UNIVERSITY OF CAPE COAST

SCREENING OF LOCAL CASSAVA GERMPLASM FOR DOMESTIC AND INDUSTRIAL PURPOSES

BY

WILLIAM JAMES ADOMAKO

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DECLARATION

Candidate's Declaration

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

Candidate's Signature: ..... Date: 13/01/2009

Name: WILLIAM JAMES ASAMAKO

Supervisors' Declaration

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

Principal Supervisor's Signature: ..... Date: 13/01/09

Name: PROF. ALEX G. CARSON

Co-Supervisor's Signature: ..... Date: 13/01/09

Name: PROF. ISAAC K ASANTE

ABSTRACT

Two experiments were conducted at the University of Ghana Farm, Legon and Plant Genetic Resources Research Institute (Bunso). The first experiment was carried out at Legon from March, 2002 to October, 2003 to evaluate 11cassava accessions. The criteria used for the evaluation were (a) tolerance to whitefly infestation and African Cassava Mosaic Virus (ACMV) disease infection (b) root tuber yield and starch yield characteristics. Based on the performance of accessions in Experiment I, seven superior cassava accessions and one check variety were selected for further evaluation in Experiment II.

Experiment II was conducted between October, 2003 and January, 2005 at two agro-ecological zones, that is, the Coastal Savanna (Legon) and Deciduous Forest (Bunso) to identify and select elite accessions with desirable agronomic traits and root tubers with high starch content.

Three accessions, namely: 'UG126', 'H0015' and 'H0008' were observed to rank highest with respect to root tuber weight and other desirable production traits. Accessions 'UG126', 'DMA030' and 'H0008' were identified as genotypes with high quality starch suitable for industrial purposes based on low solubility, high swelling volume, swelling power and high peak viscosity.

For domestic purposes, for example, the preparation of 'fufu' and 'banku', 'UCC 90', 'UG126', 'H0008' and 'DMA 030' can be used based on high setback viscosities of their starches.

It is suggested that further field evaluations of the cassava genotypes be made over a longer period of time so that genotype × location × year interactions can be further studied.

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DEDICATION

I dedicate this work to the blessed memory of my late father, Kwabena Acheampong and also to my young daughter, Nana Amma.

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CHAPTER ONE

INTRODUCTION

Cassava (*Manihot esculenta*, Crantz) together with other tropical root and tuber crops such as yam, cocoyam, taro and sweet potato are increasingly becoming important sources of calories for both human and livestock. Cassava as a root crop has a number of attributes that have made it an attractive crop for small farmers with limited resources in marginal agricultural areas (Cooke and Coursey, 1981; Wenham, 1995)

Cassava's adaptability to relatively marginal soils and erratic rainfall conditions, its high productivity per unit of land and labour, the certainty of a yield even under the worst conditions, and the possibility of maintaining a continuous supply year round make this crop a basic component of the farming system in most areas of Sub-Saharan Africa.

In Africa the majority of cassava produced is for human consumption. This is because cassava produces exceptional carbohydrate yields, much higher than those of maize and rice and second only to yams (de Vries *et al.*, 1967). Cassava is now the largest single most important source of food energy providing over 37% of the calories in the diet of over 500 million people in tropical Africa (Hahn and Keysen, 1985; Horton and Fano, 1985; CIAT, 1992). The leaves of cassava which contain 5.1 to 6.9% protein (Onwueme, 1992; Oomen and Grubben, 1978; Gomez and Valdivieso 1985) are also used extensively as vegetables in Democratic Republic of Congo (Zaire), Sierra

Leone, Tanzania and several other African countries to provide protein, vitamins and minerals (Almazan and Theberge, 1989; Lutalado and Ezumah, 1981; Osiru *et al.*; 1992). The remainder of cassava produced in Africa is for animal feed and starch-based products (starches and alcohol). While the use of cassava flour is common, the partial substitution of wheat by cassava flour in bakery products is more recent and mostly as part of Research and Development (R&D) projects.

In Ghana cassava is produced in all regions except in the Upper East (MOFA 2002a) with large cultivation concentrated in the southern part of the country where rainfall is well distributed and bi-modal. Land area planted to cassava has increased nation-wide from 532,000 hectares in 1993 to 807,000 hectares in 2003 (MOFA, 2004). Root production has correspondingly increased from 5,973,000 Mt in 1993 to 10,239,000 Mt in 2003. Also estimated level of per capita consumption of cassava (kg/head/year) has increased from 145.2 in 1980 to 151.4 in 2000, an estimated increase of 4.3 percent.

Some inter-regional trade of cassava roots exists and limited volumes are being exported to the European markets. For instance, several West African countries including Ghana have ventured into the European markets with mixed successes. The major limitation to this export market is the fixed 145,000 Mt quota for African, Caribbean and Pacific (ACP) member countries (Henry *et al.*, 1998).

Cassava starch production in Africa is still very minor but increasing. Most starch utilizing industries import from the European countries and/or United States of America. However, a private sector interest does exist in

several countries regarding future starch processing investments. In Ghana the government has launched an ambitious President's Special Initiative (PSI) on cassava which is designed to develop the cassava starch industry to become a key contributor to Ghana's export revenue as well as a major vehicle for job creation and poverty reduction in rural communities.

Indeed one of the key elements of the programme is the development of new cassava varieties of high yields as well as high starch content (ASCO, 2004). Under the programme, industrial grade starch would be produced, part of which would be used by the incipient local textile industries being set up in the country to produce garments for export to the US markets under the US government's African Growth and Opportunities Act (AGOA).

Cultivar classification in cassava is usually based on pigmentation and shape of leaves, stems and roots. Cultivars most commonly vary in yield, root diameter and length, disease and pest resistance levels, time to harvest, cooking quality and temperature adaptation (O'Hair, 1998). Currently, three improved cassava varieties, namely: Afisiafi, Gblemoduade and Abasafitaa, all originating from the International Institute of Tropical Agricultural (IITA) have been released to farmers in Ghana (Afuakwa *et al.*, 1999).

Research activities on root ad tuber crops received insignificant attention in Ghana until the advent of the National Agricultural Research Programme (NARP) in 1992. Research into root and tuber crops was made a priority by NARP on the basis that these crops contribute 46% to Agricultural Gross Domestic Product (MOFA, 2004). Cassava as a root crop on its own contributes 22% to Ag. GDP (Al-Hassan, 1989).

As a follow-up to NARP research activities on root and tuber crops, Root and Tuber Improvement Programme (RTIP) was initiated by the International Fund for Agricultural Development (IFAD) and the Government of Ghana. The main development objective (goal) of RTIP is to enhance food security and increase incomes of resources-poor farmers on a sustainable basis by facilitating access to new but locally adaptable technologies of root and tuber crops. Root and Tuber Improvement Programme research activities on cassava are on-going and have been given the needed boost and urgency by the initiation of the President's Special Initiative on cassava cultivation.

Problem Statement

Even though local accessions of cassava abound and farmers plant them in order to satisfy their food requirements and tastes, and also to provide some security against the risks of pests and diseases and effects of unfavourable environment, they have not been vigorously screened to identify and select accessions for tolerance to common pests and diseases and for early bulking.

Also the functional properties, such as swelling volume, swelling power, solubility and the pasting characteristics of starch which have important implications for industrial and domestic uses of starch of most promising local cassava accessions have not been studied in detail.

Recent agronomic evaluations of local cassava accessions from different parts of the country have revealed that some are promising in terms of root yield, starch yield and are early maturing with low cyanide contents and have acceptable cooking qualities (Amenorpe, 2002).

There is the need, therefore, for further research work to be carried out on some of these promising accessions in different agro-ecological zones in Ghana to identify and select local cassava accessions that are high yielding in terms of root and starch, that are early maturing, relatively resistant to pests and diseases and have starch with desirable functional properties and pasting characteristics for domestic and industrial uses.

Project Purpose (Main Objective)

To evaluate elite local cassava genotypes in specific and different agro-ecological zones and select for clones which are tolerant to whitefly infestation and African Cassava Mosaic Virus (ACMV) disease infection, are high root tuber yielders, and have high starch contents that show acceptable functional properties and pasting characteristics.

Project Objectives (Specific Objectives)

By the end of the study, it is expected that field experiments and laboratory tests would have been carried out to:

a. Identify cassava genotypes that are tolerant to whitefly infestation and ACMV disease infection.

b. Determine which cassava genotypes have high root tuber yields and show other desirable agronomic traits.

c. Identify cassava genotypes that produce high starch yields and have starch with acceptable functional properties and pasting characteristics.

CHAPTER TWO

LITERATURE REVIEW

Origin and Distribution

According to Antonio (1999), Oslen and Schaal (1999) the geographical origin and the area of domestication of cassava are disputed matters. However, it is generally accepted that cassava originated in the neotropics (northeastern Brazil, extending towards Paraguay and to Western and Southern Mexico) and spread rapidly from South America in post-Columbian times. Cassava arrived on the west coast of Africa, via Gulf of Benin and the river Congo at the end of the sixteenth century. It spread to the east coast of Africa via the islands of Ré-union, Madagascar and Zanzibar at the end of the eighteenth century. Cultivation spread inland from both sides. The crop was taken to Asia during the seventeenth century (Thresh *et al.*, 1994a; Jennings, 1995; Purseglove, 1968; Rogers, 1963).

Doku (1969) has stated that cassava has been grown in Ghana since 1750. The crop was first introduced to the Volta region and from here it spread slowly to parts of the Ashanti and Brong-Ahafo regions in the forest belt. It is now grown in all the ten regions except the Upper West (MOFA, 2002a).

Botany

Manihot esculenta, Crantz (Syn. *Manihot utilissima*, Pohl.) (2n=36) belongs to the plant family Euphorbiaceae which has two sections: the

Arboreae, which contains tree species and is considered the more primitive, and the Fruticosae, which contains shrubs adapted to savanna grassland or desert. Cassava belongs to the latter. It is a dicotyledonous plant and is of interest because of its edible roots (Jennings, 1995). Cassava is a cultigen, unknown in the wild state (Rogers, 1963).

Kay (1987) and Janssens (2001) have provided a detailed botanical description of cassava. The crop is a shrubby, semi-woody plant which may grow to a height of 1-3m. It is a perennial plant but is usually grown as an annual or a biennial. Like all Euphorbiaceae the plant parts contain latex.

The root system of cassava is well developed and this gives the crop a good drought tolerance. Moreover, the effectiveness of its root hair is accentuated by the presence of endomycorrhizas (symbiotic associations between the roots and lower fungi growing in the external root tissues). The storage roots develop as swellings of adventitious roots, a short distance from the stem by a process of secondary thickening. The tubers consist of a periderm, storage parenchyma, xylem vessels and fibres. (Fig.1)

The tubers are rich in starch arranged in bundles and measure 30-80 cm in length and 5-10 cm in diameter. The weight of the tubers usually varies from 1-4 kg and under certain conditions may grow to a length of 1m. Root tubers have a brownish or reddish peel and the fibre content rises as the plant gets older.

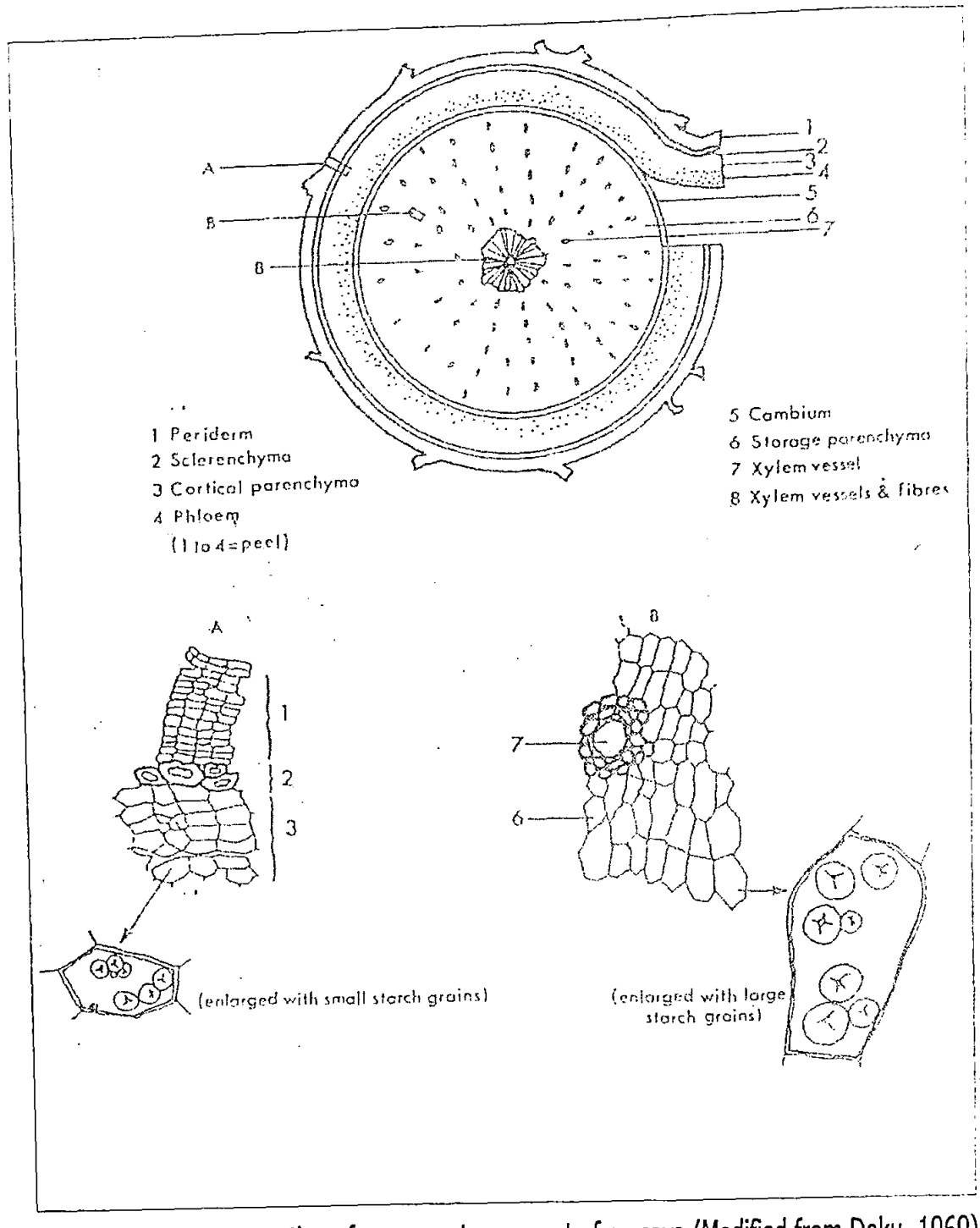

Figure 1: Transverse section of a young storage root of cassava (Modified from Doku, 1969)

The stems, whose diameter is not more than 2-4 cm, are usually slender and glabrous and for the most part filled with pith and because of this are very

fragile until lignification is complete. The stems vary in colour and it can be silver green, light brown, brown or dark brown. The older parts of stems consist of prominent knob-like scars which are the nodal positions where leaves were originally attached. The internodes vary considerably, depending on varieties and environment (Onwueme, 1982; IITA, 1990).

Two types of branching patterns are observed on cassava plants: the forking and lateral branching. Forking branching occurs at the apex of the stem when the apical meristem changes to the reproductive state and it is often associated with flowering. Lateral branching occurs on any part of the main stem at some distance from the apex.

Branching height determined on mature plants only (i.e. the height from the ground base to the first forking point) may be low branching, high branching or no branching at all. The height of cassava plants varies not only genetically but also with environmental conditions such as altitude, temperature, insulation, soil fertility, lodging and if leaves are harvested or not (Nweke *et al.*, 1992). For instance, cool temperatures are known to delay the time for first fork formation (Irikura *et al.*, 1979; IITA, 1990). High temperatures, on the other hand, above 28°C reduce forking height (Keating, 1981). Long photoperiods cause plants to branch several times within a short time and the total number of active apices is greatly increased. Time of planting also affects the branching height of cassava (IITA, 1990). Intercropping with a more competitive species may alter the branching pattern and where there is competition among cultivated crops for light, branching may occur at a higher level than in pure stand. Therefore, branching height is standardized in relative terms.

A cassava plant is considered low branching if the first branch occurs at a point below a third of the total height; high branching if the point of first branch occurs at a point above a third of the total height of the plant; and no branching at all. Which branching height is desired depends on the circumstance; low branching is desired for weed control while high or no branching is desired for intercropping but not suitable for weed control and often is early to lodge (Nweke *et al.*, 1992).

The leaves are spirally arranged according to a phyllotaxy of 2/5 and have multiple lobes (usually five, but sometimes three, seven or nine) of variable shape. A single plant may have two or three different leaf shapes. This is called foliar polymorphism. The colour of the leaves, sometimes crimson when young, is light to dark green. The leaves are borne on petioles which are longer than the leaf blade and measure 5 to 30cm in length. The petioles, like the leaf veins, are green, red to crimson and more rarely whitish.

Cassava is a monoecious plant. The plant inflorescence is a terminal raceme consisting of unisexual flowers. The female flowers are located at the base of the raceme and are pink, crimson, yellowish or greenish in colour. They have no corolla. The male flowers are located at the top of the inflorescence. Within the same raceme the male flowers bloom a week later than the female ones (protogyny) – a situation that favours cross-pollination by insects. The fruit is a dehiscent three-lobed that bursts noisely at maturity when it releases three seeds. The ellipsoidal seeds, 10-12mm long, have a well-developed caruncle typical of the family Euphorbiaceae.

Cyanide in Cassava

Onwueme and Charles (1994) have stated that virtually all parts of the cassava plant contain small but significant quantities of cyanide or cyanogenic compounds. The cyanide in cassava exists roughly as two types: (a) the free cyanide made up mainly of cyanohydrins, small amounts of hydrocyanic acid (HCN) which is gaseous above 26°C and CN^- ion (under alkaline conditions). (b) the bound cyanide existing as two cyanogenic glycosides, namely linamarin and lotaustralin. About 1/4 to 1/2 of the total cyanide is present as free cyanide, while the rest is bound cyanide. Of the bound cyanide, linamarin constitutes about 93% while lotaustralin is approximately 7% (Bradbury and Holloway, 1988).

Linamarin is synthesized in the leaves from the amino-acid valine, while lotaustralin is synthesized from the amino-acid isoleucine. From the leaves, the glycosides are translocated to other parts of the plant. In the cassava tuber, the concentration of cyanide ranges from 1-100 mg/100g fresh weight, but the range of concentration is a varietal characteristics. Some cassava cultivars are characterized as sweet cultivars and can produce as little as 2mg of HCN per 100g of fresh roots, while bitter ones may produce about 50 times as much. For all types, cyanide content is usually higher in the peel of the tuber than in the flesh. For fresh roots, values of total cyanogenic potential range from approximately 50 to 1500 mg HCN equiv./kg on a dry weight basis.

As a rough guide to acute toxicity in fresh roots, Coursey (1973) published the following guidelines: -

Innocuous:less than 50 mg HCN equiv./kg fresh peeled root.

Moderately poisonous:50-100 mg HCN equiv./kg fresh peeled root.

Dangerously poisonous: over 100 mg HCN equiv./kg fresh peeled root.

The toxicity of ingested cyanogenic glycosides in man is not well understood but Bourdoux *et al.*, (1980) postulate that they decompose at the alkaline pH level in the small intestines of man to yield an equal amount of cyanide and cause toxic effects. Toxicity of hydrogen cyanide is indicated by an estimated minimal lethal dose of 0.3-0.5 mg/kg body weight (Montegomery, 1969). Consumption of cassava with high cyanogenic glycosides content have been associated with a number of cyanide induced disorders including tropical ataxic neuropathy (Osuntokun, 1981), iodine deficiency disorders like goiter and dwarfism (Ermans *et al.*, 1983), acute toxic effects (Mlingi *et al.*, 1992) and the paralytic disease, konzo (Tylleskar *et al.*, 1992).

Vines and Rees (1964) have noted that in cases of human malnutrition, where the diet lacks protein and iodine, underprocessed roots of high HCN cultivars may result in serious health problems and even sudden death. This is because small quantities of HCN inhibit the activity of cytochromes (chromoproteins) resulting in cyanide poison by preventing cellular respiration mechanisms in which cytochromes are involved.

The cynogenic glycosides are soluble in water and tend to decompose if heated up to 150°C. They can be hydrolysed at ambient temperatures under the influence of the enzyme linamarase, to produce corresponding cynohydrins. The resulting cynohydrins as well as those normally present in the tissue, in turn breakdown to give HCN and ketones. This breakdown is spontaneous at pH above 5.0, but in the acid medium is catalysed by a hydroxy-nitrile lyase (Onwueme and Charles, 1994; Vasconcelos *et al.*, 1990).

In the intact plant tissue, linamarase occurs in the cell wall, and is physically separated from the glycosides, which occur in the vacuole. It is only when cassava tissue is crushed that linamarase is able to come in contact with the glycosides and hydrolyse them.

In general, the following methods are utilized for reducing the cyanide level of cassava before consumption:

(i) Crushing, maceration or pulverization to bring linamarase in contact with the glycosides, followed by removal of the resulting HCN by squeezing out the juice and heating.

(ii) Decomposing the glycosides directly by heating them above 150°C.

(iii) Sun/oven drying which removes about 80% of the free cyanide and 80-90% of the bound cyanide.

(iv) Retting i.e. prolonged soaking in water of the tuber. Apparently, fermentation micro-organisms attack the tuber during retting, making it more permeable. This permits glycosides, which are water soluble, to leach out from the tuber into the water. The micro-organisms and linamarase may also directly hydrolyse the glycosides during retting.

Sinha and Nair (1968) have noted that within each cultivar, there are some factors which may influence the cyanide level. Plant age is one factor: as the plant gets older, the cyanide in the tuber increases, attains a peak, and then declines. Plants growing on soils low in potassium or high in nitrogen also tend to have higher cyanide content. The season and other geographic factors also affect cyanide level in cassava (Grace, 1977).

Environmental Requirements

Climatic Conditions

Cassava is a typical tropical plant but the approximate boundaries for the culture may be accepted as from 30°N to 30°S latitude. The bulk of cassava growing, however, is located between 20°N and 20°S. In coastal zones and in some monsoon climates, cassava produces an acceptable crop outside the tropics. This is illustrated by large scale cassava cultivation in Southern Queensland (Australia), the South of Brazil and Natal in South Africa. The highest root production can be expected in the tropical lowlands below 1500m altitude (Tindall, 1983). At altitudes above 1800m, it develops only very slowly and it is susceptible to frost (Janssens, 2001; Yanock, *et al.*, 1988; Hahn and Keysen, 1985).

Cassava grows best in a sunny, wet climate. Nevertheless, its adaptability means it can also be grown in relatively dry regions. It is a sun-loving plant that needs plenty of sunshine. Nonetheless, long days slow down tuberization since cassava is a short-day plant. Most varieties of cassava initiate storage roots only under short days (10-12 hours) resulting in high storage root weight and storage root number. It has been observed that long days enhance excessive shoot growth and delay storage root development resulting in production of fewer storage roots (Bolhuis, 1966). High temperature, combined with long days, or low temperature combined with short days delays storage root development (Osiru *et al.*, 1995).

Its photosynthetic cycle is in-between that of a C_3 and a C_4 plant. (During photosynthesis, C_3 plants produce a three-carbon compound – 3 phosphoglyceraldehyde, 3-PGA. C_4 plants produce a four-carbon product –

malate or aspartate). Cassava cannot withstand violent winds and must be planted in sheltered sites (Janssens, 2001; Osiru *et al.*, 1995).

The mean annual temperatures for optimal growth lie between 25° and 29°C. Temperatures below 16°C are harmful to cassava and its growth stops altogether below 10°C (risk of chilling injury).

Despite its drought-tolerance, it must get a minimum amount of water of 500 mm per year spread over six months. The optimum annual precipitation lies between 1,000 and 1,500 mm per year. Cassava can survive a dry season of 3-4 months and does so by shedding most of its leaves and reducing its growth rate. However, an ample supply of moisture is essential during the first month or two after planting (Onwueme and Sinha, 1991). Fresco (1986) has noted that yields from cassava planted in the late rainy season are likely to be lower than those planted at the onset of the rains because the planting date influences yield since photosynthesis is likely to slow down during the dry season. Silvestre (1989) has also stated that when a dry season occurs, the cassava tubers stop growing and sometimes decrease in weight owing to a loss of water and their starch content increases.

Soil

It is reported that cassava is a hardy plant which can tolerate a wide range of soils except hydromorphic or too sandy soils. Cassava prefers deep, friable, well-drained sandy-clay soils and tolerates a wide range of soil pH of 4 to 8.0. Heaviest yields are obtained on a deep, loose permeable soils with a high humus content. On account of the formation of mycorrhizas, cassava thrives on desaturated soils with a low phosphorus content. But soils that are

excessively fertile and especially those with an excess of nitrogen limit tuberization (Janssens, 2001; Yanock *et al.*, 1988).

Growth and Growth Period

Silvestre (1989) has given a detailed description of the growth and growth period of cassava. When cassava stem cutting is planted, the roots grow first and then the buds which will produce the stems appear. This is the striking phase, which takes from 3 to 6 days. During the first month, the roots spread out rapidly, at first horizontally, then more or less vertically. During this period the stem grows slowly – it is known as the establishment phase, during which the plant lives mainly on the reserves contained in the cutting.

The third phase is that of aerial development, which lasts for about 3-4 months after planting. During this phase, the stems grow extremely fast and the plant creates the foliage which will enable it to produce the reserves that it will store in the tubers. The next phase is that of tuber development. Some roots start to swell during the preceeding phase, but this process accelerates when the foliage is fully developed, that is, when it completely covers the ground. During this stage, storage of starch in the tubers is irregular, varying with the age of the plant and also according to the season.

Pests

Pests of cassava are grouped under four main headings (IITA; 1990). Vertebrates, Nematodes, Mites and Insects.

Vertebrate Pests

There are two major vertebrate pests of cassava: the African bushfowl, *Francolinus bicalcaratus, bicalcaratus* and cane rat *Thryonomys sweinderianus*. Bushfowl become pests only after the tubers have been formed and after grain crops have been harvested. They peck at the soil with their beak until contact is made with the tubers, upon which they feed. Tubers damaged in this way are easily invaded by rot – causing micro-organisms, leading to their total loss. In highly infested areas, tuber loss resulting from bushfowl damage may be as high as 30%.

Cane rats eat cassava stems and tubers. They dig at the tubers, and the wounds made on large tubers during feeding become sources of infection for the smaller tubers. On unprotected farms, yield losses can be as high as 40%.

Nematodes

At least 45 genera and species of nematodes are known to be associated with cassava. They infect the roots and render them more susceptible to rot-causing organisms. The root-knot nematode, *Meloidogyne incognita*, is a particularly serious problem in Africa's cassava-growing areas. The lesion nematode, *Pratylenchus brachyurus*, the spiral nematode, *Helicotylenchus erythrinae* and the reinform nematode, *Rotylenchus reniform* are also found on cassava. An attack by these pests causes the plant to lose vigour and the resulting yield losses range between 17 and 50% (IITA, 1990).

Mites

The most important cassava mite pests in Africa are cassava green spider mite (CGM) and red spider mite (RSM). Green spider mite sucks cells from leaf tissue. The damage first appears on the surface of developing and newly formed leaves. Symptoms vary from a few chlorotic spots to complete chlorosis. Heavily attacked leaves are stunted and deformed. Mite incidence is high in the dry season and leads to a 20-80% tuber yield loss, depending on severity of the attack.

