.05
Residual	16	12.9911	0.8119		
Total	23	79.4904			

Variate: Gari

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPE	7	56.1636	8.0234	30.24	<.05
Residual	16	4.2450	0.2653		
Total	23	60.4086			

Variate: Retention

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPE	7	22376.4	3196.6	13.44	<.05
Residual	16	3805.0	237.8		
Total	23	26181.5			

Variate: Bulk density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPE	7	0.07732166	.01104595	53.17	<.05
Residual	16	0.00069810	00004363		
Total	23	0.07801976			

Variate: Swelling capacity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
GENOTYPE	7	4.50858	0.64408	22.21	<.05
Residual	16	0.46399	0.02900		
Total	23	4.97256			

B. Sensory Evaluation of Gari from YFC Genotypes

SENSORY EVALUATION FORM

DATE: JUNE, 2020.

Gender……

General attributes of panelists:

(a) willingness to participate in the sensory analysis tests, (b) regular consumers of gari, (c) they must be of sound health, no allergies, and dentures, (d) are not color blind and could taste sweet, bitter, and umami tastes, and (e) could identify roasted gari flavors.

SENSORY EVALUATION PARAMETERS	**SAMPLES**							
	ABC	**BCD**	**CDE**	**DEF**	**EFG**	**GHI**	**IJK**	**BAC**
APPEARANCE (colour)								
TASTE (sourness/ how nice it is in mouth)								
TEXTURE (graininess/ how it feels in mouth)								
SMELL (how it smells during eating)								
OVERALL ACCEPTABILITY								

REFERENCE SCALE	INTERPRETATION
1	Dislike extremely
2	Dislike very much
3	Dislike moderately
4	Dislike slightly
5	Neither like or dislike
6	Like slightly
7	Like moderately
8	Like very much
9	Like extremely

COMMENTS……

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