UNIVERSITY OF GHANA, LEGON

GENOTYPE BY ENVIRONMENT INTERACTION EFFECT ON BETA-CAROTENE AND SOME YIELD COMPONENTS OF YELLOW ROOT CASSAVA (*Manihot esculenta* Crantz) GENOTYPES IN GHANA

BY

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A DOCTORAL THESIS SUBMITTED TO THE DEPARTMENT OF BOTANY, FACULTY OF SCIENCE, UNIVERSITY OF GHANA, LEGON, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHYLOSOPHY (Ph.D.) IN BOTANY.

JUNE, 2008

DEDICATION

I dedicate this work to my beloved wife Catherine Edith and children Kenneth, Gwladys, Joel and Merveille They should never forget that hard work, persistence, courage, and patience are keys of success in this world

DECLARATION

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

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ACKNOWLEDGEMENTS

First, I would like to express my sincere gratitude, and thanks to Prof. I. K ASANTE for guiding me through this study. I wish to acknowledge his company and support during the data collection both at the field and laboratory I am also grateful for his cheerful and patient supervision during the final preparation of this dissertation

I am also extremely thankful to Professor Emeritus E LAING for the supervisory role he played in bringing me this far His professional and technical advice to me is worthy to be acknowledged.

I am also indebted to Dr A. G. O. DIXON for initiating this programme through Prof I. K. ASANTE The financial support for this work from the International Institute of Tropical Agriculture Harvest Plus Challenge Programme through Dr. A. G O DIXON is highly commendable

I am also grateful to the Staff of the Department of Botany for their support

I would also like to thank the Staff of the following Institutions for provision of experimental plots and labour.

(i) Wenchi Agricultural Station Ministry of Food and Agriculture (MOFA), specially Mr E BOAMPONG.

(ii) Plant Genetic Resources Research Institute, Bunso. Council for Scientific and Industrial Research (CSIR)

(iii) Pokuase Research Station of Crops Research Institute. CSIR

I wish to acknowledge the assistance from the Head, Department of Nutrition, Noguchi Memorial Institute for Medical Research (NMIMR), Legon, for the provision of laboratory space at the laboratory of Nutrition of the Noguchi Memorial Institute for Medical Research of the University of Ghana, Legon, I would like to express my special thanks to all the staff mainly to Mr Edward ADDO my specially thanks to all staff of NMIMR, especially Mr Edward ADO for his support during the laboratory analysis of the beta-carotene I would also like to thank Ms. Araba SAEED, Ms Ekuya BOATENG and Mr Kwami OSEI for their various technical assistances

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List of Abbreviation and Symbols

ACMV: African cassava mosaic virus

AMMI: Additive main effect and multiplicative interaction

ANOVA: Analysis of Variance

CIAT: International Centre of Tropical Agriculture

CGIAR: Consultative Group on International Agricultural Research

CRI: Crops Research Institute

CORAF: Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles

COSCA: Collaborative Study of Cassava

CV: Coefficient of Variation

DF: Degree of freedom

DFID: Department for International Development

E: Environment

ENV: Environment

FAOSTAT: United Nation Food and Agriculture Organization Statistics

G: Genotype

GCV: Genotypic Coefficient of Variation

G x E: Genotype by Environment Interaction

G: Genotype

h^2: Heritability Broad Sense

HCN: Hydrogen Cyanide

HI: Harvest index

HPLC: High Performance Liquid Chromatography

IITA: International Institute of Tropical Agriculture

IFPRI: International Food Policy Research Institute

IPCA: Interaction principal components axis

LSD: Least significant difference

MAP: Month after planting

M&E: Monitoring and Evaluation

MOFA: Ministry Of Food and Agriculture of Ghana

MS: Mean Square

Mt: Metric tons

NS: Non Significant

PC1: First principal component axis

PC2: Second principal component axis

PCV: Phenotypic coefficient of variation

PE: Petroleum Ether

PSI: President's special initiative

SS: S of Square

UCC: University of Cape Coast

WECARD: West and Central African Council for Agricultural Research and Development

σ_g^2: Genotypic variance

σ_e^2: Environmental variance

σ_{ge}^2: Genotype by environment interaction variance

σ_p^2: Phenotypic variance

ABSTRACT

Nine yellow root and one white root cassava genotypes were evaluated in ten environments in [illegible] variability and heritability of their agronomic traits and beta carotene content in [illegible] as to identify cassava genotypes that combine high root yield, high dry matter [illegible] carotene content in storage root. Such cassava genotypes can be used to combat [illegible] read vitamin A deficiency for children under the age of five and for pregnant and [illegible] omen. This study started in 2004 at Wenchi Agricultural station with a preliminary [illegible] of 35 yellow root cassava genotypes in a Randomized Complete Block Design with two replications. Nine yellow root genotypes namely 01/1224; 01 1235; 01 1368, 01/1371; 01 1412, 01 1417, 01 1442; 01/1610; 01 1663 were selected from the first year experiment based on their root yield and the deep yellowish colour of their root flesh. In 2005 two experiments were conducted at Wenchi in the Forest-Savannah Transition zone and at Bunso in the Deciduous Forest zone in a randomized complete block design with the nine yellow root cassava genotypes and one white root cassava namely Wenchi009 as check. In 2006, one additional location namely Pokuase in the costal savannah zone was added to Wenchi and Bunso to conduct the same field experiment. Each experiment was harvested two times (9 and 12 or 14 months after planting). At each harvest, field data were collected on number of plant harvested, number of storage root, storage root weight, storage root dry matter content, fresh shoot weight, harvest index and root mealiness. Beta carotene content analyses were carried out at Noguchi Medical Research Centre on yellow root cassava using High Performance Liquid Chromatography (HPLC) with a mobile phase made of acetonitrile: dichloromethane: methanol in the ratio 70:20:10 at a flow rate of 2.5 ml/min. Data collected were analyzed using the computer software GenStat Discovery Edition Release 4.2DE; MATMODEL 3.0, GGE biplot. Analyses of results showed statistically significant difference for genotypes, environments as well as Genotype by environment interaction for the agronomic traits such

sprouting, number of plants, number of storage roots per plant, average weight of storage root, fresh shoot weight, root dry matter content, root dry yield, harvest index and mealiness. Only the interaction GxE of root yield was not significant. The local check Wenchi009 was the overall best genotype for dry matter content and the mealiness. For other agronomic traits the best genotypes were 01/1368, 01/1663 and 01/1412. For the beta carotene characteristics there are significant differences between genotypes for beta carotene content per root, beta carotene content in storage root per plant and in storage root per hectare but no difference for beta carotene concentration. The best genotype for beta carotene contents was 01/1417 follow by 1371 and 1368.The differences between environments were highly significant for all beta carotene traits. The highest value of beta carotene concentration in fresh root was recorded in environments E_1, E_3, E_7 and E_8. These environments were all characterized by harvest at 9 months after planting. For beta carotene concentration, beta carotene content per storage root, beta carotene content in storage roots per plan and beta carotene content in storage roots per hectare, the best environments were E_9 (9 MAP at Pokuase) and E_1 (9 MAP at Wenchi in 2013). The interactions Genotype by Environment did not show any difference for the beta carotene traits. Positive and highly significant correlations were found between some agronomic variables and beta carotene variables except beta carotene concentration which was only highly correlated with harvest Index. Based on the above results the yellow root cassava genotypes 01/1368 and 01/1417 which combined high fresh storage root yield, high dry root yield with high beta carotene content in storage root can be proposed for on farm testing and released to tackle the vitamin A deficiency in Ghana.

1. INTRODUCTION

Vitamin A deficiency is a nutritional problem among many developing countries. In Sub-Saharan Africa, three million children under the age of five suffer total or partial blindness caused by vitamin A deficiency (Hagenimana *et al.*, 1999).

In Ghana vitamin A deficiency is a problem for children under the age of five and for pregnant and lactating women. Current estimate indicates that about 27% of children under 5 years of age are underweight and the main nutritional problems include inadequate intake of energy and protein, iodine deficiency disorders, iron deficiency (anaemia) and vitamin A deficiency (Rikimaru *et al.* 1996). According to studies conducted by the Centre of Social Studies of the University of Ghana, vitamin A deficiency accounts for death of one out of six of all children between the ages of 6 and 59 months. Although these problems are enormous, their full magnitude is unappreciated because usually there are no obvious signs of the problems, and the victims themselves are not aware. As a result not enough attention is paid to vitamin A deficiency (Takyi 1999).

In general, vitamin A intake is often inadequate because of the seasonality of foods, the early abandonment of exclusive breastfeeding, high morbidity levels, and the practice of not giving vitamin A rich foods to young children (McGuire, 1993). Since the early 1990s the main strategy for combating vitamin A deficiency in Public Health programmes has been to distribute capsules containing massive doses of vitamin A (Kennedy and Oniang'o, 1993). The results have been impressive - more than 12 million children received vitamin A supplement in 1997, and the total number of children suffering from blindness related to severe vitamin A deficiency has dropped (Kapinga *et al.*, 2001). Nevertheless, many families, particularly in rural areas, do not have access to capsules or

fortified foods, so chronic deficiency is widespread. However, similar effect could be achieved by an equivalent consumption of pro-vitamin A (beta-carotene) and vitamin A rich foodstuffs, as the safest and most appropriate long-term approach to controlling vitamin A deficiency (Rahmathullah *et al.*, 1990). Importantly, the primary source of all nutrients for people comes from agricultural products. Therefore, plant foods which provide concentrated pro-vitamin A carotenoids can contribute to improved human health. Research has demonstrated that micronutrient-enrichment traits are available within the genomes of some major staple food crops including cassava, that could allow for substantial increases in the levels of pro-vitamin A carotenoids (as well as other nutrients and health-promoting factors) without negatively impacting crop yield (Welch, 2001).

Cassava is one of the most important crops grown in Ghana. It is a major staple food in Ghana contributing 22% of Agricultural Gross Domestic Product (PPMED 1991) compared to 5% for maize, 2% for rice, sorghum and millet, 14% for cocoa, 11% for forestry, 7% for fisheries and 5% for livestock (Al-Hassan, 1989; Dapaah, 1996).

Cassava is the most important carbohydrate food crop providing various items of diet for Ghanaians (Asafu-Agyei, 1992).

The importance of cassava in Ghana is confirmed in terms of crop area, total production, contribution to Agricultural Gross Domestic Product and the food expenditure shares (Alderman and Higgens, 1992). Land area under cassava cultivation in Ghana, increased nation-wide from 532,000 hectares in 1993 to 807,000 hectares in 2003 (MOFA, 2004). Storage root production correspondingly increased from 5.97 million Mt in 1993 to 10.24 million Mt in 2003. According to Nweke, Spencer & Lynam 2002, in the late 1990s in Ghana, roughly 60 percent of the cassava planted was sold as a cash crop. This is

probably one of the reasons why the government of Ghana 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.

To date all the improved and released varieties of cassava being used by Ghanaian farmers as planting materials on large, medium and small scales are white flesh varieties. Despite the release of very high beta-carotene rich sweet potato varieties in Ghana such as (CRI-Apomuden with up to 12,000 µg/100g, the limited use of sweet potato and the limited processing technologies available and adapted to the Ghanaian situation do not permit the potential benefits of orange flesh sweet potato to reach the target consumers. However the HarvestPlus Challenge Programme of the Consultative Group for International Agricultural Research (CGIAR) has bred high-yielding yellow to orange flesh cassava genotypes to contribute to the fight against vitamin A deficiency According to Rodriguez-Amaya and Kimara 2004, beta-carotene is the predominant carotenoid in cassava Large genetic variation in carotenoid content has been reported after screening roots from thousands of cassava genotypes Studies have been conducted on retention of beta-carotene of cassava roots that had been boiled, oven-dried, sun-dried, shadow-dried, or used for gari preparation. It is also found that oven-drying, shadow drying and boiling retained the highest levels of beta-carotene (71 9%, 59 2% and 55 7%, respectively) and gari the lowest (about 34.1%) Chavez *et al.* 2007. Increasing the consumption of orange-fleshed cassava roots and their processed foods products can provide a significant proportion of the required dietary vitamin A intake

There is the need, therefore, to evaluate some of these promising genotypes in different agro-ecological zones in Ghana to identify and select yellow root cassava varieties that

are high yielding in terms of fresh storage root, dry matter content and high beta-carotene content

Cassava and its various preparations including fufu, gari and konkonte are very popular foods throughout Ghana (Ofori *et al.*, 2000) and the per capita annual fresh weight consumption of cassava in Ghana is 148 kg/head, the highest of all staple crops (Okai *et al.*, 1995)

Germplasm with high yield, early bulking, and beta-carotene enriched root quality characteristics for specific end-uses is therefore needed. The evaluation of elite cassava genotypes that combine good agronomic performance and high beta-carotene content across agroecological zones would lead to release of improved cassava varieties over the existing ones. This will further enhance food security improve health and could increase incomes of resource-poor rural farmers.

The objectives of the study were to:

(i) evaluate agronomic performance of yellow root cassava genotypes in three major agroecological zones of Ghana,

(ii) evaluate beta carotene content in storage roots of yellow cassava genotypes grown in three major agroecological zones of Ghana,

(iii) estimate the variability and heritability of agronomic traits and beta-carotene content of yellow root cassava genotypes,

(iv) identify for selection yellow root cassava genotypes that combine desirable agronomic traits (high fresh root yield and high dry matter content) with high beta carotene content in storage root

2. LITERATURE REVIEW

2.1 Origin and Distribution of Cassava

Recent reviews of accumulated evidences have generally concluded that cassava has multiple origins (Renvoize, 1973). (Spath, 1973) suggested four separate areas of origin: Guatemala and Mexico, the coastal savannas of north-western South America, eastern Bolivia and north western Argentina and eastern Brazil. Based on studies from southern United States to Argentina, (Rogers and Appan 1973) defined, within the genus *Manihot*, 98 species widely distributed throughout the lowland tropics of the Americas. (Nassar 1978) defined four centers of diversity of the wild species: Central Brazil, Western Mexico, Northeast Brazil and Western Mato Grosso and Eastern Bolivia. The three Brazilian centres have some species in common, most notably from the heterophylla section which is closely related to the cultivated species (Rogers and Appan, 1973). Cassava appears to have evolved under highly localized biological and physical influences. Because of early and wide dispersal of the crop and relatively low levels of genetic interchange among regions, many distinct and locally adapted gene pools evolved (Hershey, C 1985). Cassava was widely distributed throughout the Americas and the Caribbean by the time the European colonists arrived in the 15th century.

Cassava was introduced to the African continent by Portuguese traders, first into West Africa via Gulf of Benin and the river Congo during the second half of the sixteenth century. Later it spread into East Africa via the islands of la Reunion, Madagascar and Zanzibar at the end of the eighteenth century. Following these two coastal introductions, cassava cultivation spread inland from both sides and slowly became established in the twentieth century as the most important food crop in many areas. The crop was taken to Asia during the seventeenth century (Thresh *et. al.*, 1994a, Jennings, 1995, Purseglove, 1968, Rogers, 1963).

In the Gold Coast (now Ghana), the Portuguese grew the crop around their trading ports, forts and castles and it became a principal food eaten by both Portuguese and slaves (Ofori *et al.*, 2000). The Akan name for cassava "Bankye" could most probably be a contraction of "Aban Kye" Gift from the Castle. Doku (1969) reported that cassava has been grown in Ghana since 1750. By the second half of the 18th century, cassava had become the most widely grown and used crop of the people of the coastal plains in Ghana (Adams, 1957). The spread of cassava from the coast into the hinterland was very slow. It became well established in most areas after the drought of 1982-1983 when all other crops failed (Korang-Amoako, et al., 1987). Cassava and its various preparations including fufu, gari and konkonte are very popular foods throughout Ghana and not only in the coastal regions, as was the case 20 years ago (Ofori *et al.*, 2000).

2.2 Botany and Morphology of Cassava

Cassava (*Manihot esculenta*, Crantz), belongs to the family of the *Euphorbiaceae*, sub family of *Crotonoideae*, tribe of *Adrianeae*, genus *Manihot* (Dulong, 1971). The *Euphorbiaceae* family has two sections the *Arboreae*, which has tree species and is considered the more primitive, and the *Fruticoseae*, which comprises shrubs adapted to savannah grassland or desert. Cassava belongs to the *Fruticoseae*. 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). It is a monoecious species with a few large pistillate flowers (female flowers) borne basally and numerous smaller staminate flowers (male flowers) borne apically in the same inflorescence (Chandraratna and Nanayakkara, 1948).

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 to 3 m. It is a perennial plant but is usually grown as an annual or a biennial. Like all Euphorbiaceae, the plant parts contain latex. There are many cultivars or clones under cultivation. They can be distinguished by such morphological characteristics as leaf size, colour and shape, branching habit, plant height, stem and petiole colour, tuber shape and colour, time to maturity and yield. Cassava varieties are often classified according to the levels of cyanogenic potential in the tuber and leaves.

Propagation is generally from stem cuttings. The number and size of shoots developed from the initial cutting is influenced by its length, size, moisture content, number of buds, orientation during planting, and environmental factors. Rooting starts from the soil-covered nodes, with calluses formed at the base of the cuttings (Cours, 1951) and of the new shoots (Cock, 1980). The number of basal roots formed is dependent on the genotype, bud development, and nutritional and hormonal factors (Indira and Sinha, 1970). 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.

Usually there are 5 to 10 storage roots per plant. They are circular in cross-section. A mature cassava storage root may range from 5 to 100 cm in length, 3 to 15 cm across and 1 to 4 kg in weight. The internal structure of the storage root consists of three regions as follows: (1) the outermost layer which is the periderm, is composed mostly of dead cork

cells which effectively seal the surface of the tuber, (ii) a thin cortex, which is usually white, but may be tinged pink, yellowish or brown, (iii) a core or pith consisting mainly of parenchyma which is rich in starch

Cassava plant grows as a shrub, with the stem reaching heights of up to 4 m and a diameter of about 2 to 4 cm in some varieties. The shoot consists of nodal units, each of which has an internode, a node, an axillary bud, and a palmate leaf on a petiole (Cock, 1980) The stem is usually slender and glabrous and for the most part filled with pith and because of this it is very fragile until lignification is completed. The stem varies in colour and it can be silver green, light brown, brown or dark brown. The older parts of the stem 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 are observed in the cassava plant (Hunt *et al.*, 1977). They are the forked branches which occur at the apex of the stem when the apical meristem changes to the reproductive state and it is often associated with flowering, and lateral branches which arise from axillary buds some distance from the apex due to unfavourable conditions such as disease The forked type of branching is synchronized with all branching occurring at about the same time (Cock, 1980).

The height of the cassava plant varies not only genetically but also with environmental conditions such as altitude, temperature, insolation soil fertility, lodging and whether 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 above 28°C, on the other hand, 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

The leaves of cassava are spirally arranged according to a phyllotaxis of 2/5. Cassava leaves have multiple lobes of variable shape, usually 5 to 7 although any number from 3 to 9 may occur 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 30 cm in length. The petioles, like the leaf veins, are green, red to crimson and more rarely whitish

2.3 Importance and utilization of Cassava in Sub-Saharan Africa

Cassava *(Manihot esculenta* Crantz*)*, is a root crop that originated from Tropical America. It is cultivated and consumed as a staple in many regions of the developing world. Sub-Saharan Africa is the world's largest producer of cassava. Cassava production in 2005 was 118.51 million tones of fresh storage roots grown in 12.07 million hectares (FAOSTAT, 2007) Over 90% of production takes place in small farms in rural areas (Spencer and Associates, 2005). Cassava is Africa's second most important food crop (Nweke *et al*., 2002). 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). Major producing countries (FAOSTAT, 2007), include Nigeria (41 56 millions tones), Democratic Republic of Congo (14.97 million

tones), Mozambique (11.46 million tones), Ghana (9.57 million tones), Angola (8.61 million tones), Tanzania (7.0 million tones), and Uganda (5.57 million tones). The leaves of cassava plant which contain 5.1 to 6.9% protein (Oomen and Grubben, 1978; Gomez and Valdivieso 1985) are also used as vegetables in Democratic Republic of Congo, 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).

Cassava is Africa's food insurance because it gives stable yields, even in the face of drought, low soil fertility, and low intensity management. It can remain in the soil until needed, spreading out the food supply over time, helping families through annual scarcities when seasonal harvests run out, and averting the tragic "boom and bust" cycle of oversupply followed by shortage (Dixon *et al.*, 2003).

Cassava thus plays an important role in food security in Africa. In addition, data collected by the Collaborative Study of Cassava in Africa (COSCA) in 563 villages scattered across 11 countries (including Ghana), which account for over 80% of cassava production on the continent of Africa, have shown that cassava generates cash income for the largest number of households in comparison with other staples. Nweke *et al.*, 2001, revealed for the first time that cassava can be transformed from being a poor man's crop to an urban food, from being a subsistent crop to industrial cash crop.

Before it is utilized as food, the cassava storage root is almost invariably peeled. The peel comprises 10-20% of the storage root and of this the cork layer represents 0.5-2% of the total weight. The edible fleshy portion makes up 80-90% of the root. The storage root flesh is composed of about 62% water, 35% carbohydrate, 1-2% protein, 0.3% fat, 1-2% fibre and 1% mineral matter (IITA, 1982).

The dependence of Ghanaians on cassava as a staple and source of livelihood is significant (Otoo *et al.*, 1995). The per capita consumption of cassava is about 148 kg compared to 88 kg for all cereals combined. According to the same authors, cassava production in Ghana is market-driven. Fifty-seven per cent of cassava produced in Ghana is marketed compared to 43% for six other countries of the Collaborative Study for Cassava in Africa (COSCA). Gari and fresh storage root are available in large quantities in many markets throughout the year in Ghana.

In Ghana, cassava storage 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)

Based on the utilization of cassava in Ghana, the farmers have various preferences of cassava varieties. In villages where gari is the main product, 60% of farmers prefer early bulking varieties, 20% prefer high yielding varieties, while 10% prefer good cooking varieties and another 10% high leaf-yielding varieties. In villages where fresh root is the main product, 67% of farmers prefer early bulking varieties while 33% want varieties with good pounding qualities. Among villages where "*kokonte*" (dry cassava chips or flour) is the main product, 50% of farmers prefer varieties which are early bulking, and 50% want varieties which have low cyanide potential (Otoo *et al.*, 1995).

Cassava roots are also used as feed for farm animals usually to substitute for part of the main ingredients in nutritionally balanced rations.

Utilizations of cassava described above are predominantly for white flesh cassava varieties meanwhile there are some local accessions with yellow flesh (*"Bankye Bodea"*) which are also used for food. Such yellow flesh cassava genotypes contain beta carotene

2.4 Environmental Requirements

Factors affecting the productivity of cassava can be classified into three broad classes: physical (climatic and edaphic), biological and physiological. The major physical factors include soil moisture availability, temperature, light (photoperiod and intensity), nutrients, pH, and relative humidity. Pests and diseases constitute the biological factors, while the physiological factors are inherent in the development processes necessary for the attainment of characteristic form and function. This depends on a chain of interrelated events which are sequential in time, gene-regulated at critical sites and times and modified by environmental influences (Whyte, 1985).

2.4.1 Climatic factors

Cassava is grown in a wide range of environment between latitudes 30° N and 30° S, although the bulk of it is grown between 20° N and 20° S (Jones, 1959). Within these latitudes, environmental factors such as temperature, rainfall, solar radiation, and soil conditions have strong influence on the physiological processes of a cassava plant and ultimately its yield (Cock, 1983). Cassava is cultivated in soils varying from rich loam to poor sand, at altitudes between sea level and 2000 m, where average annual temperatures are between 15°C and 35°C, and annual rainfall varies from 500 to 5000 mm. 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 storage root production can be expected in the tropical lowlands below 1500 m altitude (Tindall, 1983). At altitudes above 1800 m, it develops only very slowly and it is susceptible to frost (Janssens, 2001, Yanock, *et al.*, 1988; Hahn and Keysen, 1985).

2.4.1.1 Temperature

Sprouting is impaired when soil temperature are below 17°C. However, time to emergence decreases with temperature up to 30°C, depending on the variety. Higher soil temperatures also reduce germination (Keating and Evenson, 1979). The optimum plant growth of cassava was observed to be at 30°C soil temperature. Rate of plant growth at 6 weeks after transplanting was 0.26, 0.97, 0.38 and 0.05 cm per day, respectively for soil temperature regimes of 22, 30, 35 and 40 °C (Lal, 1974). Temperature differentially affects the different phases of root bulking. Where temperature may favour storage root initiation, it can reduce root growth and /or maturity, which tends to be complicated by day and night temperatures. Low night temperatures favour storage root initiation while high day temperatures (29°C) slightly increase photosynthesis with high rate of respiration (CIAT, 1976). Higher numbers of storage roots are produced at low night temperatures while larger roots are formed at higher temperatures (Bodlaender, 1960). High temperature, combined with long days, or low temperature combined with short days, delays storage root development (Osiru *et. al.*, 1995). It is difficult to separate the effect of soil temperature from that of soil moisture stress, since high soil temperature is always accompanied by high soil moisture stress.