Red spider mite is visible to the naked eye as a red speck with four pairs of legs. Symptoms of attack appear on the upper surface of fully mature leaves as chlorotic pin pricks along the main vein; these pin pricks may increase to cover the whole leaf, turning the surface reddish-brown. Under severe attack, the leaves may die and be shed. Infestation starts in the dry season, and it is during this season that most damage is done.

Insects

There are at least six major insect pests of cassava in Africa (IITA, 1990): the cassava mealybug, *Phenacoccus manihoti,* the variegated grasshopper, *Zonocerus variegatus*, the elegant grasshopper, *Z. elegans*; the cassava scale insect, *Aonidomytilus albus*; the coreid bug, *Pseudotheraptus devastans*; and the whitefly, *Bemisia tabaci*. Of these insect pests, the whitefly is the most important since it is the vector of African Cassava Mosaic Virus (ACMV) disease and is prevalent throughout Africa.

Whitefly

The whitefly (*Bemisia tobaci*, Gennadius) is a major pest of many crops in diverse parts of the world, mainly in the tropics. According to Fishpool and Burban (1994) its effects can be three-fold (i) direct damage, such as chlorosis of leaves, can be induced by feeding while heavy infestations may cause an overall reduction in plant vigour (Byrne *et. al.*, 1990) (ii) the production of abundant, sticky honeydew, which can, in cotton, hinder processing and provide medium upon which moulds readily grow. (iii) *B. tabaci* is a major vector of plant pathogens, known or thought to be viruses (Ohnescorge, 1986; Duffus, 1987; Cohen, 1990; Brown, 1991). *B. tabaci* is the only known insect vector of ACMV disease. This virus causes a disease that is the main biotic constraint on cassava production in Africa (Geddes, 1990).

Fishpool and Burban (1994) have stated that the phenology of *B. tabaci* populations in newly planted cassava crops in Côte d'Ivoire repeatedly follow a similar pattern. Although planting date, cassava variety and climatic conditions influence the size of the whitefly populations and the timing of events, the qualitative structure of this pattern recurs (Fishpool *et al.*, 1988).

There is a slow but steady immigration into and establishment in the crop by adults as soon as the shoots have grown sufficiently to be exploited by the insect. Reproduction commences at once and the first small, locally produced cohort matures to adulthood some three weeks after the initial colonization. There is then an increasingly rapid build up in the size of the population until about three to four months after planting, representing three to five generations. Population levels are maintained, with fluctuations around

this maximum for a short period of up to three to four weeks, followed by a more or less rapid decline.

The pattern of exponential build of *B. tabaci* populations within young crops is probably attributable to a number of factors, including optimum nutritional quality of the food plant and low numbers of predators, parasitoids and/or pathogens. The decline at three to five months probably also has a number of contributory causes, including a decrease in the nutritional quality of the crop. It is to be noted that from about four to five months after a cassava crop is planted there is a reduction in the partitioning of resources devoted to aerial growth and the process of tuberization begins (Silvestre and Arraudean; 1983).

Otim-Nape *et al.*, (1994) have found from a study on the effect of ACMV on Ugandan cassava that numbers of adult whiteflies on cassava were not significantly correlated with any of the plant growth or yield characters measured. However, the whiteflies on cassava cause little direct damage and are mainly important in transmitting ACMV. Correlations were all negative, suggesting a slight detrimental effect of whiteflies on growth. It was also observed that there were a positive but not significant correlation between whitefly numbers and ACMV disease symptom score.

Diseases

The major diseases of cassava are leaf diseases, stem diseases and tuber rot (IITA, 1990).

African Cassava Mosaic Virus (ACMV) disease

This is a leaf disease and was first reported in East Africa (Tanzania) in 1894 and has been studied since the 1930s (Hahn and Keysen, 1985; Thresh *et al.*, 1994a). It has been shown to be caused by a whitefly-borne geminivirus that occurs in all the main cassava growing areas in Africa with some incidence reported in India and Indonesia. The disease is relatively rare in South America. The disease is generally regarded as the most important disease on cassava. Geddes (1990) ranked it as the most important vector-borne disease of any crop in Africa.

Symptoms of the disease include a whitish or yellowish chlorosis of the young leaves, accompanied by leaf distortion and reduction in leaf size. The growth of the entire plant is stunted, and the normal increase in tuber weight is disturbed so that yield is significantly reduced. The percentage starch content of the tubers is also reduced and in some instance there may be continuous longitudinal splits as well as malformation of the tuber (Narasimhan and Arjunan, 1973).

Alagianagalingam and Ramakrishnan (1970), Ninan *et al.*, (1976) and Murant *et al.*, (1973) have noted that at the cellular level several symptoms have also been ascribed to the cassava mosaic disease. Leaves of infected plants have fewer and smaller chloroplasts, and the content of chlorophyll, carbohydrate sugars and starch are lower. The photosynthetic rate is decreased, and there is increased activity of chlorophyllase enzyme in the leaves and amylase in the tubers. There is a decrease in total lipids, phospholipids and triglycerides in the leaves and petioles. In addition, there is a decrease in the amount of laticifers in the infected leaf portions.

The effects of ACMV disease on the yield of cassava have been assessed at different times and in at least twelve countries including Nigeria, Congo, Kenya, Côte d'Ivoire and Togo (Fargette, *et al.*, 1988; Thresh *et al.*, 1994b). These studies were made on naturally infected plants in farmers fields or experimental plantings and also in special plots established with ACMV infected and uninfected cuttings. The losses reported were variable and ranged from the insignificant to the almost total. Nevertheless, the following generalizations, among others are valid (Thresh, *et al.*, 1994a): (i) Plants grown from infected cuttings sustain a greater yield loss than those of the same variety infected later by whiteflies, and plants infected at a late stage of crop growth are virtually unaffected (ii) There are big varietal differences in response to infection. (iii) There is a positive relationship between the extent and severity of symptoms and yield loss (iv) Effects on yield are influenced by crop duration.

Terry and Hahn (1980) have estimated the annual crop losses due to African cassava mosaic virus disease to be 11% in Africa. Studies of individual varieties have indicated losses due to ACMV disease ranging from 20 to 95% (Beck and Chant, 1958; Jennings, 1960; Seif, 1982; Fargette, *et al.*, 1988; Thresh, *et al.*, 1994b).

Cours (1951) assessed a range of local cassava varieties in Madagascar and studied the interrelationships between symptom severity, leaf area, yield and virus incidence. His results indicated that severe symptoms were associated with restricted leaf area, low yields and a high incidence of infection. He observed that varieties which developed relatively mild symptoms had a low incidence of infection, grew satisfactorily and in some

instances outyielded those that were not affected. This suggests that only plants with severe symptoms should be discarded in breeding programmes and that slight symptoms have no serious detrimental effects. Vandevenne (1975) working on a trial with many different and local and introduced cassava varieties in Côte d'Ivoire observed that there was a negative correlation between yield and the severity of the leaf symptoms caused by ACMV.

Cassava bacterial blight disease (CBB)

This is the most widespread bacterial disease of cassava and second in importance only to ACMV disease in Africa. The causal organism is a bacterium, *Xanthomonas compestris, pathovar manihotis*. The symptoms include characteristic angular water-soaked leaf spot, blight, gum exudation, stem-die back, wilt and vascular necrosis. Severe attack results in rapid defoliation of the plant, leaving bare stems commonly referred to as 'Candlesticks'. Yield loss varies from 20 to 100%, depending upon cultivar, bacterial strain and environmental conditions (IITA, 1990).

Cassava anthracnose disease (CAD)

This is a stem disease caused by *Colletotrichum gloeosporioides* f. sp. *manihotis*. It occurs in all major cassava-growing areas in Africa. The fungus attacks mainly the stem, twigs and fruits, causing deep wounds ('cankers'), leaf spotting and tip die back. The incidence and severity of the disease have not been correlated with yield loss in the field but the infected stems produce poor quality planting material which does not establish well in the following planting season and thus yields are reduced.

Sclerotium rot

Caused by a fungus, *Sclerotium rolfsii*, this is the most common tuber disease and occurs on roots and tubers at all stages of development. It can be recognized by the appearance of a white mycelial growth on infected roots and tubers. As the fungus penetrates the tubers, the plants begin to show mild wilting symptoms.

Soft rot

The disease is caused by *Phytophthora drechsleri* and *Fusarium solani*, and occurs under wet conditions and cooler temperatures. The causal organisms attack and kill small feeder roots and cause necrotic brown lesions on older roots. As the roots decay, they infect the tubers which then emit pungent odours. Unharvested tubers become more susceptible to soft rot. When roots and tubers rot, the entire plant wilts, defoliates and dies.

Dry rot

Dry rot tuber disease is caused by several fungi; including *Fomes lignosus, Armillariella mellea, Rosellinia necatrix* and *Botryodiplodia theobromae*. The disease usually occurs on land that has recently been cleared of trees and shrubs. Infected tubers are typically covered with rhizomorphs (thread-like network of mycelia) of the fungus. The plant wilts, but does not shed its leaves. Eventually the entire plant dehydrates, turns brown and appears scorched.

Genotype and Environment Interaction

The basic cause for differences between genotypes in their yield stability is a wide occurrence of genotype x environment (G x E) interactions. G x E interaction is a differential genotypic expression across environments. Genotypes refer to the set of genes possessed by individuals that are important for the expression of traits under investigation. The environment is usually defined as all non-genetic factors that influence expression of traits. It may include all sets of biophysical factors including water, nutrition, temperature and diseases that influence the growth and development of individuals and thereby influencing expression of traits (Basford and Cooper, 1998).

Genotype by environment interaction is a major concern in plant breeding for two main reasons: it reduces progress from selection and secondly it makes cultivar recommendation difficult because it is statistically impossible to interpret the main effects (Kang and Magari, 1996). Genotype by environment interaction occurs in both short-term and long-term crop performance trials (Eberhart and Russel, 1966).

For these reasons it is often desirable to find genotypes that show little interaction with environments. Such genotypes may be regarded as stable (Piepho, 1994). Different concepts and definitions of stability have been developed and applied to crop breeding programmes and evaluation of yield trials (Lin *et al.*, 1986; Becker and Leon, 1988; Delacy *et al.*, 1996). According to Becker and Leon (1988) two different concepts of stability exist, the static and dynamic. With the static concept, stable genotypes possess unchanged or constant performances regardless of any variation of environmental conditions. That means its variance among environments is

zero. The dynamic concept, however, allows a predictable response to environments and a stable genotype has no deviation from this response to environments. The term stability, thus, refers to the character of a crop that withstands fluctuations of environments, in other words, the cultivar is consistent in performance, whether at high or low yield levels across a wide range of environments.

Lin *et al.*, (1986) have reviewed and classified basic stability parameters into three types. Type A stability which Becker and Leon (1988) named as static is analogous to homeostasis where a genotype is stable if its among-environment variance is small. It is based on deviations from the average cultivar effect (Finlay and Wilkinson, 1963; Francis and Kannenberg 1978). For type B stability (dynamic concept) a genotype is considered to be stable if its response to environments is parallel to the mean response of the genotypes in the trial (Plasteid and Peterson 1959, Plasteid, 1960; Shukla, 1972), while type C stability states that a genotype is stable if the residual mean square from the regression model on the environmental index is small (Eberhart and Russel, 1966; Lin and Binns, 1988; Kang and Gorman, 1989; Crossa *et al.*, 1991).

According to Romagosa and Fox (1993) there are two major approaches for studying GXE interaction and adaptation. The first is the parametric (empirical and statistical one) approach, which is more common and involves relating observed genotypic responses, in terms of yield, to a sample of environmental conditions. The second is the non-parametric (analytical clustering) approach, which defines environments and phenotypes in terms of biotic and abiotic factors. In practice, however, most breeding

programmes incorporate some elements of both approaches (Becker and Leon, 1988; Romagosa and Fox, 1993).

Recent developments comprise application of a multiplicative interaction model, the Additive Main Effects and Multiplicative Interaction (AMMI) (Piepho, 1996, Crossa *et al.*, (1990). AMMI combines analysis of variance for genotype and environment main effects with principal components analysis of the GXE interaction into a unified approach, and is especially useful in analyzing multi-location trials (Gauch, 1988; Zobel *et al.*, 1988).

Mba and Dickson (1995) carried out three separate multilocational trials comprising newly develop cassava clones of the International Institute of Tropical Agriculture (IITA) in the humid forest and savanna agro-ecologies of Nigeria at several locations between 1983 and 1989. Evaluation was carried out for production traits and reactions to the economic pests of cassava aimed at identifying high yielding and stable cassava clones.

There were highly significant differences in varieties for the main effects (environments and genotypes) as well as the G×E interaction effects for fresh storage root yield, root number and reactions to African cassava mosaic disease. The relative contributions of the G×E interaction to the total variation observed were either equivalent or greater than the contribution of the genotypes to the total variation, an indication that cassava was very sensitive to G×E, and unless the G×E interaction was properly manipulated by targeting varieties to target agro-ecological zones, breeders would face tremendous problems in their selection procedures for wide adaptation.

They also observed that all the production and resistance traits had relatively high heritabilities. For instance, heritability estimates for fresh

storage root yield ranged between 80 and 93 percents. The h^2 for all other production traits varied between 68 and 92 percents. It was explained that the clones used in the study have been highly selected for these traits over years under similar environmental conditions and hence the high heritability estimates obtained.

Genetic variance and heritability estimates

The total genetic variance is the part of the phenotypic variance which can be attributed to genotype differences among phenotypes where the phenotypic variance is the total variance among phenotypes when grown over the range of environments. Heritability in the broad sense is the ratio of total genetic variance to phenotypic variance (Dudley and Moll, 1969).

Estimates of genetic variance and heritabilities can be of value at various stages of a plant breeding programme. According to Dudley and Moll (1969) the various stages of any plant breeding programme are: assembly or creation of a pool of variable germplasm, selection of superior individuals from the pool, and utilization of the selected individuals to create a superior variety.

Asante and Dixon (2002) studied three traits, namely: root number, root weight and fresh root yield of some cassava genotypes and analyzed for heritability. They found out that the heritability per plot ranged between 0.69 and 0.86 which according to them indicated that non-additive effect of the genotypic variance was small.

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Wricke Ecovalence (Wi)

Wricke (1962) defined the concept of ecovalence as the contribution of each genotype to the Genotype by Environment Interaction (GEI) sum of squares. The ecovalence (Wi) or the stability of the i^{th} genotype is its interaction with the environments squared and summed across environments, and expressed as:

$$Wi = \lfloor Yij - Yj. - Y.j - Y.. \rfloor^2$$

where; Yij is the mean performance of genotype i in the j^{th} environment and $Y_{i.}$ and $Y_{.j}$ are the genotype and the environment mean deviations respectively, and Y.. is the overall mean.

For this reason, genotypes with a low W_i value have smaller deviations from the mean across environments and are thus more stable. According to Becker and Léon (1988) ecovalence measures the contribution of a genotype to the GEI, and a genotype with zero ecovalence is regarded as stable.

Stability variance (Shukla, 1972)

Shukla (1972) defined the stability variance of genotype i as its variance across environments after the main effects of environmental means have been removed. Since the genotype main effect is constant, the stability variance is thus based on the residual (GE_{ij} + e_{ij}) matrix in a two-way classification.

Cultivar superiority or Performance measure (P_i)

According to Lin and Binns (1988) the cultivar superiority or performance measure is the squares of the differences between an entry mean and the maximum mean at a location, summed and divided by twice the number of locations. Genotypes with the smallest values tend to have larger yields and are more stable than other genotypes.

Additive main effects and multiplicative interaction (AMMI)

The additive main effects and multiplicative interaction (AMMI) method integrates analysis of variance and principal components analysis into a unified approach (Gauch, 1988). According to Zobel *et al.*, (1988) and Crossa *et al.*, (1990), it can be used to analyze multilocation trials. The AMMI method is more appropriate in the initial statistical analysis of yield trials, because it provides an analytical tool of diagnosing other modules as sub-cases when these are better for particular data sets (Gauch, 1988). Secondly, AMMI summarizes patterns and relationships of genotypes and environments (Zobel *et al.*, 1988; Crossa *et al.*, 1990). The third use is to improve the accuracy of yield estimates. Gains have been obtained in the accuracy of yield estimates that are equivalent to increasing the number of replicates by a factor of two to five (Zobel *et al.*, 1988; Crossa *et al.*, 1990). Such gains may be used to reduce testing cost by reducing the number of replications to include more treatments in the experiment, or to improve efficiency in selecting the best genotypes.

Cassava Starch

Starch is the storage form of carbohydrates in plants. The starch that is produced by the plant is deposited as granules in colourless plastids (leucoplants) in the cytoplasm. Each type of plant creates granules that have a characteristic size and shape (Freeland-Graves and Peckham, 1987; Knight, 1969; Jones, 1983).

Pure isolated starch is a white, amorphous, relatively tasteless solid which possesses no odour, and which is insoluble in cold water. Starch granules are characterized by a birefringence, that is, the ability to refract

polarized light (Richard *et al*; 1991). The birefringence, indicates that the granule has a high degree of molecular orientation (Lineback, 1984). The starch granule appears to have a Maltese cross pattern. The centre of the cross is the initial growing point of the granule.

Chemical and microphotography techniques have elucidated that native starch is composed of two polysaccharides (polymers) – amylose and amylopectin. However, depending on its natural sources, certain minor components may be present. These include lipids, protein, phosphate and ash.

Amylose and Amylopectin

Amylose generally accounts for about 15 to 30% of native starch and it is sparingly soluble in hot water. Essentially amylose is a linear polymer in which the glucose units are linked by α- D-1, 4 glucosidic bonds (Manners, 1968). Molecular weight determinations indicate that the amylose has a degree of polymerization of many thousand glucose units.

Occasionally, there may be a slight degree of branching in the amylose molecule. The molecule is coiled in the shape of a flexible helix with a period of six to seven units. The interior of the helix contains predominantly hydrogen atoms and is lipophylic, while the hydroxyl groups are positioned on the exterior of the coil (Whistler *et al.*, 1984)

According to Freeland-Graves and Peckham (1987), inside each flexible coil, there is enough space for an iodine molecule. This characteristic forms the basis for the starch test. If iodine is added to a solution containing starch, the iodine is inserted within the coil and makes it rigid. This

transformation colours the starch mixture blue if the helix (or glucose chain) is long or reddish purple if the helix length is short.

Amylopectin is a highly branched polysaccharide chain. It constitutes about 70-80% of the weight of most common starches. The linear portions of the molecule are linked with α - 1, 4 glucosidic bonds but, every 20-25 glucose units, another polyglucosidic branch is attached by α - 1, 6 bonds (Manners, 1968). The molecular weight of amylopectin is much higher than that of amylose but this branched polymer is more compactly organized.

Gallant *et al.*, (1997) have postulated that amylopectin is arranged in the granule as clusters of radially oriented chains organized in super helical and semi-crystalline blocks. The proposed model has emerged mainly from chain length distribution analysis of debranched amylopectin (Hizukuri, 1986), electron microscopy (Oostergetel and Van Bruggen, 1993), polarized light microscopy (French, 1972), electron diffraction microscopy and fibre X-ray crystallography (Imberty *et al.*, 1988; Imberty and Perez, 1988; Imberty *et al.*, 1991).

The relative proportion of amylose and amylopectin in starches are responsible for the differences in cooking characteristics of the different types of starches. Starches containing a higher percentage of amylopectin have a higher peak viscosity and paste stability, this means that the starch will produce a thicker paste which will be less likely to break down during cooking (Bainbridge *et al.*, 1996). Amylose becomes cloudy when heated with water and is capable of forming a gel. Amylopectin remains clear when heated with water and does not set a liquid or gel.

Starch Gelatinization

During the cooking of starch mixtures, several changes take place that are significant in the preparation of typical starch products. When starch granules are added to cold water, a small amount of water is absorbed causing a reversible swelling. A temporary suspension in which the starch granules do not dissolve is also formed. The starch tends to settle out of the mixture as soon as the mixture is allowed to stand (Freeland-Graves and Peckham, 1987).

When the starch mixture is heated, the water begins to penetrate the starch granules in quantity, causing them to swell and lose their birefringence. Swelling is reversible up to the point at which the molecular structure within the granules is disrupted and birefringence is lost. Over a relatively narrow temperature range, all the granules swell irreversibly and are said to have undergone gelatinization. Continued heating of the gelatinized starch grains (*pasting*) causes the starch granules to swell enormously and soften, forming a viscous paste. If the paste is fluid, it is called a sol; if it is solid, it is called a gel.

The primary event that occurs when starch is gelatinized in an aqueous medium is granule swelling. As the temperature of an aqueous suspension of starch is raised above the gelatinization or pasting range, hydrogen bonds continue to be disrupted, water molecules become attached to the liberated hydrogen groups and the granules continue to swell. As a direct result of granule swelling, there is a parallel increase in starch solubility, paste clarity and paste viscosity (Knight, 1969; Mat-Hashim *et al.*, 1992). Also the additional increase in the viscosity of the starch paste with further heating is believed to be the result of starch being exuded out of the starch grain into the

surrounding medium. The starch molecules trap the free water and inhibit its free flow.

Perhaps the most important variable characteristics of different starches when observed are the ways the starches form paste when heated with water. The differences are evident in a number of ways: in the temperatures at which the granules start to swell; the way the viscosity increases as the temperature increases and more granules become hydrated; the way the viscosity increases as the paste cools; and the degree to which the paste breaks down under the effect of shearing actions (Jones, 1983).

The process of gelatinization and pasting vary with the type of starch and size of the starch granule. Generally, starches with large granules swell at lower temperatures than those with smaller granules. For example, potato, waxy corn, and tapioca starch thicken at much lower temperatures than do regular corn and wheat starch. Continued heating of the starch mixture after it has achieved its peak viscosity will decrease the thickness of the starch paste. The ability of starch to swell and produce a viscous paste when heated in water (or treated with certain chemicals) is its most important practical use in the food industry since they affect the texture and digestibility of starchy foods.

Gelatinization temperature

Gelatinization of starch takes place over a definite range of temperature known as gelatinization temperature. The pasting (or peak gelatinization) temperature is the temperature at which irreversible swelling of the starch granules occur leading to peak viscosity.

Moorthy (1994) studied the gelatinization temperatures of starch of seven cassava varieties and found out that two varieties gelatinized earlier with gelatinization temperature range of 12°C. No relationship between granule size and gelatinization temperature was observed. Pasting temperatures were also determined using a viscograph and all the values obtained were similar except one variety that showed a lower pasting temperature.

Pasting temperatures of starch from four varieties of cassava commonly cultivated in Ghana were found to range from 64 to 67°C (Boakye *et al.*, 2001). Working on seven varieties of a related root and tuber crop, sweet potato, Oduro *et al.*,(2000) observed that the pasting temperatures were relatively high and varied between 72 and 73.3°C.

According to Bainbridge *et al.*, (1996) starches with lower pasting temperatures are generally considered to be easier to cook. However, lower pasting temperatures are also associated with low paste stability, which is usually considered to be an undesirable property. Low pasting temperature and low paste stability indicate that fewer associative force and cross-links are present within the starch granule.

Paste viscosity

An important property of starch is that it provides a viscous paste (thickened starch mixture) when heated in presence of water. It is this viscosity which accounts for the use of starch in textile, paper, adhesive and food industries. Cassava is well known for high viscosity of its paste.

When starch of different varieties of cassava was studied using a Brabender Viscograph three peak patterns were generally observed (Moorthy, 1994). They were: -

(i) Single stage gelatinization with high peak viscosity and high viscosity breakdown.

(ii) Two-stage gelatinization with high peak viscosity and breakdown.

(iii) Broad two-stage gelatinization with medium viscosity and medium breakdown.

Moorthy (1994) in another study involving five varieties of cassava having different cooking quality observed that the starch of one variety had a medium peak viscosity, low viscosity breakdown but high setback viscosity. Another variety had slightly lower peak viscosity and setback viscosity. A third variety, on the other hand, had a very high peak viscosity which tinned down considerably on heating and the setback viscosity was low. The results seemed to indicate some relationship between cooking quality and starch rheology since the variety with medium peak viscosity and high setback viscosity reasonably had good cooking quality compared to the variety with high peak viscosity and low setback viscosity which had poor culinary quality.

Viscosity analysis

The peak viscosity is the highest viscosity reached during the heating phase of the Brabender Visco-Amylograph. At this point, there is a majority of granules that are fully swollen but intact. For any particular type of starch, the more granules that are available to be hydrated the higher the peak viscosity will be. During the high temperature hold phase at 95°C, the starch granules

begin to breakdown and solubilisation continues resulting in a drop in viscosity and a trough viscosity is recorded. The peak viscosity value and viscosity at 95°C are measures of the ability of the starch to form a paste on cooking. The higher the value the thicker the paste will be. Jones (1983) and Kim *et al.*, (1995) have noted that a high viscosity is desirable for industrial use, for which a high thickening power is required. The difference between the peak and trough viscosities is termed the "breakdown". The rate of decrease in viscosity depends on the temperature and the nature of the material itself.

During the cooling phase, the solubilised starch molecules begin to reassociate and the viscosity begins to increase again towards the cold paste or final viscosity. In sufficient concentration, this usually causes the formation of a gel. This second rise, representing the difference between the paste and hot paste viscosities is known as the setback (retrogradation).

Retrogradation of cooked starch involves both of the constituent polymers: amylose and amylopectin, with amylose undergoing retrogradation at a much more rapid rate than does amylopectin. Retrogradation of amylopectin is believed to involve primarily association of its outer branches and requires a longer time than retrogradation of amylose. The highly branched chains of the amylopectin molecule project out too much and interfere with bonding to other molecules (Ring, 1993).

When a cooled starch gel that has been standing for a while is cut, there is leakage of liquid from the gel. This leakage or separation of fluid from a gel is called syneresis or weeping (Freeland-Graves and Peckham, 1987).

A low setback value shows that the starch gives a non-cohesive paste which is useful in many industrial applications (Kim *et al.*, 1995). A high setback value

is useful if the starch is to be used in domestic products such as *fufu*, which require a high viscosity and paste stability at low temperature (Oduro *et al.*, 2000).

In addition to the peak, stability of viscosity is also a very important factor which decides the applicability of starch in food and industry. Paste stability is determined by subtracting the viscosity value after 15 minutes at 95°C from the value for paste viscosity at 95°C (Oduro *et al.*, 2000). The paste stability at 95°C measures the tendency of the paste to break down during cooking. High paste stability is frequently a requirement for industrial uses of starch.

A starch with low paste stability has very weak cross-linking within the granules and requires less heating. In this respect cassava starch is inferior to maize starch because its viscosity is rapidly reduced on heating under shear showing that the strength of associative forces is not very high. This leads to a long and cohesive texture for its paste, which is not desirable in food and textile applications (Moorthy, 1994).

Boakye *et al.*, (2001) have demonstrated that pasting behaviour of starch from four varieties of cassava, namely: 'Akosua Tumtum', 'Ankra', 'Abosome Nsia' and 'Adwoa Smart' showed significant variations ($p < 0.05$) in peak viscosity and viscosity at 95°C. Values recorded for peak viscosity and viscosity at 95°C ranged from 320 to 585 BU. The cold paste viscosities were very high for all the samples indicating the tendency of the starch samples to associate or retrograde on cooling.

In another work, Oduro *et al.*, (2000) studied the pasting characteristics of starch from seven new varieties of sweet potato and observed that the peak

viscosity and viscosity at 95°C ranged from 480 BU for variety 'Dugbadza' to 600 BU for 'Sauti'. After the onset of pasting, the viscosity of all the samples increased rapidly, but the viscosity at 95°C and after the first holding periods were lower than the peak viscosity, reflecting the strength of the starch pastes. Based on other physiochemical properties and the pasting characteristics of the seven sweet potato varieties, they concluded that variety L/Red will be suitable for domestic applications while 86/0250 will be better for many industrial purposes.

Factors affecting gelatinization and pasting

A number of factors affect the gelatinization and pasting of starch among which are the following:

(i) *Shear*: The extent and force of stirring can disrupt the structure of the starch granule. This can cause the granules to loose their contents and as such there would not be enough structure and hydrogen bonding to hold the polymers together. Over stirring as well as over cooking will decrease the starch paste viscosity. An increase in shear rate will result in a decrease in viscosity.

(http://osu.orst.edu/instruct/nfm236/starch/index.cfm, 2001).

(ii) *Types and Amount of Starch*: With native starches, the greater the amount of amylopectin the more viscous the starch paste (because amylopectin contributes greatly to paste viscosity), whereas the greater the amount of amylose the firmer the gel (the greater the gel strength). Generally, starches with large granules swell at lower temperatures than starch with smaller

provide evidence of non-covalent bonding between molecules within the starch granules.

Generally good quality starch with a high starch content and paste viscosity will have a low solubility and high swelling volume and swelling power. High solubility, low swelling volume and swelling power are indicative of poor quality starches that produce thin, low stability pastes when cooked (Bainbridge *et al.*, 1996).

Moorthy (1994) studied the swelling behaviour of eight varieties of cassava and found out that the swelling volume of the different varieties varied from 25.5 to 41.8 ml/g of starch. No correlation was obtained between viscosity and swelling volume. It was observed that during the growth periods, starch of two varieties, maintained their swelling volumes within small ranges, while some varieties expressed wide variations which indicated that these varieties were very much susceptible to environmental influences. The results also indicated some relationship between cooking quality and swelling volumes, since it was observed that one of the varieties that had steady swelling volume also produced root tubers with good cooking quality.

Studies conducted by Boakye *et al.*, (2001) on the swelling behaviour of starch from four local varieties of cassava in Ghana showed that swelling volume ranged from 24.17 to 30.20 ml/g and the swelling power from 27.5 to 36.1 g/g. Solubility values of the samples showed significant differences ($p<0.05$) with a range of 12.4 to 14.9%. They attributed the differences in swelling behaviour to varietal differences. Moorthy and Ramarujam (1986) have also reported that the swelling power and solubility of cassava starch are dependent on varietal differences, environmental factors and age of crop.

Modification of starches

Starch has special properties which have been exploited for various purposes. However, some of these are not suitable for some specific applications and methods are available to modify these undesirable characteristics. A modified starch is one that has been chemically and/or physically modified to create suitable properties for use in the food industry. The methods that are available for the modification of starch can be non-degradative, using physical treatments, incorporation of chemicals and chemical treatments. These chemical treatments are based on the availability of a large number of hydroxyl groups in the starch molecules, which can be made to react in many ways with various reagents. The other type of modification, degradative modification included dextrinisation (dry heat treatment of starch granules to form dextrins), hydrolytic oxidation and hydrolysis to low molecular weight compounds (Moorthy, 1994).

Food uses of cassava

The importance of cassava in the world food supply is due to its durability as a plant and also due to it being a cheap and excellent source of dietary carbohydrate. Cassava is consumed in a wide variety of forms. In many areas, the roots are consumed as a major staple, although in some places boiled fresh cassava roots are eaten as a vegetable. In large parts of Africa, particularly Central Africa, the leaves are also consumed as a leafy vegetable (Dorosh, 1988).

In Ghana, cassava roots are usually prepared and eaten in the form of *fufu, ampesi, agblima, akple, banku*, and *yakayeke*. The roots can be roasted

and eaten and they can also be processed into dry chips (*kokonte*), *gari*, biscuits, buns and doughnuts, breads and cakes (MOFA, 2000b).

Feed uses of cassava

Cassava roots are used as feed for farm animals usually to substitute for a part of the main ingredients in nutritionally balanced rations. For example, Gomez *et al.*, (1984) in Colombia reported that when cassava was substituted for maize in a poultry broiler ration at levels of up to 30%, there was no significant difference in the performance at all levels, but the 20% level substitution was the most economical. It was noted that high levels of cassava intake were more acceptable for broiler production than for laying hens. Egg production and quality could be adversely affected by nutritional imbalances associated with rations high in cassava.

In the case of pigs, the performance was progressively better as the level of cassava feed was increased to 40%. In view of the potential value of cassava to supply energy to dairy cattle, it has been used in a great number of experiments as the main source of energy, resulting in higher milk and fat yields and live weight grains (Pineda and Rubio, 1972). Similar results have been obtained for beef cattle when steers fed on commercial concentrate and cassava-based diets gained weight significantly faster than those fed bran or maize and cob-based diets. Better performance of bulls has also been reported by Montilla *et al.*, (1975) on 40% cassava rations rather than on maize meal. Similar findings for goats and sheep where cassava enhanced the utilization and hence nitrogen retention have been reported.

Non-Food Applications of Starches

TABLE 1: Some non-food application of starches

Adhesives	**Metals Industry**
Hot-melt glues	Foundry core binder
Stamps, book binding, envelopes	Sintered metal additive
Labels (regular and water proof)	Sand casting binder
Wood adhesives, laminations	
Automotive, engineering	**Textiles Industry**
Pressure sensitive adhesives	Warp sizing
Corrugation	Fabric finishing
Paper sacks	Printing
Explosives Industry	
Wide range binding agent	**Cosmetic and Pharmaceutical Industry**
Match-head binder	Dusting powder
Paper Industry	Make-up
Internal sizing	Soap filler/extender
Filler retention	Face creams
Surface sizing	Pill coating, dusting agent
Paper coating (regular and colour)	Tablet binder/dispersing agent
Carbonless paper stilt material	**Mining Industry**
Disposable diapers, feminine products	Ore flotation
	Ore sedimentation
Construction Industry	Oil well drilling muds
Concrete block binder	**Miscellaneous**
Absestos, clay/limestone binder	Biodegradable plastic film
Fire-resistant wallboard	Dry cell batteries
Plywood/chipboard adhesive	Printed circuit boards
Gypsum board binder	Leather finishing
Paint filler	

Source: (http://www.fao.org/ag/agsi/starch41.htm, 2001)

(http://home3.inet.tele.dk/starch/isi/applic/applic.htm,2001)

CHAPTER THREE

MATERIALS AND METHODS

INTRODUCTION

Two field experiments were conducted. Experiment 1 was carried out from March 2002 to April 2003, and Experiment 2 from October 2003 to January 2005.

EXPERIMENT 1: Evaluation of thirteen cassava genotypes for pest and disease tolerance and production traits.

The objective of Experiment 1 was to evaluate eleven local cassava accessions using two released varieties as checks. The criteria used for the evaluation were:

a. Tolerance to whitefly infestation and African Cassava Mosaic Virus (ACMV) disease infection.

b. Acceptable production traits in terms of stated agronomic characters.

The top eight cassava genotypes on the basis of their tolerance to ACMV disease and high root tuber and starch yields were selected for further evaluation in Experiment 2.

Location of farm site and land preparation

The experimental farm was located at the University of Ghana Farm, Legon. An area of about 0.45 ha was cleared and ploughed in the first week of March 2002.

Experimental design and field layout

Randomized Complete Block (RCB) design was used with three replications. Each block measured 50m long and 9m wide with 2m spacing between blocks. Each block was then divided into thirteen plots. The treatments were made up of 13 cassava genotypes. Each plot was 9m long. Three-row plots were used with rows 1m apart and plants within a row 1m apart.

Planting materials

Eleven cassava accessions, namely: 'H0001', 'H0008', 'H0015', 'UG115', 'UG126', 'UCC096', 'UCC90', 'Bosome Nsia', 'DMA 002', 'DMA 030', and 'CRI/001/102' were selected as experimental materials. The selection was based on the results of previous experimental work done by Amernope (1998, 2002) and Ampong-Mensah (2000). The planting materials (accessions) have been previously selected from germplasm collections maintained at the various germplasm conservation centres and from farmers' fields throughout Ghana. Specifically, the accessions were obtained from Greater Accra Region (University of Ghana Farm); Brong Ahafo Region (Nkoranza, Dormaa Ahenkro, Wenchi and Asunafo); Eastern Region (Bunso); Volta Region (Bodada-Buem in the Jasikan District, SSNIT Flats area and

Akoepe in the Ho District). Other accessions came from the Western and Central Regions. Two improved and released varieties – 'Afisiafi' and 'Tek bankye' – were used as checks.

Planting

Planting of cassava cuttings, each measuring 30 cm long was done in the third week of March, 2002. Cassava accessions and checks were randomly assigned to plots within each block. The planting distances were 1m between rows and 1m between plants.

Weed control

The first weed control using a hoe was done three weeks after planting. The second was carried out four weeks after the first weeding and subsequent weedings were done when necessary.

Data collection

Data collection started one month after planting on pest and disease. Yield and yield components and starch extraction and starch yield data of the thirteen cassava genotypes were collected at twelve months after planting (12MAP).

Whitefly population

Whiteflies (*Bemisia tabaci*) are the vectors of African cassava mosaic virus (ACMV) disease on cassava plants. Determining their population on cassava plants would therefore aid in assessing the relationship between

numbers of whiteflies and the severity and incidence of ACMV disease infection.

Direct counts of adult whiteflies on the crop were made (Mound (1965), Hill (1968), Gerling and Horowitz (1984) and Fargette *et al.*, (1985)). Five plant stands that were affected by ACMV disease were randomly selected from each plot. On each plant, five leaves were randomly selected and each leaf was carefully turned over and the number of adult whiteflies on the leaf under surface was counted and recorded. The mean number of whiteflies was then computed. Counting of whiteflies was done early in the morning around 6am when the environment was cooler and the insects less active than later in the day. The counts were done one month after planting and were repeated at the third and sixth months after planting.

African Cassava Mosaic Virus (ACMV) disease score

Plants infected by ACMV disease have their leaves reduced in size, misshapen and twisted, with chlorotic areas separated by green leaves. Leaflets may show a nearly uniform mosaic pattern.

Scoring for ACMV disease was done one, three and six months after planting. The following ordinal scoring system (IITA, 1990) was used.

1 = no symptoms observed.

2 = mild chlorotic pattern on entire leaflets or mild distortion at base of leaflets appearing green and healthy.

3 = strong mosaic pattern on entire 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.

All the plants in each plot were scored and the mean ordinal score computed.

Number of root tubers

From each plot, three cassava plant stands were randomly selected from the middle row and uprooted using cutlass. The number of root tubers was counted and the mean computed for each plant stand. Harvesting of cassava took place at twelve months after planting.

Fresh root weight (kg)

The fresh root weight was determined by weighing all the fresh root tubers harvested from the three separate plant stands together and dividing by three to obtain the fresh root weight per plant.

Individual tuber weight (g)

The fresh root weight per plant obtained as described above was divided by the mean number of tubers per plant to obtain the individual tuber weight.

Fresh shoot weight (kg)

This was determined by weighing the shoots (leaves and stems) of harvested cassava plants and then dividing by three to obtain the fresh shoot weight per plant.

Fresh root yield (t/ha)

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

Harvest index

The Harvest Index (HI) was calculated as weight of tubers divided by weight of above-ground parts plus weight of tubers (Cock *et. al.*, 1979).

Starch weight (g)

Cassava root tubers were peeled, washed and cut into small cubes. Five hundred-gram weight of each sample was milled with excess de-ionized water in a Philips blender. The starch slurry was then filtered through a muslin cloth into a plastic container. The residue was milled again and filtered through the muslin cloth in the plastic container to ensure maximum extraction of starch granules. Each milling and extraction process took about 5 minutes.

The distillate was allowed to stand for about three hours after which the supernatant was drained away. The pure white starch in the plastic

container was dried in the sun for about six hours after which it was allowed to cool and then weighed using analytical weighing scale.

Starch content (%)

Starch content (%) was determined based on dry starch weight using the following relationship.

$$Starch \quad content\ (\%) \quad = \quad \frac{Weight\ of\ dry\ starch\ x\ 100}{Weight\ of\ sample\ fresh\ root\ tuber}$$

Starch yield (g/plant)

Starch yield was computed by multiplying the fresh root weight (kg) per plant of a given accession or check by its percentage starch content.

Dry root tuber weight (g)

Five hundred-gram weight of fresh root tuber cubes from each cassava accession and check was dried overnight for about a 24-hour period at 70°C. The sample were allowed to cool in desiccators for about 20 minutes and then weighed to obtain the dry weight.

Root tuber dry matter content (%)

Based on the results obtained from the determination of dry root weight, the dry matter content (%) was calculated using this formula:

$$Dry\ matter\ content\ (\%) \quad = \quad \frac{Sample\ dry\ root\ weight\ x\ 100}{Sample\ fresh\ root\ weight}$$

Dry root yield (g/plant)

Dry root yield was computed by multiplying the fresh root weight (kg) per plant by its percentage dry matter content.

Data analysis

Data collected was subjected to statistical analyses, using Statistical Analyses Systems (SAS) computer software for Analysis of Variance (ANOVA), and Correlation. Count data on whitefly population and ordinal scores of ACMV disease were subjected to logarithmic transformation using the relationship log (X+1) where X is the original data (Gomez and Gomez, 1984) before analysis of variance was performed on the data set. However, the reported values in the results are the antilog of each transformed data reduced by 1.

Experiment 2: Evaluation of eight cassava genotypes at two agro-ecological zones for acceptable production traits and starch yield characteristics

The objective of Experiment 2 was to evaluate seven elite local cassava accessions for tolerance to pest and disease and high root tuber and starch yield traits in two agro-ecological zones. The two agro-ecological zones selected were Coastal Savanna and Deciduous Forest. These agro-ecological zones are defined on the basis of climate, reflected by the natural vegetation and influenced by the soils. The agro-ecological zones were chosen because they are high cassava producing zones in Ghana.

Experimental location

Coastal savanna

This type of vegetation occurs in the dry equatorial climatic region. This is the zone which receives the least amount of rain in Ghana between 740 and 890mm annually. Relative humidity is, however, high throughout the year and thus compensates for the scanty annual rainfall (Boateng, 1960; Dickson and Benneh, 1988).

The soils in this zone are the savanna ochrosols (highly coloured soils) which differ from the forest ochrosols in being less richly supplied with organic matter and nutrients. The soils are generally acid or mildly acid.

The specific area selected as the coastal savanna experimental site was the University of Ghana Farm, Legon. An area of about 0.225ha was cleared and ploughed in the first week of October, 2003.

Deciduous forest

This zone is distinguished from the rain forest by the fact that many of the trees in its upper and middle layers exhibit deciduous characteristics (shedding of leaves) during the long dry season; usually from November to March when the influence of the harmattan is greatly felt. The annual rainfall is between 1250 and 1750mm (Boateng 1960; Dickson and Benneh, 1988).

The principal soils are the forest ochrosols which range in colour from brown to orange. These soils contain greater quantities of nutrients because they are less leached by rainfall and are generally alkaline. Plant Genetic Resources Research Institute (PGRRI) experimental farm area located at Bunso was selected as a representative site of a deciduous forest zone. A

land area of about 0.225 ha was cleared and ploughed in the second week of October 2003.

Experimental design and field layout

The Randomized Complete Block (RCB) design was used at both sites. The experimental areas at both sites were divided into three blocks. Each block measured 23m long and 11m wide with 2m spacing between blocks. Each block was then divided into eight plots and each plot measured 5m by 5m with 1m spacing between plots.

Planting materials and planting

Seven cassava accessions, namely: 'Bosome Nsia', 'H0001', 'UCC 90', 'DMA 030', 'UG 126', 'H0015' and 'H0008' were selected as experimental planting materials based on tolerance to ACMV disease and high root tuber and starch yields. One improved and released variety, 'Afisiafi'which displayed better resistance to ACMV disease than 'Tekbankye', (also a check treatment in Experiment 1) and showed desirable agronomic traits was used as a check (control).

Cassava cuttings each measuring about 30 cm long and selected from mature parts of cassava stems were planted in the third and fourth weeks of October 2003 at the University of Ghana Farm, Legon and at the Plant Genetic Resource Research Institute, Bunso, experimental farm site respectively. The accessions and the check were randomly assigned to plots within each block. The cuttings were planted 1m between rows and 1m between plants.

Weed control

The first weed control using a hoe was done three weeks after planting. The second weeding was done four weeks after the first one and subsequent weedings were carried out when necessary.

Data collection

Data collection started at one month after planting at both agro-ecological zones. The response variables on which data were collected and the procedures for data collection were the same as have been presented and described in Experiment I. Apart from data on whitefly population and level of African Cassava Mosaic Virus (ACMV) disease infection which were collected at one, three and six months after planting, all other agronomic data were collected at two plant growth stages, that is, at eight and twelve months after planting at both locations.

Additional data were collected on starches extracted from tubers of the various cassava genotypes at both locations on the following parameters:

Functional properties of starch

To determine the functional properties of starch, that is, the swelling volume, swelling power and solubility of starch, the following procedure was adopted based on the modification of the method of Leach *et al.*, (1959).

An aqueous starch suspension was prepared by weighing 1g of dry starch into a previously weighed graduated 50ml centrifuge tube and 40ml of distilled water was added. The suspension was heated to 85°C in a water bath, shaking gently to ensure that the starch granules remain in suspension until

gelatinization occurs (5 minutes). The gelatinized sample was held at 85°C in the water bath for 30 minutes. The sample was cooled to room temperature under running water and then centrifuged for 15 minutes at 2200 rpm.

(a) Swelling volume

Swelling volume was obtained directly by reading the volume of the swollen sediment in the tube.

(b) Solubility

The soluble starch was decanted carefully into a cleaned and weighed glass crucible and evaporated in an oven at 105°C. The percentage solubility was then calculated from the dried residue,

$$\textit{that is, \% Solubility} = \frac{\textit{Weight of soluble starch x 100}}{\textit{Weight of sample (dry basis)}}$$

(c) Swelling power

Swelling power was determined by weighing the sediment and expressing swelling power as the weight (g) of swollen sediment over gram dry starch, that is, swelling power was determined using the following relationship:

$$\textit{Swelling power} = \frac{\textit{Weight of sedimented paste x 100}}{\textit{Weight of sample (dry basis) x (100-\% Solubility)}}$$

Pasting characteristics

The pasting characteristics of the starch samples were determined using the Brabender Viscograph instrument. First, the moisture content of

each sample was determined using an electronic moisture meter. The value of the moisture content of a sample was fed into the software of the Brabender Viscograph and the instrument automatically indicated the weight of starch sample to be used and the quantity of distilled water to be added to make a starch slurry (suspension).

The slurry was then put into the measuring bowl of the instrument and heated at a rate of 1.5°C/min. by means of a thermo-regulator. The start temperature was 50°C. When the suspension reached 95°C, it was held constant for 15 minutes (first holding period) while being continuously stirred. The paste was then cooled down to 50°C at a rate of 1.5°C/min, and held at this temperature for another 15 minutes (second holding period).

At the end of the process which took 1 hour 30 minutes, the following records were read from the Viscograph printed out by the instrument:

(a) Pasting temperature (°C)

(b) Pasting time (in minutes)

(c) Peak viscosity (in Brabender Units [BU])

(d) Viscosity at 95°C (BU)

(e) Viscosity after 15 minutes at 95°C (BU)

(f) Viscosity at 50°C (BU)

(g) Viscosity after 15 minutes at 50°C (BU)

(h) Paste stability at 95°C (BU)

(i) Paste stability at 50°C (BU)

(j) Setback viscosity (BU)

(k) Breakdown viscosity (BU)

Paste stability at 95°C and paste stability at 50°C were computed as the difference between viscosity at 95°C and viscosity after 15 minutes at 95°C; and the difference between viscosity at 50°C and viscosity after 15 minutes at 50°C respectively.

Determination of pH

Five grams of starch sample from each cassava genotype was weighed and made into slurry with 50ml of distilled water. The pH of the starch slurry was determined using corning Pinnacle pH meter.

Data analysis

Analyses of variance were conducted for yield and associated traits. Data were analyzed over two locations and at two harvesting ages. The F- tests and significance of the various main effects and interactions were determined using the appropriate error terms and degrees of freedom. Duncan's multiple range test was used to separate means whenever significant differences were detected (Gomez and Gomez, 1984). The proportions of the total sum of squares contributed by each source of variation were computed.

Stability analyses using Cultivar Superiority or Performance Measure (P_i) (Lin and Binns, 1988); Ecovalence (Wricke, 1962); Stability Variance (Shukla, 1972) and Additive Main Effects and Multiplicative Interaction (AMMI) (Piepho, 1996) were conducted. All analyses were done using Agrobase (Agrobase, 2000).

Variance components estimates

Variance components were estimated from mean squares of the combined analysis of variance data from two locations and at two harvesting ages.

Phenotypic variance, (σ_p^2), was estimated as

$$\sigma_P^2 = \sigma_g^2 + \sigma_{gl/l}^2 + \sigma_{e/rl}^2$$

Where σ_g^2 represents the variance component due to genotypes within populations, while σ_{gl}^2 represents the variance components due to genotype x environments. σ_e^2 is the variance components due to genotype x replication within environments (pooled whole plot error) while l and r represent the number of environments and replications respectively (Finne *et al*; 2000).

Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were estimated as:

$$PCV = \frac{\sqrt{\sigma_p^2}}{\bar{X}} x \quad 100$$

and

$$GCV = \frac{\sqrt{\sigma_g^2}}{\bar{X}} x \quad 100$$

Heritability (broad sense, h^2) was estimated as the ratio of genotypic variance to the phenotypic variance: $h^2 = \frac{\sigma_g^2}{\sigma_p^2}$ (Singh and Chaudhary, 1985)

CHAPTER FOUR

RESULTS

Experiment 1: Whitefly and ACMV scores for thirteen cassava genotypes cultivated at University of Ghana Farm, Legon and determined at three growth ages.

Whitefly population

One month after planting (MAP), the mean adult whitefly population was highest on accession H0015 with a mean count of 7 ranging from 5 to 11. The lowest count was recorded on H0008 with a mean value of 1 ranging from zero to 3 (Table 2). Eight cassava genotypes, including the two check varieties, that is, Afisiafi and Tek bankye registered mean whitefly counts above the overall mean of 6. The other genotypes had values below the mean. Accession 'H0008' had significantly ($P<0.05$) lower number of whiteflies than the remaining genotypes which showed no significant differences amongst themselves.

Recorded mean values of adult whitefly population on the cassava accessions and varieties 3MAP showed that 'UCC 096' was the least infested by whiteflies and 'H0015' the most infested. Generally the mean number of whiteflies counted on the genotypes were lower than that observed 1MAP

(Table 2), No significant (P>0.05) differences with respect to whitefly population 3MAP were detected among the genotypes.

TABLE 2: Whitefly population on eleven cassava accessions and two varieties determined at one, three and six months after planting (MAP) at Legon

Accession	Whitefly population		
	IMAP	3MAP	6MAP
H0008	0.56 b (0.1933)	1.03 a (0.3075)	0.69 fg (0.2279)
UCC 096	4.42 a (0.7338)	0.92 a (0.2833)	1.47 cdefg (0.3927)
H0001	5.96 a (0.8427)	2.80 a (0.5798)	1.23 defg (0.3483)
AFISIAFI*	6.62 a (0.8930)	2.46 a (0.5391)	2.42 abcde (0.5340)
H0015	7.23 a (0.9163)	2.36 a (0.5263)	2.89 abcd (0.5899)
UG 126	5.17 a (0.7905)	2.86 a (0.5866)	3.85 ab (0.6857)
UCC 90	6.19 a (0.8566)	2.51 a (0.5454)	4.07 a (0.7050)
UG 115	5.89 a (0.8380)	2.59 a (0.5551)	1.85 abcdef (0.4548)
TEK BANKYE*	6.78 a (0.8910)	2.76 a (0.5752)	3.34 abc (0.6375)
BOSOME NSIA	5.31 a (0.8015)	1.30 a (0.3617)	0.59 g (0.2014)
CRI/001/102	6.77 a (0.8903)	2.20 a (0.5051)	1.16 efg (0.3345)
DMA 030	7.19 a (0.9133)	3.0 a (0.4771)	1.19 defg (0.3404)
DMA 002	2.87 a (0.5874)	1.81 a (0.4487)	1.74 bcdefg (0.4378)
Mean	5.47 (0.8109)	2.35 (0.5250)	2.04 (0.4829)
C.V.(%)	26.03	33.79	33.10
P-Value	0.0139	0.1488	0.0031
S.E	1.47	0.382	0.325

* Released varieties (Control)

Means with the same letter within a column are not significantly (P<0.05) different

Values in brackets are transformed data.

The whitefly population decreased further at 6 MAP for most of the entries. The counts ranged from a low mean value of 1 on Bosome Nsia to a relatively high value of 4 on 'UCC 90'. Differences among genotypes were significant (P<0.05).

Level of African Cassava Mosaic Virus (ACMV) disease infection

Table 3 shows the ordinal scores of African cassava mosaic virus disease infection. Accession H0008 showed the highest level of tolerance of ACMV disease IMAP. 'DMA 002' was the most susceptible to ACMV disease at that growth stage of the plants with the highest mean symptom score value of 3. The two check varieties, that is, Afisiafi and Tek bankye had mean ordinal scores of 2 each.

At 6MAP, the highest ACMV disease score was registered by 'DMA 002' with a mean score of 4 and the lowest score by 'H0008' with a mean value of 1 (Table 3). The grand mean for the genotypes was 3 and seven genotypes including the two check varieties recorded ordinal scores higher than the grand mean.

TABLE 3: African cassava mosaic virus disease score on eleven cassava accessions and two varieties assessed at Legon.

Accession	Ordinal scores		
	IMAP	3MAP	6MAP
H0008	1.0 h (0.3010)	1.13 I (0.3284)	1.03 f (0.3075)
UCC 096	2.46 abcd (0.5391)	4.03 a (0.7016)	3.80 a (0.6812)
H0001	2.72 abc (0.5705)	3.15 cd (0.6180)	2.76 bc (0.5752)
AFISIAFI*	2.33 bcd (0.5224)	2.83 de (0.5832)	2.86 b (0.5866)
H0015	1.70 ef (0.4314)	2.40 fg (0.5315)	2.36 cd (0.5263)
UG 126	1.13 gh (0.3284)	1.80 h (0.4472)	1.76 e (0.4409)
UCC 90	1.19 gh (0.3404)	1.70 h (0.4314)	1.70 e (0.4314)
UG 115	2.90 ab (0.5911)	3.40 bc (0.6435)	3.17 b (0.6201)
TEK BANKYE*	2.21 cde (0.5065)	2.69 ef (0.5670)	2.93 b (0.5944)
BOSOME NSIA	2.06 de (0.4857)	2.58 ef (0.5539)	2.33 cd (0.5224)
CRI/001/102	2.91 ab (0.5922)	3.33 cd (0.6365)	3.17 b (0.6201)
DMA 030	1.49 fg (0.3962)	2.22 g (0.5079)	1.96 de (0.4713)
DMA 002	3.03 a (0.6053)	3.70 ab (0.6721)	3.93 a (0.6928)
Mean	2.09 (0.4899)	2.69 (0.5670)	2.60 (0.5563)
C.V.(%)	10.13	4.71	6.28
P-Value	0.0001	0.0001	0.0001
S.E	0.10	0.05	0.07

* Released varieties (Control)
All values are means of three replications.
Means with the same letter within a column are not significantly different at the 5%.
Values in brackets are transformed data.

NB: Score scale.

1 = no symptoms observed.