2.4.1.2 Light

Cassava is a sun-loving plant that needs plenty of sunshine. Any increase or decrease in solar radiation will affect the size of the plant and hence yield. Owing to the minimal differences in day length in the tropics, photoperiod may not play a major role in the productivity of cassava. Short-days conditions, however, promote root bulking (Bolhius, 1966), possibly because storage root inducing substance is formed under this photoperiod. Nonetheless, long days promote stem growth and as such limit the supply of assimilates

to the storage root and then slow down tuberization (Lowe *et al.*, 1976). Most varieties of cassava initiate storage roots only under short days (10-12 hours) resulting in high storage root weight and storage root number. The optimal day length for root bulking in cassava seems to be 12 hours (Bolhius, 1966; Otoo, 1983)

Higher light intensities favour root bulking (Bodlaender, 1960). Shading has been found to markedly affect root growth rate with little effect on top growth rate (Cock *et al.*, 1979; Kumar and Hrishi, 1979) Cock *et al.* (1979) found that shading to 95% had little effect on leaves older than 30 days, while higher shading caused rapid leaf abscission. The decline in photosynthetic rates with leaf age under high light intensity seem to be genotype specific, since different rates of reductions were observed among the clones tested by Aslam *et al.* (1977)

2.4.1.3 Water

Although cassava is tolerant to drought (Onwueme, 1978), higher yield levels are obtained with a longer moisture cycle or with conservation by mulching (IITA, 1982). Despite its drought-tolerance, it needs a minimum amount of water of 500 mm per year spread over six months. The optimum annual precipitation requirement for cassava growth lies between 1,000 and 1,500 mm per year. Cassava can survive dry periods of about 6 months or more (Hahn *et al.*, 1977). 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 reported that during dry season, cassava storage roots stop growing and sometimes decrease in weight owing to a loss of water while their starch content

increases. Ghuman and Lal (1983), found that irrigation significantly increases root yield and root diameter, with these effects being more pronounced in unmulched than in mulched treatments

2.4.1.4 Soils

Cassava is grown in almost all soil types provided they are not water-logged, too shallow or too stony, but being a root crop, cassava does best in deep, friable, well-drained sandy-clay soils which permit enlargement of the storage roots. Cassava tolerates a wide range of soil pH from 4 to 8 0 High yields are obtained in a deep, loose permeable soil with high humus content. On account of the formation of mycorrhizas, cassava thrives on desaturated soils with 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) High fertility may result in excessive vegetation growth at the expense of storage root and starch formation Cassava will produce an economic crop in exhausted soils unsuitable for other production and consequently is often the last crop taken in the rotation in shifting cultivation It is exhaustive of potassium. Important soil physical and cultural factors that affect cassava production include soil temperature, rooting depth, methods of seedbed preparation and soil erosion which result in loss of fertility (Hahn *et al.*, 1979). Although cassava yields relatively well on poor soils in comparison with many other crops, large supplies of nutrients are necessary for its production. Cassava root yields are also influenced by soil temperatures, especially temperature regimes that unfavourable to root growth (Whyte, 1985).

2.4.2 Biological factors

The biological constraints, especially diseases and pests, are among the factors that contribute to low productivity. In West Africa, production risks of cassava are high; adverse agronomic conditions and pests easily combine to reduce storage root yields by about 50% (Herren and Bennett, 1984). Pests and diseases cause severe yield losses in cassava, the extent of loss can be as high as total crop failure, depending on the type of disease or pest and time of attack. Pests of cassava are grouped under four main headings (IITA, 1990), Vertebrates, nematodes, mites and insects while the major diseases of cassava are leaf diseases, stem diseases and storage root rot

2.4.2.1 Cassava Vertebrate Pests

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

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

2.4.2.2 Cassava Insect And Arthropod Pests

Many 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 reniform nematode, *Rotylenchulus 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).

The economically important arthropods are mostly exotic species. Notable amongst these are the cassava mealybug (*Phenacoccus manihoti*), cassava green mite (*Mononychellus tanajoa*), whiteflies (*Aleurodicus dispersus*), and the larger grain borer (*Prostephanus truncatus*). During the 1970s and 1980s, cassava mealybug and cassava green mite plagued the cassava belt in Africa. By the early 1990s, however, the mealybug was under effective classical biological control, mainly by the introduced parasitoid *Apoanygyrus (Epidinocarsis lopezi)* (Herren and Neuenschwander, 1991). The green mite has been the major continent-wide pest problem causing 30-80% loss in root yield, depending on severity of the attack. IITA's search for sustainable solutions to the mite problem focuses largely on the use of exotic predatory mites (Phytoseiidae) for use in biological control campaigns (Yaninek and Herren, 1988). The situation has changed with the introduction of *Tetranychus aripo* in Benin, Cameroon, Ghana and Nigeria. In on-farm trials *T. aripo* reduced the pest *(Mononychellus tanajoa)* populations by an average of two thirds with root yields increased by a third in the target areas where the exotic natural enemies were established (IITA, 1998).

The spiralling whitefly, *Aleurodicus dispersus*, a native species in Caribbean and Central America, has in recent years spread into West and Central Africa (Neuenschwander, 1994b). The pest was introduced into Africa serendipitously with two aphelinid parasitoids, *Encarsia haitiensis* and *Encarsia guadeloupae*, which are exerting biological control in parts of West Africa (d'Almeida *et al.*, 1997). However, a more effective

control would appear to require introduction of other natural enemies, for example the predatory coccinellid *Nephaspis* sp.

The larger grain borer is a neotropical pest introduced into Africa in 1981 from Central America (Dunstan, and Magazine, 1981). It is a key pest of stored maize, but in dry processed cassava chips it causes up to 74% loss in biomass after 4 months of infestation (Hodges *et al.*, 1985). In parts of West Africa, classical biological control of the pest in stored maize by the introduced histerid predatory beetle *Teretriosoma nigrescens* has been established (Borgemeister, *et al.*, 1997). The predator also appears to be a potentially effective biological control candidate against the pest in stored dry cassava (Helbig and Schulz, 1996)

Economically important indigenous pests of cassava are few and generally polyphagous. Amongst these, the variegated grasshopper, *Zonocerus variegatus* and various species of termites are of widespread geographical importance. Early nymphs of the grasshopper commonly occur as dense aggregates on host plants, especially on the exotic weed *Chromolaena odorata* and reproductive adults re-aggregate at oviposition sites (Modder, 1994)

2.4.2.3 Cassava Diseases and Weed Pests

Diseases and weeds also cause varying degrees of cassava crop damage and yield loss.

2.4.2.3.1 Cassava Mosaic Disease

Among pathogens, the cassava mosaic virus, which causes the cassava mosaic disease, is most important. The disease causes an estimated annual loss of 28-40% of root yield in Africa (Thresh *et al.*, 1994). The epidemiology of the disease involves a wide range of interacting factors including polyphagy in the virus vector (*Bemisia tabaci*), genetic

heterogeneity in populations of *B. tabaci*, and variations within and between vector populations in the ability to transmit the virus and parasitism of the vector. The whitefly *Bemisia tabaci* is cosmopolitan in distribution but it may have a Mid-Eastern origin (Greathead, 1989). The insect is the known vector of geminiviruses that causes cassava mosaic disease. Studies of individual varieties have indicated losses due to African Cassava Mosaic Virus (ACMV) disease ranging from 20 to 95% (Beck and Chant, 1958; Jennings, 1960, Seif, 1982; Fargette, *et. al.*, 1988; Thresh, *et. al.*, 1994b).

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.*, 1994). (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 later stage of crop growth are virtually unaffected (ii) There are 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

A thorough understanding of these factors will contribute significantly to the management of cassava mosaic disease. Presently, however, the impact of the disease is best mitigated through the propagation of germplasm that is resistant to the virus

2.4.2.3.2 Cassava Bacterial Blight Disease

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 campestris. 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)

2.4.2.3.3 Cassava Fungal Diseases

About 20 fungal diseases have been reported to affect the leaves, stems and roots of cassava

Leaf fungal disease is Cercospora leaf spot. There are three types of Cercospora leaf spot The most common one is brown leaf spot, caused by *Cercosporidium henningsii* The other types are leaf blight, caused by *Cercospora vicosae* and the white leaf spot caused by *Cercospora caribae* Although severe attacks by these micro-organisms have been reported in several African countries, they are not known to kill cassava plants. The symptoms are restricted to older leaves and set in after tuberization has occurred Yield losses are minor for white leaf spot and leaf blight but may reach about 20% for brown leaf spot (IITA, 1990)

The most important cassava stem disease which occurs in all major cassava-growing areas in Africa is the Cassava Anthracnose disease (CAD) It is caused by *Colletotrichum gloeosporioides* f. sp. *manihotis*. The sap-sucking coreid bug, *Pseudotheraptus devastans*, is reported to be partly responsible for the spread of the disease (IITA, 1990). 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 materials which do not establish well in the following planting season and thus yields are reduced.

Soil-borne pathogens attack cassava roots, causing damping-off disease at the early stages of growth or soft rot or dry rot in storage root prior to harvest. The most important diseases are (i) Sclerotium rot, caused by a fungus, *Sclerotium rolfsii*, this is the most common storage root disease and occurs on roots and storage toots at all stages of development It can be recognized by the appearance of a white mycelial growth on infected roots As the fungus penetrates the storage roots, the plants begin to show mild wilting symptoms. (ii) Soft rot storage root disease 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 storage roots which then emit pungent odours. When roots rot, the entire plant wilts, defoliates and dies. (iii) Dry rot storage root disease 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 storage roots 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

2.4.2.3.4 Cassava Weeds

Weeds can cause as high as 80% production losses (Akobundu, 1980), if left unchecked, particularly during the first 3-4 months after planting The common weed species in cassava agroecosystems include grasses e.g., spear grasses *(Imperata cylindrica)*,

bermuda grass *(Cynodon dactylon)*, guinea grass *(Panicum maximum)*, feathery pennisetum *(Pennisetum polystachion)*; sedges e.g., purple nutsedge, *Cyperus rotundus* and *Mariscus alternifolius*; and broad leaf weeds, e.g., Siam weed, *(Chromolaena odorata)*, wild poinsettia *(Euphorbia heterophylla)*, giant sensitive weed *(Mimosa invisa)*, goat weed *(Ageratum conyzoides)* and Tridax, *(Tridax procumbens)*. Weed control is one of the most important factors in obtaining high root yield in cassava. Most farmers grow cassava at a lower plant population than it is necessary to provide effective ground cover. Under these conditions, three weedings are necessary for good crop yield (Hahn *et al.*, 1979).

2.4.3 Physiological factors

Cassava productivity is affected by physiological factors among which the cyanide, the harvest index and carotenoids in cassava

2.4.3.1 Cyanide in Cassava

A major problem associated with the widespread use of cassava is the presence of cyanogenic glucosides, linamarin (up to 96%) and lotaustralin which can be converted to toxic hydrogen cyanide (HCN) (Rosling, 1988). An endogenous beta-glucosidase found in cassava can hydrolyse linamarin and lotaustralin to cyanohydrins which, in turn, can break down to HCN. All tissues of cassava contain cyanogenic glucosides, an acyanogenic cassava genotype is yet to be found (Bokanga *et al.*, 1994). Cyanogenic glucosides, cyanohydrins and HCN can be found simultaneously in cassava products. The sum of concentrations of these three elements has been defined as 'cyanogenic potential' (Bokanga, 1994). Cyanogenic glucosides are synthesized in the leaves (Kock *et al.*, 1992), and translocated to all other parts of the plant including the edible storage roots

(Ramanujam and Indira, 1984). Storage root parenchyma generally has a lower cyanogenic potential than the storage root cortex or the leaves (Bokanga, 1994)

Although cassava is often described as "bitter" or "sweet" according to the amount of cyanide present, the sweetness or bitterness is not always associated with HCN (Coursey, 1973) 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 goitre 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 case of human malnutrition, where the diet lacks protein and iodine, under-processed roots of high HCN cultivars may result in serious health problems and even sudden death.

Environmental factors during the growing season contribute significantly to variation in cyanogenic potential among genotypes, within a genotype, and in various parts of the plant De Bruijn (1971) noted that different clones do not react in the same way to changing ecological conditions with regard to HCN content Although the glucoside content increases with an increased rate of nitrogen fertilizer application, potassium and farmyard manure application tend to decrease it Hahn *et al.* (1977) reported that low cyanide content in cassava appears to be regulated by a recessive minor gene complex

2.4.3.2 Harvest Index

The physiological and biochemical processes occurring during the development of a plant are integrated so that an equilibrium state is established at all times during growth, differentiation, and development Changing the internal equilibrium alters the final product and the extent of this alteration in relationship to yield is dependent on the degree of association between the two (Whyte, 1985). Although root yield is highly correlated

with total plant weight within a single genotype at various stages of plant growth (Boerboom, 1978b, de Bruijn, 1982; Tan 1980), this relationship does not always hold true across genotypes In other words, a large plant does not necessarily promise a high root yield

The harvest index, which is the ratio of root weight over total plant weight, is therefore a parameter which reflects the dry matter distribution within the plant in favour of root yield In a crop such as cassava where the economic yield comes from a vegetative part (specifically, the adventitious roots which are modified into storage organs) the harvest index is generally much larger than may be expected from a crop whose economic yield results from fruits or seeds, such as grain legumes or cereals (Lian, 1985). Also structurally speaking, higher harvest indexes are possible in root crops since the plant is not required to "hold up" a heavy yield (Coursey and Haynes, 1970). Therefore harvest index has been found to be one of the most important parameters in the selection for yield potential in cassava (Lian, 1985) A genotype with a high harvest index may be assumed to be physiologically more efficient, since most of its dry matter production is channelled towards storage in the roots. However, root storage takes a lower priority to top growth within a cassava plant Dry matter storage in the roots results from any surplus over dry matter requirements for the production of new leaves, maintenance of existing leaves, and maintenance and weight gain of stems and branches This was experimentally demonstrated by topping plants to arrest leaf production, resulting in increased dry matter storage in the root (Tan and Cock, 1979a).

2.4.3.3 Carotenoids In Cassava

Carotenoids are notable for their wide distribution, structural diversity, and various functions More than 600 carotenoids, not including *cis* and *trans* isomers, have been isolated and characterized from natural sources (Pfander, 1987).

The normal white root cassava genotypes contain only small amounts of beta-carotene (Bradbury and Holloway, 1988) but yellow root cassava contains up to about 100 times as much (McDowell and Oduro, 1983). Beta-carotene is the predominant carotenoid in cassava, but as a mixture of the *trans*- and *cis*-forms (Rodriguez-Amaya and Kimura, 2004). However the determination of the *trans*- and the *cis*-isomers individually makes the analysis more expensive and complicated. Because the *cis*-isomers of beta-carotene are difficult to obtain, their quantification is done using the *trans*- beta-carotene curve

Cassava like sweet potato does not contain etherified carotenoids and has low lipid content; hence saponification is unnecessary

2.4.3.4 Importance of beta-carotene to human heath

Beta-carotene, α-carotene, and beta-cryptoxanthin are provitamins A. Structurally, vitamin A (retinol) is essentially one-half of the beta-carotene molecule. Consequently, beta-carotene is the most potent provitamin A, it is also the most widespread (Rodriguez Amaya, 1993). Vitamin A activity of a carotenoid is the result of an unsubstituted beta-ring with an 11-carbon polygene chain.

Carotenoids have been credited with other beneficial effects on human health enhancement of the immune response and reduction of the risk of degenerative diseases such as cancer, cardiovascular diseases, cataract and mascular degeneration (Astrog, 1997; Bendich, 1994, Burri, 1997, Gaziano and Hennekens, 1993, Krinsky, 1993; Mayne 1996; Olson, 1999a, Olson and Krinsky, 1995). The action of carotenoids against diseases

has been attributed to an antioxidant property, specifically, their ability to quench singlet oxygen and interact with free radicals (Palozza and Krinsky, 1992). Other benefices include carcinogen metabolism, inhibition of cell proliferation, enhancement of cell differentiation, stimulation of cell to cell communication, and filtering of blue light (Olson 1999[a] and 1999[b]).

2.4.3.5 Factors affecting quantity and composition of carotene

Foods vary qualitatively and quantitatively in their carotenoids composition. Green vegetables, leafy and non-leafy, have lutein, β-carotene, violaxanthin, and neoxanthin as the principal carotenoids with defined quantitative patterns. The relative proportions of these carotenoids are fairly constant, but they vary considerably in their absolute concentrations.

Carotenes predominate in the few carotenogenic root crops (e.g. carrot, sweet potato), and xanthophylls predominate in maize (seed). Qualitative and, quantitative differences exist in a given food due to factors such as variety, stage of maturity, climate/geographic site of production, part of the plant utilized, conditions during agricultural production, post harvest handling, processing and storage conditions.

Differences in carotenoids among cultivars of the same food are well documented and can be either both qualitative and quantitative or only quantitative (Gross, 1987, 1991, Rodriguez-Amaya, 1993). Mean beta-carotene content of sweet potato cultivars, for example, varies from 10 to 26,600 µg/100g (Almeida-Muradian and Penteado, 1992, Hagenimana *et al.*, 1999, Huang *et al.*, 1999, K'osambo *et al*., 1998, Takahata *et al.*, 1993).

Stage of maturity is one factor that affects carotenoid composition. Maturation in vegetables and ripening in fruits are generally accompanied by enhanced carotenogenesis

(Arima and Rodriguez-Amaya, 1988, Gross, 1987, 1991, Mercadante and Rodriguez-Amaya, 1998, Rodriguez-Amaya, 1993).

Farming practices may also influence carotenoid composition. For example, comparison of kale cultivars at the same stage of maturity from natural and conventional farms using agrochemicals, revealed significantly higher concentrations of all constituent carotenoids in samples collected from the natural farm (Mercadante and Rodriguez-Amaya, 1991). In contrast, a comparison between conventionally produced and hydroponic leafy lettuce gave no significant difference in the constituent carotenoids (Kimura and Rodriguez-Amaya, 2003)

2.4.3.6 Effects of processing on carotenoids

Many carotenogenic foods are seasonal and processing at peak harvest minimizes losses and makes the products available all year and permit transportation to other places. Processing and storage of foods should however, be optimized to prevent or reduce degradation while accentuating bioavailability.

Percent retention or loss of carotenoids during processing and storage of food has been reported. However, despite some experimental inadequacies and discrepancies in the data, some conclusions can be drawn (Rodriguez-Amaya, 1997).

Carotenoid biosynthesis may continue, in fruits, fruit vegetables and root crops even after harvest, provided the plant materials are kept intact and the enzymes responsible for carotenogenesis are present. However in leaves and other vegetables, post harvest degradation of carotenoids may prevail, especially at high storage temperatures and under conditions that favour wilting.

Carotenoids are naturally protected in plant tissues, however cutting, shredding, chopping and pulping of fruits and vegetables increase exposure to oxygen and caused carotenoid oxidation.

Whatever the processing method, carotenoid retention decreases with longer processing time, higher processing temperature, and cutting or pureeing of the food. Rapid processing at high temperature is a good alternative. Current knowledge therefore suggests that processing conditions should be optimized to minimize losses of carotenoids while enhancing their bioavailability.

2.4.3.7 General procedure for carotenoid analysis in cassava

There is substantial qualitative and quantitative variation in carotenoid composition of foods. Even with a particular food, compositional variation occurs due to such factors as variety/cultivar, geographic or climate effects, season, maturity and part of the plant utilized. Thus, conclusive identification of the carotenoids in a food sample should be accomplished before quantification is carried out. In general, it is sufficient to quantify only the principal carotenoids Quantifying the minor carotenoids increases analytical complexity, requiring chromatographic resolution, identification, and standards of the different carotenoids. These can introduce more errors besides making the analysis longer, laborious, and costly The additional results obtained are often of no practical use. (Rodriguez- Amaya and Kimura, 2004).

When numerous samples have to be analyzed, such as in selecting varieties or breeding lines that meet the desired provitamin A level, it is costly and unnecessary to go directly to HPLC quantification. A degree of accuracy is not needed at this point. Simply inexpensive and rapid screening methods that verify if a sample is above or below the

target level can be used to select those that are likely to meet the desired levels. The accurate but expensive HPLC method can then be used only for the chosen samples.

2.4.3.7.1 Sampling

To obtain meaningful and reliable analytical results, the samples must be representative of the entire lot under investigation and adequately prepared for analysis. According to Kratochvil and Taylor (1981), the major steps in sampling are

(i) Identification of the population from which the sample is to be collected;

(ii) Selection and collection of samples;

(iii) Reduction of sample to a laboratory-size sample suitable for analysis

Horwitz (1988) defined anything sent to the laboratory as a laboratory sample and considered reduction of the laboratory sample to a test sample for analysis as part of the sampling process. Pomeranz and Meloan (1994) differentiated sampling and sample preparation as follows the aim of sampling is to secure a portion of the material that satisfactorily represents the whole, while the purpose of sample preparation is to homogenize the large sample in the laboratory and subsequently reduce it in size and amount for analysis.

Once the sampling site and time of collection are decided, the following questions should be addressed (Kratochvil and Taylor, 1981)

(a) How many samples should be taken?

(b) How large should each be?

(c) From where in the bulk material and how should they be taken?

(d) Should individual samples be analysed, or should a composite be prepared?

To evaluate changes in composition as a function of variables such as time, temperature, and location, systematic sampling should be used and the results should be statistically analysed.

2.4.3.7.2 Sample preparation

The purpose of sample preparation is to homogenize the large sample in the laboratory and subsequently reduce it in size and amount for analysis. Following this rationale, sample preparation includes all operations between the receipt of the laboratory sample and the weighing of the sample to be analysed

The sample that is brought to the laboratory is usually too large, both in bulk and in particle size for direct analysis It must therefore be transformed into a homogenous, small sample for analysis, while maintaining its representativity Homogenization and sub-sampling may be done simultaneously or consecutively in either order Physical operations, such as chopping, cutting into pieces, mixing, milling, blending, and sieving, are carried out along with bulk reduction, such as quartering or riffling The process can be performed manually or by using commercially available mills, blenders, grinders, and riffle cutters. The food product is usually analysed in the form in which it is consumed therefore inedible portions (e g. peel seed, shell) are removed prior to sample preparation.

According to Pomeranz and Meloan (1994), the problems encountered by analysts in the preparation of samples for analysis include

a. difficulty in obtaining representative small samples from large samples,
b loss of plant material
c difficulty in removal of extraneous material from plants without removal of plant constituents including the analyte,

d. enzymatic changes before and during analysis,

e compositional changes during grinding,

f changes in unstable components

2.4.3.7.3 Acetone phase Extraction of beta carotene

A good extraction procedure should release all the carotenoids from the food matrix and bring them into solution, without altering them. The solvent chosen should efficiently extract all carotenoids present in the sample.

Extraction, partition and open column chromatography (OCC) should be carried out under a fume hood to protect the analyst from inhaling solvent vapour. Breathing hexane, for example, should be avoided due to neurotoxicity of some of its oxidative metabolites (Schiedt and Liaaen-Jensen, 1995). Because the solvents used in extraction or partition will ultimately be removed or at least reduced by evaporation, solvents with low boiling points should be chosen to avoid prolonged heating. Thus the lower boiling fractions of petroleum ether (b p 35-60° C) should be used instead of the higher boiling fractions.

When extracting carotenoids from biological samples, such as foods like cassava, which contain large amounts of water, a water-miscible organic solvent (e g , acetone, methanol, ethanol, or mixtures thereof) should be used to allow better solvent penetration Acetone has been widely used for carotenoid extraction, however, the advent of high performance liquid chromatography (HPLC) has seen tetrahydrofuran (THF) become a popular extraction solvent

2.4.3.7.4 Chromatographic separation

Food samples typically contain both the apolar carotenes and the more polar xanthophylls. Whatever the method used, the chromatographic process should be able to cope with this polarity range.

In open column chromatography (OCC), the column has to be packed for each analysis. A definite advantage of HPLC over OCC is that reproducible separations can be performed by using a reusable column under controlled conditions without undue exposure to air or light. The most important properties to be considered in selecting the mobile phase are polarity, viscosity, volatility, and toxicity. In addition, it must be inert with respect to the carotenoids. Many solvent systems have been suggested as mobile phases for carotenoids, but the primary solvents are acetonitrile and methanol with most systems being slight modifications of some basic combinations (Craft, 1992). Acetonitrile has been widely used because of its lower viscosity and slightly better selectivity for xanthophylls when a monomeric C_{18} column is used (Khachik *et al.*, 1986). Addition of triethylamine to acetonitrile-based solvents was found to enhance carotenoid recovery (Hart and Scott, 1995)

Other solvents used as modifiers are tetrahydrofuran (THF), ethyl acetate, hexane, acetone and water. In some cases methanol has been added to an acetonitrile-based mobile phase. Craft (1992) investigated nine solvents modifiers and found THF to be most beneficial modifier of methanol

2.4.3.7.5 Quantification

Carotenoids in solution obey the Beer-Lambert law, that is, their absorbance is directly proportional to the concentration. Thus, carotenoids are quantified spectrophotometrically, provided accurate absorption coefficients in the desired solvent

are available. Some published values may contain significant levels of error or uncertainty (Britton, 1995)

In OCC methods, the quantification step is fairly straightforward. The separated carotenoid fractions are simply collected and quantified spectrophotometrically using their tabulated absorption coefficients.

In quantitative analysis by HPLC the following facts should be considered:

(a) Carotenoids absorb maximally at different wave lengths and have different absorption coefficients

(b) Solvent effects on absorption are substantial

(c) Obtaining and maintaining carotenoid standards, which are required for calibration, is difficult

HPLC quantification is carried out by means of internal or external calibration, for which the concentrations of the standards are also determined spectrophotometrically as in OCC. A constant supply of carotenoid standards is needed and the accuracy of the analytical results depends on how accurately the concentrations of the standards solutions are known. Unfortunately, only a few carotenoid standards (e. g. beta-carotene, lycopene) are available commercially

In the calibration process, the analyst has to prepare standard solutions of varying concentrations, inject each of these solutions, and construct the standard curve. This curve should be linear and pass through the origin and must bracket the concentrations of the food samples. Khachik *et al.* (1992) suggested the following guidelines for the validity of the standards and instrumentation: (a) the correlation coefficient should be greater than 0.9 (b) the intercept should be very close to zero and (c) the relative standard deviation of the regression (standard error of the estimate divided by average concentration of standards multiplied by 100) should be less than 5%. If any of these parameters is out of

range, the standards as well as the HPLC instrumentation should be carefully examined and the standard curve rerun. Mantoura *et al.* (1997) recommended that the correlation coefficient should be greater than 0.95

2.4.4 Genetic and Environment Interaction

Cassava improvement work involves several stages including multilocational trials of the selected clones. Cassava cultivars have specificity and, or limited adaptation due to their high sensitivity to genotype-by-environment interaction. According to Smith and Zobel (1990), cited by Okai *et al.* (1995), such multilocational trials face genotype (G) by environment (E) interaction, which arises when clones are grown in environmentally diverse settings. Genotype by environment (G x E) interaction is a differential genotypic expression across environments The basic cause for differences between genotypes in their yield stability is a wide occurrence of (G x E) interactions. 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 set of biophysical factors like water, nutrition, temperature and diseases that influence the growth and development of individuals and thereby influencing expression of traits (Basford and Cooper, 1998).

The importance of G x E interaction in breeding of cassava in West Africa has been reported (Otoo *et al.*, 1991). The genotype by environment interaction is the change in cultivars' relative performance over environments, resulting from the differential response of the genotypes to various edaphic, climatic and biotic factors (Dixon *et al*., 1991). G x E 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). G x E interaction occurs in both short-term and long-term crop performance trials (Eberhart and Russel, 1966) The diverse production/cropping systems and large environmental variability of the agroecological zones where the crop is grown, as well as its diverse utilization forms demand that a series of cultivars adapted to specific ecological conditions and targeted end-uses are developed

There are conflicts regarding descriptions of stability in the literature, primarily due to (a) varying concepts of stability and (b) controversy concerning the statistical technique that best explains G x E interaction. Genotypes that show little interaction with environments may be regarded as stable (Piepho, 1994). Evenson *et al* (1978) discussed the distinction between genotype stability and adaptability A genotype is stable if at a given location, its yield varies little from year to year, and is adaptable if its average yield over the years varies little across locations

The analysis of variance (ANOVA) is an additive model that describes only the main effect adequately (Snedecor and Cochran, 1980; Kempton, 1984; Freeman, 1985). The significant of G x E interaction could be tested, but it does not show the particular pattern of genotypes or environments that give rise to such interactions. Principal Component Analysis (PCA), a multiplicative model does not describe the additive main effects. Linear Regression combines both additive and multiplicative components and thus analyse main effect and interaction, it confounds the interaction with the main effects (Wright, 1971), thus reducing its power for significant testing A G x E interaction may be considered not significant with analysis of variance, yet in reality the interaction may be significant In recent developments, a powerful statistic tool for analyzing G x E interaction (multiplicative interaction model) has been introduced in the agricultural

context as Additive Main Effects and Multiplicative Interaction (AMMI) (Piepho, 1996; Crossa *et al.*, 1990) The AMMI model was termed as a hybrid model since it integrates and encompasses several statistical models applied to yield trial data including the additive analysis of variance (ANOVA), for genotype and environment main effects, the multiplicative components analysis of the G x E interaction (PCA) and Finlay-Wilkinson linear regression models. (Gauch, 1988; Zobel *et al* , 1988).

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. This means a zero variance among environments. The dynamic concept, however, allows a predictable response to environments and a stable genotype has no deviation from its 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) identified three concepts (types) of stability. 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 all genotypes in the trial (Plasteid and Peterson, 1959, Plasteid, 1960; Shukla, 1972) and 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)

2.4.5 Genetic variance and heritability estimate

Dudley and Moll, (1969) gave the following definitions in relation to genetic variance and heritability.

(a) Broad sense Heritability is the ratio of total genetic variance to phenotypic variance.

(b) Narrow sense Heritability is the ratio of additive genetic variance to phenotypic variance.

(c) Phenotypic variance is the total variance among phenotypes when grown over the range of environments of interest to the breeder

(d) The total genetic variance is the part of the phenotypic variance which can be attributed to genotypic differences among the phenotypes

(e) The genotype-environment interaction variance is that part of the phenotypic variance attributable to the failure of differences between genotypes to be the same in different environments

Estimates of genetic variance and heritability 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. They scored and analyzed for heritability and found that the genotypes differed significantly for each of the three traits. Heritability per plot ranged between 0 69 and 0.86 indicating that non-additive effect of the genotypic variance was small Phenotypic and genotypic variances differed significantly, which reflected an environmental influence on the genotypes.

In three separate multilocational trials comprising of 14, 15 and 25 newly developed cassava clones, conducted in several locations between 1983 and 1989 in Nigeria, Mba and Dixon (1995) found out in combined analyses over locations, a range of h^2 estimates of 69 to 93 percents for some yield components (Fresh storage root yield, dry yield, root number and dry matter) The low values of 30 and 41% of h^2 were obtained for resistance to cassava anthracnose disease (CAD) and to cassava green mite (CM) respectively

Using the Additive Main Effects and Multiplicative Interaction (AMMI) model to evaluate ten cassava clones in eighteen environments (location and year combinations) in Ghana, Okai *et al.* (1995), found out that the model revealed a highly significant ($P<0.01$) environment (E), genotype (G) and G x E interaction. The highly significant G x E interaction indicated that the ten cassava genotypes responded differently to variations in the environments. The variation may have resulted from different climatic conditions due to annual seasonal changes, edaphic, biotic and abiotic stresses.

3 MATERIALS AND METHODS

3.1 Experimental sites

The field experimentations of this study were conducted in the three agroecological zones of Ghana at three locations namely, Wenchi in the Forest-Savannah Transition agroecological zone, Pokuase in the Coastal Savannah agroecological zone and Bunso in the Deciduous Forest agroecological zone.

The Forest-Savannah Transition zone has two rainy seasons with an annual rainfall of 1,300 - 1,800 mm. The major rainy season is from April to June and the minor is from September to November. Soil fertility is fairly high but the soil is liable to erosion. Major crops grown include maize, plantain, cassava, yam, cocoyam, cotton, tobacco, groundnut, tomato, pepper, eggplant, cowpea and beans.

The area selected and used as representative of the forest-savannah transition agroecological zone was the Wenchi Agricultural Station of the Ministry of Food and Agriculture (MoFA). The field work started from the Wenchi station on 8th July 2004 on an area of 0.1 ha cleared, ploughed and planted with 38 yellow root cassava genotypes together with 5 white root cassava local materials. In 2005 a land area of about 0.243 ha was cleared and ploughed and planted on 26th July 2005. The following year an area of 0.273 ha was ploughed and planted on 28th July 2006. The climatic conditions (rainfall and rain days) during 2004-2007 at Wenchi are presented in Figures 1 and 2.

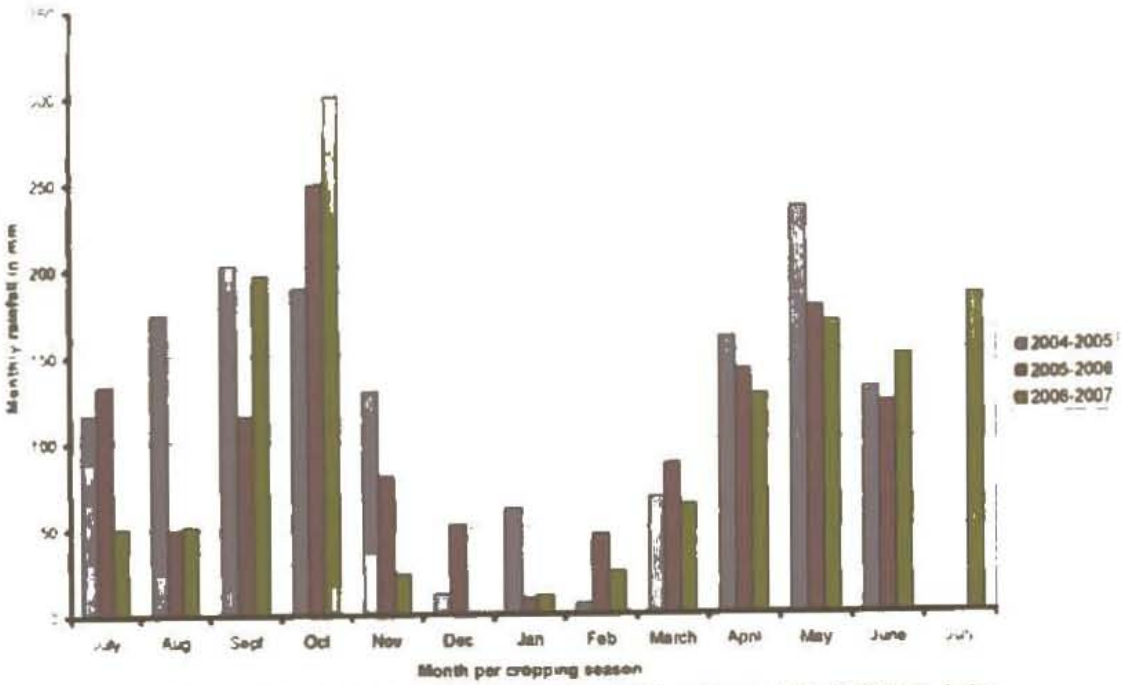


Fig. 1: Monthly rainfall at Wenchi agric. station from July 2004 to July 2007

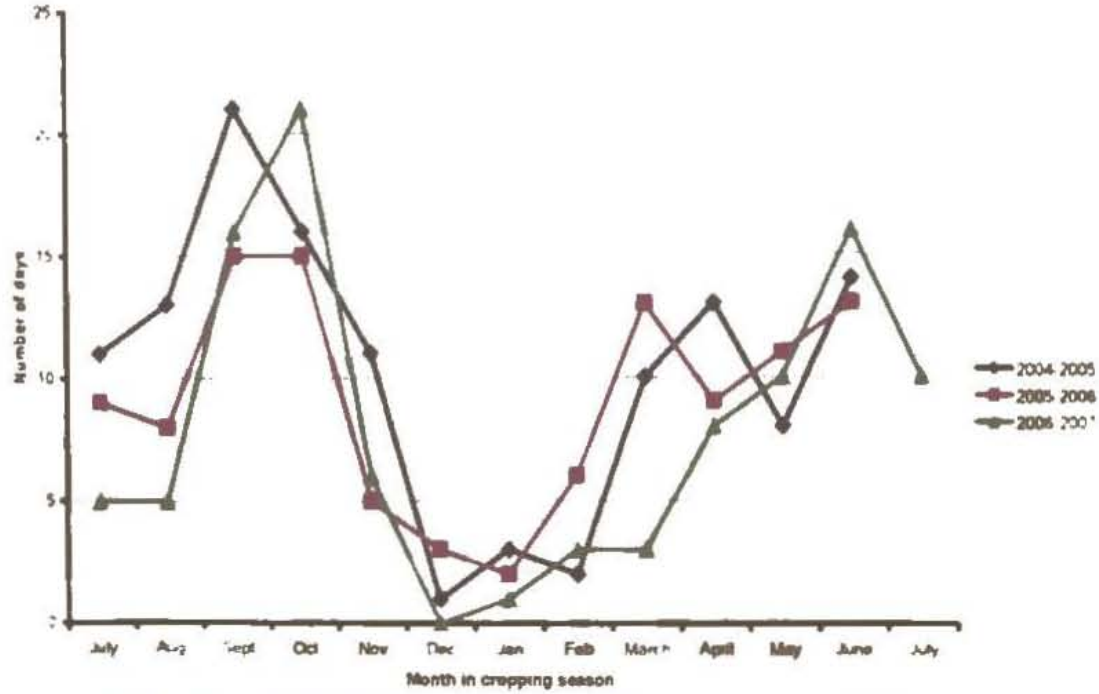


Fig. 2: Monthly raindays at Wenchi agric. Station from July 2004 to July 2007

After the forest-savannah transition zone, the field experimentation was extended to the Semi-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. It has two rainy seasons March to July and September to November and the annual rainfall is between 1250 and 1750 mm (Boateng, 1960, Dickson and Benneh, 1988). The soil is generally alkaline, containing greater quantities of nutrients because they are less leached by rainfall. The soil is suitable for cocoa, coffee, oil palm, maize, plantain, cocoyam, cassava, rice and vegetables including eggplant, beans, pepper and okro (Boateng ,1960; Dickson and Benneh, 1988).

The Plant Genetic Resources Research Centre (PGRC) experimental farm located at Bunso was the area selected as representative of the deciduous forest agroecological zone The experiment started in 2005 on a land area of about 0.243 which was cleared, ploughed and planted on 22nd July 2005 The following year an area of 0.273 ha was ploughed and planted on 4th May 2006 The monthly rainfall and rain days during the two cropping years are presented in Figures 3 and 4.

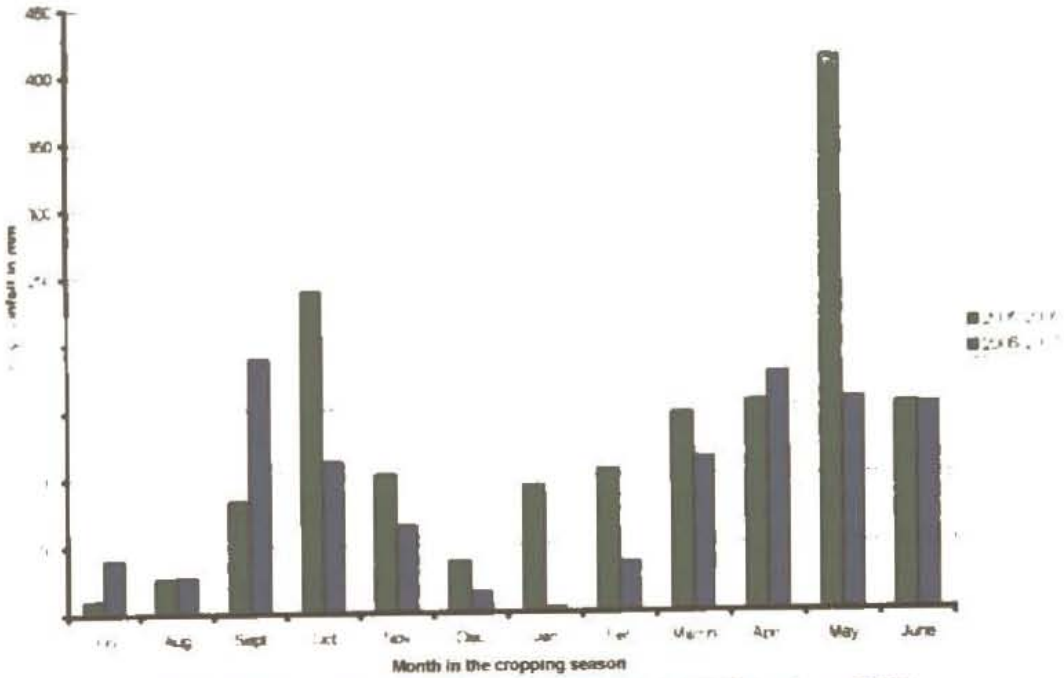


Fig. 3: Monthly rainfall at Bunso from July 2006 to June 2007

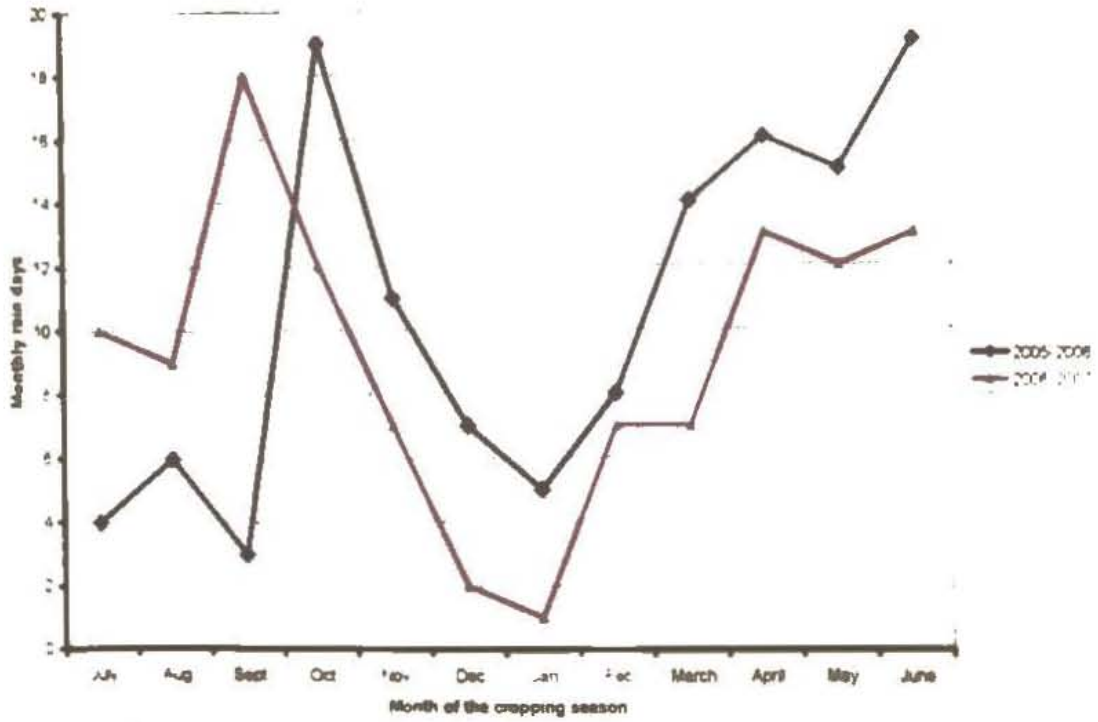


Fig. 4: Monthly rain days at Bunso from July 2006 to June 2007

The third agroecological zone Coastal Savannah forms 7% of the land area of Ghana. 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 890 mm annually. Relative humidity is, however, high throughout the year and thus compensates for the scanty annual rainfall (Boateng, 1960; Dickson and Benneh, 1988) It has two rainy seasons. The major rainy season is from March/April to June whilst the minor is from September to October. Relief is gentle and soils are either heavy clay or light textured and underlain by clay. The soils are generally acid or mildly acid. Among the crops grown are cassava and maize. Vegetables are grown on lighter soils while rice, cotton and sugarcane are planted on the heavier soils. Coconut is found on the coastal fringe

The specific area selected as the coastal savannah agroecological zone was the Crops Research Institute Station at Pokuase where an area of about 0.273 ha was cleared, ploughed and planted on 26th April 2006. The characteristics of the rainfall and the rain days during that cropping season are described by the Figures 5 and 6.

As presented above the number of locations increased from one year to another based on availability of planting materials. Combination of locations (Wenchi, Bunso and Pokuase); years (2005-2006 and 2006-2007) and harvest ages (9, and 12 or 14 months after planting), gave a total of 10 different environments in which the experimental materials were evaluated. Descriptions of the 10 environments are presented in Table 1.

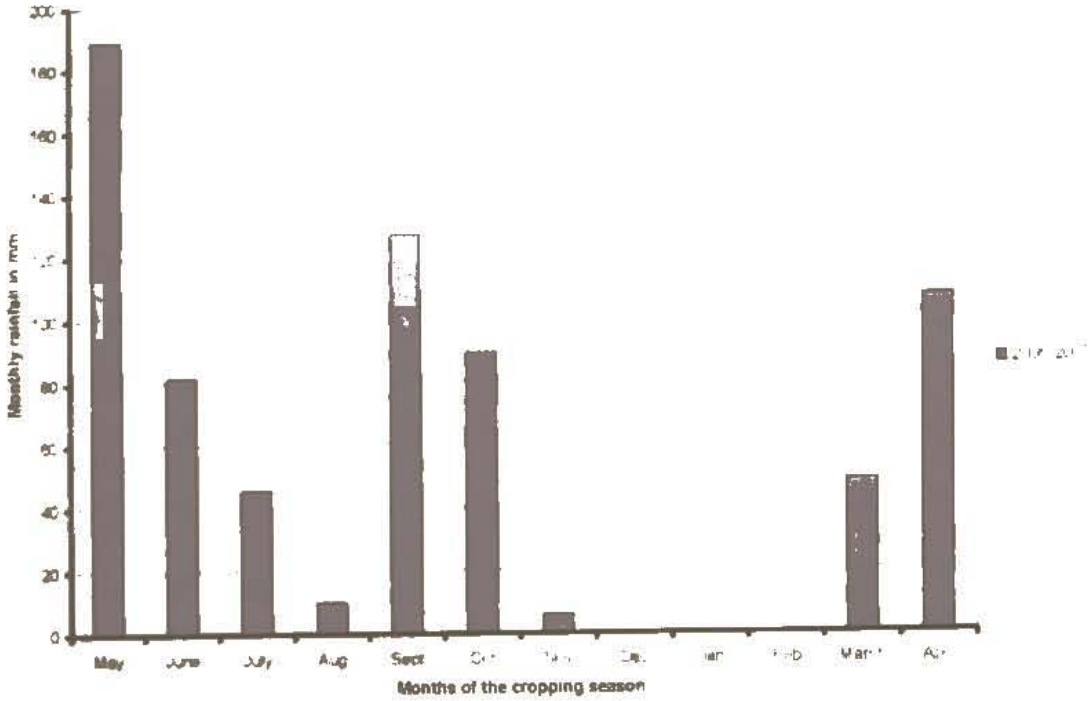


Fig. 5: Monthly rainfall at Pokuase during the season 2006-2007

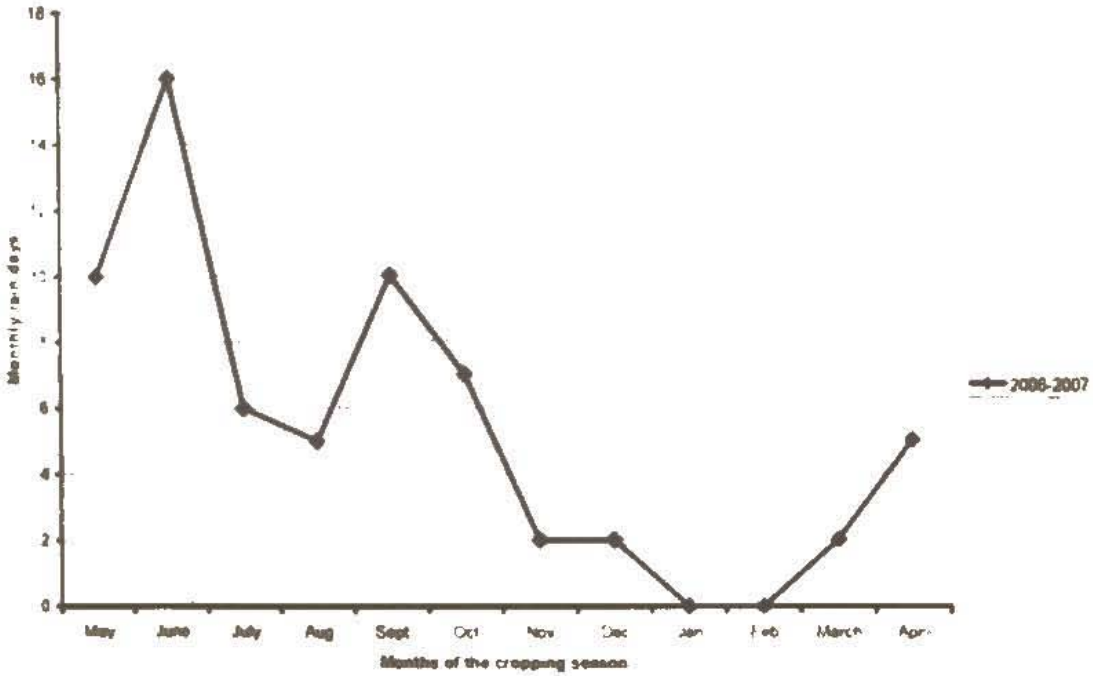


Fig. 6: Monthy rain days at Pokuase during the cropping season 2006-2007

TABLE 1: Description of the 10 environments in which nine yellow root and one white root cassava genotypes were evaluated

Designation	Name of location	Year of experiment	Time of harvest
Environment 1	Wenchi	2005-2006	9 MAP
Environment 2			14 MAP
Environment 3			9 MAP
Environment 4		2006-2007	12 MAP
Environment 5			9 MAP
Environment 6	Bunso	2005-2006	14 MAP
Environment 7			9 MAP
Environment 8		2006-2007	12 MAP
Environment 9			9 MAP
Environment 10	Pokuase	2006-2007	12MAP

3.2 Planting materials and Planting

In the first year of the experiment in 2004, fifteen cuttings of each of thirty-eight (38) yellow root cassava genotypes (Table 2) received from the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria were planted in three replications (5 cuttings per genotype per replication) with 5 white root local cassava varieties at Wenchi Agricultural Station (Brong Ahafo). At harvest 12 months after planting, these genotypes were evaluated for their fresh root yield, dry matter content, harvest index and yellowish colour of their root Nine of the yellow root cassava genotypes were selected based on the yellowish colour of the fresh storage root combined with their fresh root yield and their dry matter content These genotypes together with one local white root cassava variety were established at two locations Wenchi and Bunso, the second year of the

experiment in July. The experiment was repeated at Wenchi, Bunso and Pokuase in the third year

The 38 genotypes are shown in Table 2. The selected 10 genotypes were as follows: 01/1224, 01/1235, 01/1368, 01/1371, 01/1412, 01/1417, 01/1610, 01/1442, 01/1663 and Wenchi 009

TABLE 2: Thirty eight yellow root cassava genotypes from IITA germplasm

N°	Genotype	N°	Genotype
1	01/1231	20	94/0330
2	01/1659	21	01/1368
3	01/1172	22	01/1273
4	01/1551	23	01/1335
5	01/1417	24	01/1646
6	00/0028	25	01/1442
7	99/7578	26	01/1610
8	01/1206	27	01/1224
9	01/1635	28	01/1663
10	1404	29	01/1235
11	01/1560	30	01/1412
12	Z97/0474	31	98/2123
13	01/1181	32	94/0006
14	01/1423	33	01/1277
15	01/1296	34	01/1662
16	00/0093	35	01/1371
17	01/1380	36	95/0379
18	01/1331	37	01/1649
19	01/1115	38	011413

3.3 Methods

3.3.1 Land preparation and field layout

The Randomized Complete Block Design (RCBD) as described by Gomez and Gomez (1984) was the experimental design used for all the five experimentations. At Wenchi and Pokuase, the plots were cleared and tilled with a disc plough to a depth of approximately 30 cm. In Bunso, no tillage was used after spraying herbicide for land clearing. In each of the site the plot area was divided into three blocks. Each block was then divided into ten

smaller plots The number of location and the plot sizes varied from year to year according to the availability of planting material. In 2005-2006 the plot size was 7 m by 6 m (six rows per plot and 7 plants per row) in each block. For the 2006-2007 the plot size of 10 m by 4 m (4 rows of 10 plants each) was used. In all the experiments the cuttings were planted at 1 m x 1 m (between rows and on the row).

3.3.2 Weed control

From planting to harvesting, weeds were controlled using hoes. The first weed control was generally at two weeks after planting. A minimum of four weedings were done for each experiment

3.3.3 Field data collection

Field data collection begun one month after planting. Data on disease and pests were collected every two to three months. Data on storage root yield components, storage root beta carotene quantification and its other related variables were collected at nine, twelve or fourteen months after planting

3.3.3.1 Disease Score Rating

African Cassava Mosaic Virus (ACMV) disease infestation was evaluated in Bunso and Pokuase at 1, 3, 6, 9 and 12 months after planting (MAP) by using the following score rating:

1. no symptom up to 20% of the leaf covered by light green symptoms of mosaic
2. 21% to 40% of leaf area covered by yellow symptoms of mosaic or apparent deformation of the leaf
3. 41% to 60% of the leaf area covered by severe symptoms with distortion and reduction of leaf size
4. 61% to 80% covered by severe symptoms of mosaic with reduction up to 50% of leaf size

5 = 81% to 100% of leaf area covered with severe symptoms and reduction more than 50% of leaf size.