2 = mild chlorotic pattern on entire leaflets or mild distortion at base of leaflets appearing green and healthy.

3 = strong mosaic pattern on entire 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.

Interrelationships of whitefly populations, African cassava mosaic virus (ACMV) disease and growth and yield characters of cassava genotypes.

Mean values from analyses of data for the eleven cassava accessions and the two varieties were used to construct a Pearson's correlation matrix for growth and yield parameters and for whitefly counts and mosaic symptom scores (Table 4).

Numbers of adult whiteflies on cassava accessions and varieties were not significantly ($P>0.05$) correlated with all the growth and yield characters except starch weight and starch content where the correlation was significant ($P<0.05$) and negative. The correlation values for number of roots, root weight, individual tuber weight, fresh root yield and shoot weight were positive but very weak ranging in value from 0.006 to 0.436. However, the correlations for harvest index, starch content, starch weight, starch yield, dry root weight, root dry matter content and dry root yield were all negative. The correlation between whitefly population and ACMV disease was very weak and positive but not significant ($P>0.05$).

The overall correlation between ACMV disease scores and the yield characters of cassava accessions and varieties were negative except starch weight and starch content where positive but not significant ($P>0.05$) correlation values were registered (Table 4). The correlation values for number of roots, shoot weight, harvest index, starch weight, starch content, dry root weight and root dry matter content were not significant. However, correlation values for root weight, individual root tuber weight, fresh root yield, starch yield and dry root yield were significant.

TABLE 4: **Correlation matrix for whitefly population, mosaic symptom ordinal scores, agronomic traits and starch yield of thirteen cassava genotypes cultivated at Legon.**

1. Whitefly count		2	3	4	5	6	7	8	9	10	11	12	13	14
2. ACMVD score	0.03^{ns}													
3. No. of Roots	0.02^{ns}	-0.55^{ns}												
4. Root weight	0.01^{ns}	-0.75^{**}	-0.86^{***}											
5. Ind. root weight	0.14^{ns}	-0.62^{*}	-0.02^{ns}	0.46^{ns}										
6. Shoot weight	0.44^{ns}	-0.50^{ns}	0.63^{*}	0.45^{ns}	0.05^{ns}									
7. Fresh root yield	0.03^{ns}	-0.79^{**}	-0.85^{***}	-0.99^{***}	0.50^{ns}	0.50^{ns}								
8. Harvest index	-0.36^{ns}	-0.41^{ns}	0.33^{ns}	0.65^{*}	0.50^{ns}	-0.37^{ns}	0.24^{ns}							
9. Dry root weight	-0.51^{ns}	-0.13^{ns}	0.35^{ns}	0.31^{ns}	0.04^{ns}	0.18^{ns}	0.31^{ns}	0.65^{*}						
10. Root dry matter	-0.51^{ns}	-0.13^{ns}	0.35^{ns}	0.31^{ns}	0.04^{ns}	0.18^{ns}	0.32^{ns}	0.21^{ns}	0.99^{***}					
11. Dry root yield	-0.10^{ns}	-0.76^{**}	0.84^{***}	0.97^{***}	0.47^{ns}	0.48^{ns}	0.97^{***}	0.42^{ns}	0.50^{ns}	0.50^{ns}				
12. Starch weight	-0.58^{*}	0.26^{ns}	0.28^{ns}	0.24^{ns}	-0.27^{ns}	-0.36^{ns}	0.24^{ns}	0.46^{ns}	0.24^{ns}	0.45^{ns}	0.26^{ns}			
13. Starch content	-0.58^{*}	0.26^{ns}	0.28^{ns}	0.24^{ns}	-0.27^{ns}	-0.36^{ns}	0.18^{ns}	0.46^{ns}	0.44^{ns}	0.44^{ns}	0.26^{ns}	0.99^{***}		
14. Starch Yield	-0.04^{ns}	-0.74^{**}	0.85^{***}	0.99^{***}	0.46^{ns}	0.44^{ns}	0.99^{***}	0.66^{*}	0.36^{ns}	0.36^{ns}	0.98^{***}	0.29^{ns}	0.29^{ns}	

*, **, *** = significant at 0.05, 0.01 and 0.001 probability levels respectively
ns = not significant (P>0.05)

Number of roots

At twelve months after planting (MAP) variety Afisiafi (control) recorded the highest of three roots per plant (Table 5). This was closely followed by accession 'H0008'. Three accessions, namely: 'UG 126', 'Bosome Nsia' and 'DMA 030' registered the same number of roots per plant of 2.44. Accession 'DMA 002' gave the lowest number of roots of 1.12 which was about two and half times lower than the highest value of 2.89 recorded by Afisiafi.

Significant ($P<0.05$) treatment effects were obtained.

TABLE 5: Agronomic traits values of eleven cassava accessions and two released varieties twelve months after planting at Legon

Cassava Accession	Number of roots per plant	Fresh root weight (kg)	Individual root weight (g)	Shoot weight (kg/plant)
H0008	2.51 ab	2.44 a	972.11 a	1.53 cd
UCC 096	2.11 bcd	1.60 cde	758.29 a	1.53 cd
H0001	2.11 bcd	1.58 cde	748.82 a	1.38 cd
AFISIAFI*	2.89 a	2.32 ab	802.77 a	2.71 a
H0015	2.37 abc	2.29 ab	966.24 a	1.64 c
UG 126	2.44 ab	2.23 ab	913.93 a	2.47 a
UCC 90	1.67 cde	1.86 bcd	1113.77 a	2.66 a
UG 115	1.60 de	1.24 ef	775.0 a	1.40 cd
TEK BANKYE*	1.38 de	1.49 cde	1079.71 a	1.49 cd
BOSOME NSIA	2.44 ab	1.67 cde	684.43 a	2.12 b
CRI/001/102	1.81 bcde	1.37 de	756.91 a	1.29 d
DMA 030	2.44 ab	2.03 abc	831.97 a	2.17 b
DMA 002	1.12 e	0.81 f	723.21 a	0.98 e
Mean	2.07	1.76	855.94	1.80
C.V. (%)	19.44	16.75	18.59	8.92
P-Value	0.0004	0.0001	0.0502	0.0001
S.E	0.33	0.25	44.86	0.13

* Released varieties (Control)
All values are means of three replications
Means with the same letter within a column are not significantly different at the 5%.

Fresh root weight (kg)

Fresh root weights obtained at 12MAP by the cassava genotypes varied from the lowest value of 0.81 kg to the highest value of 2.44 kg recorded by 'DMA 002' and 'H0008' respectively (Table 5). Variety 'Afisiafi' and three other accessions excluding H0008 registered fresh root weights that were above 2.0 kg. Tek bankye which was also a release variety and three other accessions excluding DMA 002 recorded fresh root weights below 2.0 kg. Treatment differences were significant ($P<0.05$).

Individual root weight (g)

Individual root weights are presented in Table 5. The values ranged between the lowest of 684.43g and the highest of 1113.77g for 'Bosome Nsia' and 'UCC 90' respectively. No significant ($P>0.05$) differences were detected amongst the treatments but quantitatively, relatively large treatment mean value differences were recorded.

Shoot weight (kg/plant)

Shoot weights of the cassava genotypes are presented in Table 5. Variety 'Afisiafi' showed the highest shoot weight of 2.71 kg/plant and accession 'DMA 002' the lowest value of 0.98 kg/plant. Accessions 'UCC 90' and 'UG 126' produced shoot weights of 2.66 kg/plant and 2.47 kg/plant respectively and these values were not significantly different from the highest value. The lowest value of 0.98 kg/plant was significantly ($P<0.05$) different from all the other remaining genotypes.

Fresh root yield (t/ha)

Table 6 shows the fresh root yield per plant of the accessions. Accession 'H0008' out-yielded all the other cassava genotypes tested with yield value of 24.4 t/ha. However, the yields obtained by 'Afisiafi', 'H0015', 'UG 126', and 'DMA 030' which were 23.2 t/ha, 22.9 t/ha, 22.3 t/ha and 20.3 t/ha in that order were not significantly different from the highest yield. The lowest yield which was 8.1 t/ha recorded by 'DMA 002' was about three times lower than the highest yield.

TABLE 6: Production traits values of eleven cassava accessions and two released varieties twelve months after planting at Legon

Cassava Accession	Fresh root yield (t/ha)	Harvest index	Dry root weight (g)	Root dry matter content (%)
H0008	24.4 a	0.61 a	201.17 ab	40.23 ab
UCC 096	16.0 cde	0.49 cde	198.83 abc	39.70 abc
H0001	15.8 cde	0.53 bc	197.17 bcd	39.43 bc
AFISIAFI*	23.2 ab	0.46 def	190.50 cde	38.10 dc
H0015	22.9 ab	0.58 ab	180.33 fg	36.07 ef
UG 126	22.3 ab	0.47 cdef	172.83 g	34.57 f
UCC 90	18.6 bcd	0.42 f	198.0 bcd	39.60 abc
UG 115	12.4 ef	0.47 cdef	173.0 g	34.60 f
TEK BANKYE*	14.9 cde	0.49 cde	189.83 de	37.97 cd
BOSOME NSIA	16.7 cde	0.44 ef	207.0	41.40 a
CRI/001/102	'3.7 de	0.51 cd	194.67 bcd	38.93 bcd
DMA 030	20.3 abc	0.48 cdef	195.17 bcd	39.03 bc
DMA 002	8.1 f	0.45 def	185.83 ef	37.17 de
Means	aaaa	0.49	191.10	38.22
C.V. (%)	16.75	6.75	2.59	2.59
P-Value	0.0001	0.0001	0.0001	0.0001
S.E	Aaaaa	0.01	4.05	0.27

* Released varieties (Control)
All values are means of three replications
Means with the same letter within a column are not significantly different at the 5%

Harvest index

Harvest index at 12 MAP for the cassava genotypes ranged from the lowest value of 0.42 to the highest of 0.61 for 'UCC 90' and 'H0008' respectively (Table 6). Significant ($P<0.0001$) treatment differences in harvest index values were observed. However, the harvest index values for the two released varieties (Afisiafi and Tek bankye) which served as the control treatments were not significantly different from each other.

Dry root weight (g)

Dry root weights of the cassava genotypes 12MAP are indicated in Table 6. Accession 'Bosome Nsia' registered the highest value of 207.0g and this was closely followed by 'H0008' and 'UCC 096' with values of 201.17g and 198.83g respectively. The dry root weight of 172.83 g manifested by 'UG 126' was the lowest and this did not differ significantly from the dry root weight of 173.0 g and 180.33 recorded by 'UG 115' and 'H0015' in that order.

Root dry matter content (%)

The range of variation in the root dry matter content of the eleven cassava accessions and two varieties was quite low. The lowest value was 34.57% and the highest 41.40% indicated by 'UG 126' and 'Bosome Nsia'. The two control varieties, that is, 'Afisiafi' and 'Tek bankye' registered values of 38.10% and 37.97% respectively which were not significantly different from each other.

The coefficient of variation (CV) value was remarkably low-2.59% - indicating a high level of precision with which the treatments were compared and a good index of reliability of the experiment (Table 6).

Dry root yield (g/plant)

Accession 'H0008' had the highest dry root yield of 981.61 g/plant and 'DMA 002' the lowest of 301.08 g/plat. The range was quite large. The dry root yield of 'Afisiafi' which was 883.92 g/plant was not significantly different from the highest yield. However, 'Tek bankye', the other control treatment had a value of 565.75 g/plant which was significantly different from the highest yield (Table 7).

Another notable observation was that the dry root yield of 'UG 115' which was 429.04 g/plant was the only value which was not significantly different from the lowest dry root yield.

TABLE 7: Agronomic traits data and starch data of eleven cassava accessions and two varieties twelve months after planting at Legon

Cassava Accession	Dry root yield (g/plant)	Starch weight (g)	Starch Content (%)	Starch yield (g/plant)
H0008	981.61 a	123.50 a	24.72 a	603.17 a
UCC 096	635.20 cde	124.0 a	24.80 a	396.80 bcd
H0001	622.99 cde	123.50 a	24.71 a	390.42 bcd
AFISIAFI*	883.92 ab	125.0 a	25.01 a	580.23 a
H0015	826.0 abc	121.50 a	24.31 a	556.69 a
UG 126	770.91 bcd	118.0 a	23.60 a	526.28 ab
UCC 90	736.56 bcde	123.676 a	24.73 a	459.98 abc
UG 115	429.04 fg	115.33 a	23.07 a	286.07 de
TEK BANKYE*	565.75 def	123.83 a	24.77 a	369.07 cd
BOSOME NSIA	691.38 bcde	117.83 a	23.57 a	393.62 bcd
CRI/001/102	533.334 ef	121.67 a	24.33 a	333.32 cde
DMA 030	792.31 abc	118.17 a	23.63 a	479.69 abc
DMA 002	301.08 g	123.83 a	24.77 a	200.64 e
Mean	674.62	121.53	24.31	428.92
C.V. (%)	16.27	4.71	4.71	16.75
P-Value	0.0001	0.5658	0.5658	0.0001
S.E	91.27	4.67	0.32	66.04

* Released varieties (Control).
All values are means of three replications.
Means with the same letter within a column are not significantly different at the 5%.

Starch weight (g)

Starch weight values are presented in Table 7. The values were quite uniform with the highest being 125 g and the lowest 115.38 g produced by 'Afisiafi' and 'UG 115' respectively. No significant treatment differences were observed among the genotypes.

Starch content (%)

Percentage starch content values from the thirteen cassava genotypes are presented in Table 7. Variety 'Afisiafi' had roots with the highest starch content of 25% and accession 'UG 115' producing roots with the lowest starch

content of 23.07%. Statistically, however, all the recorded values were not significantly different from each other.

Starch yield (g/plant)

At the growth stage of 12 MAP, accession 'H0008', variety 'Afisiafi' and accession 'H0015' were the three top starch yielders with values of 602.68g/plant, 580.23g/plant, and 556.69g/plant respectively (Table 7). 'DMA 002' was the accession identified with the lowest starch yield of 200.64g/plant. The other control variety, that is, 'Tek bankye' performed poorly with a starch yield of 369.07g/plant as compared to that registered by variety 'Afisiafi'. Significant ($P<0.05$) treatment effects were registered.

Rankings of accessions and varieties for various production traits

Agronomic traits:

Table 8 gives the ranks of the genotypes with respect to agronomic traits scored. The top ten ranking genotypes that performed well were: 'H0008', 'Afisiafi' (control), 'DMA 030', 'H0015', 'Bosome Nsia', 'UG 126', 'UCC 096', 'UCC 90', 'H0001' and ' CRI/001/102'.

Out of these, the first nine genotypes were selected excluding 'UCC 096' because the observed morphological characteristics of its root tubers were not desirable. For instance, the roots were unusually long and thin, very fibrous at the proximal end and brittle at the distal end resulting in cleavages when being up-rooted.

TABLE 8: Rankings of eleven cassava accessions and two varieties in terms of agronomic characteristics

Accession/ variety	No. of roots	Fresh root weight (kg)	Fresh root yield (t/ha)	Harvest index	Root dry matter content (%)	Dry root yield (g/plant)	Rank sum	Overall rank
H0008	2	1	1	1	2	1	8	1
UCC 096	5	8	8	5	3	8	37	7
H0001	5	9	9	3	5	9	40	8
AFISIAFI*	1	2	2	8	8	2	23	2
H0015	4	3	3	2	11	3	26	3
UG 126	3	4	4	7	13	5	36	6
UCC 90	7	6	6	11	4	6	40	8
UG 115	8	12	12	7	12	12	63	11
TEKBANKYE*	9	10	10	5	9	10	53	10
BOSOME	3	7	7	10	1	7	35	5
NSIA	6	11	11	4	7	11	50	9
CRI/001/102	3	5	5	6	6	4	29	4
DMA 030	10	13	13	9	10	13	68	12
DMA 002								

*Released varieties (Control)

Rank: 1= highest... 10 = lowest

Overall rank: lowest = best; highest = worst

Starch yield characteristics

Summary of starch yield characteristics are presented in Table 9. The ranking procedure followed the same pattern as was done with the agronomic traits. The ten outstanding starch yielders were: 'H0008', 'Afisiafi', 'UCC 096', 'H0015', 'UCC 90', 'UG 126', 'H0001', 'DMA 030', 'Bosome Nsia' and 'Tek bankye'. The first nine genotypes were selected excluding 'UCC 096' because of its unusual root characteristics which have been alluded to already.

TABLE 9: Rankings of eleven cassava accessions and two varieties in terms of starch yield characteristics

Accessions /variety	Starch weight (g)	Starch content (%)	Starch yield (g/plant)	Rank sum	Overall rank
H0008	5	5	1	11	2
UCC 096	2	2	7	11	2
H0001	5	6	9	20	7
AFISIAFI*	1	1	2	4	1
H0015	7	8	3	18	5
UG 126	9	10	4	23	9
UCC 90	4	4	6	14	3
UG 115	11	12	12	35	12
TEKBANKYE*	3	3	10	16	4
BOSOME NSIA	10	11	8	29	11
CRI/001/102	6	7	11	24	10
DMA 030	8	9	5	22	8
DMA 002	3	3	13	19	6

* Released varieties (Control)

Rank: 1= highest, ...; 10 = lowest

Overall rank: lowest = best; highest = worst

Whitefly populations and ordinal scores of ACMV disease

Owing to the lack of significant (P>0.05) correlations between whitefly counts and most of the plant characteristics studied (Table 4), whitefly counts were not considered in the selection process of elite cassava genotypes. However, ACMV disease severity was taken into account in the selection process and the summary results are shown in Table 10. In contrast to the ranking procedure adopted in agronomic traits and starch yield characteristics where cassava genotypes were ranked from the highest score to the lowest, ACMV disease ranking was done from the lowest (the least affected genotype) to the highest (the most susceptible).

TABLE 10: Rankings of thirteen cassava genotypes in terms of ordinal scores of ACMV disease assessed at one, three and six months after planting (MAP)

Accessions /variety	1 MAP	3 MAP	6 MAP	Rank sum	Overall rank
H0008	1	1	1	3	1
UCC 096	9	13	11	33	11
H0001	10	9	7	26	9
AFISIAFI*	8	8	8	24	8
H0015	5	5	6	16	5
UG 126	2	3	3	8	3
UCC 90	3	2	2	7	2
UG 115	11	11	10	32	10
TEKBANKYE*	7	7	9	23	7
BOSOME NSIA	6	6	5	17	6
CRI/001/102	12	10	10	32	10
DMA 030	4	4	4	12	4
DMA 002	13	12	12	37	12

* Released varieties (Control)

Rank: 1= highest, ...; 10 = lowest

Overall rank: lowest = best; highest = worst

The 10 genotypes that were least affected by ACMV disease were: 'H0008', 'UCC 90', 'UG 126', 'DMA 030', 'H0015', 'Bosome Nsia', 'Tek bankye', 'Afisiafi', 'H0001' and 'UG 115'. Eight genotypes were selected including Afisiafi but excluding Tek bankye because it performed relatively poorly in other plant characteristics considered when compared to Afisiafi, the other released check variety.

Conclusion

From the results obtained and the analyses made, it has been demonstrated clearly that seven cassava accessions, namely: 'H0008',

'H0015', 'UG 126', 'DMA 030', 'UCC 90', 'H0001' and 'Bosome Nsia' and one of the released varieties, that is, 'Afisiafi', were the top performers with respect to the plant characteristics studied. Therefore, those cassava accessions were selected for further evaluation, using Afisiafi as the check variety in two agro-ecological zones, Legon (coastal savanna) and Bunso (deciduous forest).

Results of Experiment II: Evaluation of eight cassava genotypes at two agro-ecological zones for acceptable production traits

Whitefly population

The number of whiteflies on seven cassava accessions and one variety counted at Legon and Bunso is shown in Table 11. The highest average number of whiteflies which was 7 was recorded on 'Afisiafi', the check variety at Legon. The lowest mean count was 1 and this was found on accession 'H0008'. The overall mean count was 4 and four cassava genotypes had mean counts below this grand mean whilst the others registered higher counts above the grand mean.

Table 11: Mean whitefly counts on seven cassava accessions and one variety at Legon and Bunso.

Accessions /variety	1MAP		3MAP		6MAP	
	Legon	Bunso	Legon	Bunso	Legon	Bunso
AFISIAFI*	7a (0.9165)	3ab (0.6085)	2a (0.5403)	2a (0.5403)	2a (0.5403)	3cd (0.6085)
BOSOME NSIA	6a(0.8651)	4a (0.7101)	1a (0.3160)	2a (0.5403)	1a (0.3160)	5a (0.7513)
H0001	6a (0.8651)	2c (0.5403)	2a (0.5403)	2a (0.5403)	2a (0.5403)	3d (0.6085)
UCC 90	2b (0.5403)	4a (0.7101)	2a (0.5403)	3a (0.6085)	1a (0.3160)	4a (0.7101)
DMA 030	1c (0.3160)	4a (0.7101)	2a (0.5403)	2a (0.5403)	1a (03160)	4a (0.7101)
UG 126	3b (0.6085)	3ab (0.6085)	2a (0.5403)	2a (0.5403)	1a (0.3160)	3d (0.6085)
H0015	6a (0.8651)	4a (0.7101)	2a (0.5403)	3a (0.6085)	2a (0.5403)	4a (0.7101)
H0008	1c (0.3160)	2c (0.5403)	1a (0.3160)	1a (0.3160)	1a (0.3160)	2c (0.5403)
Mean	4 (0.7101)	3 (0.6085)	2 (0.5403)	2 (0.5403)	1 (0.3160)	3 (0.6085)
C.V. (%)	14.75	12.32	38.57	17.70	59.89	5.64
P – Value	0.0001	0.0182	0.5059	0.0988	0.1898	0.0001
S.E	0.02	0.16	0.37	0.19	0.44	0.67

* Released varieties (Control)
All values are means of three replications.
Means with the same letter are not significantly different at the 5% level.

The range of whitefly counts at Bunso was quite narrow than what was obtained at Legon. The maximum mean count was 4 and the minimum 2 with an overall mean of 3. At both Legon and Bunso, accession 'H0008' recorded the lowest mean number of whiteflies. Significant ($P<0.05$) differences in whitefly population were observed at both location 1MAP.

Relatively low adult whitefly population values were recorded at both Legon and Bunso on the cassava genotypes 3MAP. Then highest mean whitefly count was 3 on 'UG 126' and the lowest was 1 on 'H0008'.

Comparable whitefly counts at Bunso were 3 on 'UCC 90' and 1 on 'H0008'. No significant ($P>0.05$) treatment effects were detected at both locations (Table 11).

At six months after planting, whitefly population on the cassava genotypes at Legon varied from a mean low value of 1 a high of 2 recorded on 'H0008' and 'H0001' respectively (Table 11). Treatment effects were not significantly ($P>0.05$) different.

Whitefly population values at Bunso were relatively higher than the values recorded at Legon. The highest mean count was 5 on 'Bosome Nsia' and the least of 2 was registered by 'H0008'. Significant differences in whitefly population were observed amongst the cassava genotypes at Bunso.

Severity of African Cassava Mosaic Virus (ACMV) disease infection

Ordinal scores of ACMV disease on the different cassava genotypes at Legon and Bunso are presented in Table 12. The mean scores varied from 1.0 on four accessions, namely: 'H0008', 'UG 126', 'DMA 030' and 'UCC 90' to a high of 1.8 scored on 'Afisiafi', the check variety. At Bunso the highest

score was 2.1 on 'Afistaff'. The lowest was 1.3 scored on four accessions - 'ECC 90', 'DMA 030', 'ECG 126' and 'H0008'. The grand mean ordinal score was 1.4 at Bunso which was higher than the grand mean score of 1.2 registered at Legon. Significant ($P<0.05$) differences in ordinal scores were noted at both locations (Table 12).

TABLE 12: Ordinal scores of African Cassava Mosaic Virus (ACMV) disease on seven cassava accessions and one variety at Legon and Bunso.

Accessions /variety	1MAP		3MAP		6MAP	
	Legon	Bunso	Legon	Bunso	Legon	Bunso
AFISIAFI*	1.8a (0.4472)	2.1a (0.4843)	2.0a (0.4771)	3.8a (0.6776)	1.7b (0.4314)	3.9a (0.6893)
BOSOME NSIA	1.1b (0.3284)	1.6b (0.4082)	1.4b (0.3766)	2.2b (0.5092)	1.5cd (0.3892)	2.6b (0.5551)
H0001	1.2ab (0.3385)	2.1a (0.4843)	1.9a (0.4624)	2.2b (0.5092)	2.0a (0.4771)	2.2bc (0.5092)
UCC 90	1.0b (0.3010)	1.0e (0.3010)	1.3b (0.3598)	1.2cd (0.3385)	1.6bc (0.4082)	1.1d (0.3284)
DMA 030	1.0b (0.3010)	1.0e (0.3010)	1.3b (0.3598)	1.3c (0.3598)	1.5cd (0.3892)	1.2d (0.3385)
UG 126	1.0b (0.3010)	1.0e (0.3010)	1.4b (0.3766)	1.2cd (0.3385)	1.5cd (0.3892)	1.2d (0.3385)
H0015	1.3b (0.3598)	1.3b (0.3598)	1.3b (0.3598)	1.9b (0.4624)	1.4de (0.3766)	2.1c (0.4843)
H0008	1.0b (0.3010)	1.0e (0.3010)	1.0c (0.3010)	1.0d (0.3010)	1.2e (0.3385)	1.0d (0.3010)
Mean	1.2 (0.3385)	1.4 (0.3766)	1.5 (0.3892)	1.9 (0.4624)	1.6 (0.4082)	1.9 (0.4624)
C.V. (%)	19.12	7.6	7.2	6.12	5.61	6.66
P – Value	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001
S.E	0.01	0.01	0.01	0.05	0.01	0.05

* Released variety (control)
All values are means of three replications
Means with the same letter are not significantly different at the 5% level.

'Afisiafi', the check variety recorded the highest ACMV disease score of 2.0 at Legon and accession 'H0008' the lowest value of 1.0. Three accessions, 'UCC 90', 'DMA 030' and 'H0015' recorded the same ordinal score of 1.3. 'Bosome Nsia' and 'UG 126' also recorded the same score of 1.4 (Table 12).

The highest ACMV disease mean score of 3.8 was again manifested by 'Afisiafi' at Bunso and the lowest mean score of 1.0 by yet again 'H0008'. Significant ($P<0.05$) differences in ACMV disease scores were obtained at both locations.

At 6 MAP the accession 'H0001' had the highest score of 2.0 at Legon whilst 'Afisiafi' the highest mean score of 3.9 at Bunso. Accession 'H0008' registered the lowest mean scores of 1.2 and 1.0 at Legon and Bunso respectively. Significant ($P<0.05$) differences in treatment mean scores were observed at both locations.

Number of roots per plant

The results of the number of roots per plant eight and twelve months after planting (8 and 12 MAP) at Legon and Bunso are presented in Table 13. differences among genotypes at Legon were significant ($P<0.05$) whilst no significant differences were detected at Bunso at 8 MAP.

It was observed that accession 'DMA 030' recorded the highest mean number of roots per plant of 7.04 at 8 MAP (Table 13) and variety 'Afisiafi' (the control treatment) the least value of 2.80 roots per plant. Comparable treatment mean values at Bunso, though not significantly different ($P>0.05$)

were relatively lower with the highest being 3.28 root per plant registered by 'H0001' and the lowest value being 2.33 roots per plant recorded by 'UCC 90'.

TABLE 13: Mean number of roots of seven cassava accessions and one variety evaluated eight and twelve months after planting (MAP) at Legon and Bunso

Accession/ variety	Number of roots per plant*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	2.80 d	2.72 a	2.84 d	2.89 a
BOSOME NSIA	3.87 cd	2.85 a	3.82 c	3.01 a
H0001	4.20 cd	3.28 a	2.40 d	3.85 a
UCC 90	3.76 cd	2.33 a	4.70 b	2.45 a
DMA 030	7.04 a	2.89 a	6.10 a	2.78 a
UG 126	4.20 cd	3.11 a	3.91 bc	3.52 a
H0015	5.78 ab	2.53 a	6.72 a	2.55 a
H0008	4.77 bc	2.52 a	3.29 cd	2.67 a
Mean	4.55	2.78	4.22	2.97
C.V. (%)	22.01	13.50	11.86	28.34
P-Value	0.0029	0.1021	0.0001	0.9112
S.E	0.36	0.39	0.18	0.87

** Released variety (control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

At 12 MAP cassava genotypes planted at Legon showed highly significant differences amongst the mean number of roots per plant. Accession 'H0015' showed the highest number of roots per plant and 'H0001' the least value of 6.72 and 2.40 kg respectively. 'H0001' had the highest number of

roots per plant and 'UCC 90' the lowest number at Bunso and as was observed at 8 MAP, the mean number of roots were not significantly different.

When the pooled results from the two locations and two ages of harvesting, that is, 8 MAP at Legon and Bunso and 12 MAP at Legon and Bunso were subjected to analysis of variance computation, it was found out that environment and genotype main effects were highly significant ($P<0.001$) contributing 54.25 and 9% to the total sum of square respectively. However, the interaction of genotype x environment was not significant ($P>0.05$) (Table 15).

Fresh root weight (kg)

Table 14 shows the results of fresh root weights of seven cassava accessions and one variety obtained from Legon and Bunso at 8 and 12 MAP. The treatment effects were significant ($P<0.05$) at both Legon and Bunso. At Legon accession 'H0015' recorded the highest fresh root weight of 1.67 kg and 'H0001' the lowest value of 0.70 kg. Variety Afisiafi which was the control treatment had a mean fresh root weight of 0.81 kg which was the same value registered by accession 'UCC 90'.

Relatively higher mean fresh root weights were obtained at Bunso where the highest mean value was 1.27 kg recorded by 'Bosome Nsia' and the least value was 1.01 kg manifested by 'H0015'showed significant difference ($P< 0.05$)

Twelve months after planting (MAP) fresh root weights of the cassava accessions and the variety (control) planted at Legon varied from the lowest value of 1.42 kg to the highest of 2.84 kg recorded by 'H0001' and 'H0015'

respectively. Significant (P<0.05) differences were registered amongst the cassava genotypes.

Fresh root weights recorded at Bunso 12MAP did not significantly (P>0.05) differ from each other even though higher values were obtained relative to the values recorded at Legon (Table 14).

Pooled data from the four environments showed very highly significant (P<0.0001) environment main effect whilst the main effect of genotype and the interaction of genotype by environment were not significant (Table 15).

TABLE 14: Mean fresh root weights of seven cassava accessions and one variety evaluated at eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Fresh root weight (kg)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	0.81 d	1.11 b	2.43 b	2.85 a
BOSOME NSIA	1.14 c	1.27 a	1.67 d	3.03 a
H0001	0.70 e	1.26 a	1.42 d	3.49 a
UCC 90	0.81 d	1.07 b	2.19 c	2.13 a
DMA 030	1.43 b	1.06 b	2.61 b	2.71 a
UG 126	1.11 c	1.20 a	2.45 b	3.24 a
H0015	1.67 a	1.01 b	2.84 a	2.39 a
H0008	0.76 de	1.15 b	2.23 c	2.28 a
Mean	0.96	1.14	2.23	2.77
C.V. (%)	7.87	7.77	8.94	32.69
P-Value	0.0001	0.0401	0.0001	0.5592
S.E.	0.03	0.09	0.08	1.12

** Released variety (control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

TABLE 15: Combined analysis of variance for number of roots per plant and fresh root weight of eight cassava genotypes evaluated in four environments

Source of Variation	Df	Number of roots per plant		Fresh root weight (kg)	
		Mean squares	Contribution to SS (%)	Mean squares	Contribution to SS (%)
Environment	3	117.332***	54.25	337.556***	78.79
Genotype	7	8.346**	9.0	1.786ns	0.97
Gen. x Env.	21	3.222ns	10.43	3.176ns	5.19
Error	64	2.668	26.32	3.023	15.05

, * = Significant at 0.01 and 0.001 probability levels respectively
ns = not Significant
SS = Sum of Squares

Individual root weight (g)

Mean values for individual root weights for the cassava genotypes at Legon and Bunso 8 and 12 MAP are shown in Table 16. 'Bosome Nsia' gave the highest value of 294.57 g and 'H0008' the least value of 159.37 g at Legon whilst 'UCC 90' and 'DMA 030' produced the highest and lowest values of 459.23g and 366.78g respectively at Bunso. At both locations treatment effects were significant ($P<0.05$).

TABLE 16: Individual root weights of seven cassava accessions and one variety evaluated at eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Individual root weight (kg)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	289.30 a	408.09 abc	855.63 a	986.16 a
BOSOME NSIA	294.57 a	445.61 ab	437.17 c	1006.64 a
H0001	164.46 bc	384.15 bc	591.67 bc	906.49 a
UCC 90	213.40 abc	459.23 a	463.93 bc	869.39 a
DMA 030	203.07 abc	366.78 c	427.87 c	974.82 a
UG 126	264.43 ab	385.85 bc	626.60 bc	920.45 a
H0015	288.70 a	399.83 abc	422.62 c	937.25 a
H0008	159.37 c	456.35 a	677.81 b	837.25 a
Mean	234.66	413.24	562.91	929.81
C.V. (%)	22.36	8.87	18.28	14.85
P-Value	0.0226	0.0432	0.0010	0.1049
S.E.	18.61	12.96	41.18	58.59

** **Released variety (control)**

* All values are means of three replications and means with the same letter within a column are not significantly different.

'Afisiafi' the released variety which served as the control treatment registered the highest value of 855.63 g at Legon 12 MAP and 'H0015' the lowest value of 422.62g. Individual root weights recorded at Bunso 12 MAP were in general higher than corresponding values at Legon but no significant ($P>0.05$) treatment effects were noted (Table 16).

Pooled analysis of variance of the individual root weights data showed very highly significant ($P<0.0001$) environment and genotype main effects and highly significant ($P<0.001$) genotype x environment interaction (Table 18).

Since the genotype by environment interaction was significant for individual root weights, it was difficult to single out superior genotypes using the main effects only. Therefore, stability analyses were done using the

following stability parameters: Cultivar superiority or performance measure (P_i) (Lin and Binns, 1988); Wricke (1962) Ecovalence (W_i); Stability variance (Shukla, 1972) and Additive Main Effects and Multiplicantive Interaction (AMMI) (Piepho, 1996). These stability parameters have been employed by Benesi *et al.*, (2004) to identify superior cassava genotypes when twenty cassava genotypes were studied in Malawi.

According to cultivar performance measure (P_i), 'Afisiafi', 'UG 126', and 'H0015' were the three most stable genotypes in relation to individual root tuber weight (Table 19). Using the W_i-ecovalence stability statistic, 'H0015', 'UG 126' and 'H0001' were the most stable accessions. Stability variance anlysis indicated that 'UG 126', 'H0015'and 'H0001' whilst AMMI computations showed 'Afisiafi', 'H0008' and 'H0001' as the most stable cassava genotypes.

The overall ranking of the genotypes for stability using the four stability parameters identified 'UG 126', 'H0015', 'H0008' and 'H0001' as the most stable genotypes (Table 19).

Shoot weight (kg/plant)

At 8MAP, the highest shoot weight was 1.39 kg per plant and the lowest was 0.98 kg per plant indicated by 'DMA 030' and 'H0001' respectively at Legon (Table 17). No significant ($P>0.05$) differences in shoot weights amongst the cassava genotypes at Legon were observed.

TABLE 17: Shoot weights of seven cassava accessions and one variety evaluated at eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Shoot weight (kg/plant)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	1.10 a	1.60 a	1.99 a	1.82 bc
BOSOME NSIA	1.19 a	1.38 b	1.02 b	2.38 b
H0001	0.98 a	1.84 a	1.24 b	2.74 b
UCC 90	1.07 a	1.36 b	1.28 b	1.74 c
DMA 030	1.39 a	1.41 b	1.33 b	1.59 d
UG 126	1.09 a	1.20 c	1.41 b	3.80 a
H0015	1.38 a	1.14 c	2.94 a	1.34 e
H0008	1.02 a	0.70 e	1.39 b	1.12 e
Mean	1.15	1.33	1.58	2.07
C.V. (%)	21.31	13.96	15.24	33.28
P-Value	0.3478	0.0031	0.0006	0.0070
S.E.	0.09	0.19	0.52	0.86

** Released variety (control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

Shoot weight values recorded by the cassava genotypes at Bunso 8 MAP ranged from the highest value of 1.84 kg/plant for 'H0001' to the lowest of 0.70 kg/plant registered by 'H0008'. The values recorded for shoot weights at Bunso were relatively higher than corresponding values obtained at Legon. Significant ($P<0.05$) treatment effects were observed at Bunso (Table 17).

TABLE 18: Combined analysis of variance for individual root weight and shoot weight of eight cassava genotypes evaluated in four environments

Source of Variation	Df	Individual root tuber weight (g)		Shoot weight (kg)	
		Mean squares	Contribution to SS (%)	Mean squares	Contribution to SS (%)
Environment	3	3479358.71***	75.25	192.861***	65.37
Genotype	7	193856.68***	5.24	8.376***	6.63
Gen. x Env.	21	58493.55**	8.86	6.935***	16.46
Error	64	23072.74	10.65	1.596	11.54

, * = Significant at 0.01 and 0.001 probability levels respectively
ns = not Significant (P>0.05)
SS = Sum of Squares

Accession 'H0015' had the highest shoot weight of 2.94 kg/plant and this was closely followed by 'Afisiafi' (a check treatment) with a value of 1.99 kg/plant at Legon 12 MAP. The lowest shoot weight value of 1.02 kg/plant was produced by 'Bosome Nsia' (Table 17).

At Bunso 12 MAP, shoot weight values varied from the highest of 3.80 kg/plant by 'UG 126' to the lowest of 1.12 kg/plant manifested by accession 'H0008'. The shoot weight difference between the highest and the lowest was quite high and the highest shoot weight was about 3 times larger than the lowest shoot weight.

Combined analysis of variance of shoot weights from the four environments showed highly significant (P<0.0001) main effects for environment, genotype x environment interaction (Table 18).

TABLE 19: **Summary of stability statistics for individual root weight from seven cassava accessions and one variety evaluated at Legon and Bunso**

Cassava Genotype	Cultivar Superiority Measure		Wi-ecovalence		Stability Variance-no Covariate		AMMI		Overall Rank
	P_i GxE	Rank	W_i GxE Stat.	Rank	σ_i^2 GxE	Rank	IPCA Scores	Rank	
AFISIAFI*	305.556	1	226504.866	8	292262.564	8	-20.1546	1	4
BOSOME NSIA	83489.961	6	43385.631	6	48103.584	6	8.6146	8	6
H0001	55643.288	5	23017.150	3	20945.609	3	0.3997	3	3
UCC 90	99043.711	8	57784.816	7	67302.498	7	5.8630	6	7
DMA 030	88818.059	7	23946.604	5	22184.881	5	6.0278	7	5
UG 126	48994.336	2	8501.931	2	1591.984	1	0.6437	4	1
H0015	50014.328	3	2656.778	1	6201.554	2	0.7195	5	2
H0008	53725.656	4	23447.036	4	21518.791	4	-2.1138	2	3

* Released variety (Control)

Fresh root yield (t/ha)

The highest fresh root yield was recorded by accession 'H0015' and the lowest by 'H0001' with values of 16.73 t/ha and 7.04 t/ha respectively at Legon 8MAP (Table 20). Highly significant (P<0.0001) differences were detected amongst the genotypes.

TABLE 20: Fresh root yields of seven cassava accessions and one variety evaluated at eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Fresh root yield (t/ha)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	8.07 d	11.10 a	23.43 b	28.50 b
BOSOME NSIA	11.37 c	12.70 a	16.70 d	30.30 a
H0001	7.04 e	12.60 a	14.20 d	34.90 a
UCC 90	8.10 d	10.70 a	21.90 c	21.30 c
DMA 030	14.33 b	10.60 a	26.10 a	27.10 b
UG 126	11.10 c	12.01 a	24.50 b	32.40 a
H0015	16.73 a	10.10 a	28.40 a	23.90 c
H0008	7.63 de	11.50 a	22.33 c	22.80 c
Mean	10.55	11.42	22.20	27.65
C.V.(%)	7.87	7.79	8.92	21.69
P-Value	0.0001	0.6697	0.0001	0.03692
S.E.	0.43	0.91	0.82	11.2

** Released variety (control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

Accession 'Bosome Nsia' registered the highest fresh root yield of 12.70 t/ha and 'H0015' the lowest yield of 10.10 t/ha at Bunso 8MAP. On the whole the fresh root yields at Bunso were higher, than comparable values

recorded at Legon at this stage of plant growth (Table 20). Treatment effects at Legon were highly significant ($P<0.001$).

At Legon 12MAP accession 'H0015' registered the highest yield of 28.40 t/ha and was followed by 'DMA 030', 'UG 126', and 'Afisiafi' with yield values of 26.10 t/ha, 24.50 t/ha and 23.43 t/ha respectively. 'H0001' recorded the lowest yield value of 14.20 t/ha.

Proportionally, higher fresh root yields were recorded by the genotypes at Bunso 12MAP and significant ($P<0.05$) differences were obtained amongst the treatment effects at Bunso as was also observed at Legon.

Except for environment main effect which was very highly significant ($P<0.0001$), genotype main effect and genotype x environment interaction were not significant ($P>0.05$) when the combined data was subjected to analysis of variance (Table 22).

Harvest index

From Table 21 it is observed that at 8MAP accession 'DMA 030' recorded the highest harvest index value of 0.53 at Legon and this was closely followed by 'H0015' and 'Bosome Nsia' with values of 0.51 and 0.49 respectively. The lowest harvest index of 0.42 was registered by 'H0001' and 'Afisiafi'. Very highly significant ($P<0.0001$) treatment effects were indicated.

TABLE 21: Harvest indices of seven cassava accessions and one variety evaluated eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Harvest index *			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	0.42 c	0.41 b	0.62 a	0.61 b
BOSOME NSIA	0.49 ab	0.48 b	0.62 a	0.56 c
H0001	0.42 c	0.45 b	0.53 b	0.56 c
UCC 90	0.43 c	0.44 b	0.63 a	0.55 c
DMA 030	0.53 a	0.43 b	0.66 a	0.63 b
UG 126	0.48 b	0.42 b	0.63 a	0.46 d
H0015	0.51 ab	0.47 b	0.67 a	0.64 b
H0008	0.43 c	0.62 a	0.62 a	0.67 a
Mean	0.46	0.47	0.62	0.59
C.V. (%)	5.07	8.15	5.50	3.38
P-Value	0.0001	0.0003	0.0089	0.0001
S.E.	0.01	0.01	0.01	0.01

** Released variety (control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

Harvest index values of the cassava genotypes recorded at Bunso varied from the highest value of 0.62 for 'H0008' to the lowest value of 0.41 for 'Afisiafi'. Very highly significant ($P<0.0001$) differences were also obtained amongst the treatment means at Bunso 8MAP.

Twelve months after planting (12MAP), accession 'H0015' manifested the highest harvest index value of 0.67 and 'H0001' the lowest value of 0.53 at Legon. Three genotypes, namely: 'H0008', 'Bosome Nsia' and 'Afisiafi' registered the same harvest index value of 0.62.

At Bunso, accession 'H0008' recorded the highest harvest index value of 0.67 and the lowest value of 0.46 was registered by 'UG 126', 12MAP. Very highly significant (P<0.0001) treatment effects were obtained (Table 21).

Pooled analysis of variance of the harvest index data from the four environments indicated very highly significant (P<0.0001) differences in the main effects of environment and genotype and their interaction (Table 22). Since the environment x genotype interaction was significant, stability analysis were carried out and the results are depicted in Table 23

The cultivar superiority measure (P_i) identified accession 'H0008' as the most stable genotype followed by 'H0015' and 'Bosome Nsia' in that order of stability. W_i-ecovalence stability statistic singled out 'Bosome Nsia', 'UCC 90', 'H0015' and 'H0008' as the most stable genotypes. Stability variance and AMMI methods established that 'UCC 90', 'Bosome Nsia', 'H0015', 'UG 126' and 'DMA 030' as the most stable accessions.

The overall ranking of the genotypes for stability on the basis of harvest index using four stability parameters grouped 'H0015', 'Bosome Nsia' and 'UCC 90' as the top three stable genotypes (Table 23).

TABLE 22: Combined analysis of variance for fresh root yield and harvest index of eight cassava genotypes evaluated in four environments

Source of Variation	Df	Fresh root yield (t/ha)		Harvest index	
		Mean squares	Contribution to SS (%)	Mean squares	Contribution to SS (%)
Environment	3	34716040.660***	80.40	0.159***	59.74
Genotype	7	167817.961ns	0.91	0.015***	13.14
Gen. x Env.	21	332675.818ns	5.39	0.007***	19.18
Error	64	269088.750	13.30	0.001	7.94

, * = Significant at 0.01 and 0.001 probability levels respectively

ns = not Significant (P>0.05)

SS = Sum of Squares

Dry weight (g)

Table 24 shows the dry root weights of the eight cassava genotypes obtained at Legon and Bunso 8MAP and 12MAP. Accession 'Bosome Nsia' recorded the highest dry root weight of 183.41g and the check variety, 'Afisiafi' the lowest value of 144.30g 8MAP at Legon.

TABLE 23: Summary of stability statistics for harvest index from seven cassava accessions and one variety evaluated at Legon and Bunso.

Cassava Genotype	Cultivar Superiority Measure		Wi-ecovalence		Stability Variance-no Covariate		AMMI		Overall Rank
	P_i GxE	Rank	W_i GxE Stat.	Rank	σ_i^2 GxE	Rank	IPCA Scores	Rank	
AFISIAFI*	0.008	6	0.004	3	0.004	4	0.0009	6	6
BOSOME NSIA	0.004	3	0.001	1	0.001	2	-0.0307	4	2
H0001	0.009	7	0.004	3	0.003	3	0.1045	7	7
UCC 90	0.007	5	0.001	1	0.000	1	-0.0289	5	3
DMA 030	0.005	4	0.006	4	0.007	5	-0.1344	2	4
UG 126	0.011	8	0.013	5	0.016	6	-0.1969	1	7
H0015	0.003	2	0.002	2	0.001	2	-0.0529	3	1
H0008	0.002	1	0.002	2	0.028	7	0.3384	8	5

* Released variety (Control)

TABLE 24: Dry root weights of seven cassava accessions and one variety evaluated eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Dry root weights (g)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	144.30 d	174.08 bc	160.80 c	184.95 cd
BOSOME NSIA	183.41 a	172.46 bc	192.30 a	180.68 d
H0001	176.01 ab	181.12 ab	192.87 a	188.18 bcd
UCC 90	166.30 bc	187.87 a	179.25 b	203.13 a
DMA 030	145.29 d	168.61 c	185.70 ab	180.86 d
UG 126	168.88 abc	179.44 abc	187.05 ab	194.03 abc
H0015	158.73 cd	172.58 bc	174.60 b	198.62 ab
H0008	171.23 abc	188.91 a	186.12 ab	196.50 abc
Mean	164.23	178.13	182.34	190.87
C.V. (%)	5.92	3.59	3.90	3.48
P-Value	0.0019	0.0119	0.0013	0.0059
S.E.	7.94	5.23	5.81	5.42

** Released variety (control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

Dry root weight values at Bunso 8MAP were relatively higher than comparable figures at Legon. The values ranged from the highest value of 188.91 g produced by 'H0008' to the lowest value of 168.61g indicated by 'DMA 030'. At Bunso the check variety recorded a value of 174.08g which was not significantly different from the lowest dry root weight.

'H0001' gave the highest dry root weight of 192.87g and 'Afisiafi' the lowest value of 160.8g at Legon 12MAP. Three accessions namely: 'DMA 030', 'UG 126' and 'H0008' registered dry root weights which were not significantly different from each other.

Accession 'UCC 90' at Bunso 12MAP out-yielded all the other genotypes in terms of dry root weight with a value of 203.13g. This was closely followed by 'H0015' with a dry root weight of 198.62g. The lowest

dry root weight was 180.68g and was recorded by 'Bosome Nsia'. Significant ($P<0.05$) treatment effects with respect to dry root weights were manifested at both locations 12MAP.

Analysis of variance of combined data showed that environment and genotype and their interaction were highly significant ($P<0.0001$) contributing 40.30, 19.26 and 21.16% respectively to the total sum of squares (Table 26).

Stability analyses employing the cultivar performance measure ranked 'H0008' as the most stable accession with respect to dry root weight. This was followed by 'H0001', 'UG 126' and 'UCC 90' in that order of stability. According to the W_i-ecovalence stability measure, 'UG 126', 'H0008' and 'H0015' were the top three stable genotypes. Stability variance and AMMI parameters identified 'UG 126', 'H0008', 'H0015', 'Bosome Nsia', 'H0001' and 'DMA 030' as the most stable accessions. The overall ranking identified 'UG 126', 'H0008', and 'H0001' as the three most stable accessions (Table 27).

Root dry matter content (%)

The results of root dry matter content of the cassava genotypes cultivated at Legon and Bunso and harvested at 8 and 12 MAP are shown in Table 25. 'Bosome Nsia' recorded the highest root dry matter content of 41.69% and 'Afisiafi' the lowest value of 32.95% at Legon 8MAP. Accession 'H0008' manifested the highest root dry matter content of 42.95% and 'DMA 030' the lowest value of 38.32% at Bunso 8 MAP. Significant ($P<0.05$) differences in root dry matter content amongst the genotypes were obtained at both agro-ecological zones 8MAP.

TABLE 25: Root dry matter content of seven cassava accessions and one variety evaluated eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Root dry matter content (%)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	32.95 c	39.55 bc	35.73 b	41.10 cd
BOSOME NSIA	41.69 a	39.18 bc	42.73 a	40.15 d
H0001	40.9 ab	41.19 ab	42.80 a	41.80 bcd
UCC 90	37.80 ab	42.71 a	39.83 a	45.13 a
DMA 030	33.02 c	38.32 c	41.87 a	40.17 d
UG 126	38.38 ab	40.80 abc	41.47 a	43.13 abc
H0015	36.08 bc	39.22 bc	39.77 a	44.17 ab
H0008	38.92 ab	42.95 a	41.20 a	43.67 abc
Mean	37.35	40.49	40.68	42.41
C.V. (%)	5.80	3.61	4.62	3.49
P-Value	0.0017	0.0118	0.0081	0.0059
S.E.	0.77	0.52	0.66	0.52

** Released variety (Control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

Root dry matter content values of the genotypes at Legon 12MAP ranged from the highest value of 42.8% for 'H0001' to the lowest value of 35.73% recorded by 'Afisiafi' the check variety (treatment). Highly significant ($P<0.001$) difference existed only between 'Afisiafi' on one hand and the remaining treatments which showed no significant differences amongst their root dry matter content values (Table 25).

In general, root dry matter content values recorded at Bunso were higher than those obtained at Legon at the same plant growth stage of 12MAP. Highly significant ($P<0.001$) treatment differences were registered at both locations.

Environment and genotype main effects were very highly significant ($P<0.001$) as well as the environment x genotype interaction when the pooled

data were subjected to analysis of variance computation (Table 26). Therefore, stability analyses were computed to identify stable genotypes.

Stability analyses using the cultivar performance measure placed 'H0008', 'H0001' and 'UG 126' as the three best stable accessions. Wi-ecovalence and stability variance (no covariate) grouped 'UG 126', 'H0008' and 'H0015' and the most stable accessions. 'Afisiafi', 'UCC 90 'and 'H0015' were identified by the AMMI analysis as the most stable genotypes. The overall ranking singled out 'H0008', 'UG 126' and 'H0015' as the most superior genotypes in terms of root dry matter content stability in the environments studied (Table 28).

TABLE 26: Combined analysis of variance for dry root weight and dry matter content of eight cassava genotypes evaluated in four environments.

Source of Variation	Df	Dry root weight (g)		Dry matter content (%)	
		Mean squares	Contribution to SS (%)	Mean squares	Contribution to SS (%)
Environment	3	2999.207***	40.30	106.450***	32.29
Genotype	7	614.205***	19.26	30.910***	21.88
Gen. x Env.	21	224.949***	21.16	11.353***	24.10
Error	64	67.268	19.28	3.358	21.73

*** = Significant at 0.01 and 0.001 probability levels.
ns = not Significant (P>0.05)
SS = Sum of Squares

TABLE 27: Summary of stability statistics for dry root weight from seven cassava accessions and one variety evaluated at Legon and Bunso.

Cassava Genotype	Cultivar Superiority Measure		Wi-ecovalence		Stability Variance-no Covariate		AMMI		Overall Rank
	P_i GxE	Rank	W_i GxE Stat.	Rank	σ_i^2 GxE	Rank	IPCA Scores	Rank	
AFISIAFI*	386.409	8	264.066	6	314.598	6	2.7073	8	8
BOSOME NSIA	96.837	5	548.863	8	694.327	8	-3.9637	1	6
H0001	42.368	2	128.792	4	134.232	4	-1.9310	2	3
UCC 90	59.007	4	161.177	5	177.412	5	2.0392	7	5
DMA 030	297.352	7	305.116	7	369.332	7	-0.3201	3	7
UG 126	52.451	3	5.705	1	-29.884	1	-0.2892	4	1
H0015	135.304	6	124.515	3	128.530	3	1.2899	6	4
H0008	30.519	1	36.355	2	10.983	2	0.4676	5	2

* Released variety (Control)

TABLE 28: Summary of stability statistics for dry root matter content from seven cassava accessions and one variety evaluated at Legon and Bunso.

Cassava Genotype	Cultivar Superiority Measure		Wi-ecovalence		Stability Variance-no Covariate		AMMI		Overall Rank
	P_i GxE	Rank	W_i GxE Stat.	Rank	σ_i^2 GxE	Rank	IPCA Scores	Rank	
AFISIAFI*	19.272	8	12.801	6	15.174	6	-1.2580	1	6
BOSOME NSIA	4.877	5	27.881	8	35.280	8	1.8912	8	8
H0001	2.130	2	6.487	4	6.755	4	0.9141	7	5
UCC 90	3.001	4	8.070	5	8.866	5	-0.9604	2	4
DMA 030	15.259	7	15.700	7	19.039	7	0.1209	5	7
UG 126	2.668	3	0.266	1	-1.539	1	0.1317	6	2
H0015	6.936	6	6.419	3	6.665	3	-0.6170	3	3
H0008	1.546	1	1.927	2	0.675	2	-0.2225	4	1

* Released variety (Control)

Dry root yield (g/plant)

The highest dry root yield value of 602.54g/plant was recorded by accession 'H0015' and the lowest value of 266.90 g/plant was registered by 'Afisiafi' at Legon 8MAP. Three cassava accession treatments, namely: 'H0001', 'H0008' and 'UCC 90' produced dry root yields that were not significantly different from the low yield value recorded by 'Afisiafi', the check treatment.

Relatively higher dry root yield values were produced at Bunso by the cassava genotypes. The highest value was 518.99 g/plant on 'H0001' and the lowest of 396.12 g/plant was recorded by 'H0015'. Significant ($P<0.05$) treatment differences were observed.