The Cassava Bacterial Blight (CBB) severity was evaluated at Bunso and Pokuase when the symptoms first appeared and after every two months. The severity of the disease was scored as follow:

1 = no symptom
2 = 10% to 25% of the leaf area destroyed
3 = 25% to 50% of the leaf area destroyed with exudation of gum on the stem and die-back
4 = 50% to 75% of leaf area destroyed, defoliations, gum on stem, apical defoliation.
5 = More than 75% of leaf area destroyed, complete apical defoliation leaving dried stem without leaf

Cassava Anthracnose Disease (CAD) was evaluated at 3, 6, 9 and 12 months after planting at Bunso and Pokuase and the scoring used was as follows.

1 = no symptoms
2 = few shallow cankers on woody (lower third) stems, late in the growing season
3 = many deep cankers and depressions on woody (lower and middle third) stems followed by distortion
4 = dramatic wilting accompanied by constriction or many oval lesions on the green stems
5 = many lesions on green stems and severe necrosis at leaf axils, followed by wilting and severe defoliation.

3.3.3.2 Pests Score Rating

Evaluation of Cassava Green Mite (CGM) was done using the following score rating

1 = no obvious symptoms
2 = moderate damage, no reduction in leaf size, scattered chlorotic spots on young leaves
3 = severe chlorotic symptoms, slight reduction in leaf size
4 = severe chlorotic symptoms and leaf size and young shoot severely reduced
5 = very severe chlorotic and significant reduction in leaf size and young shoot portion; extensive defoliation, candlestick appearance of young shoots

Cassava Mealybug (CM) was evaluated by using the following scale.

1 = no obvious symptoms
2 = slight bunch top appearance, and slight reduction in leaf size and internode length
3 = moderate bunch top symptoms, and serious reduction in leaf size and internode length
4 = severe bunch top symptoms, obvious reduction of internode length and severe reduction in leaf size and leaf area.

5 = candlestick appearance, internode length reduced, young portion of shoot curved and completely defoliated

3.3.3.3 Number of plants harvested per hectare

Three rows of seven plants each were harvested at nine and fourteen months respectively after planting for the 2005-2006 trials on a plot size of 21 m^2. For the 2006-2007 experiment two rows of ten plants each were harvested at nine and twelve months after planting on a plot size of 20 m^2. These were converted into number of plants harvested per hectare

3.3.3.4 Percentage of plant stands at harvest

The percentage of plant stands at harvest was obtained by expressing the number of plants harvested on a plot as a percentage of the total number of plants on the plot

3.3.3.5 Number of storage roots per plant

The number of storage roots per plant was obtained by dividing the number of storage root harvested per plot by the real number of plants uprooted per plot

3.3.3.6 Number of storage roots per hectare

The number of storage roots from the plants harvested in sub-section 2.2.3.4 was counted and converted to number of storage roots per hectare

3.3.3.7 Fresh storage root weight per plant

Fresh storage roots from the plants harvested in sub-section 2.2.3.4 were weighed and divided by the number of stands. This was expressed as fresh storage root weight per plant

3.3.3.8 Fresh storage root yield per hectare (t/ha)

The fresh storage root yield per hectare was obtained by weighing the fresh storage root from sub-section 2 2 3 4 and converted to tonnes per hectare. This was then expressed as fresh storage yield per hectare

3.3.3.9 Average storage root weight (g)

The average storage root weight was obtained by dividing the weight of the fresh storage root from a plot by the total number of storage roots counted.

3.3.3.10 Fresh shoot weight per plant (kg)

The tops (leaves, stems and stumps) of the plants harvested from a plot was weighed and divided by the number of plants This was then recorded as fresh shoot weight per plant

3.3.3.11 Fresh shoot yield per hectare (t/ha)

The shoot yield per hectare was obtained by weighing the shoot harvested per plot and converted to tonnes per hectare

3.3.3.12 Harvest index

The harvest index (HI) was calculated as weight of storage roots divided by total weight of the plant (weight of above-ground parts plus weight of storage roots) (Cock *et. al.*, 1979)

3.3.3.13 Mealiness

To evaluate for mealiness, a fresh storage root selected at random per plot was cut in the middle portion to obtain a cylindrical cassava sample. Each sample was tagged and put in a small cotton sack All the samples were put in a cooking pot and boiled in water for one hour Each sample was evaluated for its mealiness following the scoring below:

1 completely soft
2 = soft and good for pounded cassava
3 = half way soft or haft way hard
4 hard but can be broken into two or three parts
5 = very hard after cooking

3.3.3.14 Storage root dry matter content (%)

One hundred and fifty to three hundred gram weight of fresh storage root cylinder was cut from the middle portion of the storage root This cylindrical portion was split longitudinally into four parts and put into a cotton sack and tagged. The samples were oven-dried at 55 °C – 65 °C for 48 hours The samples were cooled in desiccators and then weighed to obtain the dry weight. The percent dry matter content was calculated by using the formula,

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

3.3.3.15 Dry root weight per plant (kg)

The dry root weight per plant was obtained by the product of percent dry matter content in sub-section 2.2.3.13 and the fresh storage root weight per plant in sub-section 2.2.3 6

3.3.3.16 Dry root yield per hectare (t/ha)

Dry storage root yield per hectare was computed by multiplying the fresh storage root yield in tonnes per hectare by its percent dry matter content.

3.3.4 Beta carotene data collection

Beta carotene analysis was carried out in the Laboratory of the Department of Nutrition of the Noguchi Memorial Institute, Legon.

The analysis was carried out following the method of Rodriguez-Amaya (1989) which involved the following steps. (a) sampling and sample preparation, (b) extraction, (c) partition to a solvent compatible with the subsequent chromatographic step, (d) saponification and washing, (e) concentration or evaporation of solvent, (f) chromatographic separation, (g) identification, and (h) quantification

3.3.4.1 Sampling and sample preparation

The laboratory samples were prepared under shade in the field after each harvest. Five storage roots were taken at random per plot. The storage roots chosen were washed, peeled, washed again and dried with absorbent paper. They were sliced into four longitudinally. Two opposite parts from each of the 5 storage roots were put together, packed in aluminium foil (laboratory sample), tied in black polyethylene sachet and kept on ice in a cooler. In the laboratory all samples of root together were grated and homogenized in a mixer or blender A sample of 100 g (analytical sample) from the homogenate was placed in a tube and kept in a deep freezer

3.3.4.2 Extraction

Ten to fifteen grams was weighed from each of the homogenates and ground using a mortar and pestle in 50 ml of cold acetone (acetone refrigerated for about 2 hours). About 3 to 5 g of celite added to facilitate the grinding The ground extract was then filtered with suction through a sintered glass funnel (or Buchner funnel). The extraction and filtration was repeated for the same sample two to four times until the residue was colourless. The mortar and pestle were also washed after each extraction with small amount of acetone

3.3.4.3 Petroleum ether (PE) Phase

About 20 ml of petroleum ether (40 - 60°C) was placed in a 500 ml separatory funnel with a Teflon stop-cock, the acetone extract was poured into the petroleum ether Three hundred millilitres of distilled water was added slowly, letting it flow along the walls of the funnel This was done without shaking to avoid formation of emulsion. After separation of the two phases, the lower aqueous phase was discarded

Washing was done four to six times with distilled water to remove residual acetone In the final washing, the lower phase was discarded as completely as possible, without discarding any quantity of the upper phase. The petroleum ether (PE) phase was later collected by passing the solution through a small funnel containing 10 g anhydrous sodium sulfate The separatory funnel was also washed with petroleum ether, combining the washings with the PE solution of carotenoids after passing through the funnel with anhydrous sodium sulfate At the end of this operation, the total volume of petroleum ether used was measured

3.3.4.4 Concentration or evaporation of solvent

Two hundred and fifty microlitres of the extract was placed in a vial. The beta-carotene of this extract was concentrated by drying the petroleum ether with nitrogen. After drying under nitrogen, the beta carotene was immediately dissolved in 400 µl of High Performance Liquid Chromatography (HPLC) mobile phase made of acetonitrile: dichloromethane methanol in the ratio 70:20:10 at a flow rate of 2.5 ml/min. After homogenization in a rotator, 20 µl of the solution was taken and injected through a 0.22 mm PTFE syringe filter (Millipore) directly into the chromatograph. Before the injection of the sample, the commercial beta-carotene was injected in the same volume for the calibration of the HPLC. After each injection the graph and the concentration of the solution injected were recorded by the HPLC machine.

3.3.5 Data analysis

Data collected was subjected to statistical analyses by using the following statistical softwares: GenStat Discovery Edition Release 4 2DE, MATMODEL 3.0, GGE biplot (Weikai Yan, 2006)

The Fisher' s protected least significant difference (LSD) 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

3.3.5.1 Variance components

The following variance components were computed genotypic variance (σ_g^2), phenotypic variance (σ_p^2), error variance (σ_e^2) and genotype x environment interaction variance (σ_{ge}^2)

3.3.5.2 Broadsense heritability

Heritability (broadsense, h^2) was estimated as the ratio of genotypic variance (σ_g^2) to the phenotypic variance (σ_p^2):

$$h^2 = \frac{\sigma_g^2}{\sigma_p^2}$$

3.3.5.3 Phenotypic Coefficient of Variation

Phenotypic Coefficient of Variation (PCV) was computed using the formula (Singh & Chaudhary, 1985):

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

Where $\bar{X}$ is the mean

3.3.5.4 Genotypic Coefficient of Variation

Genotypic coefficient of variation (GCV) was computed by using the formula (Singh & Chaudhary, 1985).

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

4. RESULTS

4.1 Sprouting at two weeks after planting

Table 3 shows levels of sprouting for the genotypes two weeks after planting. Genotype 01/1371 gave the lowest percentage sprouting (33.33%) while genotype 01/1368 gave the highest score (98.33%). From combined analysis of variance (Table 4) there was a highly significant difference among genotypes, among environments and genotype x environment interaction ($P<0.001$). The best genotypes were 01/1368, 01/1663 and 01/1442. Environment E_{10} (Pokuase at 12 MAP for 2006-2007) gave the highest sprouting rate followed by environments E_9, E_4 and E_8 of the same cropping year 2006-2007 at 9 MAP at Pokuase, 12 MAP at Wenchi and 12 MAP at Bunso, respectively.

4.2 Number of plants harvested per hectare

Average number of plants harvested per hectare is shown in Table 5. The lowest average number of plants per hectare (5311) was recorded by genotype 01/1235, while the highest was recorded by genotype 01/1368. Analysis of variance (Table 6) for the number of plants harvested per hectare showed highly significant differences ($P< 0.001$) among genotypes and environments, respectively. Based on the least significant difference (LSD 5%), the genotypes can be grouped into five categories, environments can be grouped into four groups. Environments E_{10}, E_9 and E_4 corresponding to 12 and 9 MAP at Pokuase and 9 MAP at Wenchi in 2006-2007 were the best. The G x E interaction was also significant meaning some genotypes are not performing the same way for this specific variable in all environments. Genotype contribution to the total sum of squares (SS) was 14.44% while the environment contribution was 35.42% and the G x E interaction accounted for 19.21% of the total sum of squares (Table 6).

Results of the AMMI analysis of the number of plants per hectare (Table 7) showed that the first principal component axis (PCA 1) of the interaction captured 41.59% of the interaction sum of squares in 20.98% of the interaction degrees of freedom Similarly, the second principal component axis (PCA 2) explained a further 19 81% of the G x E interaction sum of squares in 18.52% of the interaction degrees of freedom. The mean squares for PCA 1 was significant at P <0.001.

4.3 Number of storage roots per hectare

Table 8 shows the number of storage roots per hectare The lowest average number of 21,378 was obtained for the local check Wenchi 009 The highest average number of roots (58,183) was registered by genotype 01/1368. For the environment, the highest number of storage roots all genotypes combined was obtained at E_9 (59,133) and E_{10} (57,392) which corresponded to the cropping season 2006-2007 in Pokuase harvested at 9 and 12 MAP respectively Combined analysis of variance (Table 9) showed highly significant ($P < 0.001$) differences among genotypes, among environments and for the G x E interaction. The genotype, environment and genotype by environment interaction contributed 23 06%, 33.96% and 19 11% respectively to the total sum of squares.

TABLE 3: Percentage sprouting of nine yellow root and one write root cassava genotypes at two weeks after planting in 10 environments

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	58 33	55 00	66.67	83 33	73.33	46.67	78 33	81.67	63 33	83.07	**68.97^{cd}**
01/1235	41.67	45 00	53.33	68.33	58.33	46 67	40 00	76 33	80 00	90 00	**59.97^{e}**
01/1368	73.33	78 33	93.33	98.33	83.33	56 67	75 00	95.00	91.67	98.33	**84.33^{a}**
01/1371	40.00	33.33	90.00	86.67	60.00	46.67	65 00	65.00	83.33	88.33	**65.83^{d}**
01/1412	63.33	61.67	56.67	71.67	76.67	55.00	86.67	78.33	78.33	86.67	**71.50^{c}**
01/1417	63.33	55.00	83 33	95.00	85.00	58 33	61 67	68 33	73 33	90.00	**73.33^{bc}**
01/1442	63 33	86 67	80 00	90 00	68 33	60.00	85 00	78 33	85 00	86.67	**78.33^{ab}**
01/1610	36.67	30.00	83.33	88.33	66.67	51.67	83 33	86.67	83 33	93.33	**70.67^{cd}**
01/1663	55 00	58 33	92.67	81.67	91 67	61.67	83 33	90.00	95 00	96.67	**83.33^{a}**
Wch009	71 67	58.33	63.33	58.33	56.67	40.00	61.67	76.67	91 67	96.67	**69.00^{cd}**
Mean	**56.67^{e}**	**56.17^{e}**	**76.17^{cd}**	**82.17^{cb}**	**72.00^{d}**	**52.33^{e}**	**72.00^{d}**	**79.63^{cb}**	**82.50^{b}**	**90.97^{a}**	*72.06*
P value (Genotype or Environment)											**< 0.001**
LSD 5% (Genotype or Environment)											**6.456**
P value (Genotype X Environment)											**< 0.001**
LSD 5% (Genotype X Environment)											**20.417**
CV (%)											**17.6**

E1 – E10 refer to environments 1 – 10

TABLE 4: Proportion of Sum of Squares for main effects and interaction for percentage sprouting for nine yellow root and one write root cassava genotypes in 10 environments,

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	0 160***	12.32%
Environment	9	0.507***	38.94%
Genotype by environment	81	0.031***	21.73%
Error	197	0.016	27.01%

*, **, *** significant at 0 05%, 0.01% and 0 001%

TABLE 5: Average number of plants harvested per hectare for nine yellow root and one write root cassava genotypes in ten environments

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	5500	5500	6667	7000	6667	3611	7833	5833	6000	8294	6290^{cd}
01/1235	4000	4500	5333	5833	5556	3056	3500	5333	8000	8000	5311^{e}
01/1368	7333	7333	9333	9500	8056	4722	7500	9333	9167	8833	8111^{a}
01/1371	3500	2833	8500	8667	5833	4167	6500	6167	8167	7167	6150^{d}
01/1412	6333	6333	5667	6500	7500	3889	8500	7333	7833	8000	6789^{cd}
01/1417	6167	5333	8167	9245	8333	4722	6167	5667	7333	8500	6963^{bc}
01/1442	6333	8500	8000	8500	6667	5278	8500	7500	8500	8167	7594^{ab}
01/1610	3500	2667	8333	7500	6389	4167	8333	7667	8333	7500	6439^{cd}
01/1663	5500	5833	9167	7833	9167	4444	8333	8667	9500	9500	7794^{a}
Wch009	6500	5500	6000	5333	5556	3333	6167	6333	9167	9333	6322^{c}
Mean	5467^{c}	5433^{c}	7517^{b}	7591^{ab}	6972^{b}	4139^{d}	7133^{b}	6983^{b}	8200^{a}	8329^{a}	6776
P value (Genotype or Environment)											<0.001
LSD 5% (Genotype or Environment)											751.6
P value (Genotype X Environment)											0.02
LSD 5% (Genotype X Environment)											2376.7
CV (%)											21.8

E1 - E10 refer to environments 1 - 10

TABLE 6: Proportion of Sum of Squares for main effects and interaction for number of plants per hectare for nine yellow root and one write root cassava genotypes in 10 environments.

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	$2.2\ 10^{7}$***	14.4%
Environment	9	$5.4\ 10^{7}$***	35.4%
Genotype by environment	81	$3.3\ 10^{6}$**	19.2%
Error	197	$2.2\ 10^{6}$	31.0%

*, **, *** significant at 0.05%, 0.01% and 0.001%

TABLE 7: AMMI Interaction analysis of variance including the first four interaction PCA axes for the number of plants per hectare of nine yellow root and one write root cassava genotypes tested in 10 environments.

Source	DF	SS	MS	Probability
Total	298	1408478193.8	4726436.9	
Treatment	99	953936945.8	9635726.7	< 0.001 ***
Genotypes	9	198660663.6	22073407.1	< 0.001 ***
Environment	9	489618489.8	54402054.4	< 0.001 ***
G X E	81	265657792.5	3279725.8	0.02 *
IPCA 1	17	110489294.3	6499370.2	< 0.001 ***
IPCA 2	15	52641212.1	3509414.1	0.09
IPCA 3	13	48092431.6	3699417.8	0.08
IPCA 4	11	23880530.9	2170957.3	0.49
Residual	25	30554323.6	1222172.9	0.97
Error	199	454541248.0	2284126.9	

*, **, *** significant at 0.05%, 0.01% and 0.001%

4.4 Average number of storage roots per plant

The number of storage roots per plant is shown in Table 10 The highest value of 7.107 was obtained for the genotype 01/1368, while the lowest value of 3.439 was recorded by Wenchi 009. The number of storage root per plant differed highly ($P<0.001$) among genotypes, environments and for the G x E interaction, respectively For this character the environments were grouped in three categories. Environments E_9 and E_{10} (Pokuase 2006-2007 at 9 and 12 MAP) constituted the best group with the highest average number of storage roots per plant while E1 (Wenchi 2005-2006 at 9 MAP) was the best in the medium group and E3 (Wenchi 2006-2007 at 9 MAP) the least in the last group. The medium and the last groups have in common six other environments (E_2, E_4, E_5, E_6, E_7 and E_8). The genotype, environment and genotype by environment interaction contributed 22 48%, 21.59% and 23 98% respectively to the total sum of squares (Table 11). Table 12 showed the results of the AMMI analysis of the number of storage root per plant. The first principal component axis (PCA 1) of the interaction captured 28.27% of the interaction sum of squares. PCA 2 explained 27.73% of the GEI sum of squares and PCA 3 captured 18 24%. The mean squares for PCA 1, PCA 2 and PCA 3 were significant at $P<0.01$, $P<0.001$ and $P<0.05$ respectively, cumulatively they contributed to 74.25% of the total GEI in 55 55% of the interaction degrees of freedom

TABLE 8: Average number of storage roots harvested per hectare for nine yellow root and one write root cassava genotypes in 10 environments.

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	34333	33333	24167	27667	23889	14444	35667	29167	42333	52750	31775^{c}
01/1235	18500	26000	31500	45000	24722	11944	13500	22500	68333	62833	32483^{c}
01/1368	52333	46000	71333	67000	46667	30833	66333	63000	75000	63333	58183^{a}
01/1371	15833	11500	23500	41000	23333	18889	26167	28833	51167	42667	28289^{c}
01/1412	37167	28833	28167	23833	25556	16667	35333	34167	48000	50667	32839^{c}
01/1417	32500	26333	40833	51000	44167	33889	34500	26500	56333	60000	40606^{b}
01/1442	42833	41500	38333	44333	49444	26111	28667	32667	74667	59667	43822^{b}
01/1610	17667	12167	51667	50167	35833	18056	47833	36500	57333	65333	39256^{b}
01/1663	25500	26000	25667	18333	46389	17500	41333	46333	85500	83000	41556^{b}
Wch009	23167	21667	6833	18000	25556	16389	16333	19500	32667	33667	21378^{d}
Mean	29983^{bc}	27333^{c}	34200^{b}	32839^{b}	34556^{b}	20472^{d}	34567^{b}	33917^{b}	59133^{a}	57392^{a}	37019
P value (Genotype or Environment)											<0.001
LSD 5% (Genotype or Environment)											6130.1
P value (Genotype X Environment)											<0.001
LSD 5% (Genotype X Environment)											19385.1
CV (%)											32.5

E1 - E10 refer to environments 1 - 10

TABLE 9: Proportion of sum of squares for main effects and interaction for number of storage roots per hectare for nine yellow root and one write root cassava genotypes in 10 environments.

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	$3.06\ 10^{9}$ ***	23.06%
Environment	9	$4.51\ 10^{9}$ ***	33.96%
Genotype by environment	81	$2.82\ 10^{8}$***	19.11%
Error	197	$1.45\ 10^{8}$	23.88%

*, **, *** significant at 0.05%; 0.01% and 0.001%

TABLE 10: Average number of storage roots per plant for nine yellow root and one write root cassava genotypes in 10 environments.

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	**Mean**
01/1224	6 565	6.094	3.511	4 233	3 583	4 622	4 602	4 671	7 383	6 312	5.158^{cd}
01/1235	4 642	5 786	6 052	7.725	4.223	3.983	3 857	4.766	8.561	7 817	5.741^{bc}
01/1368	7.121	6.256	7.635	7.033	5 687	6.302	8 658	6 764	8 188	7 428	7.107^{a}
01/1371	4.526	3 986	2.765	4 703	4 048	4 292	3 879	4.539	6.242	6.015	4.499^{d}
01/1412	5.934	4 549	4.867	3.511	3 416	4.667	4 293	4 675	6 196	6 342	4.845^{d}
01/1417	5.283	5 090	5.074	5.790	5.228	7 311	5 678	4.684	7 728	7.084	5.895^{b}
01/1442	6 884	4 858	4.760	5.280	7.190	4 797	3 391	4 286	8 784	7 193	5.742^{bc}
01/1610	4 967	4.389	6 202	6.607	5 333	4 428	5 766	4 817	6 931	8 796	5.824^{b}
01/1663	4.569	4 300	2 724	2.352	5 019	3 845	5 040	5 376	8 987	8 708	5.092^{cd}
Wch009	3 581	3 895	1 280	3.389	4.456	4 944	2 598	3.034	3 560	3.667	3.439^{e}
Mean	5.407^{b}	4.920^{bc}	4.487^{c}	5.062^{bc}	4.818^{bc}	4.919^{bc}	4.776^{bc}	4.761^{bc}	7.256^{a}	6.935^{a}	5.334
P value (Genotype or Environment)											**< 0.001**
LSD 5% (Genotype or Environment)											**0.6965**
P value (Genotype X Environment)											**< 0.001**
LSD 5% (Genotype X Environment)											**2.2025**
CV (%)											**25.6**

E1 - E10 refer to environments 1 - 10

TABLE 11: Proportion of sum of squares for main effects and interaction for number of storage roots per plant for nine yellow root and one write root cassava genotypes in 10 environments.

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	28.82***	22.48%
Environment	9	27 68***	21.59%
Genotype by environment	81	3 42***	23.98%
Error	197	1.87	31.95%

*, **, *** significant at 0.05%, 0.01% and 0.001%

TABLE 12: AMMI Interaction analysis of variance including the first four interaction PCA axes for the number of storage roots per plant of nine yellow root and one write root cassava genotypes tested in 10 environments.

Source	DF	SS	MS	Probability
Total	298	1154.514	3.874	
Treatment	99	784 865	7 928	< 0 001 ***
Genotype	9	259.335	28.815	< 0.001 ***
Environment	9	248.822	27.647	< 0.001 ***
G X E	81	276.708	3.416	< 0.001 ***
IPCA 1	17	78 239	4 602	0 001 **
IPCA 2	15	76 754	5 117	< 0.001***
IPCA 3	13	50 467	3 882	0.016*
IPCA 4	11	30.117	2.738	0 143
Residual	25	41 132	1.645	0.625
Error	199	369 649	1 857	

*, **, *** significant at 0 05%, 0 01% and 0 001%

4.5 Fresh storage roots yield per hectare (t/ha)

The highest average storage root yield per hectare (28.38 tons/ha) was obtained for genotype 01/1368 and the lowest was recorded by the local check Wenchi (8.49 t/ha) (Table 13) The average yield among the 10 genotypes was 20 55 t/ha There were highly significant differences ($P < 0.001$) among the genotypes, environments and for genotype by environment interaction. Environments E_{10} and E_2 gave the highest fresh storage root yield (Table13) Environment E_3 scored the lowest average fresh storage root yield (8.23 tons/ha) Genotype, environment and genotype by environment interaction contributed 23 98%, 24.86% and 23.52% to the total sum of squares, respectively (Table 14). These three main sources of variation accounted almost equally for the sum of squares Results for the AMMI analysis of storage root yield per hectare are presented in Table 15. The first principal component axis (PCA 1) and the second principal component axis (PC 2) of the interaction captured 36.78% and 25.27 % sum of squares in 39.5% of the interaction degrees of freedom, respectively

TABLE 13: Average fresh storage root yield per hectare (t/ha) for nine yellow root and one write root cassava genotypes in 10 environments.

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	**Mean**
01/1224	23.55	28.22	4.92	14.67	9.03	11.47	13.63	24.22	24.22	19.82	**17.37^{de}**
01/1235	15.47	35.62	10.43	31.32	9.83	12.44	8.27	9.28	31.63	29.02	**19.33^{cd}**
01/1368	27.68	41.80	12.97	32.90	24.64	38.31	19.12	31.93	26.48	27.98	**28.38^{a}**
01/1371	8.93	9.32	6.38	22.87	12.86	18.75	10.68	19.40	21.28	13.05	**14.35^{e}**
01/1412	27.63	37.62	7.85	21.97	13.44	25.28	14.88	24.15	36.87	38.78	**24.85^{abc}**
01/1417	23.50	30.77	12.40	33.47	28.06	33.94	15.17	26.75	23.70	37.88	**26.56^{ab}**
01/1442	21.93	31.25	9.27	24.63	24.89	18.17	12.32	19.02	29.40	26.17	**21.70^{bc}**
01/1610	10.32	17.08	7.63	34.60	15.28	16.44	18.05	20.98	26.43	27.25	**19.41^{cd}**
01/1663	16.33	24.88	9.33	9.05	26.58	24.28	20.72	41.13	32.43	45.40	**25.01^{abc}**
Wch009	9.65	15.43	1.08	7.43	9.06	10.67	4.87	9.45	8.57	8.68	**8.49^{f}**
Mean	**18.50^{e}**	**27.20^{a}**	**8.23^{g}**	**23.29^{cd}**	**17.37^{ef}**	**20.98^{de}**	**13.77^{f}**	**22.63^{cd}**	**26.10^{bc}**	**27.40^{a}**	***20.55***
P value (Genotype or Environment)											**< 0.001**
LSD 5% (Genotype or Environment)											**3.908**
P value (Genotype X Environment)											**0.999**
LSD 5% (Genotype X Environment)											**NS**
CV (%)											**37.4**

E1 – E10 refer to environments 1 – 10

TABLE 14: Proportion of sum of squares for main effects and interaction for fresh storage root yield per hectare for nine yellow root and one write root cassava genotypes in 10 environments.