Dry root yields of the cassava genotypes cultivated at Legon 12 MAP varied from the lowest value of 607.76 g/plant to the highest of 1129.47 g/plant representing a range value of 521.71 g/plant for the genotypes (Table 29). Significant ($P<0.05$) differences in dry root yields were observed amongst the genotypes.

TABLE 29: Dry root yields of seven cassava accessions and one variety evaluated eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Dry root yield (g/plant)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	266.90 d	439.01 c	868.24 c	1171.35 c
BOSOME NSIA	475.27 b	497.59 a	713.59 d	1216.55 c
H0001	280.03 d	518.99 a	607.76 e	1458.82 a
UCC 90	306.18 d	457.0 b	872.28 c	961.27 e
DMA 030	472.19 b	406.19 c	1092.81 b	1088.61 d
UG 126	426.02 c	489.60 b	1016.02 b	1397.41 b
H0015	602.54 a	396.12 d	1129.47 a	1055.66 d
H0008	295.79 d	493.93 a	918.76 c	995.68 e
Mean	390.62	462.30	902.37	1168.17
C.V. (%)	6.14	8.06	10.08	34.10
P-Value	0.0001	0.0010	0.0001	0.0301
S.E.	8.46	10.92	36.32	39.42

** Released variety (Control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

At the deciduous forest zone of Bunso, dry root yield values varied from 961.27 to 1458.82 g/plant representing a range value of 497.55 g/plant. The range values at both locations were quite high. Significant ($P<0.05$) differences in dry root yields emerged among the genotypes cultivated at Bunso.

When the combined dry root yield data were subjected to analysis of variance computation, environment main effect was very highly significant ($P<0.0001$). However, genotype main effect and genotype x environment interaction were not significant ($P>0.05$) (Table 31).

Starch weight (g)

Starch weights varied from 111.25g recorded by 'DMA 030' to 122.03g registered by 'Bosome Nsia' at Legon 8MAP (Table 30). The range was quite narrow and no significant differences in dry starch weights were observed among the genotypes.

TABLE 30: Starch weights of seven cassava accessions and one variety evaluated eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Starch weight (g)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	111.29 a	131.63 a	113.98 a	143.86 a
BOSOME NSIA	122.03 a	127.33 a	123.62 a	143.61 a
H0001	119.79 a	130.36 a	119.57 a	146.19 a
UCC 90	111.83 a	134.86 a	116.39 a	143.99 a
DMA 030	111.25 a	133.83 a	113.01 a	139.67 a
UG 126	119.74 a	131.81 a	119.72 a	139.02 a
H0015	113.43 a	136.01 a	114.37 a	149.73 a
H0008	116.33 a	132.26 a	119.66 a	139.33 a
Mean	115.71	132.26	117.54	143.18
C.V. (%)	6.21	5.02	4.43	4.97
P-Value	0.4136	0.8167	0.2458	0.5823
S.E.	5.86	5.42	4.25	5.81

** Released variety (Control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

Quantitatively, higher starch weight values were recorded by the cassava genotypes at Bunso 8MAP. The values ranged between 127.33 g produced by 'Bosome Nsia' and 136.01g shown by 'H0015'; and as was observed at Legon, no significant (P>0.05) treatment effects were manifested. Combined analysis of variance was performed on the pooled starch weight data from the four environments. Apart from environment main effect which was very highly significant (P<0.0001), genotype main effect and the genotype x environment interaction were not significant (P>0.05) (Table 31).

TABLE 31: Combined analysis of variance for dry root yield and starch weight of eight cassava genotypes evaluated in four environments.

Source of Variation	Df	Dry root yield (g/plant)		Starch weight (g)	
		Mean squares	Contribution to SS (%)	Mean squares	Contribution to SS (%)
Environment	3	64372977.5***	81.23	4049.006***	75.56
Genotype	7	234011.7^{ns}	0.69	35.001^{ns}	1.52
Gen. x Env.	21	493415.3^{ns}	4.36	42.203^{ns}	5.5
Error	64	509739.7	13.72	43.725	17.41

, * = Significant at 0.01 and 0.001 probability levels respectively
ns = not Significant (P>0.05)
SS = Sum of Squares

Starch content (%)

Starch content values of tubers from the various cassava genotypes are presented in Table 32. Eight months after planting the starch content values varied from 22.77% recorded by 'Afisiafi' to 25.0% indicated by 'Bosome Nsia' at Legon. No significant (P>0.05) treatment effects were detected.

TABLE 32: Percentage starch of seven cassava accessions and one variety evaluated eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Percentage starch			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	22.77 a	26.90 a	25.33 a	29.40 a
BOSOME NSIA	25.0 a	26.03 a	27.47 a	29.40 a
H0001	24.57 a	26.67 a	26.57 a	29.90 a
UCC 90	22.90 a	28.20 a	25.87 a	29.43 a
DMA 030	22.80 a	26.70 a	25.11 a	28.57 a
UG 126	24.53 a	26.97 a	26.60 a	28.43 a
H0015	23.23 a	27.83 a	25.41 a	30.63 a
H0008	23.87 a	27.03 a	26.59 a	28.50 a
Mean	23.71	27.04	26.12	29.28
C.V. (%)	6.19	4.61	4.43	4.94
P-Value	0.3970	0.5312	0.2464	0.5718
S.E.	0.52	0.44	0.41	0.51

** Released variety (Control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

The range of percentage starch values obtained at Bunso 8MAP was between 26.03 and 28.2%. 'UCC 90' recorded the highest value and 'Bosome Nsia' the lowest. No significant (P>0.05) differences in percentage starch values amongst the genotypes were observed.

Percentage starch of root tubers of the different cassava genotypes increased marginally at the plant growth stage of 12 MAP at both Legon and Bunso. At Legon the highest percentage starch value of 27.47% was recorded by 'Bosome Nsia' whilst it was 'H0015' that produced the highest percentage starch of 30.63% at Bunso. 'DMA 030' yielded the lowest percentage starch value of 25.11% at Legon and 'UG 126' the least value of 28.43% at Bunso. At both locations no significant (P>0.05) differences in treatment mean values were manifested.

Pooled analysis of variance of percentage starch data showed that environment main effect was very highly significant (P<0.0001); genotype and genotype x environment interaction were not (Table 34).

Starch yield (g/plant)

Accession 'H0015' produced the highest starch yield of 387.94 g/plant at Legon 8MAP. This was followed by 'DMA 030' with a yield value of 326.04 g/plant and 'H0001' produced the lowest starch yield of 171.99 g/plant (Table 33). The starch yield of 'Afisiafi', the check variety, was 184.44 g/plant and this yield value was not significantly different from the lowest starch yield value of 171.99 g/plant.

TABLE 33: Starch yields of seven cassava accessions and one variety evaluated eight and twelve months after planting (MAP) at Legon and Bunso

Accession / variety	Starch yield (g/plant)*			
	8 MAP		12 MAP	
	Legon	Bunso	Legon	Bunso
AFISIAFI**	184.44 d	298.59 b	615.52 b	837.90 b
BOSOME NSIA	285.0 c	330.58 a	458.75 d	890.82 a
H0001	171.99 d	336.04 a	377.29 e	1043.51 a
UCC 90	185.49 d	301.74 b	566.55 c	626.86 e
DMA 030	326.04 b	283.02 b	655.37 b	774.25 c
UG 126	272.28 c	323.64 a	651.70 b	921.13 a
H0015	387.94 a	281.08 b	721.64 a	732.06 d
H0008	181.41 d	310.85 b	592.96 c	649.80 e
Mean	249.32	308.19	579.97	809.54
C.V. (%)	8.71	12.16	7.60	26.09
P-Value	0.0001	0.0307	0.0001	0.0010
S.E.	7.6	9.67	17.62	15.40

** Released variety (Control)

* All values are means of three replications and means with the same letter within a column are not significantly different.

'H0001' recorded the highest starch yield of 336.04 g/plant at Bunso and 'H0015' the least value of 281.08 g/plant. Generally, the starch yield values recorded at Bunso were higher than corresponding genotype values obtained at Legon. Significant ($P<0.05$) differences in treatment effects were recorded at both locations 8MAP.

Starch yield values of the genotypes obtained at Legon 12 MAP varied from a high value of 721.64 g/plant produced by cassava accession 'H0015' to a low value of 377.29 g/plant registered by 'H0001' (Table 33). 'Afisiafi' the check variety produced a starch yield of 615.52 g/plant which was about 15% lower than the highest yield of 721.64 g/plant. There were significant ($P<0.05$) differences in starch yield values amongst the cassava genotypes planted at Legon.

At Bunso significant ($P<0.05$) differences in starch yield were recorded amongst the genotypes as quantitative differences in starch yield values were registered.

Pooled analysis of variance of starch yield data indicated that only environment main effect was very highly significant ($P<0.0001$); the other sources of variation were not significant (Table 34).

TABLE 34: Combined analysis of variance for starch content and starch yield of eight cassava genotypes evaluated in four environments.

Source of Variation	Df	Starch content (%)		Starch yield (g/plant)	
		Mean squares	Contribution to SS (%)	Mean squares	Contribution to SS (%)
Environment	3	55.359***	29.43	27878528.23***	80.26
Genotype	7	3.359^{ns}	4.17	121238.18^{ns}	0.81
Gen. x Env.	21	5.153^{ns}	19.17	243206.80^{ns}	4.90
Error	64	4.166	47.23	228429.3	14.03

, * = Significant at 0.01 and 0.001 probability levels respectively
ns = not Significant ($P>0.05$)
SS = Sum of Squares

Functional properties of starches

Starch from 'Afisiafi', the check variety, recorded the highest swelling volume of 26.17 ml/g at Legon, and accession 'UCC 90' the lowest value of 16.30 ml. Significant ($P<0.05$) variation in swelling volume values was noted amongst the genotypes at Legon (Table 35).

At Bunso, swelling volume values ranged from the lowest value of 17.0 ml/g indicated by starch from 'UCC90' to the highest of 28.67 ml/g again registered by starch from Afisiafi (Table 35). On the average, swelling volume of starches obtained from Bunso were higher than those from Legon.

Accession 'UCC 90' produced starch that had the lowest solubility of 7.21% and 'H0001' the starch with the highest value of 11.19% at Legon. The range was quite narrow. The mean solubility value was 9.70% and three genotypes, including Afisiafi recorded values below this mean value.

The trend in the variation of solubility of starches produced from the genotypes cultivated at Bunso was very similar to that observed at Legon. Starch from 'UCC 90', as was the case at Legon, had the lowest solubility of 8.01% and 'UG 126' starch the highest of 10.82% (Table 35). At both locations differences among genotypes were present.

Starches from the genotypes cultivated at the two different agro-ecological locations showed significant ($P<0.05$) differences in their swelling power values (Table 35). Afisiafi starch produced the highest swelling power values at both locations. Accession 'DMA 030' starch from Legon and Bunso registered the lowest swelling power values of 25.33 g/g and 28.33 g/g from the respective locations. Generally, swelling power values were relatively higher at Bunso than at Legon.

TABLE 35: Swelling volume, solubility and swelling power of seven cassava accessions and one variety cultivated at Legon and Bunso.

Accession/ variety	Swelling volume (ml/g)		Solubility (%)		Swelling power (g/g)	
	Legon	Bunso	Legon	Bunso	Legon	Bunso
AFISIAFI*	26.2 a	28.7 a	9.3 b	10.3 a	53.3 a	56.7 a
BOSOME NSIA	17.8 c	21.7 bc	10.2 ab	8.2 bc	33.7 cd	36.3 c
H0001	19.8 c	19.0 cd	11.2 a	10.2 ab	34.0 cd	36.3 c
UCC 90	16.3 c	17.0 d	7.2 c	8.0 c	31.7 d	35.3 c
DMA 030	19.0 bc	22.0 bc	8.9 b	9.8 abc	25.3 e	28.3 d
UG 126	20.3 bc	24.3 b	10.2 ab	10.8 a	40.7 b	43.7 b
H0015	22.7 ab	21.8 bc	10.3 ab	10.6 a	39.0 bc	42.0 b
H0008	20.3 bc	23.7 b	10.3 ab	10.4 a	41.0 b	42.0 b
Mean	20.3	22.3	9.7	9.8	37.3	40.1
C.V. (%)	11.92	9.85	8.87	11.10	9.39	5.61
P-Value	0.0068	0.007	0.0022	0.0398	0.0001	0.0001
S.E.	0.9	0.8	0.3	0.4	1.2	0.8

* Released variety (Control)
All values are means of three replications and means with the same letter within a column are not significantly different.

Pasting characteristics

The pasting temperature values of the different starches obtained from eight cassava genotypes when grown at Legon ranged between a low value of 52.7°C and a high of 66.0°C. 'Bosome Nsia' recorded the highest pasting temperature and 'UCC 90' the lowest (Table 36). The pasting temperature of 'Afisiafi' which was a check variety was 65.7°C and this value was not significantly ($P>0.05$) different from the highest pasting temperature value of 66.0°C.

Pasting temperature values recorded from starches obtained from Bunso varied from 53.4 to 63.6 °C from tubers of 'UCC 90' and 'DMA 030' respectively. The mean pasting temperature of the starches was 60.8 °C which was lower than the mean of 62.4°C obtained at Legon. Starch from 'Afisiafi'

at Bunso registered a pasting temperature of 62.6 °C and this value was not significantly (P>0.05) different from the highest value recorded (Table 36).

TABLE 36: Pasting characteristics of starch from seven cassava accessions and one variety cultivated at Legon and Bunso.

Accession/ variety	Pasting temperature (°C)		Pasting time (minutes)		Peak viscosity (BU)	
	Legon	Bunso	Legon	Bunso	Legon	Bunso
AFISIAFI*	65.7 a	62.6 ab	11.3 a	10.6 a	891.7 b	1291.7 bc
BOSOME NSIA	66.0 a	62.8 ab	12.4 a	10.1 a	830.0 c	1234.0 cd
H0001	65.6 a	63.1 ab	12.4 a	10.4 a	969.7 a	1192.3 d
UCC 90	52.7 b	53.4 d	11.1 a	11.6 a	941.3 ab	1316.0 abc
DMA 030	64.0 a	63.6 a	11.6 a	10.7 a	899.7 b	1398.7 a
UG 126	54.2 b	56.8 c	10.3 a	9.2 a	976.3 a	1378.0 ab
H0015	65.8 a	60.4 b	10.3 a	8.4 a	893.0 b	1316.3 abc
H0008	65.2 a	63.4 a	11.8 a	9.4 a	988.7 a	1269.3 cd
Mean	62.4	60.8	11.4	10.1	923.8	1299.5
C.V. (%)	4.0	2.42	13.32	17.57	3.00	3.65
P-Value	0.0001	0.0001	0.5414	0.4809	0.0001	0.0017
S.E.	0.9	0.5	0.5	0.6	9.8	16.8

* Released variety (Control)
BU = Brabender units
All values are means of three replications and means with the same letter within a column are not significantly different.

Significant (P<0.05) differences in treatment effects with respect to peak viscosity of starches extracted from the eight cassava genotype treatments were observed at both Legon and Bunso (Table 36). Quantitatively, peak viscosity values of starches from Bunso were higher than those from Legon. The mean peak viscosity value at Bunso was 1299.5 BU and at Legon it was 923.8 BU which was about 29% lower than the mean value at Bunso.

Accession 'H0008' produced the starch that registered the highest peak viscosity of 988.7 BU at Legon and 'Bosome Nsia' the lowest value of 830 BU. 'DMA 030' starch had the highest peak viscosity value of 1398.7 BU and 'H0001' the lowest value of 1192.3 BU at Bunso.

There were significant ($P<0.05$) variations in the viscosity values of starches at 95°C obtained from Legon but no significant ($P>0.05$) differences among viscosity at 95°C values at Bunso. Relatively higher values were obtained at Bunso as compared to values from Legon. 'H0008' recorded the highest viscosity value of 396.7 BU and 'UCC 90' the lowest value of 325.0BU at Legon. At Bunso starch from 'H0008' again produced the highest viscosity of 418.3 BU and 'H0001' the lowest of 359.0 BU (Table 37).

TABLE 37: Viscosity values of starches from seven cassava accessions and one variety cultivated at Legon and Bunso.

Accession/ variety	Viscosity at 95°C (BU)		Viscosity after 15 mins. at 95°C (BU)		Viscosity at 50°C (BU)	
	Legon	Bunso	Legon	Bunso	Legon	Bunso
AFISIAFI*	357.0 bc	407.3 a	239.3 c	301.7 a	457.7 cd	645.7 a
BOSOME NSIA	339.7 bcd	365.3 a	213.7 d	274.7 a	448.0 d	587.0 b
H0001	357.0 bc	359.0 a	255.0 abc	265.3 a	477.0 c	506.7 c
UCC 90	325.0 d	394.3 a	236.7 c	305.7 a	506.7 b	623.3 ab
DMA 030	339.0 bcd	417.7 a	248.3 bc	325.0 a	523.3 b	653.3 a
UG 126	360.3 b	366.3 a	268.0 ab	285.0 a	531.3 ab	628.3 ab
H0015	328.7 cd	365.0 a	249.3 bc	280.0 a	528.7 ab	517.7 c
H0008	396.7 a	418.3 a	276.0 a	321.3 a	554.0 a	648.0 a
Mean	350.4	386.7	248.3	294.8	503.3	601.3
C.V. (%)	4.51	7.23	4.62	9.06	2.88	4.22
P-Value	0.0017	0.0691	0.0004	0.1240	0.0001	0.0001
S.E.	5.6	9.9	4.1	9.5	5.1	8.9

* Released variety (Control)
BU = Brabender units
All values are means of three replications and means with the same letter within a column are not significantly different.

The range of values recorded for viscosity at 95°C after 15 minutes of starches from Legon was from a low of 213.7 BU to a high of 276 BU from 'Bosome Nsia' and 'H0008' respectively. At Bunso the values varied between 265.3 and 324BU registered by 'H0001' and 'DMA 030' respectively (Table

37). Treatment effects were significantly ($P<0.05$) different for starches obtained at Legon whilst no significant ($P>0.05$) differences in viscosity at 95°C after 15 minutes were observed for starches from Bunso.

Viscosity values at 50°C of starches from Legon varied from a low value of 448.0 BU for 'Bosome Nsia' to a high value of 554 BU for 'H0008'. The value recorded for starch of 'Afisiafi' was 457.7 BU and this value was lower than the mean of 503.3 BU for the genotypes. Starches of five genotypes had values above the mean (Table 37).

Comparatively, higher viscosity values were obtained from starches of the genotypes cultivated at Bunso than at Legon. The maximum value was 653.3 BU for 'DMA 030' and the minimum of 506.7 BU for 'H0001' at Bunso. Significant ($P<0.05$) differences existed among the cassava genotypes with respect to viscosity values of starches at 50°C at both locations (Table 37)

The lowest viscosity at 50°C after 15 minutes was 432.3 BU produced by starch from 'Bosome Nsia'. This was closely followed by starch from 'Afisiafi' with 444.4 BU at Legon (Table 38). Starch of 'H0008' registered a value of 539.3 BU and this was the highest viscosity value for the genotypes at Legon. The mean viscosity value was 491.3 BU and five genotypes had values above the mean and the remaining below it including 'Afisiafi', the check variety. Treatment effects were significantly ($P<0.05$) different.

TABLE 38: Viscosity and Paste stability values of starches from seven cassava accessions and one variety cultivated at Legon and Bunso.

Accession/ variety	Viscosity after 15mins. at 50°C (BU)		Paste stability at 95°C (BU)		Paste stability at 50°C (BU)	
	Legon	Bunso	Legon	Bunso	Legon	Bunso
AFISIAFI*	444.33cd	635.3 a	107.7 ab	105.7 a	13.3 a	10.3 abc
BOSOME NSIA	432.3 d	582.3 b	102.7 abc	90.7 a	15.7 a	4.7 c
H0001	465.3 c	497.7 c	102.0 abc	93.7 a	11.7 a	9.0 abc
UCC 90	491.7 b	617.3 ab	88.3 bc	88.7 a	15.0 a	6.0 bc
DMA 030	511.7 ab	648.0 a	87.3 bc	92.7 a	11.7 a	5.3 c
UG 126	521.0 a	616.7 ab	92.3 bc	81.3 a	10.3 a	11.7 ab
H0015	524.7 a	504.0 c	79.3 c	85.0 a	9.3 a	13.7 a
H0008	539.3 a	638.7 a	120.7 a	97.0 a	14.7 a	9.3 abc
Mean	491.3	592.5	97.5	91.8	12.7	8.8
C.V. (%)	3.0	4.29	13.59	10.79	19.74	36.94
P-Value	0.0001	0.0001	0.0380	0.1877	0.0645	0.0411
S.E.	5.2	8.9	4.7	3.5	0.9	1.1

* Released variety (Control)
BU = Brabender units
All values are means of three replications and means with the same letter within a column are not significantly different.

The variation of viscosity values at 50°C after 15 minutes at Bunso was from the highest value of 648.7 BU by 'DMA 030' to the lowest of 497.7 BU registered by 'H0001'. The mean for the genotypes at Bunso was 592.5 BU, quite higher than the mean of 491.3 BU obtained at Legon and indicating that viscosity at 50°C after 15 minutes values at Bunso were higher than those at Legon (Table 38). Significant ($P<0.05$) differences in viscosity values at 50°C after 15 minutes were recorded among the genotypes.

Paste stability at 95°C values recorded for starches from Legon ranged from the lowest of 79.3 BU to the highest value of 120.7 BU. Accessions 'H0015' and 'H0008' registered the lowest and highest values respectively. Significant ($P<0.05$) treatment effects were noted (Tale 38).

Starches originating from Bunso had paste stability at 95°C values varying from 81.3 to 105.7 BU but no significant (P>0.05) differences in paste stability values were detected among the genotypes.

Paste stability at 50°C values obtained from starches at Legon varied from a low value of 9.3 BU registered by starch of accession 'H0015' to a high value of 15.7 BU recorded by starch of 'Bosome Nsia'. The mean value for the genotypes was 12.7 BU and half of the genotypes showed paste stability values above and the other half below this value (Table 38). However, no significant (P>0.05) treatment effects regarding paste stability at 50°C of starches existed.

On the average paste stability at 50°C values of starches produced from Bunso were lower than comparative figures at Legon. The highest value was 13.7 BU for accession H0015 and the lowest 4.7 BU recorded by starch of 'Bosome Nsia'. Significant (P<0.05) differences in paste stability at 50°C among the treatments were noted (Table 38).

Five cassava accessions, namely: 'H0015', 'H0008', 'DMA 030', 'UCC 90' and 'UG 126' produced starches with high setback viscosity values relative to the remaining three genotypes at Legon (Table 39).

TABLE 39: Setback viscosity, breakdown viscosity and pH values of seven cassava accessions and one variety cultivated at Legon and Bunso.

Accession/ Variety	Setback viscosity (BU)		Breakdown viscosity (BU)		pH values	
	Legon	Bunso	Legon	Bunso	Legon	Bunso
AFISIAFI*	218.3 b	344.0 a	662.3 b	990.0 ab	6.9 bc	7.6 a
BOSOME	234.7 b	312.3 ab	616.0 c	959.3 b	7.1 b	7.5 a
NSIA	222.0 b	241.3 c	714.7 a	959.3 b	6.8 bc	7.4 a
H0001	270.0 a	317.7 ab	704.7 a	1043.7 ab	6.9 bc	7.4 a
UCC 90	275.0 a	328.3 ab	651.3 b	1116.7 a	7.3 b	7.6 a
DMA 030	263.3 a	343.3 a	708.3 a	1123.0a	6.6 c	7.3 a
UG 126	279.3 a	271.7 bc	643.7 bc	1059.7 ab	8.3 a	7.7 a
H0015	278.0 a	326.7 ab	729.3 a	948.0 b	7.0 bc	7.4 a
H0008	255.1	310.7	678.8	1025.0	7.1	7.5
Mean	4.67	10.59	2.81	6.90	3.74	3.15
C.V. (%)	0.0001	0.0194	0.0001	0.0374	0.0001	0.3910
P-Value	4.2	11.6	6.7	25.0	0.1	0.1
S.E.						

* Released variety (Control)
BU = Brabender units
All values are means of three replications and means with the same letter within a column are not significantly different.

The mean setback viscosity was 255.1 BU and the five accessions with high setback viscosities had values above this mean while the remaining, 'Afisiafi' inclusive registered lower values.

Starch from 'Afisiafi' showed the highest setback viscosity value of 344 BU at Bunso and 'H0001' starch the lowest value of 241.3 BU. The mean for the group at Bunso was 306.4 BU and six genotypes including 'Afisiafi' gave values higher than this mean (Table 39).

Significant ($P<0.05$) differences in setback viscosity values among the genotypes were manifested at both locations.

Breakdown viscosity values of starches obtained from the genotypes at Legon varied from 616.0 BU for 'Bosome Nsia' starch to 714.7 BU for starch from 'H0001' (Table 39). Starch from 'Afisiafi' which was the check variety

recorded a breakdown viscosity value of 652.3 BU which was lower than the mean of 675.5 BU for the group at Legon. Significant ($P<0.05$) differences in treatment means were observed.

There were tremendous increases in breakdown viscosity values for starches extracted from cassava genotype tubers grown at Bunso. The highest value was 1093.0 BU obtained from 'UG 126' and the lowest 959.3 BU registered by starch from 'Bosome Nsia'. Variety 'Afisiafi' recorded a remarkable value of 990.0 BU which was not significantly ($P>0.05$) different from the highest breakdown viscosity value (Table 39).

pH value of starch

pH values of starches obtained from the genotypes grown at Legon varied from the lowest value of 6.6 recorded by starch from accession 'UG 126' to the highest value of 8.3 of accession 'H0015' starch (Table 39). The mean pH value was 7.1 and 'Afisiafi', the check variety registered a pH value of 6.9 which was relatively lower than the mean value. Significant ($P<0.05$) treatment effects regarding pH values were discerned.

The range of pH values of starches obtained from Bunso was quite narrow. The highest value was 7.7 and the lowest 7.3, a range value of 0.4. The same accessions, that is 'H0015' and 'UG 126' produced starches that recorded the highest and the lowest pH values at both locations (Table 39).

Variance components estimates

Table 40 shows the results of estimated variance components of agronomic and starch yield traits of the cassava genotypes evaluated at two

locations and at two ages of harvesting, that is, 8 and 12 months after planting at Legon and 8 and 12 months after planting at Bunso.

Estimates of phenotypic coefficient of variation were highest for individual root tuber weights and number of roots with values of 57.81 and 49.64% respectively. Starch content and dry matter content registered the lowest phenotypic coefficient of variation values of 8.11 and 14.50% respectively. Intermediate phenotypic coefficient of variation values were recorded for fresh root weight, fresh root yield and starch yield traits.

Genetic coefficient of variation values were greater for individual root tuber weights and number of roots than for the other agronomic traits (Table 40). The trend of genetic variation was quite similar to that observed for phenotypic coefficient of variation. For instance, starch content recorded the lowest genetic variation as it did for the phenotypic coefficient of variation.

TABLE 40: Estimates of variance components, phenotypic coefficient of variation, genotypic coefficient of variation and broad sense heritability of agronomic traits and starch yield of eight cassava genotypes cultivated in four environments.