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	1114.4***	23.88%
Environment	9	350.1**	7.50%
Genotype by environment	81	58.9^{NS}	11.36%
Error	197	121.4	57.25%

NS non significant, *, **, *** significant at 0.05%, 0.01% and 0.001%

TABLE 15: AMMI Interaction analysis of variance including the first four interaction PCA axes for the storage roots yield in tons per hectare of nine yellow root and one write root cassava genotypes tested in 10 environments.

Source	DF	SS	MS	Probability
Total	297	42001 453	141 419	
Treatment	99	17953.369	181.347	0 009**
Genotypes	9	10029.561	1114.395	< 0.001 ***
Environments	9	3150 692	350 077	0 003 **
G X E	81	4773.117	58.927	0 999^{NS}
IPCA 1	17	1755 499	103.265	0.633
IPCA 2	15	1206.226	80.415	0 819
IPCA 3	13	715 295	55 023	0 947
IPCA 4	11	439.889	39.989	0 978
Residual	25	656 207	26.248	0.999
Error	198	24048 084	121.455	

NS non significant, *, **, *** significant at 0 05%, 0.01% and 0 001%

4.6 Fresh storage roots weight per plant (kg)

Table 16 shows the average fresh root weight per plant. Genotype Wenchi 009 recorded the lowest value of 1.486 kg, while the highest value of 4.094 kg was recorded by genotype 01/1417. There were highly significant differences among genotypes, environments and genotype by environment interaction, respectively (Table 17). Based on the least significant difference at 5%, the genotypes 01/1412; 01/1235 and 01/1368 belong to the same group of best genotypes (highest fresh root weight per plant). The best environments were E_2 and E_6 (> 5 kg per plant). The poorest environment was E_3 with an average of 1.121 kg of fresh root per plant. Genotype, environment and G x E interaction accounted for 14.77%, 37.39% and 17.76% of the total sum of squares respectively (Table 17). Results of the AMMI analysis (Table 18) showed that the first principal component axis (PCA 1) and the second principal component axis (PCA 2) of the interaction captured 39.93% and 25.69% of the interaction sum of squares, respectively. Furthermore, the mean squares for PCA 1 and PCA 2 were significant at $P < 0.001$ and $P < 0.05$ respectively.

TABLE 16: Average fresh storage roots weight per plant (kg) for nine yellow root and one write root cassava genotypes in 10 environments.

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Mean
01/1224	4.669	5.226	0.714	2.265	1.354	3 866	1.775	4 014	4 698	2.454	3.103^{def}
01/1235	3.932	7.970	2.107	5 465	1.627	4 155	2 051	2 874	4.019	3.637	3.784^{abc}
01/1368	3 796	5.697	1.403	3 467	2 998	7 430	2 506	3 451	2 884	3.233	3.686^{abcd}
01/1371	2 674	3.253	0.751	2 634	2.226	4.254	1 541	3 095	2 643	1.772	2.484^{f}
01/1412	4 432	5.958	1 342	3 245	1.767	7.954	1.807	3 334	4.675	4 865	3.938^{ab}
01/1417	3 800	5.977	1 567	3.882	3 343	7 250	2 501	4 719	3 435	4.471	4.094^{a}
01/1442	3 603	3 764	1 177	2 941	3 500	3 430	1 444	2 533	3 483	3 238	2.911^{c}
01/1610	2 867	5.552	0.912	4 831	2.294	3.948	2 183	2 820	3 214	3.689	3.231^{cde}
01/1663	2.987	4.143	1.053	1.166	2 862	5 435	2.583	4 809	3 420	4 794	3.325^{bcde}
Wch009	1 524	2.863	0.180	1 403	1 542	3 384	0 611	1 458	0 947	0.953	1.486^{g}
Mean	3.428^{b}	5.040^{a}	1.121^{d}	3.130^{b}	2.351^{c}	5.111^{a}	1.900^{c}	3.311^{b}	3.342^{b}	3.311^{b}	*3.204*
P value (Genotype or Environment)											< 0.001
LSD 5% (Genotype or Environment)											0.665
P value (Genotype X Environment)											0.024
LSD 5% (Genotype X Environment)											2.104
CV (%)											40.8

TABLE 17: Proportion of sum of squares for main effects and interaction for data for fresh storage root weight per plant for nine yellow root and one write root cassava genotypes in 10 environments.

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	18.26***	14.77%
Environment	9	46.24***	37.39%
Genotype by environment	81	2.44*	17.76%
Error	197	1.71	30.08%

*, **, *** significant at 0.05%; 0.01% and 0.001%

TABLE 18: AMMI Interaction analysis of variance including the first four interaction PCA axes for the storage root weight per plant of nine yellow root and one write root cassava genotypes tested in 10 environments

Source	DF	SS	MS	Probability
Total	297	1114.732	3.753	
Treatment	99	777.319	7.852	< 0.001 ***
Genotypes	9	163.643	18.183	< 0.001 ***
Environments	9	415.658	46.184	< 0.001 ***
G X E	81	198.019	2.445	0.022 *
IPCA 1	17	79.068	4.651	< 0.001 ***
IPCA 2	15	50.877	3.392	0.017 *
IPCA 3	13	34.441	2.649	0.101
IPCA 4	11	16.029	1.457	0.585
Residual	25	1.036	0.259	0.961
Error	198	337.412	1.704	

*, **, *** significant at 0.05%, 0.01% and 0.001%

4.7 Average fresh storage root weight (g)

Table 19 shows the average fresh storage root weight. The lowest value was scored by the genotype Wenchi 009. The best genotypes were 01/1417 and 01/1412 followed by genotypes 01/1663 and 01/1235. Similarly, the best environments which gave the highest results were E_2 and E_6. There were highly significant differences among genotypes, environments and genotype by environment interaction (Table 20). Environment contributed 56.63% to the total sum of squares of the weight of individual storage root, while genotype and the genotype by environment interaction contributed for 12.05% and 13.7%, respectively (Table 20)

4.8 Fresh top shoot weight per hectare (t/ha)

Values for fresh top shoot weight per hectare are presented in Table 21. The lowest value of 4.30 t/ha was obtained for genotype 01/1371 in environment E_2 while the highest shoot weight of 38. 25 t/ha was scored for genotype 01/1663 in environment E_8 On the average, genotypes 01/1368 and 01/1663 registered the highest value and the local check Wenchi 009 has score the lowest value of 9.78 t/ha The best environment was E_4, while the poorest were E_5 (10.35 t/ha), E_1 (11.55 t/ha) and E_7 (11.97 t/ha). There were highly significant differences among genotypes, environments and genotype by environment interaction (Table 22). Genotype, environment and G x E interaction contributed 19.43%, 37.87% and 19.70% to the total sum of squares, respectively (Table 22). Environmental influence was the most predominant

TABLE 19: Average fresh storage root weight (g) for nine yellow root and one white root cassava genotypes in 10 environments.

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	687 7	848 3	202 2	520.4	368 0	822 3	376 3	864.4	616 3	406.7	571.3^{d}
01/1235	841.0	1361 8	329.7	713.9	393.5	1027 3	498 4	535.4	469 3	485.8	665.6^{bc}
01/1368	531.8	920 0	183.7	495.5	506.5	1150.0	286.1	499 4	353 3	449 7	537.6^{d}
01/1371	595.5	800 0	303.7	588.5	554.6	989 3	382.0	663.6	425.4	303 4	560.9^{d}
01/1412	791.2	1318.2	270.4	843.4	519.5	1560.7	423 9	720.2	768.8	818 8	803.5^{a}
01/1417	720.0	1198.5	311.6	690 5	648.3	1061.6	462 8	1021 1	442 5	634 9	719.2^{ab}
01/1442	518.0	781 4	246.6	553.0	453.9	741 8	424.8	604.0	390 7	455 3	517.0^{d}
01/1610	574.1	1266.1	147.9	738.7	434.0	896 9	376.3	580.2	461 2	418 8	589.4^{cd}
01/1663	668.4	966.5	510.7	483.3	569 3	1423 8	506 9	887 1	385 1	556 4	695.8^{b}
Wch009	425.2	741 0	185 8	388 2	349 4	684 5	236 6	476 4	264.0	240 5	399.2^{e}
Mean	**635.6^{b}**	**1020.2^{a}**	**269.2^{e}**	**601.5^{b}**	**479.7^{c}**	**1035.8^{a}**	**397.4^{d}**	**685.2^{b}**	**457.7^{c}**	**477.0^{c}**	***605.9***
P value (Genotype or Environment)											**< 0.001**
LSD 5% (Genotype or Environment)											**85.75**
P value (Genotype X Environment)											**< 0.001**
LSD 5% (Genotype X Environment)											**271.16**
CV (%)											**27.8**

E1 - E10 refer to environments 1 - 10

TABLE 20: Proportion of sum of squares for main effects and interaction for average weight of individual fresh storage root for nine yellow root and one write root cassava genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	0.41***	12.05%
Environment	9	1.92***	56.63%
Genotype by environment	81	0.05***	13 07%
Error	197	0 03	18.25%

*, **, *** significant at 0.05%, 0.01% and 0.001%

4.9 Fresh shoot weight per plant (kg)

Values of the shoot weight per plant were presented in Table 23. From this results the three main sources of variation, genotype, environment and genotype by environment interaction revealed highly significant differences ($p < 0.001$) The Fisher's protected least significant difference (LSD) at 5% was 0.47 kg and the average highest fresh shoot weight per plant was obtained for genotypes 01/1610 (3.572 kg) and 01/1663 (3.209 kg). The average lowest value (1 616 kg) was registered for the local check Wenchi 009. For the environments, the highest value (4.145 kg) was registered in the location of Wenchi at the harvest age of 12 months after planting during the cropping season 2006-2007 (E_4). The least value was obtained in E_5 (1.372 Kg) and E_7 (1.675 kg) corresponding to the location of Bunso at the harvest age of 9 months after planting in 2005-2006 and 2006-2007 respectively The genotype, the environment and the G x E interaction for the shoot weight per plant contributed 15.47%, 31 12% and 23 37% respectively to the total sum of squares as per Table 24.

TABLE 21: Average fresh shoot weight in tons per hectare for nine yellow root and one write root cassava genotypes in 10 environments.

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Mean
01/1224	16 42	18 17	9.77	20 63	5 81	8 53	10 85	17 00	16 72	26 55	15.04^{cd}
01/1235	9.62	13.23	15.95	34.47	4.94	7.89	5 88	9 23	20.10	22.77	14.41^{cd}
01/1368	16.07	19 97	23.02	49.50	15.81	23 39	14.72	30 07	25.77	27.48	24.58^{a}
01/1371	6 55	4.30	16 90	44.83	7.50	8 89	10.20	16 72	23.43	20.77	16.01^{cd}
01/1412	11 70	12.30	11 78	21.05	5.06	9.64	9.45	14 58	17 00	21.98	13.45^{d}
01/1417	9 58	10.65	15 17	30.07	14.92	20.56	11.92	20 58	17.33	23.05	17.38^{c}
01/1442	14 63	17.67	24.20	40.42	10.39	11.97	9.00	13 67	17.05	15.47	17.45^{c}
01/1610	11 08	16.22	19 73	34.68	10.25	16 81	19 70	27 00	26 93	32 28	21.47^{b}
01/1663	12.75	17.02	19.73	23.17	21.75	24 83	18.33	38 25	30.32	36.58	24.27^{ab}
Wch009	7 05	7 37	8.35	15.73	7.08	5 92	9.62	9 87	11 60	15.18	9.78^{e}
Mean	11.55^{ef}	13.69^{de}	16.46^{d}	31.45^{a}	10.35^{f}	13.84^{de}	11.97^{ef}	19.70^{c}	20.62^{c}	24.21^{b}	*17.38*
P value (Genotype or Environment)											< 0.001
LSD 5% (Genotype or Environment)											3.099
P value (Genotype X Environment)											< 0.001
LSD 5% (Genotype X Environment)											9.798
CV (%)											35.0

E1 – E10 refer to environments 1 – 10

TABLE 22: Proportion of sum of squares for main effects and interaction for average fresh shoot yield per hectare for nine yellow root and one write root cassava genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	684.80***	19.43%
Environment	9	1334.82***	37.87%
Genotype by environment	81	77.14***	19.70%
Error	197	37.03	23.0%

*, **, *** significant at 0.05%, 0.01% and 0.001%

TABLE 23: Average fresh shoot weight per plant (kg) for nine yellow root and one write root cassava genotypes in 10 environments.

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	3.368	3.370	1.556	3.098	0.871	2.920	1.407	2.820	3.165	3.162	2.574^{d}
01/1235	2.417	2.975	3.054	5.964	0.722	2.807	1.515	2.124	2.612	2.816	2.701^{cd}
01/1368	2.239	2.737	2.453	5.195	1.914	4.778	1.915	3.203	2.807	3.221	3.046^{bc}
01/1371	1.954	1.417	1.988	5.157	1.268	2.123	1.407	2.560	2.895	2.925	2.369^{de}
01/1412	1.922	1.958	2.040	3.155	0.655	3.099	1.145	2.051	2.138	2.755	2.092^{e}
01/1417	1.574	2.080	1.921	3.330	1.766	4.330	1.904	3.566	2.314	2.713	2.550^{de}
01/1442	2.406	2.071	3.052	4.884	1.495	2.280	1.067	1.816	2.080	1.965	2.312^{de}
01/1610	3.101	6.281	2.366	4.795	1.434	3.917	2.405	3.736	3.232	4.454	3.572^{a}
01/1663	2.405	2.834	2.144	2.904	2.344	5.623	2.326	4.442	3.200	3.869	3.209^{ab}
Wch009	1.119	1.381	1.404	2.970	1.247	1.936	1.660	1.536	1.269	1.636	1.616^{f}
Mean	2.251^{d}	2.711^{cd}	2.198^{d}	4.145^{a}	1.372^{e}	3.381^{b}	1.675^{e}	2.785^{c}	2.571^{cd}	2.952^{bc}	*2.604*
P value (Genotype or Environment)											< 0.001
LSD 5% (Genotype or Environment)											0.471
P value (Genotype X Environment)											< 0.001
LSD 5% (Genotype X Environment)											1.489
CV (%)											35.5

E10 refer to environments 1 10

F1

TABLE 24: Proportion of sum of squares for main effects and interaction for average fresh shoot weight per plant for nine yellow root and one write root cassava genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	9 64***	15 47%
Environment	9	19 39***	31.12%
Genotype by environment	81	1 62***	23.37%
Error	197	0.86	30.03%

*, **, ***: significant at 0.05%, 0.01% and 0.001%

4.10 Harvest Index

The harvest index values were presented in Table 25 The lowest value of 0.112 was recorded by genotype Wenchi 009 in environment E_3, while the highest value of 0.755 was recorded by genotype 01/1412 in environment E_2 On the average the best genotypes for harvest index were 01/1412 (0 631) and 01/1417 (0.607). The best environments were E_1 and E_6 Very highly significant differences ($P<0.001$) were observed among genotypes, environments and for the genotype by environment interaction. Harvest index values were mainly influenced by the environment as explained by its contribution of 55 51% to the sum of squares compared to 16 40% due to genotypes, 13.85% due to G X E interaction and 14.24% due to error (Table 26)

TABLE 25: Harvest index for nine yellow root and one write root cassava genotypes in 10 environments.

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	**Mean**
01/1224	0 600	0.618	0.326	0.411	0 610	0 581	0.557	0 588	0.592	0 439	**0.532^{de}**
01/1235	0 618	0.721	0.391	0.477	0 709	0 592	0.574	0.519	0.609	0.551	**0.576^{bc}**
01/1368	0 640	0.679	0 363	0.400	0 636	0 598	0.561	0 520	0.506	0.504	**0.541^{de}**
01/1371	0.598	0.712	0 266	0.339	0 638	0 662	0.522	0 553	0.476	0.368	**0.513^{ef}**
01/1412	0.703	0.755	0 381	0.459	0.736	0.729	0.612	0 626	0.684	0.626	**0.631^{a}**
01/1417	0.708	0.742	0 448	0 525	0.663	0 617	0.569	0.590	0.590	0.616	**0.607^{ab}**
01/1442	0 599	0.643	0.269	0 383	0 683	0 600	0.572	0 584	0.628	0.625	**0.559^{cd}**
01/1610	0 479	0.460	0.272	0 498	0 637	0 510	0 491	0 441	0 502	0 458	**0.475^{gh}**
01/1663	0 557	0.592	0.319	0.279	0.550	0 492	0.537	0 517	0.515	0 556	**0.491^{fg}**
Wch009	0.576	0.682	0.112	0 297	0.554	0 647	0.346	0 493	0.420	0 342	**0.447^{h}**
Mean	**0.608^{b}**	**0.509^{d}**	**0.660^{a}**	**0.315^{f}**	**0.407^{e}**	**0.641^{a}**	**0.603^{b}**	**0.534^{cd}**	**0.543^{c}**	**0.552^{c}**	***0.537***
P value (Genotype or Environment)											**< 0.001**
LSD 5% (Genotype or Environment)											**0.032**
P value (Genotype X Environment)											**< 0.001**
LSD 5% (Genotype X Environment)											**0.102**
CV (%)											**11.8**

E1 - E10 refer to environments 1 - 10

TABLE 26: Proportion of sum of squares for main effects and interaction for harvest index for nine yellow root and one write root cassava genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	0.101***	16.40%
Environment	9	0 343***	55.51%
Genotype by environment	81	0.009***	13 85%
Error	197	0.004	14.24%

*, **, *** significant at 0 05%, 0.01% and 0.001%

4.11 Mealiness

Values for mealiness are shown in Table 27. The best genotype across all environments was the local check Wenchi 009 with an average score of 1 228. The best environment was E_7. The percentage contribution of the genotype to the total sum of squares was 57 86% against 7 59% for the environment and 15 30% for the interaction genotype by environment (Table 28) Genotype contribution was more than seven times the contribution of the environment to the total sum of squares of the mealiness score This means that mealiness of the cassava root was dependant of genotype than the environment

4.12 Percentage dry matter content of storage root (%)

The values of the dry matter content of the storage root are shown in Table 29. The average mean of dry matter content of the storage root was 31.50%. The analysis of variance (ANOVA) revealed highly significant difference for storage root dry matter content among genotypes, environments and for genotype by environment interaction. The highest dry matter (38.91%) was obtained for the local check Wenchi 009 followed by 01/1224 with 35.70%. The lowest dry matter (27.56%) was registered by the genotype 01/1371. For the environments, the highest value of dry matter (38.88%) was obtained in E_6 followed by E_7 (35.15%) and E_5 (34.34%). The genotype, the environment and the G x E interaction for the storage root dry matter contributed 29.79%, 40.00% and 12.37% respectively to the total sum of squares (Table 30). According to the results of the AMMI analysis of percentage storage root dry matter (Table 31), only the mean squares of the first principal component axis (PCA 1) of the interaction was significant ($P<0.001$). The PCA 1 captured 55.73% of the interaction sum of squares in less than 21% of the interaction degrees of freedom

TABLE 27: Average mealiness score for nine yellow root and one write root cassava genotypes in 10 environments.

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	4.667	4.667	4.667	5.000	5.000	5.000	5.000	4.000	5.000	5.000	4.802^{a}
01/1235	5.000	3.667	5.000	5.000	5.000	5.000	3.333	4.424	3.333	5.000	4.576^{ab}
01/1368	4.667	4.667	4.667	5.000	4.000	4.667	3.667	4.333	5.000	5.000	4.567^{ab}
01/1371	3.333	5.000	5.000	5.000	5.000	5.000	5.000	4.667	5.000	5.000	4.800^{a}
01/1412	4.667	4.000	5.000	5.000	5.000	5.000	4.667	5.000	5.000	5.000	4.833^{a}
01/1417	5.000	4.667	5.000	5.000	5.000	5.000	1.333	5.000	4.000	5.000	4.500^{ab}
01/1442	4.000	4.667	4.924	4.333	5.000	4.667	4.000	5.000	5.000	5.000	4.659^{a}
01/1610	4.333	5.000	5.000	5.000	3.000	5.000	3.333	2.333	4.667	4.667	4.235^{bc}
01/1663	3.667	2.667	4.924	5.000	4.333	4.000	2.000	3.667	3.667	4.667	3.859^{c}
Wch009	1.333	1.027	1.000	1.000	1.000	1.667	1.000	1.000	1.000	2.333	1.228^{d}
Mean	4.067^{c}	4.004^{c}	4.511^{ab}	4.533^{ab}	4.233^{bc}	4.500^{ab}	3.333^{d}	3.942^{c}	4.267^{bc}	4.668^{a}	*4.206*
P value (Genotype or Environment)											< 0.001
LSD 5% (Genotype or Environment)											0.381
P value (Genotype X Environment)											< 0.001
LSD 5% (Genotype X Environment)											1.204
CV (%)											17.8

E1 – E10 refer to environments 1 – 10

TABLE 28: Proportion of sum of squares for main effects and interaction for mealiness score for nine yellow root and one write root cassava genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	35.49***	57.86%
Environment	9	4.65***	7.59%
Genotype by environment	81	1.06***	15.30%
Error	197	0.56	19.25%

*, **, *** significant at 0.05%, 0.01% and 0.001%

TABLE 29: Average Percentage of dry matter content in storage root (%) for nine yellow root and one write root cassava genotypes in 10 environments.

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	34 65	39 86	31 39	36 48	38 96	40.89	38 49	33.06	35 91	27.29	35.70^{b}
01/1235	23.72	27.31	31 38	30.15	33.17	38.17	31.34	27 80	27 24	22 38	29.27^{def}
01/1368	28.08	30.13	34.07	33 90	31.65	38 04	32.98	28.90	26 06	23.98	30.78^{d}
01/1371	27.10	24 38	28 32	32 72	32.55	25 48	31.83	25.79	27.37	20.10	27.56^{g}
01/1412	26.19	23 80	28 04	31 60	31.58	41.23	36.32	27.99	27.60	20 37	29.47^{def}
01/1417	25.12	26.89	28 05	30 26	31.07	36 05	33.68	28 66	30 81	19 41	29.00^{ef}
01/1442	23.75	30.27	23.14	31.29	30.69	38.85	31.40	28.81	28.87	19.15	28.62^{fg}
01/1610	30 34	28 80	35 95	30 86	36.02	39.06	36 89	31 95	35.39	25.63	33.09^{c}
01/1663	27 99	28.38	34 33	32 18	35.08	42 89	34.51	32 22	34 64	23 50	32.57^{c}
Wch009	37 10	37.11	35.63	36 52	42.66	48 20	44.09	36 68	37 66	33.49	38.91^{a}
Mean	28.40^{e}	29.69^{e}	31.03^{cd}	32.60^{c}	34.34^{b}	38.88^{a}	35.15^{b}	30.19^{d}	31.15^{cd}	23.53^{f}	*31.50*
P value (Genotype or Environment)											< 0.001
LSD 5% (Genotype or Environment)											1.682
P value (Genotype X Environment)											0.003
LSD 5% (Genotype X Environment)											5.32
CV (%)											10.5

E1 – E10 refer to environments 1 – 10

TABLE 30: Proportion of sum of squares for main effects and interaction for dry matter content in storage root for nine yellow root and one write root genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	332.8***	20.70%
Environment	9	558.9***	34.77%
Genotype by environment	81	28 98*	16.22%
Error	197	20.89	28.30%

*, **, *** significant at 0.05%, 0.01% and 0.001%

TABLE 31: AMMI Interaction analysis of variance including the first four interaction PCA axes for the percentage of the storage root dry matter for nine yellow root and one write root cassava genotypes tested in 10 environments

Source	DF	SS	MS	Probability
Total	295	14468 526	49.046	
Treatments	99	10373 371	104.782	<0.001 ***
Genotypes	9	2995 521	332.836	< 0.001 ***
Environments	9	5030.203	558.911	< 0.001 ***
G X E	81	2347 648	28.983	< 0.035 *
IPCA 1	17	1308 484	76.969	0.001 ***
IPCA 2	15	425 601	28.373	0 171
IPCA 3	13	251 909	19.377	0 526
IPCA 4	11	155.501	14.136	0.760
Residual	25	206 152	8.246	0.996
Error	196	4095 155	20 894	

*, **, *** significant at 0 05%, 0.01% and 0.001%

4.13 Storage root dry yield per hectare (t/ha)

Table 32 shows values for storage root dry yield per hectare. The general mean of storage root dry yield for the 10 genotypes across the 10 environments was 6.28 t/ha. The highest value was registered by genotypes 01/1368 (8 78 t/ha) while the lowest value 3.26 t/ha was registered by local check, Wenchi 009. Out of the ten environments 5 of them (E_6, E_9, E_2, E_4, and E_8) were grouped (LSD5% = 1.275 t/ha) in the first category of high average dry yield. The last category of least average storage root dry yield was composed of two environments which were E_7 (4.80 t/ha) and E_1 (5.20 t/ha).The main sources of variation, genotype, environment and G x E interaction were highly significant for the storage root dry yield (Table 33). For the storage root dry yield, the genotype, the environment and the genotype by environment interaction accounted respectively for 21 20%, 21 83% and 25 68% of the total sum of squares while the error contributed 31 28% to the same sum of squares (Table 33).

4.14 Storage root dry weight per plant (kg)

Storage root dry weight mean values are presented in Table 34. The mean values ranged from 0.600 kg to 1 184 kg per plant Combined analysis of variance showed highly significant difference among genotypes, environments but the G x E interaction was significant at 0.05% level of significant (Table 35). LSD5% of 0.228 kg grouped the following genotypes into one genetic group. 01/1224, 01/1235, 01/1368, 01/1412, 01/1417, 01/1610 and 01/1663; the following were also grouped into another group: Wenchi 009, 01/1371 and 01/1442 The best environment was E6 (1 964 t/ha) Environment accounted for the larger proportion (42.41%) of the total sum of squares while genotype and the G x E interaction contributed for 9.59% and 18 35% sum of squares respectively (Table 35)

TABLE 32: Average dry yield of storage roots per hectare (t/ha) for nine yellow root and one write root cassava genotypes in 10 environments.