Entry	No. of roots per plant	Fresh root weight (kg)	Individual root tuber weight (g)	Fresh root yield (t/ha)	Dry matter content (%)	Starch content (%)	Starch yield (g/plant)
Genotypic variance (σ_g^2)	8.35	1.79	103856.68	167817.96	30.91	3.36	121238.18
Environmental variance (σ_e^2)	0.22	0.25	1922.73	22424.06	0.28	0.35	19035.78
Variance component associated with gxl (σ_{gl}^2)	0.81	0.79	14623.39	83168.95	2.84	1.29	60801.7
Phenotypic Variance (σ_p^2)	9.37	2.83	120402.8	273410.97	34.03	4.99	201075.66
Phenotypic Coefficient of Variation (%)	49.64	41.46	57.81	35.0	14.50	8.11	39.36
Genotypic Coefficient of Variation (%)	45.45	32.38	53.69	27.42	13.82	6.65	30.57
Broad sense heritability (h^2)	0.89	0.63	0.86	0.61	0.90	0.67	0.60

Broad sense heritability estimates (h^2) ranged from the lowest value of 0.61 to the highest of 0.90 recorded for fresh root yield and dry matter content respectively. Estimated heritability values for number of roots (0.89) and individual root tuber weights (0.86) were also comparatively high. Heritability values for starch content (0.67), fresh root yield (0.61) and starch yield (0.60) were similar on the average when compared with the other recorded values.

CHAPTER FIVE

DISCUSSIONS

EXPERIMENT I

Whiteflies, mosaic severity and plant yield

Adult whitefly population numbers were not significantly ($P>0.05$) correlated with mosaic ordinal scores. This result is consistent with the results of Fauquet *et al.*, (1988) who found that differences in rates of ACMV disease spread between sites in Côte d'Ivoire were not directly related to adult whitefly numbers.

Otim-Nape *et al.*, (1994) has also reported the lack of any significant correlation between whitefly numbers and mosaic severity when he studied the effects of African cassava mosaic genninivirus on the main cassava varieties grown in three districts of western Uganda. He attributed the lack of significant correlation between the two variables to the fact that the plants with symptoms must have been infected sometime before the whitefly counts were made and that many of the plants were likely to have been established from infected cuttings.

Similar explanation can be assigned to the observed lack of significant correlation between whitefly populations and mosaic severity in this study. This is because the cassava genotypes tested were obtained from diverse origins including various germplasm conservation centres and from farmers'

field throughout Ghana and therefore could not be considered entirely free of ACMV disease infection.

Except for the correlations between whitefly numbers and starch weight and starch content which were significant ($P<0.05$) and negative suggesting a slight detrimental effect, the correlations between whitefly population and the other cassava yield characteristics were not significant ($P>0.05$). This observation supports the view that adult whiteflies on cassava cause little direct damage (Otim-Nape *et al.*, 1994).

The negative and significant correlations between ACMV disease ordinal scores and most of the yield characters studied indicate that the disease reduces the overall yield in cassava. According to Chant *et al.*, (1971) and Ayanru and Shama (1982), the ACMV which causes the cassava mosaic disease behaves like Indian cassava mosaic virus in decreasing the area and impairing the efficiency of the photosynthetic tissues. Thus, the reduction in yield as symptom intensity increases is likely to be related to the degree to which metabolic and photosynthetic processes of the plant are affected. Yield losses of cassava plants due to ACMV diseases ranging from 20 to 95% have been reported (Beck and Chant, 1958; Jennings, 1960; Seif, 1982; Fargette *et al.* 1988, Thresh *et al.*, 1944b).

Yield and yield components

The number of roots per plant varied between 1.2 and 2.89 and the range of these figures is rather low when compared to what Otim-Nape *et al.* (1994) have reported after studying 13 cassava varieties in three districts of western Uganda. They reported a range of 1.0 to 10.0 roots per plant.

The differences in the number of roots per plant which were significant ($P<0.05$) in this work could be attributed to varietal differences.

Magoon *et al.* (1970) after studying a large number of F_1 cassava plants obtained from crosses among three plants of diverse origin found out that yield was closely related to the number of storage roots (range 1 to 12). It is therefore, likely that cassava genotypes identified in this work with relatively large root numbers per plant may produce higher yields. Variety 'Afisiafi', accessions 'H0008', 'UG 126', 'Bosome Nsia' and 'DMA 030' recorded the highest number of roots per plant and therefore they are likely to give higher root yields.

Fresh root weights recorded in this experiment were relatively lower in values than what had been reported in literature. For instance, Fargette *et al.*, (1988) in Côte d'Ivoire and Terry and Hahn (1980) in Nigeria have found that when harvested after 12 months cassava yields per plant were 2.4 – 5.2 kg and 1.4 – 3.0 kg respectively. The range of fresh root weights in this work was 0.81 – 2.44 kg.

Cock *et al.*, (1979) have noted that few tubers per plant, low individual tuber weight and low harvest index which indicate poor partitioning or accumulation of assimilates in storage organs are attributes of a cassava plant that may result in low tuber yield. This may explain why relatively low fresh tuber weights were obtained in this experiment.

The highest fresh root yield recorded in this experiment was 24.4 t/ha and the lowest was 8.1 t/ha produced by accession 'H0008' and accession 'DMA 002' respectively. Significant ($P<0.05$) treatment effects were noted. When the yield components, that is, number of roots per plant, fresh root

weight (kg), individual root weight (g) and harvest index are examined it is observed that apart from individual root weight (g) all the other variables indicated significant ($P<0.05$) treatment mean differences. Therefore, it can be inferred that the significant differences in fresh root yield are directly linked to the yield components, that is, higher or lower values of yield components are reflected in the fresh root yield values.

Chitiyo and Kasele (2004) studied 18 new introduced cassava varieties and two local accessions at two locations in Zimbabwe and reported a fresh root yield range of 2.7 to 12.9 t/ha. Nweke (1996) surveyed 501 cassava farms in Southeast Nigeria and estimated that the overall mean of fresh root yield was 11.9 t/ha. These reported yields indicate that the yields obtained in this work are relatively high.

However, work done by Afuakwa *et al.* (1999) on four cassava genotypes, namely: 'Gblemoduade', 'Abasafitaa', 'Tekbankye' and 'Afisiafi' showed the average fresh root yield at 12 months maturity to be 33-38 t/ha; 26-31 t/ha; 26-31 t/ha and 27-30 t/ha respectively. These yield values are far higher than what is reported in this work. Two of these genotypes, that is, Tekbankye and Afisiafi were included in the treatment in this experiment as checks and their fresh root yields were quite low when compared to what is reported by Afuakwa *et al.* (1999).

The low root yields recorded by 'Tekbankye' and 'Afisiafi' at Legon may be attributed to the environment in which these varieties were cultivated since Hunt *et al.* (1997) and Janssens (2001) have noted that growth and development of cassava storage root and yield in general depend on the climate, soil fertility and other factors. Legon is situated in the coastal

savanna zone where rainfall is scanty and the soils are less richly supplied with organic matter and nutrients (Boateng, 1960; Dickson and Benneh, 1988).

As it has been explained by Cock *et al.* (1979) and Hunt (1990), harvest index is the ratio (quotient) between the weight of tubers or the marketable component of the crop to the weight of above-ground parts plus weight of tubers (total weight of crop) and hence cassava genotypes with large tuber weights will show high harvest index values. Therefore the high harvest index values registered by accessions 'H0008' and 'H0015' are accounted for by the large root weights recorded by these accessions.

Harvest index values reported for cassava genotypes elsewhere are similar to what is recorded here. For instance, Otim-Nape *et al.* (1994) produced harvest index data for thirteen cassava genotypes and ten out of this number showed a harvest index range of 0.4 to 0.8 and a mean of 0.6 and Nweke (1996) stated a mean harvest index of 0.5 from 497 cassava farms surveyed.

According to Braima *et al.* (2000) the percentage dry matter content in cassava roots determines the quantity and quality of the products obtained after the roots are processed. They also stated that cassava varieties whose storage roots have 30% or more dry matter are said to have high dry matter content. Going by this assertion all the cassava genotypes studied in this experiment have high dry matter content.

Benesi *et al.* (2004) evaluated twenty cassava genotypes at two locations in Malawi and reported root dry matter values that ranged between 37.63 and 47.6%. Afuakwa *et al.* (1999) have stated dry matter content values

of 30%, 27%, 30% and 40 for 'Afisiafi', 'Gblemoduade', 'Abasafitaa' and 'Tekbankye' respectively. These reported dry matter content values compare favourably with the figures obtained in this work, even though the present reported values are on the high side.

The significant ($P<0.05$) difference observed amongst the treatment effects may be attributed to genetic differences amongst the cassava genotypes as has been indicated by the studies of Pérez *et al.* (2001).

Dry root yield data were obtained by multiplying root dry matter content (%) of a genotype by its corresponding fresh root weight (kg). Therefore where a cassava genotype produces high fresh root weight and high root dry matter content, the dry root yield (g/plant) will also be high. This explains why accessions like 'H0008', 'H0015' and 'DMA 030' and variety 'Afisiafi' recorded high dry root yields.

As has been indicated earlier root dry matter content and by extension dry root yield is of significance in the selection of elite cassava genotypes for it determines the quantity of products obtained after the roots are processed.

Starch content and yield

The range of variation in starch content (%) values was quite narrow (between 23.07 and 25.01%) but the values fall within the range stated in literature elsewhere. Radley (1976) has stated that on average the tubers of cassava contain 20 – 30% starch, but variations have been obtained as low as 12% and as high as 33% starch. Janssens (2001) has reported 20-40% as the range of starch content in cassava tubers.

No significant (P>0.05) differences were observed amongst the cassava genotypes tested with respect to starch content, which in essence, statistically means that the differences noted cannot be attributed to varietal differences.

Starch yield values were obtained, as in the case of dry root yield, by multiplying starch content (%) by fresh root weight (kg). Since starch content values were not significantly (P>0.05) different from each other, the significant (P<0.05) differences observed in starch yield were due to significant (P<0.05) differences detected amongst fresh root weights.

If starch yield is considered as an important factor in the selection of promising cassava genotypes, then 'H0008' stands out as the genotype that should be selected.

EXPERIMENT II

Yield and yield components

Results obtained indicate that the main effects of genotype and environment provide complete description of the data set (Moore and Cabe, 1993) pertaining to the number of roots per plant.

Accessions 'DMA 030' and 'H0015' performed best in all the environments in relation to the number of roots per plant. Therefore, they can be recommended for planting at Legon and Bunso since as it has been noted by Magoon *et al.* (1970) that root tuber yield in cassava is closely related to the number of storage roots.

Significant varietal differences were observed at 8 and 12 MAP at Legon in contrast to no significant treatment effects at Bunso at 12MAP. The

possible explanation for this observation is that the reliable rainfall pattern during the experimental period and the rich soils at Bunso enabled the cassava plants to grow and develop their root tubers to the maximum so that any apparent varietal differences could not be manifested.

On the basis of the results obtained, where the environment main effect contributed nearly 80% to the total variation observed in fresh root weights, 12MAP at Bunso was identified as the environment in which the cassava genotypes performed well.

The overall rankings of the cassava genotypes studied using the four stability statistics identified 'UG126', 'H0015' and 'H0008' as the top 3 stable genotypes. The least stable genotypes are 'UCC 90', 'Bosome Nsia' and 'DMA 030'.

According to Benesi *et al.*, (2004), cassava genotypes that are stable could be presumed universal, and thus, their agronomic traits, such as root tuber weight are not dependent on environments. On the other hand, those that are unstable are specifically adapted to certain environments.

Based on this principle, therefore, accessions 'UG126', 'H0015' and 'H0008' can be presumed universal with respect to individual root weight. Their individual root tuber weights are not dependent on the environments. In contrast, however, 'UCC 90', 'Bosome Nsia' and 'DMA 030' depend on the environment to manifest either their high or low yield potential with regard to root tuber weight.

Genotype main effect and genotype x environment interaction were not significant ($P \geq 0.05$). The environment main effect which was very highly

significant (P<0.0001) indicates that Bunso 12MAP is the environment in which the cassava genotypes performed well.

Apparently, results from the analyses of fresh root tuber yield data are the same as the results from the analyses of fresh root tuber weights. This is because fresh root tuber yield data were directly computed from fresh root tuber weights.

Harvest index values indicate the proportion of the total fresh or dry matter of a crop which appears in the economically important fraction. It typically represents the portion of edible yield. For this reason, a high harvest index value is a desirable plant character.

The results of this wok indicate that accessions 'H0015', 'Bosome Nsia' and 'UCC 90' are stable accessions with respect to harvest index and therefore can be selected for any environment.

However, accessions 'UG 126', 'H0001' and variety 'Afisiafi' must be selected for specific environments if their potentials to produce high or low harvest index values are to be realized.

Mahungu (1998) has noted that there is a shift in the paradigm factor and root yield alone is not sufficient to justify the production of a particular cassava variety. Root dry matter content among other factors is a critical factor. In this work, the combined analysis of variance of the root dry matter content data indicates very highly significant (P<0.0001) environment and genotype main effects and their interaction.

Since root dry matter is a critical factor in the selection of cassava varieties as has been alluded to by Mahungu (1998), and employing the principle that stable cassava genotypes are universal (Benesi *et al.*, 2004).

accessions 'H0008', 'UG 126' and 'H0013' can be recommended for cultivation in the two agro-ecological zones, especially at Bunso where relatively higher root dry matter content values were obtained.

Starch content and yield

Starch content and yield are related in the sense that starch yield values were obtained by the multiplication of root starch content of a given cassava genotype by its corresponding fresh root weight per plant.

Pooled analysis of variance of starch content data and starch yield data basically gave the same results. Environment main effect was highly significant ($P<0.0001$) in each case, and genotype main effect and genotype by environment interaction were not significant.

Benesi *et al.* (2004) studied the starch yield of 20 cassava varieties grown at two locations in Malawi and found highly significant differences between locations. They attributed the differences observed to differences in the distribution of rainfall over the two locations. The extended dry weather in one of the locations forced cassava varieties planted there to over-use their food reserves by breaking down some of the starch into sugars for survival during the dry season.

They also observed that location made the largest contribution to the variation observed and genotype main effect and genotype by environment interaction were not significant. Based on their results, they suggested that when and where cassava is grown and harvested for starch matters if one wants to maximize starch yield from tubers.

The findings in this experiment are similar to the results obtained by Benesi *et al.* (2004). Therefore, their concluding remarks are also relevant to

this work. Environment main effect was very highly significant while the genotype main effect and genotype x environment interaction are not as was the case in Benesi *et al.* (2004) work.

It can be concluded, therefore, that to maximize starch yield from cassava tubers the environment in which the varieties are grown is a major significant agronomic factor. In particular, and from the results obtained in this work, growing the cassava accessions and variety at Bunso and harvesting at 12 MAP will maximize starch yield.

Genetic variation and heritability

The heritability (broad sense) estimates recorded for some of the production traits, such as number of roots per plant, individual root tuber weight, dry matter content and starch content were sufficiently high to warrant meaningful selection from the cassava genotypes from the test environments. This is because a high h^2 of about 70 percent and above suggests a relatively high component of the heritable portion of variation which is the portion exploited by the plant breeder (Mba and Dixon, 1995). The significance of these results is that with high values of h^2, even such simple selection procedures as recurrent phenotypic selection would be rewarding. Where very high h^2 values were obtained, for instance, number of roots per plant and dry matter content, it is seen that there is very little difference between Genetic Coefficient of Variation (GCV) and Phenotypic Coefficient of Variation (PCV). Since the genotypic component of variation is part of the phenotypic variation, it then means that the non-genetic component (error and interaction

effects) is very minimal. This is indeed most desirable and can aid in the phenotypic selection of the cassava genotypes.

The heritability (h^2) for the production traits recorded in this work which varied between 60 and 90 percents compare favourably with the work of (Mba and Dixon, 1995) who reported h^2 values that varied between 68 and 92 percents for similar production traits of cassava. In general, a high heritability value for a trait implies there is greater chance of the properties of that trait being transferred from parents to progenies. This also means that the trait can easily be improved. Low heritability, on the other hand, will have a smaller chance of transfer of properties from parents to progenies and will therefore be more difficult to improve.

Functional properties

The swelling volume values of the 8 cassava genotypes obtained in this work ranged between 16.30 and 26.17 ml/g at Legon and between 17.0 and 28.67 ml/g at Bunso. Moorthy (1994) studied the swelling behaviour of starch from eight cassava varieties and found out that the swelling volume of the different starches varied from 25.5 to 41.8 ml/g. The values obtained by Moorthy (1994) are relatively higher than what are reported here since Moorthy's lowest value is roughly the same as the highest value obtained at Legon.

The significant ($P<0.05$) differences in swelling volume values obtained in the work are indicative that swelling volume of cassava starch is dependent on variety among other factors as has been found out by Moorthy and Ramarujan (1986).

Studies conducted by Boakye *et al.* (2001) on the starch from four varieties of cassava normally cultivated in Ghana, namely: 'Ankra', 'Akosua Tuntum', 'Adwoa Smart' and 'Abosome Nsia' showed that the swelling power ranged between 27.5 and 36.1 g/g. The swelling power values of starch from 8 cassava genotypes reported by Moorthy (1994) varied from 35.1 to 54.3 g/g. These reported values indicate that the swelling power figures obtained from starch of the 8 cassava genotypes studied which varied from 25.33 to 53.33 g/g at Legon and from 35.33 to 56.67 g/g at Bunso are quite similar to what Moorthy obtained.

The significant ($P<0.05$) differences in treatment means found in swelling power values at both Legon and Bunso suggest that the cassava genotypes produce starch with different swelling power properties, that is, the differences in swelling power values can be attributed to varietal differences.

Recorded starch solubility values at Legon varied from 7.21 to 11.19% and from 8.01 to 10.82% at Bunso. Moorthy (1994) has reported a relatively higher starch solubility values that ranged between 17.7 and 27.6% when he studied the swelling behaviour of starch from 8 Indian cassava genotypes.

Starch solubility values of starch of seven varieties of a related crop, that is, sweet potato, obtained by Oduro *et al.* (2000) when they studied the pasting characteristics of these starches are similar to what is presented in this work. They reported a range between 6.82 and 11.94% which is closely comparable to the ranges of 7.21 to 11.19% at Legon and 8.01 to 10.82% at Bunso.

Significant ($P<0.05$) differences amongst the treatments were obtained at both locations. These differences are attributable to varietal differences as has been postulated by Moorthy and Ramarujan (1986).

Generally, good quality starch will have a low solubility, high swelling volume and high swelling power. High solubility, low swelling volume and swelling power are indicative of poor quality starches that produce thin, low stability when cooked (Bainbridge *et al.* 1996).

Using this principle as a guide, variety 'Afisiafi' and accessions 'UG 126', 'H0008', and 'H0015' were the top four cassava genotypes cultivated at Legon that have good quality starch in relation to their functional properties. At Bunso, 'Afisiafi', 'H0015', 'H0008', 'Bosome Nsia' and 'DMA 030' produced starches that have good functional properties.

Pasting Characteristics

The pasting temperature is the temperature at which irreversible swelling of the starch granules occur leading to peak viscosity. In a constant heating rate experiment as in the case with the Brabender Visco-amylograph, it is directly related to the time to reach peak viscosity. In this experiment the pasting temperatures of starches obtained from the cassava genotypes cultivated at Legon varied from 54.2 to 66.0°C (a range value of 11.8°C) and at Bunso from 53.40 to 63.57°C (a range value of 10.17°C).

The pasting temperatures of starches from seven cassava varieties, namely: M'-4', 'Kalikan', 'H-1687', 'H-2304', 'H-226', 'H-97' and 'H-165' were studied by Moorthy (1994) at the Central Tuber Crops Research Institute, Kerala, India. He found out that starch of varieties 'H-165' and 'H-1687'

gelatinized earlier and their pasting temperature range value was relatively higher, that is above 12°C.

The results reported in this work bear some similarity to the study of Moorthy (1994). The pasting temperature range values are 11.8°C and 10.17°C for starches from Legon and Bunso respectively and these figures compare favourably with the range value of above 12°C reported by Moorthy.

Boakye *et al.* (2001) found the pasting temperature range of 64 to 67°C for starches from four varieties of cassava commonly cultivated in Ghana. 'Bosome Nsia' which was one of the cassava genotypes studied by Boakye *et al.* (2001) was also included in the present research work. The mean pasting temperature of starch from 'Bosome Nsia' at Legon and Bunso was 64.39°C which falls within the range reported by Boakye *et al.* (2001). This reinforces the notion that the results reported in this work agree to a large extent with similar research work done elsewhere.

According to Bainbridge *et al.* (1996) starches with lower pasting temperatures are generally considered to be easier to cook. Therefore, accessions 'UCC 90' and 'UG 126' will be easier to cook since they registered the lowest pasting temperatures at both Legon and Bunso. However, lower pasting temperatures are also associated with low paste stability, which is usually considered to be an undesirable property. Low pasting temperature and low paste stability are indicative that fewer associative forces and cross-links are present within the starch granules.

The peak viscosity is the highest viscosity reached during the heating phase of the Brabender Visco-Amylograph. At this point, there is a majority of starch granules that are fully swollen but intact. For any particular type of

starch, the more granules that are available to be hydrated the higher the peak viscosity will be.

Cassava genotypes cultivated at Legon produced starches with peak viscosity values that ranged between 830.0 and 988.67 Brabender units (BU), and at Bunso a variation of 1192.33 to 1398.67 BU. These values are relatively higher when compared to the viscosity values reported by Boakye *et al.* (2001). They reported a range between 445 and 585 BU for starch from four cassava varieties.

The peak viscosity value and viscosity at 95°C are measures of the ability of the starch to form a paste on cooking. The higher the viscosity the thicker the paste will be. Jones (1983) and Kim *et al.* (1995) have noted that a high viscosity is desirable for industrial use for which a high thickening power is required. For this reason, accessions 'H0008', 'UG 126' and 'H0001' cultivated at Legon and 'DMA 030', 'UG 126' and 'H0015' at Bunso are the cassava genotypes that can be cultivated to produce starch for industrial purposes since their starches produced the highest peak viscosities and highest viscosities at 95°C.

Paste stability at 95°C is the difference between paste viscosity value at 95°C and paste viscosity value after 15 minutes at 95°C (first holding period). The paste stability at 95°C measures the tendency of the paste to breakdown during cooking. High paste stability is frequently a requirement for industrial uses of starch (Kim *et al.* 1995). A starch with low paste stability has very weak cross-linking within the granules and requires less heating.

Starch from 'H0008' cultivated at Legon demonstrated the highest paste stability at 95°C although this value was not significantly different from

values produced by starches from 'Afisiafi', 'Bosome Nsia' and 'H0001'. No significant ($P>0.05$) differences were monitored amongst the paste stability values of the cassava starches obtained from Bunso. Therefore, for industrial purposes, 'H0008', 'Bosome Nsia', 'H0001' and 'Afisiafi' can be cultivated at both locations to produce starch of high paste stability.

When a starch paste is cooled from the phase at which it was held for 15 minutes at 95°C to 50°C, there is an increase in viscosity. This increase indicates the tendency of the starch particles to associate or retrograde.

A low setback or retrogradation viscosity value shows that the starch gives a non-cohesive paste which is useful in many industrial applications as has been reported by Kim *et al.* (1995). In contrast a high setback viscosity value is useful if the starch is to be used for domestic purposes, such as *fufu* and *banku* preparation which require a high viscosity and paste stability at low temperatures (Oduro *et al.* 2000).

Five cassava accessions, namely; 'H0008', 'H0015', 'DMA 030', 'UG 126' and 'UCC 90' cultivated at Legon produced starch with high setback viscosity values. At Bunso, starches from 'H0008', 'UG 126', 'DMA 030', 'UCC 90', 'Bosome Nsia' and 'Afisiafi' recorded high values of setback viscosity.

Following this observation, therefore, 'Bosome Nsia', 'Afisiafi' and 'H0001' cultivated at Legon and 'H0001' and 'H0015' grown at Bunso may be recommended for industrial uses based on their relatively low setback viscosity values.

pH values

Ingram (1975) has stated the pH specifications for cassava starch as between 4.5 and 7.0. The pH values recorded for starch from 'Afisiafi', 'H0001', 'UCC 90', 'UG 126' and 'H0008' cultivated at Legon fall within this range. 'Bosome Nsia' and 'H0015' produced starch with slightly higher pH values above the stated range. Significant ($P<0.05$) treatment effects were obtained indicating varietal differences with respect to pH values.

All the pH values of starch obtained from the cassava genotypes grown at Bunso were slightly just above the recommended range. No significant ($P>0.05$) varietal differences were detected.

Boakye *et al.* (2001) have reported a pH range from 3.22 to 4.01 of starches from 4 cassava varieties and Barimah and Mantey (2002) a pH variation from 3.78 to 6.82 of starch samples that were dried using different methods. The sun-drying starch gave the highest pH values and Barimah and Mantey (2002) surmised that this might be due to fermentation that might have occurred during the process.

The pH values recorded in this work are relatively higher than what have been documented by Boakye *et al.* (2001) and Barimah and Mantey (2002). All the starches in this present work were sun-dried and as has been suggested by Barimah and Mantey (2002), the high pH values might be due to fermentation of the starches during the sun-drying process.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The 11 cassava accessions and 2 released varieties as checks evaluated in Experiment I on the bases of tolerance to whitefly infestation and African Cassava Mosaic Virus (ACMV) disease infection; root tuber yield; dry matter content and yield; starch content and yield showed in most cases significant ($P<0.05$) differences among the accessions with respect to the parameters measured.

No significant ($P>0.05$) correlations existed between whitefly counts and most of the other variables measured. However, ACMV disease effects on most measured plant characters were significant and negative which indicated that ACMV disease had slight detrimental effects on agronomic traits and starch content and yield characteristics of the cassava genotypes studied.

Significant ($P<0.05$) differences among cassava genotypes were detected with respect to agronomic traits such as number of roots, fresh root weight, fresh root yield and harvest index. Cassava accessions and varieties did not manifest any significant ($P>0.05$) differences among themselves in relation to starch weight and content. The results, however, indicated that the cassava genotypes significantly differed with respect to starch yield.

On the criteria of cassava genotypes least affected by ACMV diseases and having higher and desirable agronomic traits, starch content and yield characteristics, 7 cassava accessions, namely: 'H0008', 'H0015', 'UG 126', 'DMA 030', 'UCC 90', 'H0001' and 'Bosome Nsia' and one variety, 'Afisiafi', as a check were selected for further evaluations at 2 agro-ecological zones in Experiment II.

Results from Experiment II showed significant ($P<0.05$) differences among the cassava accessions and the check variety at specific and combined locations with respect to the agronomic traits and starch yield characteristics evaluated. For such plant characters as individual root weight, shoot weight, fresh root yield and harvest index, significant ($P<0.05$) differences were observed either at 8 and 12 MAP at both Legon and Bunso or at 8 or 12 MAP at any of the 2 locations.

Combined analyses of data obtained from the 2 locations and age at harvest indicated significant ($P<0.05$) main effects for environment and genotype, and the interaction between environment and genotype for individual root tuber weight, shoot weight, harvest index, dry root weight and dry matter content.

Stability analyses performed to identify stable genotypes across environments where the GXE was significant showed that for individual root tuber weight, 'UG 126', 'H0015' and 'H0008' were the top 3 most stable genotypes; 'H0015', 'Bosome Nsia' and 'UCC 90', the top 3 stable genotypes in relation to harvest index; and with respect to dry root weight, 'UG 126', 'H0008' and 'H0001' the most stable accessions.

The heritability (broad sense) estimates recorded for some of the production traits, such as number of roots per plant, individual root tuber weight, dry matter content and starch content were sufficiently high to warrant meaningful selection from the cassava genotypes from the test environments

The functional properties, that is, swelling volume, solubility and swelling power of the starches obtained from the cassava genotypes indicated that variety 'Afisiafi', and accessions 'UG 126', 'H0008', 'H0015', 'Bosome Nsia' and 'DMA 030' produced starches with desirable qualities in terms of low solubility, high swelling volume and swelling power for industrial purposes.

Studies of the pasting characteristics of the starches using the visco-amylograph instrument indicated that accessions 'H0008', 'UG 126', 'H0001', 'DMA 030' and 'H0015' produced good quality starches for industrial purposes based on high peak viscosity and viscosity at 95°C.

For domestic purposes, for instance, for the preparation of *fufu* and *banku*, for which lower pasting temperatures and high setback viscosity values are required, 'UCC 90' and 'UG 126' were identified as the most suitable even though other accessions such as 'H0008' and 'DMA 030' can be used.

Apparently, depending upon what criteria are used to select starches for industrial or domestic purposes, the results obtained in this work show that one or two of the cassava accessions can be used for both industrial and domestic purposes.

The results presented in the work have demonstrated that some local cassava accessions are tolerant to the ACMV disease and that they can

produce high root and starch yields in spite of the slight detrimental effects of ACMV disease.

Recommendations

- Cassava accessions 'H0008', 'H0015', 'H0001', 'UG 126' and 'DMA 030' are recommended to be grown at both agro-ecological zones based on their tolerance to ACMV disease infection, high root tuber and starch yields.
- Of the two agro-ecological zones, deciduous forest zone is recommended and harvesting the crop at 12MAP is to be preferred to harvesting at 8MAP
- Accessions 'UG126', 'H0008', 'H0001' and 'DMA 030' are recommended for industrial purposes based on their starch qualities such as low solubility, high swelling volume and swelling power, high peak viscosity and high paste stability values.
- Accessions 'UG 126', 'DMA 030' and 'UCC 90' are recommended for domestic purposes, such as for the preparation of *fufu* and *banku* since they produced starches of high setback viscosity values.
- It is recommended that a longer period of time, for instance 3 years can be used for further evaluations of the cassava genotypes studied. This will allow for more data to be collected and extensive statistical analyses made on genotype x location x year interactions.
- It is also recommended that the study (trials) be extended to other agro-ecological zones in Ghana such as the transitional and Guinea savanna since cassava is widely grown in Ghana.

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APPENDIX 1: EXPT. I, LEGON 12MAP

Appendix 1a:

TABLE 1a: Mean squares of agronomic traits of eleven cassava accessions and two varieties harvested twelve months after planting (MAP) at Legon

Source of Variation	Df	Number of roots per plant	Fresh root weight (kg)	Individual root tuber weight (g)	Shoot weight (kg/plant)
Variety	12	7.212***	6.376***	57093.90^{ns}	29.504^{ns}
Replication	2	1.535	3.828	94191.30	1.50
Error	24	1.456	0.786	26167.0	32.515
C.V. (%)		19.44	16.75	18.59	4.71

*** = Significant at 0.1 % level
ns = not significant at 5%

Appendix 2a:

TABLE 2a: Mean squares of agronomic traits of eleven cassava accessions and two varieties harvested twelve months after planting (MAP) at Legon

Source of variation	Df	Fresh root yield (t/ha)	Harvest index	Dry root weight (g)	Root dry matter content (%)
Variety	12	637619.658***	8.75x10^{-3}***	333.632***	13.3345***
Replication	2	382846.154	3.33x10-3	87.199	3.488
Error	24	78568.376	1.11x10-3	24.567	0.983
C.V. (%),		16.75	6.75	2.59	2.59

*** = Significant at 0.1 % level

Appendix 3a:

TABLE 3a Mean squares of dry root yield and starch yield data of eleven cassava accessions and two varieties harvested twelve months after planting (MAP) at Legon

Source of variation	Df	Dry root yield (g/plant)	Starch weight (g)	Starch content (%)	Starch yield (g/plant)
Variety	12	949680.42***	29.234^{ns}	1.169^{ns}	385503.979***
Replication	2	440281.62	5.718	0.229	202970.333
Error	24	2599491.44	32.739	1.309	56697.222
C.V. (%)		16.27	4.71	4.71	18.49

*** = Significant at 0.1 % level
ns = not significant at 5%

Appendix 4a:

TABLE 4a: Mean squares of whitefly population data collected on thirteen cassava genotypes at different growth stages at Legon

Source of variation	Df	1 MAP	3 MAP	6 MAP
Variety	12	$8.308x10^{-2}$ **	$4.824x10^{-2ns}$	$1.684x10^{-1}$**
Replication	2	$2.367x10^{-2}$	$3.229x10^{-2}$	$7.233x10^{-2}$
Error	24	$2.248x10^{-2}$	$2.959x10^{-2}$	$5.763x10^{-2}$
C.V. (%)		33.10	33.79	41.10

*** = Significant at 1 % level
ns = not significant at 5%
MAP: Months after planting.

Appendix 5a:

TABLE 5a: Mean squares of African Cassava Mosaic Virus (ACMV) disease ordinal scores collected on thirteen cassava genotypes at one, three and six months after planting (MAP) at Legon

Source of variation	Df	1 MAP	3 MAP	6 MAP
Variety	12	$9.986x10^{-2}$***	$3.324x10^{-2}$***	$3.568x10^{-2}$***
Replication	2	$1.03x10^{-3}$	$1.06x10^{-3}$	$2.03x10^{-3}$
Error	24	$2.79x10^{-3}$	$1.632x10^{-2}$	$1.17x10^{-3}$
C.V. (%)		10.06	4.71	6.28

*** = Significant at 0.1 % level MAP: Months after planting.

APPENDIX 2: EXPT. II – LEGON DATA

Appendix 1b:

Table 1b: Mean squares of agronomic traits of seven cassava accessions and one variety harvested eight and twelve months after planting (MAP) at Legon.

Source of variation	Df	Number of roots per plant		Fresh root weight (kg)		Individual root tuber weight (g)	
		8 MAP	12 MAP	8 MAP	12 MAP	8 MAP	12 MAP
Variety	7	5.845**	7.033***	0.397***	2.544***	9618.464*	206722.038***
Replication	2	0.008	0.118	0.005	0.055	421.42	12252.575
Error	14	1.029	0.252	0.007	0.051	2768.351	13559.810
C.V. (%)		22.01	11.86	7.87	8.94	22.36	18.283

* = Significant at 5 % level
** = Significant at 1 % level
*** = Significant at 0.1 % level

Appendix 2b:

Table 2b: Mean squares of agronomic traits of seven cassava accessions and one variety harvested eight and twelve months after planting (MAP) at Legon.

Source of variation	Df	Shoot weight (kg/plant)		Fresh root yield (t/ha)		Harvest index	
		8 MAP	12 MAP	8 MAP	12 MAP	8 MAP	12 MAP
Variety	7	0.074^{ns}	0.390***	$1.324x10^{7}$**	$84x10^{7}$***	$5.68x10^{-3}$***	0.005**
Replication	2	0.321	0.067	$1.718x10^{5}$	$1.6x10^{6}$	$3.9x10^{-3}$	0.001
Error	14	0.06	0.050	$2.254x10^{5}$	$1.7x10^{6}$	$5.56x10^{-4}$	0.001
C.V. (%)		21.31	15.24	7.87	9.016	5.07	5.49

** = Significant at 1 % level
*** = Significant at 0.1 % level
ns = not significant at 5 % level

Appendix 3b:

Table 3b: Mean squares of agronomic traits of seven cassava accessions and one variety harvested eight and twelve months after planting (MAP) at Legon.

Source of Variation	Df	Dry root weight (g)		Root dry matter content (%)		Dry root yield (g/plant)	
		8 MAP	12 MAP	8 MAP	12 MAP	8 MAP	12 MAP
Variety	7	586.176**	339.076**	29.690**	15.869**	44970.362***	337095.774***
Replication	2	284.880	62.263	13.977	2.978	88.542	5565.208
Error	14	94.578	50.547	4.70	3.532	572.264	10518.197
C.V. (%)		5.92	3.90	5.80	4.62	6.14	10.08

** = Significant at 1 % level
*** = Significant at 0.1 % level

Appendix 4b:

Table 4b: Mean squares of starch yield data of seven cassava accessions and one variety harvested eight and twelve months after planting (MAP) at Legon.

Source of Variation	Df	Starch weight (g)		Starch content (%)		Starch yield (g/plant)	
		8 MAP	12 MAP	8 MAP	12 MAP	8 MAP	12 MAP
Variety	7	56.911^{ns}	40.647^{ns}	2.444^{ns}	2.0ns	21170.474***	148667.157***
Replication	2	4.777	56.254	0.230	2.778	372.798	3707.356
Error	14	51.676	27.128	2.156	1.339	462.496	2484.117
C.V. (%)		6.21	4.43	6.19	4.43	8.71	7.6

*** = Significant at 1 % level
ns = not significant

Appendix 5b:

Table 5b: Mean squares of whitefly population data collected on eight cassava genotypes at one, three and six months after planting (MAP) at Legon.

Source of variation	Df	1 MAP	3 MAP	6 MAP
Variety	7	0.213***	0.027^{ns}	0.063^{ns}
Replication	2	0.027	0.002	0.019
Error	14	0.009	0.028	0.037
C.V. (%)		14.75	38.57	59.89

*** = Significant at 0.1 % level ns = not significant

Appendix 6b:

Table 6b: Mean squares of African Cassava Mosaic Virus (ACMV) disease ordinal scores data collected on eight cassava genotypes at one, three and six months after planting (MAP) at Legon

Source of variation	Df	1 MAP	3 MAP	6 MAP
Variety	7	$7.49x10^{-3}$ ns	$9.36x10^{-3}$ ***	$5.1x10^{-3}$ ***
Replication	2	$5.6x10^{-3}$	$1.6x10^{-4}$	$5.8x10^{-4}$
Error	14	$4.04x10^{-3}$	$7.7x10^{-4}$	$5.1x10^{-4}$
C.V. (%)		19.12	7.20	5.61

*** = Significant at 0.1 % level
ns = not significant

APPENDIX 3: EXPT. II – BUNSO DATA

Appendix 1c:

Table 1c: Mean squares of agronomic traits of seven cassava accessions and one variety harvested eight and twelve months after planting (MAP) at Bunso.

Source of Variation	Df	Number of roots per plant		Fresh root weight (kg)		Individual root tuber weight (g)	
		8 MAP	12 MAP	8 MAP	12 MAP	8 MAP	12 MAP
Variety	7	2.716 ns	2.177 ns	0.301**	8.464 ns	3881.176*	59161.310 ns
Replication	2	2.993	3.406	0.056	15.620	10566.905	399179.167
Error	14	1.248	1.450	0.068	6.054	1342.864	27450.595
C.V. (%)		13.49	28.34	7.76	32.69	8.87	14.85

* = Significant at 5 % level
** = Significant at 1 % level
ns = not significant

Appendix 2c:

Table 2c: Mean squares of agronomic traits data collected from seven cassava accessions and one variety harvested eight and twelve months after planting (MAP) at Bunso.

Source of Variation	Df	Shoot weight (kg/plant)		Fresh root yield (t/ha)		Harvest index	
		8 MAP	12 MAP	8 MAP	12 MAP	8 MAP	12 MAP
Variety	7	1.665**	27.319**	$2.97x10^{7}$ **	$8.464x10^{8}$ ns	0.013***	0.013***
Replication	2	0.175	6.415	$5.11x10^{6}$	$15.620x10^{8}$	$2.0x10^{-3}$	$2.92x10^{-5}$
Error	14	0.298	5.869	$6.89x10^{6}$	$7.013x10^{8}$	$1.4x10^{-3}$	$3.9x10^{-4}$
C.V. (%)		13.96	33.28	7.79	32.69	8.14	3.38

** = Significant at 1 % level
*** = Significant at 0.1 % level
ns = not significant

Appendix 3c:

Table 3c: Mean squares of agronomic traits data collected from seven cassava accessions and one variety harvested eight and twelve months after planting (MAP) at Bunso.

Source of Variation	Df	Dry root weight (g)		Root dry matter content (%)		Dry root yield (g/plant)	
		8 MAP	12 MAP	8 MAP	12 MAP	8 MAP	12 MAP
Variety	7	167.873*	213.649**	8.769*	10.643**	85275.949**	1246752.458^{ns}
Replication	2	29.783	20.143	1.531	1.014	12957.580	2457132.075
Error	14	40.957	44.015	2.136	2.197	12115.623	663294.58
C.V. (%)		3.59	3.48	3.61	3.49	8.06	34.10

* = Significant at 5 % level
** = Significant at 1 % level
ns = not significant

Appendix 4c:

Table 4c: Mean squares of starch yield data collected from seven cassava accessions and one variety harvested eight and twelve months after planting (MAP) at Legon.

Source of Variation	Df	Starch weight (g)		Starch content (%)		Starch yield (g/plant)	
		8 MAP	12 MAP	8 MAP	12 MAP	8 MAP	12 MAP
Variety	7	22.203^{ns}	41.855^{ns}	1.401^{ns}	1.758^{ns}	43341.143*	637506^{ns}
Replication	2	4.980	118.569	0.212	5.018	1667.792	563011
Error	14	20.058	30.663	1.052	0.998	13576.058	446439
C.V. (%)		5.02	4.97	4.61	4.94	12.15	36.09

* = Significant at 5% level
ns = not significant

Appendix 5c:

Table 5c: Mean squares of whitefly population data collected on eight cassava genotypes at one, three and six months after planting (MAP) at Bunso.

Source of variation	Df	1 MAP	3 MAP	6 MAP
Variety	7	$2.213x10^{-2}$ *	$1.836x10^{-2\,ns}$	$2.844x10^{-2}$ ***
Replication	2	$2.596x10^{-2}$	$9.775x10^{-2}$	$2.227x10^{-2}$
Error	14	$6.01x10^{-3}$	$8.34x10^{-3}$	$1.27x10^{-3}$
C.V. (%)		12.32	17.70	5.64

** = Significant at 1 % level
*** = Significant at 0.1 % level
ns = not significant

Appendix 6c:

Table 6c: Mean squares of African Cassava Mosaic Virus (ACMV) disease ordinal scores data collected on eight cassava genotypes at one, three and six months after planting (MAP) at Bunso

Source of variation	Df	1 MAP	3 MAP	6 MAP
Variety	7	$2.115x10^{-2}$ ***	$4.694x10^{-2}$ ***	$5.702x10^{-2}$ **
Replication	2	$6.0x10^{-4}$	$1.14x10^{-3}$	$8.8x10^{-4}$
Error	14	$7.9x10^{-4}$	$7.2x10^{-4}$	$8.7x10^{-4}$
C.V. (%)		7.60	6.12	6.66

** = Significant at 1 % level *** = Significant at 0.1 % level

APPENDIX 4: EXPT. II – LEGON & BUNSO

Appendix 1d:

Table 1d: Mean squares of functional properties of starch samples collected from eight cassava genotypes cultivated at Legon and Bunso.

Source of variation	Df	Swelling volume (ml/g)		Swelling power (g/g)		Solubility (%)	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Variety	7	27.399**	36.951***	4.444**	3.511*	207.429***	207.405***
Replication	2	2.885	2.198	1.181	2.918	24.667	6.542
Error	14	5.849	4.817	0.741	1.185	12.286	5.065
C.V. (%)		11.92	9.85	8.872	11.10	9.38	5.61

* = Significant at 5 % level
** = Significant at 1 % level
*** = Significant at 0.1 % level

Appendix 2d:

Table 2d: Mean squares of pasting characteristics of starch samples collected from eight cassava genotypes cultivated at Legon and Bunso.

Source of variation	Df	Pasting temperature (°C)		Pasting time (minutes)		Peak viscosity (BU)	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Variety	7	92.884***	41.902***	2.047 ns	3.065 ns	8888.851***	14270.661**
Replication	2	7.403	3.042	5.768×10^{-1}	4.847	1443.167	12562.042
Error	14	6.238	2.162	1.308	2.118	771.261	2244.803
C.V. (%)		4.0	2.42	13.32	17.57	3.0	3.64

** = Significant at 1 % level BU = Brabender units
*** = Significant at 0.1 % level
ns = not significant

Appendix 3d:

Table 3d: Mean squares of pasting characteristics of starch samples collected from eight cassava genotypes cultivated at Legon and Bunso.

Source of variation	Df	Viscosity at 95°C.(BU)		Viscosity after 15 mins. at 95°C (BU)		Viscosity at 50°C (BU)	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Variety	7	1581.024**	1951.333*	1121.375***	1444.286ns	4390.571***	10383.214***
Replication	2	1519.542	481.542	262.167	829.542	45.292	1200.875
Error	14	250.113	782.637	131.928	713.875	210.625	642.446
C.V. (%)		4.51	7.24	4.62	9.06	2.88	4.21

* = Significant at 5 % level
*** = Significant at 0.1 % level
ns = not significant

Appendix 4d:

Table 4d: Mean squares of pasting characteristics of starch samples collected from eight cassava genotypes cultivated at Legon and Bunso.

Source of variation	Df	Viscosity after 15 minutes at 50°C (BU)		Paste stability at 95°C (BU)		Paste stability at 50°C (BU)	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Variety	7	4746.327***	10789.714***	527.613*	167.333 ns	16.042 ns	30.643*
Replication	2	17.042	1177.125	208.292	314.292	5.292	8.75×10^{-1}
Error	14	218.470	645.125	175.720	98.244	6.292	10.446
C.V. (%)		3.0	4.29	13.59	10.79	19.73	36.93

* = Significant at 5 % level BU = Brabender units
*** = Significant at 0.1 % level
ns = not significant

Appendix 5d:

Table 5d: Mean squares of Setback viscosity, breakdown viscosity and pH values of starch samples collected from eight cassava genotypes cultivated at Legon and Bunso.

Source of variation	Df	Setback viscosity (BU)		Breakdown viscosity (BU)		pH values	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Variety	7	1800.952***	3911.238*	4965.042***	15124.952*	$8.256x10^{-1}$***	$6.368x10^{-2}$ ns
Replication	2	887.042	1948.167	312.542	19603.50	$2.263x10^{-1}$	$3.924x10^{-2}$
Error	14	142.470	1081.595	362.827	5015.881	$7.037x10^{-2}$	$5.562x10^{-2}$
C.V. (%)		4.66	10.58	2.81	6.91	3.74	3.15

* = Significant at 5 % level BU = Brabender units
*** = Significant at 0.1 % level
ns = not significant

APPENDIX 5: EXPT. II – LEGON & BUNSO

Appendix 1e:

Table 1e: Mean squares from analysis of variance for functional properties of starch of seven cassava accessions and one variety evaluated at Legon and Bunso.

Source	DF	Swelling volume (ml)		Swelling power (g/g)		Solubility (%)	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	2.885	2.198	1.181	2.918	24.667	6.542
Genotype	7	27.399**	36.951***	4.444**	3.511*	207.429***	207.405***
Error	14	5.850	4.817	$7.409x10^{-1}$	1.185	12.286	5.065
C.V. (%)		11.92	9.85	8.87	11.10	9.38	5.61

* = Significant at 5 % level
** = Significant at 1 % level
*** = Significant at 0.1 % level

Appendix 2e:

Table 2e: Mean squares from analysis of variance for pasting characteristics of starch of seven cassava accessions and one variety evaluated at Legon and Bunso.

Source	DF	Pasting temperature (°C)		Pasting time (minutes)		Peak viscosity (BU)	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	7.403	3.042	5.768×10^{-1}	4.847	1443.167	12562.042
Genotype	7	92.884***	41.902***	2.047ns	3.065ns	8888.851***	14270.661**
Error	14	6.238	2.162	2.308	3.118	771.262	2244.804
C.V. (%)		4.0	2.42	13.32	17.57	3.01	3.65

** = Significant at 1 % level BU = Brabender units
*** = Significant at 0.1 % level
ns = not significant

Appendix 3e:

Table 3e: Mean squares from analysis of variance for pasting characteristics of starch of seven cassava accessions and one variety evaluated at Legon and Bunso.

Source of variation	DF	Viscosity at 95°C (BU)		Viscosity after 15 mins. at 95°C (BU)		Viscosity at 50°C (BU)	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	1519.542	481.542	262.167	829.542	45.292	1200.875
Genotype	7	1581.024**	1951.333^{ns}	1121.375***	1444.286 ns	4390.571***	10383.214***
Error	14	250.113	782.637	131.929	713.875	210.625	642.446
C.V. (%)		4.51	7.24	4.63	9.06	2.88	4.22

** = Significant at 1 % level BU = Brabender units
*** = Significant at 0.1 % level
ns = not significant

Appendix 4e:

Table 4e: Mean squares from analysis of variance for pasting characteristics of starch of seven cassava accessions and one variety evaluated at Legon and Bunso.

Source of Variation	DF	Viscosity after 15 minutes at 50°C (BU)		Paste stability at 95°C (BU)		Paste stability at 50°C (BU)	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	17.042	1177.125	208.292	314.292	5.292	$8.75x10^{-1}$
Genotype	7	4746.327***	10789.714***	527.613*	167.333^{ns}	16.042^{ns}	30.643*
Error	14	218.470	645.125	175.720	98.244	6.292	10.446
C.V. (%)		3.01	4.29	13.59	10.79	19.74	36.938

** = Significant at 1 % level BU = Brabender units
*** = Significant at 0.1 % level
ns = not significant

Appendix 5e:

Table 5e: Mean squares from analysis of variance for pasting characteristics and pH values of starch of seven cassava accessions and one variety evaluated at Legon and Bunso.

Source of variation	DF	Setback Viscosity (BU)		Breakdown Viscosity (BU)		pH Values	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	887.042	1948.167	312.542	19603.5	$2.263x10^{-1}$	$3.924x10^{-2}$
Genotype	7	1800.952***	3911.238*	4965.042***	15124.952*	$8.256x10^{-1***}$	$6.368x10^{-2}$
Error	14	142.470	1081.595	362.827	5015.881	$7.04x10^{-2}$	$5.562x10^{-2}$
C.V. (%)		4.67	10.586	2.81	6.91	3.74	3.15

** = Significant at 1 % level BU = Brabender units
*** = Significant at 0.1 % level
ns = not significant

APPENDIX 6: EXPT. II – LEGON & BUNSO

Appendix 1f:

Table 1f: Mean squares from analysis of variance for agronomic traits data of seven cassava accessions and one variety evaluated at Legon and Bunso eight and twelve MAP

Source	DF	Number of roots per plant				Fresh root weight (kg)			
		8 MAP		12 MAP		8 MAP		12 MAP	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	$7.917x10^{-2}$	2.994	$1.18x10^{-1}$	3.406	$1.03x10^{-2}$	$5.57x10^{-2}$	$5.5x10^{-2}$	15.620
Genotype	7	5.845**	2.716^{ns}	7.033***	2.177^{ns}	2.782***	$3.0x10^{-1\ ns}$	2.544***	8.464^{ns}
Error	14	1.029	1.248	$2.52x10^{-1}$	6.061	$6.76x10^{-3}$	$6.84x10^{-2}$	$5.12x10^{-2}$	10.013
c.v. (%)		22.01	13.50	11.86	28.34	7.87	7.77	8.94	32.69

MAP = Months after planting

Appendix 2f:

Table 2f: Mean squares from analysis of variance for agronomic traits data of seven cassava accessions and one variety evaluated at Legon and Bunso eight and twelve MAP

Source	DF	Individual root weight (g)				Shoot weight (kg/plant)			
		8 MAP		12 MAP		8 MAP		12 MAP	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	421.418	10566.910	12252.575	399179.167	$3.21x10^{1}$	$1.75x10^{1}$	$6.69x10^{2}$	6.415
Genotype	7	9618.464*	3881.176*	2.07x105***	59161.310^{ns}	$7.45x10^{2ns}$	1.665**	$3.9x10^{1***}$	27.319**
Error	14	2768.351	1342.864	13559.810	27450.595	$6.03x10^{2}$	$2.98x10^{1}$	$4.97x10^{2}$	5.870
c.v. (%)		22.36	8.87	18.28	14.85	21.31	13.96	15.24	33.28

MAP = Months after planting

Appendix 3f:

Table 3f: Mean squares from analysis of variance for agronomic traits data of seven cassava accessions and one variety evaluated at Legon and Bunso eight and twelve MAP

Source	DF	Fresh root yield (kg/ha)				Harvest index			
		8 MAP		12 MAP		8 MAP		12 MAP	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	515416.7	$5.116x10^{6}$	$4.85x10^{6}$	$1.56x10^{9}$	$3.9x10^{-3}$	$2.02x10^{-3}$	$8.34x10^{-4}$	$2.92x10^{5}$
Genotype	7	$3.97x10^{7***}$	$2.97x10^{7ns}$	$2.5x10^{8***}$	$8.46x10^{8ns}$	$5.69x10^{3***}$	$1.31x10^{2***}$	$5.18x10^{3**}$	$1.29x10^{2}$
Error	14	676369.0	$6.89x10^{6}$	$5.21x10^{6}$	$1.0x10^{9}$	$5.57x10^{-4}$	$1.44x10^{-3}$	$1.18x10^{-3}$	$3.91x10^{4}$
c.v. (%)		7.87	7.79	9.02	32.69	5.07	8.15	5.50	3.38

MAP = Months after planting

Appendix 4f:

Table 4f: Mean squares from analysis of variance for agronomic traits data of seven cassava accessions and one variety evaluated at Legon and Bunso eight and twelve MAP

Source	DF	Dry root weight (g)				Root dry matter content (%)			
		8 MAP		12 MAP		8 MAP		12 MAP	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	284.88	29.783	62.263	20.143	13.977	1.531	2.979	1.014
Genotype	7	586.176**	167.873*	339.076**	213.649**	29.690**	8.769*	15.869**	10.643**
Error	14	94.578	40.957	50.547	44.015	4.70	2.136	3.532	2.197
c.v. (%)		5.92	3.59	3.90	3.48	5.80	3.61	4.62	3.49

MAP = Months after planting

Appendix 5f:

Table 5f: Mean squares from analysis of variance for dry root yield and starch weight of seven cassava accessions and one variety evaluated at Legon and Bunso eight and twelve MAP.

Source	DF	Dry root yield (g/plant)				Starch weight (g)			
		8 MAP		12 MAP		8 MAP		12 MAP	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	88.542	12957.580	5745.633	2.46×10^{6}	4.777	4.980	56.255	118.569
Genotype	7	44970.362***	85275.949***	3.37×10^{5}***	1.25×10^{6} ns	56.911 ns	22.203 ns	40.647 ns	41.855 ns
Error	14	572.264	12115.623	1.05×10^{4}	1.95×10^{6}	51.676	44.058	27.128	50.663
c.v. (%)		6.14	8.06	10.08	34.10	6.21	5.02	4.43	4.97

MAP = Months after planting

Appendix 6f:

Table 6f: Mean squares from analysis of variance for starch and starch yield of seven cassava accessions and one variety evaluated at Legon and Bunso eight and twelve MAP

Source	DF	Starch Content (%)				starch yield (g/plant)			
		8 MAP		12 MAP		8 MAP		12 MAP	
		LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO	LEGON	BUNSO
Replication	2	2.3×10^{-1}	2.117×10^{-1}	2.778	5.018	372.80	1667.792	3707.356	5.63×10^{5}
Genotype	7	2.444 ns	1.401 ns	2.004 ns	1.758 ns	21170.47***	43341.143*	148667.157***	6.38×10^{5} ns
Error	14	2.157	1.552	1.339	2.089	462.50	13576.058	2484.117	9.46×10^{5}
c.v. (%)		6.19	4.61	4.43	4.94	8.71	12.16	7.60	36.09

MAP = Months after planting