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	8 12	11.23	1.51	5.37	3.52	4.70	5.21	7 88	8.69	5 35	6.16^{ef}
01/1235	3 74	9.63	3 25	9 43	3.15	4.58	2.73	2.31	8.66	6.39	5.39^{f}
01/1368	7 78	12.56	4.42	11.14	8.15	14 77	6.26	9.16	6.85	6 71	8.78^{a}
01/1371	2 53	2 28	1.82	7 47	4.11	4 47	3.46	5.15	5 85	2 73	3.99^{g}
01/1412	7 22	8.94	2 30	7 00	4.22	10.30	5 32	6.59	10.10	8 38	7.05^{bdc}
01/1417	5.91	8 31	3.50	10.05	8.81	11 82	5.10	7.69	7.33	7 48	7.60^{abd}
01/1442	5.12	9.43	1.59	7.73	7.45	7.12	3.84	5 48	8.50	4 96	6.12^{ef}
01/1610	3 34	5.16	2.72	10 67	5.74	6.63	6.66	6.70	9 33	7 02	6.40^{def}
01/1663	4 61	7 11	3 93	2 94	9 35	10.38	7.12	13.22	11 20	10 62	8.05^{ab}
Wch009	3.59	4 94	0 51	2 76	3 83	5.16	2.14	3 45	3.26	2.98	3.26^{g}
Mean	5.20^{de}	7.96^{a}	2.55^{f}	7.46^{ab}	5.83^{cd}	7.99^{a}	4.80^{e}	6.76^{abc}	7.98^{a}	6.26^{bcd}	*6.28*
P value (Genotype or Environment)											< 0.001
LSD 5% (Genotype or Environment)											1.275
P value (Genotype X Environment)											< 0.001
LSD 5% (Genotype X Environment)											4.033
CV (%)											39.9

E1 - E10 refer to environments 1 - 10

TABLE 33: Proportion of sum of squares for main effects and interaction for storage root dry yield in tons per hectare for nine yellow root and one write root cassava genotypes in 10 environments.

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	89.69***	21.20%
Environment	9	92.37***	21.83%
Genotype by environment	81	12.23***	25.68%
Error	197	6.27	31.28%

*, **, ***: significant at 0.05%, 0.01% and 0.001%

TABLE 34: Average storage root dry weight per plant (kg) for nine yellow root and one write root cassava genotypes in 10 environments.

Genotypes	Environments										Mean
	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	
01/1224	1 602	2.071	0.220	0 831	0.528	1 567	0 680	1.319	1 680	0.661	1.116[a]
01/1235	0 933	2 162	0.655	1 648	0 539	1 573	0 651	1.003	1.090	0 802	1.106[a]
01/1368	1 059	1.707	0.478	1 173	0.939	2.835	0 824	0.990	0 748	0.772	1.153[a]
01/1371	0.750	0.798	0.214	0 862	0.711	1.063	0.499	0.819	0 721	0.365	0.680[b]
01/1412	1.155	1 412	0.392	1 031	0.556	3 205	0 659	0.928	1 287	0.045	1.167[a]
01/1417	0.957	1.603	0 434	1 171	1 043	2 499	0.833	1 356	1 057	0 889	1.184[a]
01/1442	0 833	1.145	0 180	0 923	1 059	1.333	0 448	0 729	0.999	0 622	0.827[b]
01/1610	0.894	1.626	0.326	1 499	0.843	1 597	0.811	0 880	1 140	0 938	1.055[a]
01/1663	0 837	1.175	0 427	0 379	1 004	2 333	0 881	1 543	1 181	1.113	1.087[a]
Wch009	0.563	1.081	0 054	0 520	0 656	1 633	0 274	0 533	0 360	0.327	0.600[b]
Mean	**0.958[cd]**	**1.478[b]**	**0.338[f]**	**1.004[cd]**	**0.788[de]**	**1.964[a]**	**0.656[e]**	**1.010[c]**	**1.026[c]**	**0.754[e]**	***0.998***
P value (Genotype or Environment)											**< 0.001**
LSD 5% (Genotype or Environment)											**0.228**
P value (Genotype X Environment)											**0.017**
LSD 5% (Genotype X Environment)											**0.7224**
CV (%)											**45%**

E1 - E10 refer to environments 1 - 10

TABLE 35: Proportion of sum of squares for main effects and interaction for storage root dry weight per plant for nine yellow root and one write root cassava genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	9	1.37***	9.59%
Environment	9	6.08***	42.41%
Genotype by environment	81	0.30*	18.35%
Error	197	0.20	29.65%

*, **, *** significant at 0.05%, 0.01% and 0.001%

4.15 Beta-carotene concentration in fresh storage root (µg/g)

The values of the beta-carotene concentration of the storage root are shown in Table 36. The mean values of the beta carotene concentration ranged from 1.28 to 9.19 µg/g. The combined analysis of variance showed no significant difference among genotypes and for G x E interaction The difference among environments was significant (< 0.001). Based on the LSD 5%, environments were grouped into four categories. The highest beta carotene concentration was registered by a group of four environments E_9, E_1, E_7 and E_5 The lowest value was reported for three environments E_3, E_{10} and E_8. The genotype, the environment and the G x E interaction contributed respectively 3.17%, 26.88% and 23.07% to the total sum of squares (Table 37). The residual error contribution to the total sum of squares was 46.66% this can explain the very high coefficient of variation 52.3% due probably to too many steps of the beta carotene analysis process, including the selection of five cassava roots, the field sampling, the laboratory sampling, the extraction, the partition to a solvent, the washing, etc

The results of the AMMI analysis of the beta carotene concentration are shown in Table 38. From these results the first principal component axis (PCA 1) of the interaction captured 51.21% of the interaction sum of squares in 25.92% of the interaction degrees of freedom PCA 1 mean square was significant at $P < 0.05$.

TABLE 36: Average beta-carotene concentration in fresh storage root (µg/g) for seven yellow root cassava genotypes in 10 environments.

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	**Mean**
01/1224	2.87	4.40	2.57	4.24	5.83	6.50	5.43	2.69	7.37	1.58	**4.35**
01/1235	7.67	3.23	1.99	3.52	4.42	3.23	8.94	2.07	5.26	2.05	**4.24**
01/1368	4.65	4.92	2.56	4.83	4.50	5.76	4.16	2.87	5.22	2.69	**4.22**
01/1371	5.47	5.65	2.82	4.87	5.50	5.41	4.90	3.57	7.69	3.19	**4.91**
01/1412	7.02	4.06	1.28	4.19	6.57	2.77	4.78	2.18	7.10	1.84	**4.18**
01/1417	6.13	4.49	2.61	4.15	5.52	4.51	9.19	2.45	4.27	2.93	**4.63**
01/1610	6.20	3.43	2.44	4.12	3.01	3.56	1.45	1.45	4.67	2.48	**3.28**
Mean	5.72^{ab}	4.31^{c}	2.32^{d}	4.28^{c}	5.05^{abc}	4.53^{bc}	5.55^{abc}	2.47^{d}	5.94^{a}	2.39^{d}	***4.26***
P value (Genotype)											**0.17**
P value (Environment)											**< 0.001**
LSD 5% (Genotype)											**NS**
LSD 5% (Environment)											**1.36**
P value (Genotype X Environment)											**0.439**
LSD 5% (Genotype X Environment)											**NS**
CV (%)											**52.3**

E1 - E10 refer to environments 1 - 10

TABLE 37: Proportion of sum of squares for main effects and interaction for average beta carotene concentration in fresh storage root for seven yellow root cassava genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	6	0.065NS	3.17%
Environment	9	0.371***	26.88%
Genotype by environment	54	0.053NS	23.07%
Error	138	0.05	46.88%

*, **, *** significant at 0.05%, 0.01% and 0.001%

TABLE 38: AMMI analysis of variance including the first four interactions PCA axes for beta carotene concentration (mg/100g) for seven yellow root cassava genotypes tested in 10 environments

Source	DF	SS	MS	Probability
Total	185	12.433	0.067	
Treatment	69	6.604	0.096	0.001**
Genotypes	6	0.395	0.066	0.258^{NS}
Environment	9	3.341	0.371	< 0.001***
G X E	54	2.868	0.053	0.395^{NS}
IPCA 1	14	1.469	0.105	0.017*
IPCA 2	12	0.669	0.056	0.359
IPCA 3	10	0.402	0.040	0.628
IPCA 4	8	0.215	0.027	0.828
Residual	10	0.113	0.011	0.993
Error	116	5.829	0.050	

*, **, *** significant at 0.05%, 0.01% and 0.001%

4.16 Beta-carotene content per fresh storage root (mg)

The average values of beta carotene content of individual fresh storage root are presented in Table 39 There was significant difference among genotypes (p=0.036). The difference between environments was also significant (P< 0.001) but there no significant difference for GXE interaction The general mean of beta carotene content per storage root was 2 227 mg, meaning that each consumer of one cassava root is taking an average of 2 23mg of beta carotene into his/her body. Among the genotypes 01/1371 and 01/1417 recorded the highest beta carotene content per tuber. The lower value (1.748 mg) was obtained with 01/1610 For the environments, the highest beta carotene content per storage root was obtained for E_2 (3.787 mg), E_6 (3.775 mg) and E_1 (3.033 mg). The lowest beta carotene content per storage root was reported for E_3 (0.449 mg) and E_{10} (0.975 mg). The environment contributed 438 74% to the total sum of squares of the average beta carotene content per root while genotype and G x E interaction for 4.31% and 21.27%, respectively (Table 40). The AMMI analysis of the beta carotene content per storage root further showed that the first principal component axis (PCA 1) of the interaction captured 56 12% of the interaction sum of squares in less than 26% of the interaction degrees of freedom (Table 41). The mean squares for PCA 1 was significant at P <0.01.

TABLE 39: Average beta carotene content in individual fresh storage root for seven yellow root cassava genotypes in 10 environments.

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	**Mean**
01/1224	1.820	3 643	0.431	1 792	1 912	3 587	1.745	1.889	3 334	0 678	2.083 ^{ab}
01/1235	4.761	3.035	0.597	1 963	1.499	2 690	3 826	1 116	2 121	0 773	2.238 ^{ab}
01/1368	1.879	4.720	0.319	1 939	1 876	5 528	0.974	1 112	1 674	0 953	2.097 ^{ab}
01/1371	2 983	5.577	0 746	2.193	2.400	4.336	1 842	1 890	2.593	0.886	2.545 ^{a}
01/1412	3 438	2 802	0 183	2 887	2.915	3 194	1.548	1.252	4.528	1 268	2.402 ^{ab}
01/1417	3 562	2.925	0 580	2.346	2.922	3.794	3.570	1 980	1 647	1 451	2.478 ^{a}
01/1610	2.788	3.807	0 287	2.492	1.021	3.296	0 456	0 664	1 850	0 819	1.748 ^{b}
Mean	3.033^{a}	3.787^{a}	0.449^{d}	2.230^{b}	2.078^{bc}	3.775^{a}	1.994^{bc}	1.415^{c}	2.535^{b}	0.975^{cd}	*2.227*
P value (Genotype)											0.036
P value (Environment)											< 0.001
LSD 5% (Genotype)											0.67
LSD 5% (Environment)											0.801
P value (Genotype X Environment)											0.135
LSD 5% (Genotype X Environment)											NS
CV(%)											58.8

TABLE 40: Proportion of sum of squares for main effects and interaction for average beta carotene content in individual fresh storage root for seven yellow root cassava genotypes in 10 environments

Source of variation	DF	Mean squares	Contribution to SS
Genotype	6	4 15*	4 31%
Environment	9	24.87***	38.74%
Genotype by environment	54	2.27NS	21.27%
Error	138	1 77	35 68%

*, **, *** significant at 0.05%, 0.01% and 0.001%

TABLE 41: AMMI analysis of variance including the first four interactions PCA axes for beta carotene content per storage root (mg) for seven yellow root cassava genotypes tested in 10 environments

Source	DF	SS	MS	Probability
Total	185	577.763	3.123	
Treatment	69	371 640	5.386	<0.001 ***
Genotypes	6	24 913	4 152	0 036 *
Environments	9	223.827	24 870	< 0.001 ***
G X E	54	122.899	2.276	0.135 NS
IPCA 1	14	68.977	4.927	0.001 **
IPCA 2	12	22.818	1 902	0.392
IPCA 3	10	19.399	1.940	0.374
IPCA 4	8	7.116	0.889	0.854
Residual	10	4.588	0 459	0 989
Error	116	206.123	1.777	

NS non significant, *, **; ***: significant at 0 05%; 0 01% and 0 001%

4.17 Beta-carotene content in storage roots per plant (mg)

The values of beta carotene content in storage roots per plant were reported in Table 42. The data of beta carotene content in storage root per plant ranged from 0.92 mg up to 29.27 mg and the general mean was 12.17 mg. Difference among genotypes was significant ($p^- 0.029$) and the best genotypes for this variable were 01/1417 (14.25 mg) and 01/1368 (14.11 mg). The effect of the interaction G x E was not significant. There was significant difference ($p< 0.001$) among environments and any of the following four environments can be considered as best for this variable E_6 (20.25mg), E_2 (18.25 mg); E_9 (18.09 mg) and E_1 (17.29 mg). The G x E interaction has contributed 24.14% to the total sum of squares The error contribution to the total sum of squares was (37.03%) while contributions to the sum of squares from environment and genotype were respectively 34.14% and 4.68%, (Table 43). Table 44 shows the results of the AMMI analysis of the beta carotene content in storage roots per plant. These results showed that the first principal component axis (PCA 1) of the interaction captured 61.07% of the interaction sum of squares in 25.92% of the interaction degrees of freedom Among the four PCAs only PCA 1 presented highly significant mean squares.

TABLE 42: Average beta carotene in fresh storage roots per plant (mg) for seven yellow root cassava genotypes in 10 environments

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	**Mean**
01/1224	12.29	16.42	1.42	8.35	7.55	12.63	8.66	8.92	23.38	3.88	**10.35^{ab}**
01/1235	21.17	14.06	4.08	15.37	5.94	11.13	16.42	6.24	18.21	6.30	**11.89^{ab}**
01/1368	13.61	22.37	3.05	13.44	12.98	38.10	9.79	7.44	13.41	6.89	**14.11^{a}**
01/1371	14.51	25.52	1.78	10.59	10.52	20.04	7.69	8.77	16.52	5.01	**12.10^{ab}**
01/1412	26.81	15.40	0.92	11.67	9.93	15.00	5.54	5.58	29.27	6.45	**12.66^{ab}**
01/1417	19.10	15.38	2.97	12.94	14.65	26.93	18.01	9.59	12.66	10.26	**14.25^{a}**
01/1610	13.57	18.57	1.77	16.46	4.41	17.95	2.60	3.22	12.98	7.19	**9.87^{b}**
Mean	**17.29^{a}**	**18.25^{a}**	**2.23^{d}**	**12.69^{b}**	**9.82^{bc}**	**20.25^{a}**	**9.82^{bc}**	**7.11^{cd}**	**18.06^{a}**	**6.57^{cd}**	***12.17***
P value (Genotype)											**0.029**
P value (Environment)											**< 0.001**
LSD 5% (Genotype)											**4.218**
LSD 5% (Environment)											**5.041**
P value (Genotype X Environment)											**0.067**
LSD 5% (Genotype X Environment)											**NS**
CV (%)											**67.7**

TABLE 43: Proportion of Sum of Squares for main effects and interaction for average beta carotene content in fresh storage root per plant of seven genotypes in 10 environments in Ghana

Source of variation	DF	Mean squares	Contribution to SS
Genotype	6	158 26*	4.68%
Environment	9	769 38***	34.14%
Genotype by environment	54	90.67^{NS}	24.14%
Error	138	64.74	37 03%

NS non significant, *; **; *** significant at 0 05%, 0 01% and 0.001%

TABLE 44: AMMI analysis of variance including the first four interactions PCA axes for beta carotene content per plant (mg) of seven yellow-fleshed genotypes tested in 10 environments in Ghana

Source	DF	SS	MS	Probability
Total	185	20280.695	109.625	
Treatment	69	12770.552	185 080	< 0.001 ***
Genotypes	6	949.575	158 263	0.029 *
Environments	9	6924.468	769.385	< 0.001 ***
G X E	54	4896 508	90 676	0.067^{NS}
IPCA 1	14	2990.285	213.592	< 0 001 ***
IPCA 2	12	710.454	59 205	0.535
IPCA 3	10	570.795	57 079	0.552
IPCA 4	8	407.831	50 979	0.615
Residual	10	217.144	21.714	0.969
Error	116	7510.144	64.743	

NS non-significant, *, **; ***significant at 0.05%, 0 01% and 0.001%

4.18 Beta-carotene content in storage roots per hectare (g)

The values of beta carotene content in storage roots per hectare are shown in Table 45. The overall mean of beta carotene per hectare was 74.7 mg. The average values ranged from 4.2 g/ha for the genotype 01/1412 at E_3 (Wenchi at 9 MAP during the cropping season 2006-2007) up to 227.2 g/ha for the same genotype at E_9 (Pokuase harvested at 9MAP during 2006-2007). This high variation (4.2 to 227.2 g/ha) of the beta carotene content of the genotype 01/1412 harvested at nine month after planting from one location to another during the same cropping season is one of the factors which can explain the very high coefficient of variation of this variable. The difference among genotypes for the beta carotene content in storage roots per hectare was significant (P=0.042). The highest beta carotene content in storage roots per hectare was obtained for 01/1368 (98.8 g) followed by 01/1417 (90.3 g). These are the best genotypes for this variable. The difference among environments was highly significant ($p<0.001$) but the G x E interaction was not significant ($P>0.05$). The overall best environment for this character was E_9 (Pokuase 9 MAP in 2006-2007) with 139.4 g per hectare and the environment given the lowest mean was E_3 (Wenchi at 9 MAP during 2006-2007) recording 16.3 g. In this study the G X E contribution to the sum of squares was 27.71% compared to 25.2% for environment and only 4.91% for genotypes (Table 46). The error contribution to the sum of squares was 42.18%. The results of the AMMI analysis of beta carotene content per hectare are shown in Table 47. The first principal component axis (PCA 1) of the interaction captured 59.60% of the interaction sum of squares in 25.92% of the interaction degrees of freedom. The mean squares for the first principal component axis (PCA 1) was significant at $P<0.001$.

TABLE 45: Average beta carotene content in fresh storage root per hectare for seven yellow root cassava genotypes in 10 environments.

	Environments										
Genotypes	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	Mean
01/1224	61.2	76.3	8.9	51 8	50.5	58.2	64.0	62	157 1	29 9	62.0^{b}
01/1235	82.0	69.3	19 3	81 7	35 3	32 0	72 7	11 7	138 6	51 4	59.4^{b}
01/1368	104 3	78.7	27 5	126 7	111 3	205 6	79.0	69 4	125 3	60 0	98.8^{a}
01/1371	47.2	152.2	15 2	92 3	59.4	103.6	49.1	54.9	139 6	42.6	75.6^{ab}
01/1412	146 6	59.2	4.2	79.9	78.0	51.2	48.2	43.7	227 2	51 2	78.9^{ab}
01/1417	105 1	89 1	24 5	115.4	121 0	128 0	96 7	54 1	82 3	86 9	90.3^{a}
01/1610	45 8	98 3	14 8	115.1	24 0	77.1	21 8	24 7	105 6	54 6	58.2^{b}
Mean	84.6^{bc}	89.0^{bc}	16.3^{e}	94.7^{b}	68.5^{bcd}	93.7^{b}	61.6^{bcd}	45.8^{de}	139.4^{a}	53.8^{cd}	*74.7*
P value (Genotype)											0.043
P value (Environment)											< 0.001
LSD 5% (Genotype)											29.55
LSD 5% (Environment)											35.32
P value (Genotype X Environment)											0.063
LSD 5% (Genotype X Environment)											NS
CV(%)											[illegible].3

TABLE 46: Proportion of Sum of Squares for main effects and interaction for average beta carotene content in fresh storage root per hectare of seven genotypes in 10 environments in Ghana

Source of variation	DF	Mean squares	Contribution to SS
Genotype	6	6837 88*	4.91%
Environment	9	23450.88***	25.20%
Genotype by environment	54	4296.95 NS	27.71%
Error	138	3044.47	42.18%

NS. non significant, *, **, *** significant at 0 05%; 0.01% and 0.001%

TABLE 47: AMMI analysis of variance including the first four interactions PCA axes for beta carotene content per hectare (g) of seven yellow-fleshed genotypes tested in 10 environments in Ghana

Source	DF	SS	MS	Probability
Total	185	837339 466	4526 159	
Treatment	69	484180.454	7017.108	< 0.001 ***
Genotypes	6	41087.276	6847.879	0.043 *
Environments	9	211057.976	23450 886	< 0.001 ***
G X E	54	232035.203	4296 948	0 063 NS
IPCA 1	14	138290 853	9877 918	< 0 001 ***
IPCA 2	12	38172.765	3181 064	0 413
IPCA 3	10	31618 084	3161 808	0 416
IPCA 4	8	14165 078	1770 635	0 791
Residual	10	9788 422	978 842	0 974
Error	1 16	353159 012	3044 474	

*, **, *** significant at 0 05%, 0.01% and 0 001%

4.19 Winning genotypes and mega-environment identification for beta-carotene content based on GGE biplot

A GGE biplot analysis has the ability to assess the genotypes for their mean performance and ability. On the biplot a single–arrowed line, the average–environment coordinate (AEC) abscissa points to higher mean across environment. A double arrowed line is the AEC ordinate and it points to greater variability (poor stability) in either direction.

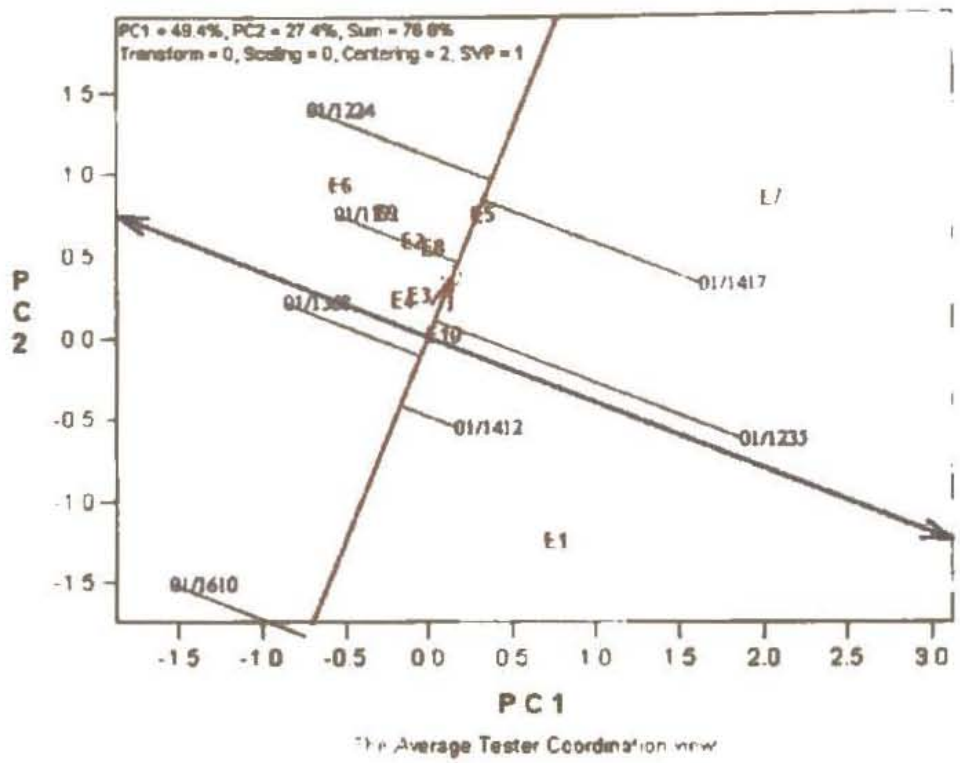
A GGE biplot has also the ability to show the which-won-where pattern of a genotype by environment dataset. On the biplot, some corner or vertex genotypes, which are the most responsive ones, can be visually identified. These are either the best or the poorest genotypes at some or all environments (Weikai *et al*., 2006).

4.19.1 Beta-carotene concentration in fresh storage root (µg/g)

Figure 7 shows the mean performance and the stability of the genotypes for beta carotene concentration in fresh storage root. Genotype 01/1224 had the highest value of beta-carotene concentration. It was followed by 01/1417 and 01/1371. Genotype 01/1610 had the lowest value of beta carotene concentration. The most stable genotype was 01/1412. The highly unstable genotype was 01/1235 followed by 01/1417, and 01/1224.

Figure E 8 gives a polygon view of GGE biplot showing which genotypes won in which environments for beta-carotene concentration in fresh storage root. The PC1 and PC2 together, which make up the GGE biplot, explained a total of 76.8% of the total variation. The vertex genotypes for the beta carotene concentration were 01/1235, 01/1610, 01/1224 and 01/1417. The genotypes 01/1371, 01/1412, and 01/1368 were located within the polygon and were found less responsive (Weikai et al., 2006). Environments E_2, E_3, E_4, E_5, E_6, E_8, E_9 and E_{10} fell in the sector with genotypes 01/1224, 01/1371 and 01/1368. Environment E_1 fell in the sector with genotype 01/1235. Environment E_7 fell in the

sector with genotype 01/1417. No environment fell in the sectors with genotype 01/1610 as vertex genotype.



The Average Tester Coordination view

FIGURE 7: Mean performance and stability of seven yellow root cassava genotypes in 10 environments for beta carotene concentration in fresh storage root

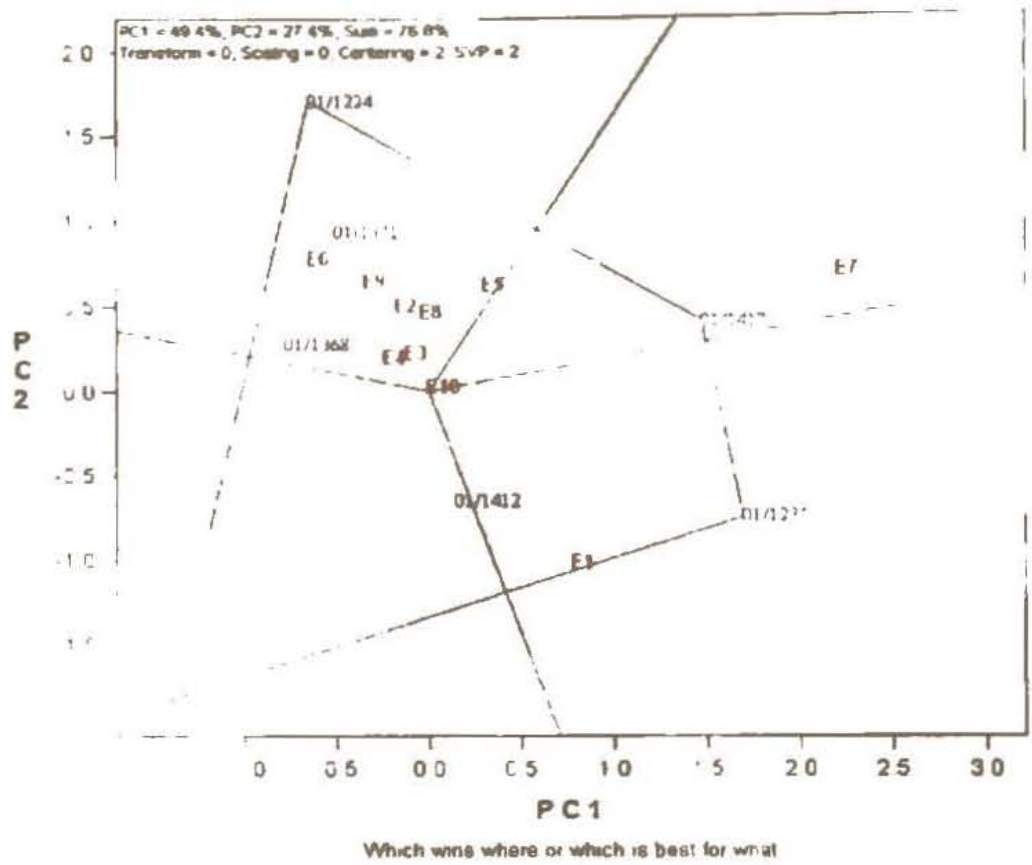


FIGURE 8: Mega-environment defined by different winning seven yellow root cassava genotypes tested in 10 environments for the beta carotene concentration in storage root.

4.19.2 Beta-carotene content per storage root (mg)

The PC1 and PC2 together, which make up the GGE biplots (Figures 9 and 10), explained a total of 72% of the total variation. The mean performance and the stability of the genotypes for beta carotene content per individual storage root are shown in Figure 9. The highest average value of beta carotene content per storage root was registered for genotype 01/1253 followed by 01/1417 and 01/1412. Genotype 01/1368 had the lowest value of beta carotene concentration followed by 01/1610 and 01/1371. The most stable genotype for beta carotene content per storage root was 01/1610 followed by 01/1371. The highly unstable genotype was 01/1412 followed by 01/1235, and 01/1417.

Figure 10 gives a polygon view of GGE biplot showing which genotypes won in which environments for beta-carotene content per storage root. The vertex genotypes for the beta carotene content in storage root were 01/1235, 01/1417, 01/1368 and 01/1412. Two genotypes were found less responsive (01/1610 and01/1371) and were located within the polygon indicating that none of these two genotypes were not the best in any of the test environments. Three mega environments were defined. The first was the genotypes 01/1235 and 01/1417 winning-niche made of E_1, E_3, E_7, E_8, and E_{10}. The second mega environment fell in the sector with genotypes 01/1412 and 01/1224 made of environments E_4, E_5 and E_9. Environments E_2 and E_6 constituted the third mega environment with genotype 01/1368, 01/1610 and 01/1371

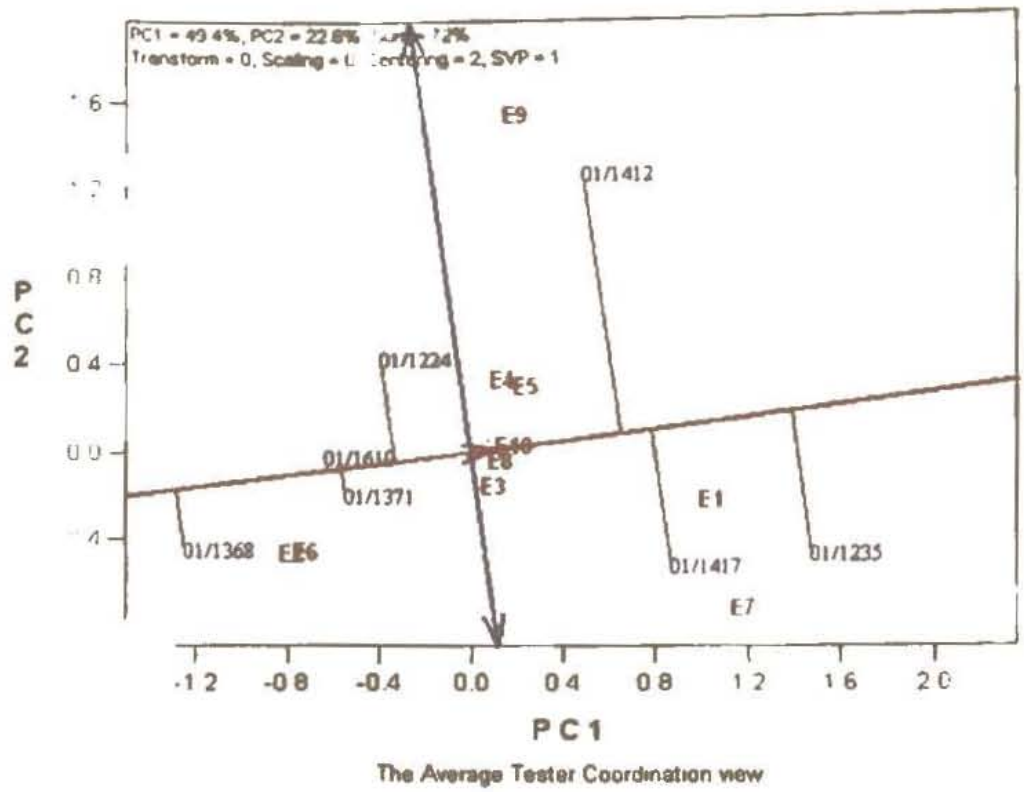


FIGURE 9: Mean performance and stability of seven yellow root cassava genotypes in 10 environments for beta carotene content per storage root

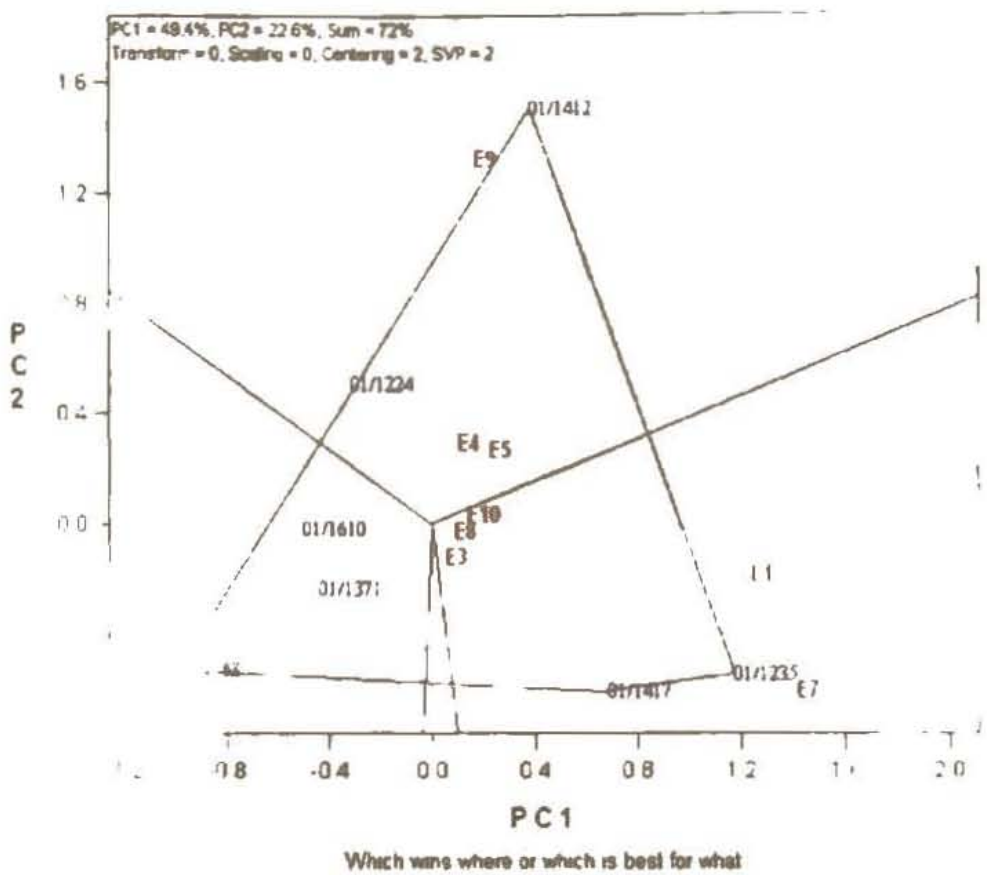


FIGURE 10: Mega-environment defined by different winning seven yellow root cassava genotypes tested in 10 environments for the beta carotene content per storage root.

4.19.3 Beta-carotene content per plant (mg)

Figure 11 shows the mean performance and the stability of the genotypes for beta carotene content per plant Genotype 01/1224 had the lowest value of the beta-carotene content per plant followed by 01/1610, 01/1412 and 01/1371. The highest value was registered for genotype 01/1417 (also the most stable) followed by 01/1368 and 01/1235. The most unstable genotype was 01/1368 followed by 01/1235, and 01/1412.

For this analysis the PC1 and PC2 together explained up to 73.7% of the total variation. The biplot of Figure12 gives a polygon view of GGE biplot showing which genotypes won in which environments for beta-carotene content per plant. The vertex genotypes for the beta carotene content per plant were 01/1412; 01/1235; 01/1417, 01/1368, 01/1610 and 01/1224 One genotype (01/1371) located within the polygon was found less responsive According to the Figure 12 four mega environments were defined. The first mega environment was the genotype 01/1417 winning-niche made of E_3, E_4, E_5, E_7, E_8, and E_{10} The second fell in the sector with genotypes 01/1412 made of environment E_9. The third mega environment was the winning niche of genotype 01/1235 and made of environment E_1. Environments E_2 and E_6 constituted the fourth mega environment with genotype 01/1368. No environment fell in the sectors with genotype 01/1224 and with genotypes 01/1610 and 01/1371

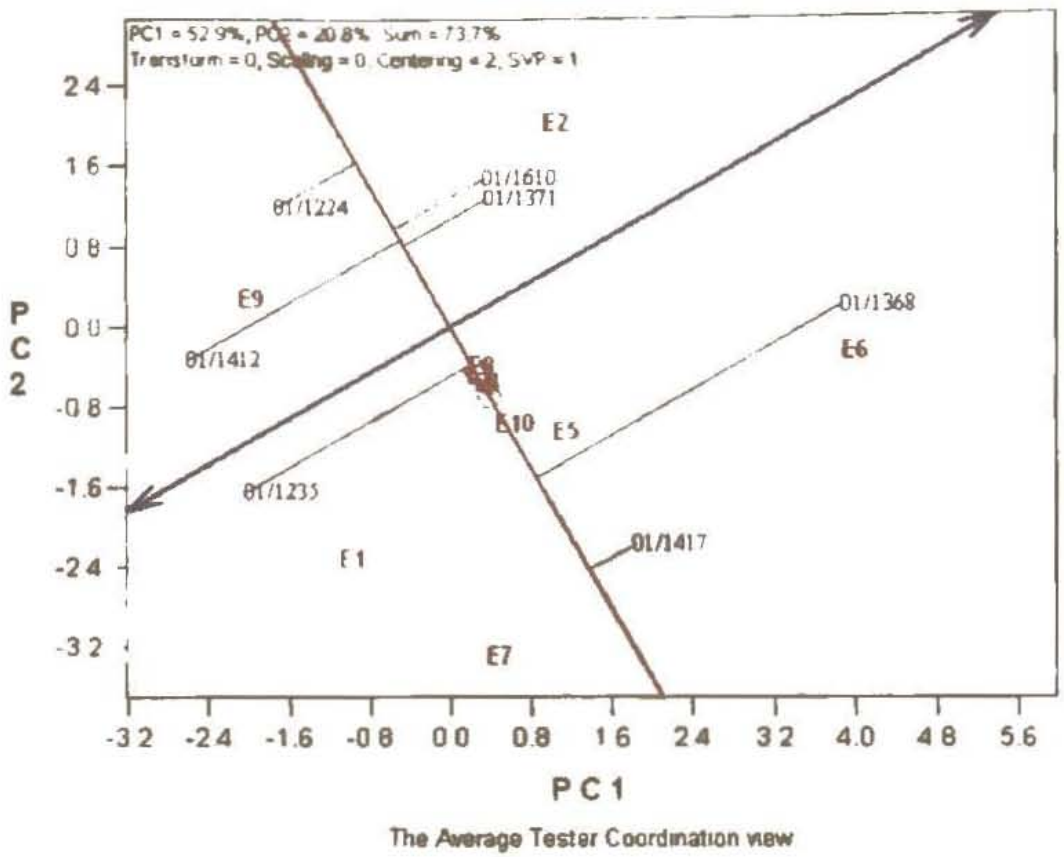


FIGURE 11: Mean performance and stability of seven yellow root cassava genotypes in 10 environments for beta carotene content in storage root per plant

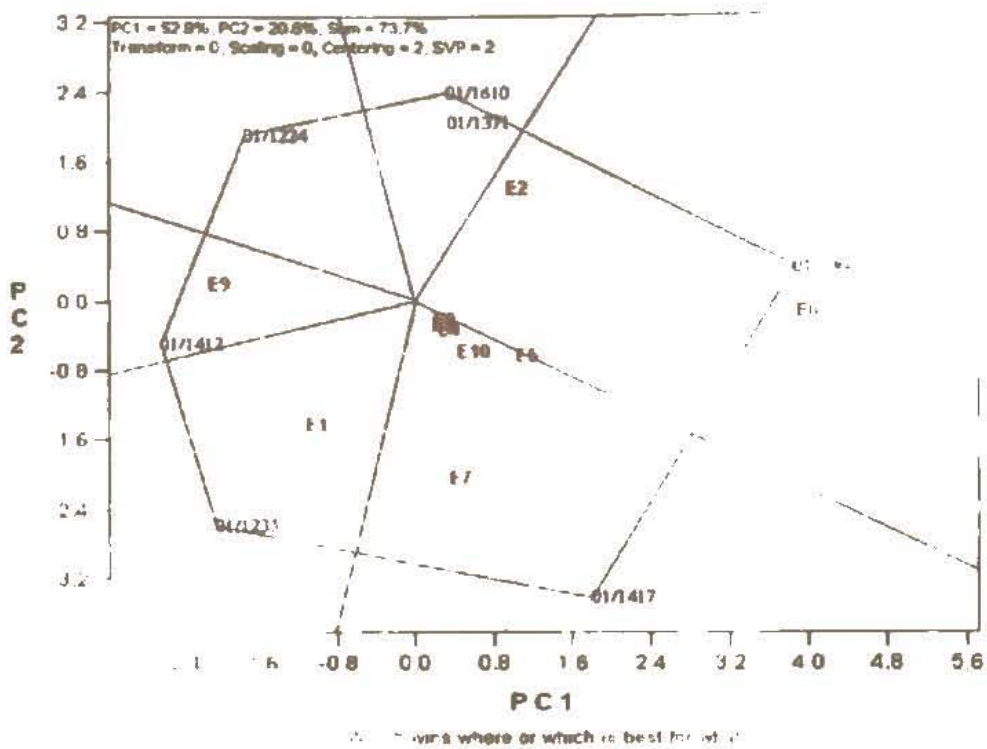


FIGURE 12: Mega-environment defined by different winning seven yellow root cassava genotypes tested in 10 environments for the beta carotene content in storage root per plant.

4.19.4 Beta-carotene content per hectare (g)

Figure 13 shows the mean performance and the stability of the genotypes for their beta carotene content in storage roots per hectare. The highest performance value was recorded for genotype 01/1368 followed by genotypes 01/1417 and 01/1412. Genotype 01/1235 had the lowest performance value of beta carotene content per hectare followed by 01/1610 and 01/1371. The genotype 01/1224 was the relatively stable genotype for the performance of beta carotene content per hectare. The highly unstable genotype was 01/1224 followed by 01/1368, 01/1417, and 01/1610.

Figure 14 below gives a polygon view of GGE biplot showing which genotypes won in which environments for beta-carotene content in storage roots per hectare. PC1 (51%) and PC2 (27 5%) together, which make up the GGE biplot, explained a total of 78.5% of the total variation. The vertex genotypes for the beta carotene content in storage roots per hectare were 01/1368, 01/1412, 01/1235 and 01/1610. The genotypes 01/1371, 01/1417, and 01/1224 were located within the polygon and were found less responsive. These three genotypes were among the poorest for beta carotene content per hectare in most or all the environments. From the Figure 10a, three mega environments were defined Environments E_3, E_4, E_5, E_6, E_7, E_8, and E_{10} fell in the sector with genotypes 01/1368 and 01/1417. Environment E_1 and E_9 constituted the second mega environment and fell in the winning niche of genotype 01/1412. Environment E_2 fell in the sector with genotypes 01/1610 and 01/1371. No environment fell in the sectors with genotype 01/1235 as vertex genotype.

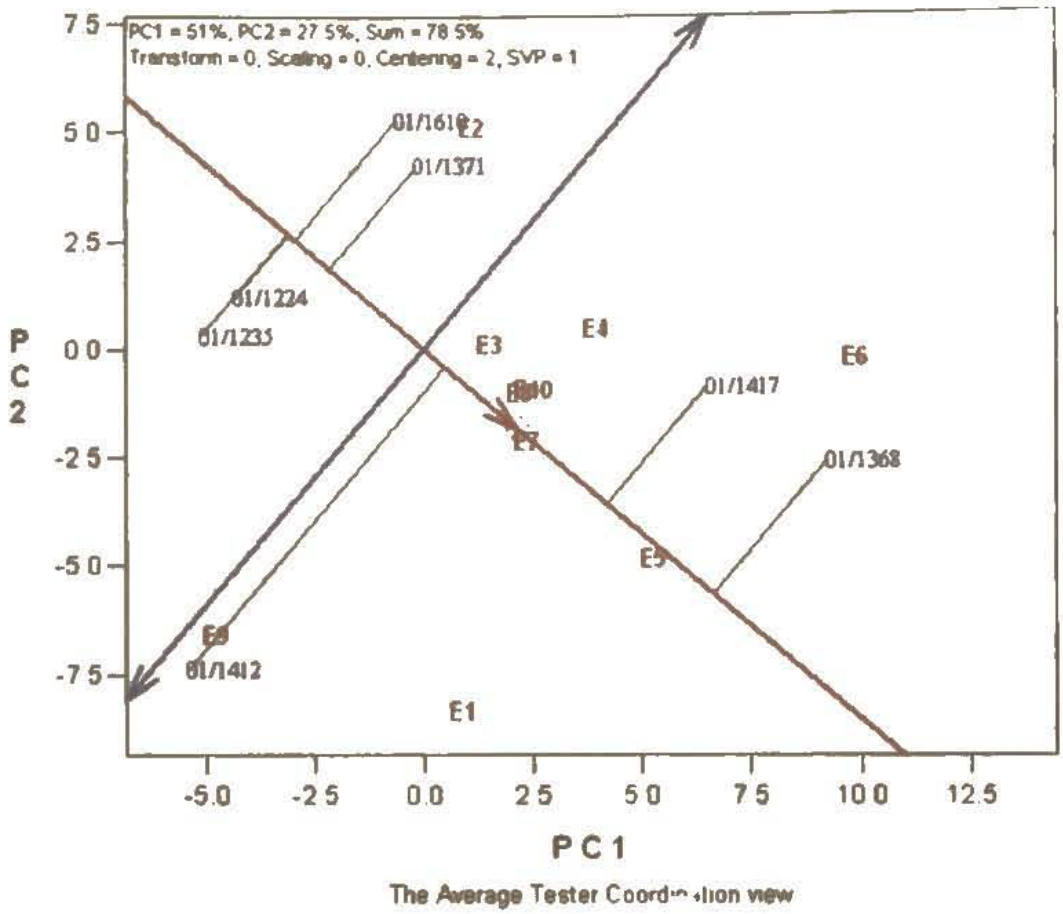


FIGURE 13: Mean performance and stability of seven yellow root cassava genotypes in 10 environments for beta carotene content in storage roots per hectare

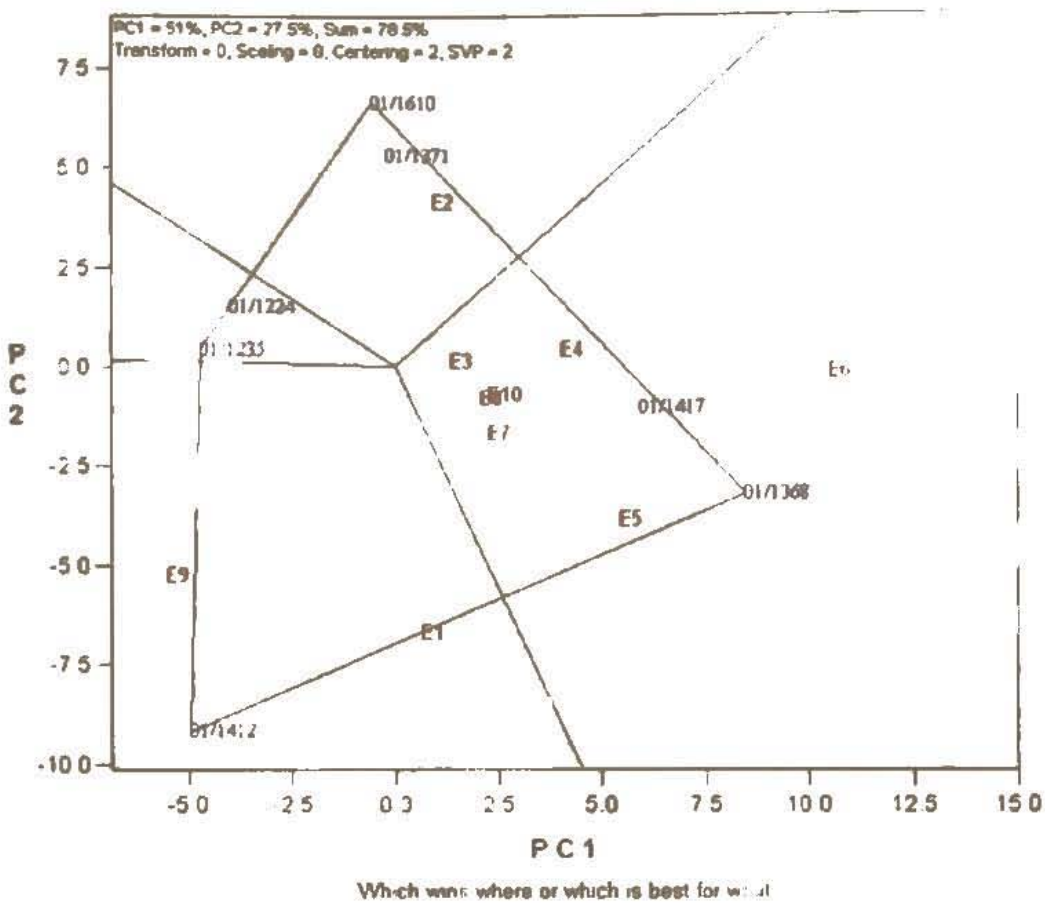


FIGURE 14: Mega-environment defined by different winning seven yellow root cassava genotypes tested in 10 environments for the beta carotene content in storage root per hectare.

4.20 Broadsense heritability, genotypic and phenotypic variances

Table 48 shows values for genotypic coefficient of variation (GCV), phenotypic coefficient of variations (PCV), variance components and broadsense heritability estimates

Values for phenotypic coefficient of variation ranged from 4.286 (for beta carotene content per hectare) to 2921 33 (for dry matter). Values for genotypic coefficient of variation ranged from 2 01 (for beta carotene content per hectare) to 1889.89 (for percent dry matter).

Environmental variance component ranged from 7.08% (for beta carotene content per hectare) to 84.9% (for harvest index). The lowest broadsense heritability of 8% was recorded for beta carotene content per root. Genotype by environment interaction variances for all the variables studied were the lowest of all the variance components. Environmental variances were the highest of all the variance components for all the variables except mealiness where genotypic variance component was the highest.

4.21 Correlation among the variables

Tables 49 and 50 show the correlations among the beta carotene and some agronomic traits for 7 genotypes In general correlation between agronomic variables and beta carotene variables were highly significant except for beta carotene concentration. There was a highly significant correlation between beta carotene concentration and harvest index (Table 49) Correlations among the agronomic variables were highly significant and positive For instance fresh root yield per hectare was highly correlated with all the 13 agronomic variables studied in this work. However correlation with dry matter was negative (Table 50) Dry matter had a positive significant correlation with only dry root weight per plant and dry root yield per hectare.

Beta carotene concentration was highly significant and positively correlated with harvest index only

TABLE 48: Genotypic variance (σ_g^2); environmental variance (σ_e^2), genotype by environment interaction variance (σ_{ge}^2); phenotypic variance (σ_p^2), broad sense heritability (h^2); phenotypic coefficient of variation (PCV) and genotypic coefficient of variation of traits in seven yellow cassava genotypes tested in 10 environments in Ghana

Variables	σ_g^2	σ_e^2	σ_{ge}^2	σ_p^2	h^2	PCV	GCV
Sprouting (%)	9.98	31.55	1.96	43.49	0.23	915.93	438.77
Mealiness	63.45	8.32	1.89	73.66	0.86	204.06	189.38
Dry Matter (%)	35.44	47.58	1.66	84.68	0.42	2921.33	1889.89
Dry Yield (Tones)	14.31	14.73	1.95	30.99	0.46	88.644	60.24
Harvest Index	25.08	84.9	2.35	112.33	0.22	1971.09	931.37
Number of root per plant	15.4	14.79	1.83	32.02	0.48	106.09	73.57
Root dry weight per plant (kg)	6.83	30.2	1.47	38.50	0.18	621.73	261.87
Root Weight (kg)	14.38	67.59	1.73	83.7	0.17	1509.95	625.86
Root Weight per plant (kg)	10.7	27.08	1.43	39.21	0.27	195.44	102.09
Top Weight per plant (kg)	11.27	22.68	1.89	35.84	0.31	229.90	128.92
Top Weight per hectare (Tones)	18.4	36.05	2.08	56.53	0.32	43.26	24.68
Yield (Tones/Ha)	18.9	19.59	2.06	40.55	0.47	30.99	21.16
Beta Carotene Concentration (µg/g)	1.54	8.36	1.03	10.93	0.14	776.07	291.31
Beta Carotene content per root (mg)	1.34	15.01	1.2	17.55	0.08	188.11	51.98
Beta Carotene content per plant (mg)	1.25	11.36	1.06	13.67	0.09	30.38	9.19
Beta Carotene Content per hectare (g)	2.26	7.08	0.91	10.25	0.22	4.286	2.01

TABLE 49: Pearson product-moment correlations among beta carotene traits and agronomic variables for seven yellow root cassava genotypes tested in 10 environments in Ghana

	Beta Carotene Content per hectare	Beta Carotene content per plant	Beta Carotene content per root	Beta Carotene Concentration
Beta Carotene Content per hectare	1.000			
Beta Carotene content per plant	0.890***	1.000		
Beta Carotene content per root	0.730***	0.881***	1 000	
Beta Carotene Concentration	0 671***	0.686***	0.757***	1.000
Mealiness	0.049 NS	0.013 NS	- 0.008 NS	- 0.061 NS
Dry Matter	- 0.032 NS	0.007 NS	0.042 NS	0.073 NS
Dry Yield	0 587***	0.548***	0.342***	0.093 NS
Harvest Index	0 268***	0.399***	0.444***	0.253***
Number of plant per hectare	0.176*	- 0.165*	- 0.261***	- 0.048 NS
Number of root per hectare	0 336***	0.073 NS	-0.212**	- 0.032 NS
Number of root per plant	0.351***	0.293***	- 0.073 NS	- 0.013 NS
Dry root weight per plant	0 372***	0.566***	0.420***	0.034 NS
Root weight	0.211**	0.432***	0.507***	0.028 NS
Root weight per plant	0.396***	0.579***	0.419***	0 021 NS
Top weight per hectare	0.307***	0.110 NS	- 0.088 NS	- 0.102 NS
Top weight per plant	0.227***	0.248***	0.063 NS	- 0.140 NS
Fresh root Yield	0.564***	0.500***	0.0291***	0.057 NS

TABLE 50: Pearson product-moment correlations among Agronomic traits

Variables	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Plant harvested (%)	1													
Mealiness	0.031NS	1												
Dry Matter (%)	-0.116*	-0.358***	1											
Dry Yield	0.282***	0.146*	0.085NS	1										
Harvest Index	-0.282***	0.156**	-0.104NS	0.344***	1									
Number of plant per ha	0.998***	0.033NS	-0.120*	0.291***	-0.228***	1								
Number of root per ha	0.721***	0.158**	-0.239***	0.539***	-0.003NS	0.709***	1							
Number of root per plant	0.213***	0.208***	-0.227***	0.555***	0.181***	0.209***	0.609***	1						
Dry root weight per plant	-0.325***	0.125*	0.223***	0.736***	0.490***	-0.317***	0.041NS	0.379NS	1					
Root weight	-0.447***	0.158**	-0.002NS	0.474***	0.478***	-0.431***	-0.305***	-0.064***	0.778***	1				
Root weight per plant	-0.281***	0.213**	-0.110NS	0.735***	0.490***	-0.271***	0.143*	0.482*	0.928***	0.800***	1			
Top weight per hectare	0.513***	0.151**	-0.121*	0.607***	-0.360***	0.512***	0.627***	0.480***	0.237***	0.032NS	0.281***	1		
Top weight per plant	-0.084NS	0.160**	-0.017NS	0.515***	-0.281***	-0.085NS	0.219***	0.419***	0.583***	0.401***	0.579***	0.754***	1	
Fresh root Yield	0.335***	0.226***	-0.252***	0.923***	0.387***	0.345***	0.628***	0.626***	0.606***	0.445***	0.742***	0.620***	0.473***	1

A = Plant harvested (%); B = Mealiness; C = Dry Matter (%), D= Dry Yield, E= Harvest Index, F= Number of plant per ha, G= Number of root per ha, H= Number of root per plant; I= Dry root weight per plant; J= Root weight, K= Root weight per plant; L= Top weight per hectare; M= Top weight per plant; N= Fresh root Yield

NS: non significant; *; **; *** significant at 0.05%; 0.01% and 0.001%

5. DISCUSSION

5.1 Sprouting at two weeks after planting

Sprouting is one of the most important early variables of final yield productivity of cassava The average sprouting observed in this study ranged from 59.97% to 84.33% with a grand mean of 72 06% (Table 3). These Figures are better than the range of 32% to 93% with a grand mean of 66 54% reported by Ntawuruhunga *et al.* (1995) for 11 cassava genotypes in a study conducted in Ibadan, Nigeria The best genotypes for early sprouting were 01/1368 and 01/1663 which also gave the highest average number of plant (Table 5) and the highest average storage root yield (Table 13) at harvest Sprouting was highly positively correlated with number of plants harvested per hectare (r = 0.998); number of root per hectare (r = 0.721) and fresh root yield per hectare (r = 0.335). These results on yellow root cassava genotypes were earlier observed for white-fleshed root cassava varieties (Akoroda *et al.*, 1997). More variables on cassava plants in the first month that are well combined would be able to shift the indirect selection close enough to direct selection for root yield at the time of harvest (Akoroda *et al.*, 1998).

Sprouting at two weeks after planting had no significant correlation with mealiness and top weight per plant Meanwhile it was negatively correlated with dry matter content, harvest index, root weight per root, root weight per plant and dry root weight per plant According to the results of this study, early selection of cassava genotypes based only on sprouting (high environmental variance) will affect negatively other factors such as the dry matter content, the root weight per root, dry root weight per plant.

5.2 Number of plants harvested per hectare

Highest number of plants per hectare was reported for the genotypes 01/1368 and 01/1663 which also gave the highest yield for storage roots per hectare. From the results

of this study, average number of plants per hectare and fresh root yield were significantly ($p<0.001$) and positively correlated. This result confirmed Dahniya and Jalloh (1992) finding for white root cassava genotype that the number of plants per hectare was most dominant in determining storage root yield. Despite this trend, there are other yellow root cassava genotypes (01/1412 and 01/1417) which were not among the best in terms of number of plants per hectare but were among the highest in terms of storage root yield as per Table 13.

This work has shown a positive and significant correlation between the number of plant harvested per hectare, the number of root per plant and the number of root per hectare. It has also negative significant correlation with the dry matter content, the average root weight per root and the root weight per plant (Table 50).

5.3 Number of storage roots per hectare and average number of storage roots per plant

The number of roots per hectare was significantly correlated with all the agronomic variables analyzed in this study except with the dry root weight per plant and harvest index However it had negative correlation with the dry matter content and the average root weight. Number of storage root per hectare was positively correlated ($P<0.000$) with beta carotene content per hectare and negatively correlated ($P<0.00$) with beta carotene content per root The fact that the number of roots per hectare had a high and positive significant correlation ($P<0\ 000$) with the average number of root per plant this may imply that any direct selection based on the number of storage roots per plant would cause on indirect effect on the number of roots per hectare

The average number of storage roots per plant also had significant ($P<0\ 001$) and positive correlation with root yield per hectare and most of the variables in the study except dry

root weight per plant. This finding confirmed the results of Mahungu (1983) who reported a high significant correlation between storage root yield and number of storage root per plant for white root cassava clones in Ibadan. In this work, genotype 01/1368 recorded the highest number of storage roots per plant as well as the highest storage root yield at harvest This was earlier reported by Mahungu *et al.* (1991) showing that the indirect selection for number of storage root per plant for white root cassava genotypes has the high degree of merit (0.82) relative to the direct selection for storage root yield. Hence the number of root per plant is an important variable to be considered for yellow root cassava selection for high root yield. The average results of number of storage roots per plant of this study which ranged from 3.4 to 7 1 was lower than the average ranges earlier reported by Maroya *et al.* (2001) in a two year study of five white root cassava genotypes in five locations in Guinea (5.6 to 8.6) and in three locations in Togo (5 4 to 8 5). These Figures were also lower than the range of 0.3 to 10.0 roots per plant reported by Otim-Nape *et al.* (1994) for 13 white root cassava varieties studied in three districts of western Uganda

The difference in number of storage roots per plant which was highly significant ($P<0.001$) in this work could be attributed to genotype differences as Wholey (1974) has stated that the number of roots per plant in white root cassava varieties is influenced by genotype, bud development, nutritional and hormonal factors.

5.4 Fresh storage roots yield per hectare (t/ha)

Fresh storage roots yield is a trait with high G x E interaction effect (Mba and Dixon, 1995) This was observed in the present study since fresh storage yield across all locations for all accessions was poor. This emphasizes the importance of multi environmental evaluations of newly developed varieties to identify the ones best suited

for different agroecologies The average fresh storage root yield recorded in this work ranged from 8 49 to 28 38 t/ha with a grand mean of 20.55 ± 1 98 t/ha. These results are comparable to the range of 9 9 to 30.1 t/ha with a grand mean of 19.2 t/ha reported by IITA (1987) for a yield trial of 13 yellow root cassava genotypes harvested at 12 months in Ibadan, Nigeria. The range of the mean yield of this study is considered slightly better when compared to the fresh root mean yield range of 10.0 to 26.9 t/ha with a grand mean of 17.32 t/ha reported by Ssemakula and Dixon (2007) for 25 yellow cassava clones and three white-fleshed cassava (checks) at five locations in Nigeria for two years and harvested at 12 months after planting.

The findings of this study in terms of average yields are also similar to the range of 11.47 to 25.14 t/ha with a grand mean of 18.17 t/ha which were obtained by Maroya and Dixon (1992) for 10 white root cassava clones evaluated in four locations in Benin from 1989 to 1991

In comparison with an earlier experiment in Ghana, the mean yield range of this study is lower than 9.81 to 35.67 t/ha with a grand average mean of 22.36 t/ha reported by Okai et *al.* (1995) for 10 white root cassava clones in 18 environments in Ghana.

There was a highly significant and positive correlation between root yield per hectare and all the remaining twelve variables. However the correlation with dry matter was negative. Therefore selection for high fresh storage roots yield will lead to an indirect selection for high performance of other variables with exception of dry matter

5.5 Fresh storage roots weight per plant (Kg)

The average range of fresh yellow root weight per plant in this work was 1.48 to 4.09 kg (Table 16). These Figures are relatively higher than the results of 1.4 3 0 kg obtained by Terry and Hahn (1980) in Nigeria for white root cassava clones harvested at 12 months

after planting. The same results from this study are relatively low when compared with 3 17 – 5 17 kg reported Ojulong *et al.* (1995) after studying 17 white root cassava clones harvested at 12 months in 10 environments (5 locations x 2 years) in Nigeria. These results can be explained by the fact that cassava productivity was highly affected by location (soil and climatic conditions) and by year (crop duration and seasonal variation).

Cock *et al.* (1979) noted that few storage roots per plant, low individual storage root 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 storage root yield. This may explain why relatively low fresh storage root weights were obtained in this experiment. The root weight per plant had a significant correlation with the other variable except with the dry matter content

5.6 Average weight per root of fresh storage root (g)

The average weight per root of fresh storage root (Table 16) registered in this study ranged from 0.399 kg (Wenchi 009) to 0.803 kg (01/1412) with a mean of 0.606 kg. The range of weight per root of fresh storage root of this study is considered slightly higher when compared to the range of 0.47 kg and 0.59 kg with a grand mean of 0.54 kg reported by Maroya *et al.* (2003) for two years on-farm testing of five white root cassava clones with 21 farmers in Benin. Weight per root of fresh storage root was highly significant by correlated with all other agronomic variables except with the dry matter and top weight per hectare. However the correlation ($P<0.000$) was negative with percentage plant harvested, number of plant per hectare, number of root per hectare and number of root per plant. Weight per root of fresh storage root was positively and significantly correlated with beta carotene content per hectare, beta carotene content per

plant and beta carotene content per root Among other factors indirect selection for high levels of these beta carotene factors will be possible through direct selection for average weight per root of fresh storage root

5.7 Fresh top shoot weight per hectare (t/ha)

In this study there were highly significant differences among genotypes, environments and G x E interaction effects for fresh top weight per hectare. This therefore reduces the usefulness of selection based only on genotypes means across different agroecological zones (Mariani and Manmana, 1986, Ivory *et al.*, 1991). Fresh top shoot weight per hectare was significantly and positively correlated with all the agronomic variables except with root weight per storage root However there were significant and negative correlations between fresh top shoot weight per hectare and percentage dry matter. Therefore yellow root cassava genotypes with low fresh top shoot weight per hectare can be targeted for high percentage dry matter content

5.8 Harvest Index

As it has been explained by Cock *et al.* (1979) and Hunt (1990), harvest index is the ratio of the weight of storage roots (useful part or the marketable component of the crop) to the total weight of the crop (sum of the above-ground parts and the under ground part of the crop) The general mean of harvest index (0.53) reported for the yellow root cassava genotypes in this study is similar to what was recorded by Nweke (1996) who reported a harvest index mean of 0.5.

Harvest Index can serve as selection criteria in the search for high-yield potential in cassava genotypes. Selecting for high harvest index therefore ensures that genotypes with excessive top growth are avoided Nevertheless, examination of top growth data of some

improved new clones showed that while harvest index and yields in those clones were higher, their shoot growth remained virtually unchanged. This seems to emphasize the need to maintain a certain amount of canopy to provide an adequate photosynthetic apparatus for dry matter production. In other words, in striving for a higher harvest index, it is still necessary to ensure enough leaves to produce the dry matter for storage in the roots. Hence in selecting for high harvest index (high yield) breeders should always verify its correlation with top weight per plant and per hectare. In this study the correlations between harvest index and top weight per plant or top weight per hectare were highly negative ($P<0.001$). Harvest Index was also highly correlated with dry root yield per hectare, mealiness, number of roots per plant, average root weight per root, fresh roots weight per plant and dry roots weight per plant

Among the 14 agronomic variables analyzed in this study, harvest index (HI) was the only one which was highly significant ($P<0.001$) and positively correlated (Table 49) with all the four beta carotene related variables. Therefore selection for higher harvest index in yellow cassava genotypes will lead to indirect selection for high concentration of beta carotene in the root.

5.9 Mealiness of cassava root

Mealiness of cassava roots is an important variable in parts of Africa where boiled cassava roots are used for "ampesi", "fufu" etc where they are not subjected to any fermentation process. This culture of consumption requires cassava varieties which are poundable and mealy when cooked. In this study, the clone Wenchi 009 used as local check was mealy almost everywhere, beside the low yield and its infection by the cassava mosaic virus, this genotype is popularly grown in Wenchi because of its good aptitude for

immediate eaten after cooking In this study, the yellow root cassava genotypes under evaluation were not mealy and therefore not good for eating or pounding after cooking. Mealiness was significantly and positively correlated with all the other characters except number of plant per hectare. It was however negatively correlated with the dry matter. Therefore selection for cassava with high mealiness will result into indirect selection for low dry matter content.

5.10 Root dry matter content in cassava

Mahungu (1998) reported 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. Percentage dry matter content in cassava roots determines the quantity and quality of the products obtained after the roots are processed (Braima *et al.*, 2000) These same authors stated that cassava varieties with 30% and above are said to have high dry matter content In the present work four of the nine yellow root cassava genotypes (01/1224, 01/1368, 01/1610 and 01/1663) had high dry matter content (Table 29). However the white root cassava genotype used as check (Wenchi 009) had a dry matter content highly ($P<0.001$) superior to those of all the nine other yellow root cassava genotypes. This finding confirmed the fact that yellow root cassava genotypes were considered to be characterized by relatively low dry matter (IITA, 1987). The average percentage root dry matter content recorded in this work ranged from 27.56 to 38.91% with a grand mean of 31.5%. These results are higher than the range of 25 0% to 34 7% with a grand mean of 29.17% reported by Ssemakula and Dixon (2007) after studying 25 yellow cassava clones and three white-fleshed cassava at five locations in Nigeria during two years.

IITA (1987) evaluated thirteen yellow root cassava clones and reported root dry matter values that ranged between 23.7% and 33.1% with a grand mean of 28.82. These reported dry matter content values are lower when compared with those of the present work

Kawano *et al.* (1987) reported that root dry matter content and root fresh yield are competing components and a negative correlation should arise between them when the assimilation by the crop reaches physiological ceiling and the variability in dry matter yield becomes limited. These authors added that if there is no indication of negative correlation between the two parameters, this suggest that a yield plateau has not yet been reached. In the present study, the correlation between these two variables was negative and significant ($P<0.000$), therefore confirming the findings of Kawano *et al.* (1987).

5.11 Storage dry root yield per hectare (t/ha)

Dry root yield of cassava is a better variable for cassava genotype evaluation than fresh root yield. In this study the yellow root cassava dry yield per hectare ranged from 3.26 to 8.78 t/ha with a general mean of 6.28 t/ha. These values are comparable to the range of 3.1 to 8.9 t/ha with a mean of 5.52 t/ha reported by Ssemakula and Dixon (2007) for 25 yellow root cassava genotypes tested in five locations during two years in Nigeria. Similar values of 2.8 to 9.5 t/ha with an average of 5.48 t/ha were reported for same yellow flesh root cassava varieties by IITA (1978). In this experiment dry root yield significantly and positively correlated with all the agronomic variables studied except percentage dry matter. Since dry root yield had a positive and highly significant correlation with total fresh root yield per hectare ($r = 0.923$) it is therefore a critical factor in the selection of cassava varieties (Mahungu, 1998).

The dry root yield also had positive and highly significant correlation with beta carotene content per hectare, beta carotene content per plant and beta carotene content per root

This implies that direct selection for high fresh yield or the dry yield may result in indirect selection for beta carotene content

5.12 Beta carotene concentration in fresh storage root and its related variables

There was no difference in carotene concentrations among the seven yellow root cassava genotypes. It can be explained by the fact that during the preliminary visual evaluations only highly coloured flesh roots were selected. Values for the beta carotene concentrations obtained in this study ranged from 1.28 mg/kg to 9 19 mg/kg and were higher than the carotene values of 1.0 to 11.3 mg kg^{-1} dry weight from six cassava cultivars equivalent to about 0.3 to 3 8 mg kg^{-1} fresh weight as reported by McDowell and Oduro (1983), using the same HPLC method. Safo-Kantanka *et al.* (1984) estimated beta carotene content of cultivar BB (Banchi Bodea) to be about 3.2 mg per kg in Ghana Ssemakula and Dixon (2007) also reported an overall mean value of 5.04 µg/g for total carotenoid concentration for 25 yellow root cassava genotypes. A value of 5.07 µg/g was also reported by CIAT 2005 for total carotenoid concentration in yellow cassava These values are however comparable to 4 26 µg/g for the present work which was calculated for only beta carotene and not total carotenoid. Similar studies in CIAT in 2005 gave a value of 4 07 µg/g for beta carotene which was really closed to 4.26 µg/g for this present study

Evaluation of beta carotene content is very important but it will be better to analyse the bioavailability of the beta carotene content of the yellow cassava genotypes It is better to know for each of these yellow root genotypes the percentage of beta carotene content which can be released and used in metabolism after consumption. It is then suggested that a further research work can be carried out to study bioavailability of the beta carotene content.

5.13 Broadsense heritability, genotypic and phenotypic variances

In this study the broadsense heritability values ranged from 0.08 for beta carotene content per root to 0.86 for mealiness (Table 48). These values are in general smaller than the values reported by previous workers. The small values of broadsense heritability of this study were related to the very high environmental variances over the genotypic variances for all the variables (except for the mealiness and the number of storage root per plant). Sagoe *et al.* (1995) in an earlier white root cassava genotypes evaluation in Ghana estimated a value of 0.97 for heritability for number of storage root which is higher than 0.48 for the same variable in this study.

Broadsense heritability value of 0.47 estimated in this study for fresh storage root yield was very low in comparison with 80.41, 85.17 and 89.9 for cassava uniform yield trials at 14, 15 and 25 months after planting in Nigeria as reported by Mba and Dixon (1995).

The value of 0.42 estimated for the broadsense heritability of dry matter content in this study was smaller than 0.80 as reported by IITA (1981). These were both lower than 93% and 92% reported by Tan (1981) and Tan (1984) respectively in previous studies on white root cassava genotype.

Heritability value of 0.22 for harvest index of this study was lower than 0.75 as reported by Tan (1981) and both lower than 0.79 and 0.89 as reported by Birader *et al.* (1978) and Tan (1984) respectively.

The highest broadsense heritability h^2 value of 0.86 of this study was estimated for mealiness. This implies that there is a relatively large component of the heritable portion of variation which is portion exploited (controlled) by the plant breeder. Hence there is high probability to breed for this character in the cassava genotypes used for this study

The fact that there was little difference between the GCV (189.4) and the PCV (204.1) for mealiness means that the non-genetic component (error and interaction effects) is very minimal. This is indeed most desirable for the plant breeder

The values of heritability observed in this study were in general smaller than the value earlier published. Yellow root cassava genotypes are very different from the white root cassava genotypes and this is observed in this study with the big differences observed in broadsense heritability (genotypic differences). There is a need to be investigated more on further studies

The values of the genotypic (GCV) and phenotypic (PCV) coefficients of variation of this study were in general very high when compared to values reported by previous workers. Only the genotypic coefficient of variation of fresh root yield reported in this study was comparable to 26.11 and 18.64 reported by Mba and Dixon (1995) for white cassava uniform yield trials harvested at 14, 15 MAP in Nigeria. The values 26.67 and 20.19 were reported for fresh root yield phenotypic coefficient of variation in the same study which are both smaller than 30.99 as estimated in this study.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The sprouting at two weeks after planting, number of plants; number of roots, fresh storage root yield, root mealiness, root dry matter content and harvest index showed in significant differences ($P< 0.001$) among genotypes, environments and G x E interaction. With respect to high fresh storage root yield per hectare, the overall high yielding yellow root cassava genotypes were 01/1368, 01/1417, 01/1663 and 01/1412. Three of these genotypes namely 01/1417; 01/1412 and 01/1368 had the highest performance for fresh root weight per plant. These same genotypes were also among the best (01/1368, 01/1417; 01/1412 and 01/1371) for beta carotene content in fresh storage per hectare. They were also found to be vertex genotypes for three different beta carotene related variables

The highest value for harvest index was recorded by genotypes 01/1412 and 01/1417. The highest value beta carotene content per storage root was recorded by genotypes 01/1371 and 01/1417. Wenchi 009 used as check recorded the overall highest percentage of dry matter content, but the lowest value of dry storage root yield per hectare. The top genotypes for dry storage root yield were namely 01/1368, 01/1663 and 01/1417 also had high fresh root yield per hectare. Among these genotypes, 01/1417 and 01/1368 recorded the highest value for beta carotene content per plant

For beta carotene concentration the difference among environments was highly significant and the highest value of beta carotene concentration in fresh root was recorded in environments E_9, E_1, E_7 and E_5. All these four environments with highest beta carotene concentration were characterized by harvest at only 9 months after planting. Genotype 01/1412 was the most stable for beta carotene concentration but the highest value of beta

carotene concentration was recorded for genotype 01/1224 which was also a vertex genotype for a mega-environment composed of eight environments including E_2, E_3, E_4, E_5, E_6, E_8, E_9 and E_{10} The genotype 01/1224 which was a low yielding material with high storage root beta carotene concentration can be used as parental line in crossing blocks together with other high yielding genotypes in yellow cassava breeding programmes.

Significant differences were recorded for beta carotene per storage root and in storage roots per plant between genotypes ($p<0.05$) and between environments ($P< 0.001$). The highest value of beta carotene per storage root was recorded for genotypes 01/1371 and 01/1417 but the genotype 01/1610 was the most stable for beta carotene content per storage root. The highest value of beta carotene in storage roots per plant was registered genotype 01/1417 which was also the most stable for the same The highest value of beta carotene content per storage root was obtained in environments E_2, E_6 and E_1 while for beta carotene content in storage roots per plant the same environments were found as the best together with E_9 No significant difference was detected for Genotype by Environment Interaction for beta carotene content per fresh storage root and beta carotene content in storage roots per plant

Significant differences ($P<0.05$) were found among genotypes for the beta carotene content in storage roots per hectare. Genotype 01/1368 has registered the highest value of beta carotene content in storage roots per hectare for which it was also a vertex genotype winning a mega-environment made of E_3, E_4, E_5, E_6, E_7, E_8 and E_{10}

The genotype 01/1368 was followed by 01/1417 and the two combined high fresh and dry storage root yield with high beta carotene content together with 01/1412 can be immediately proposed as high yielding beta-carotene enriched cassava varieties for a nutritional programme to complement food for vitamin A deficiency The genotype

genotype the best for the beta carotene content per hectare it is also the best for carotene concentration.

Results of these experimentations were influenced by the environmental variations. This was revealed by the highest values of environmental variances computed for all the variables of this study except for mealiness where the genotypic variance component was the highest. However G x E interaction variances were the lowest for all the variables studied.

Positive and highly significant correlations were found between some agronomic variables and beta carotene variables except beta carotene concentration which was only highly correlated with harvest index. Beside the harvest index, the beta carotene concentration was not correlated with any of the twelve other agronomic variables. If this result is confirmed by another study, then the harvest index will become more useful than its actual use as indicator of fresh root yield productivity.

6.2 Recommendations

Considering the environmental effect on beta carotene related variables it was suggested that all the initial 38 yellow root cassava genotypes be evaluated in multi location trials in all the major cassava growing agro-ecological zones of Ghana

On the bases of the high agronomic performance characteristics such as sprouting at two weeks, number of plant harvested per hectare, fresh root yield per hectare, fresh root weight per plant, number of roots per plant, dry storage root yield per hectare etc., combined with beta carotene content characteristics, the genotypes 01/1368, 01/1412 and 01/1417, should be recommended for on-farm testing and if successful, should be proposed for released at least to be used for beta carotene enriched gari since their fresh and dry storage root yields and beta carotene content were high and stable.

For small scale cassava producers and cassava consumers it was proposed the genotype 01/1417 for its high fresh root yield per hectare combined with its high performance and stability for beta carotene content in fresh roots per plant.

For industrial use, it was proposed the genotype 01/1368 with highest performance in fresh root yield per hectare and highest beta carotene content per hectare.

For breeders who would like to improved beta carotene content of the local mealy genotypes through crossing it was proposed to consider the genotypes 01/1224, 01/1417 and 01/1368 as parental lines because of respectively (1) the high performance in beta carotene concentration in a very wide range of environments, (2) high yield and the stability in beta carotene content per plant and (3) the highest performance in fresh root yield and carotene content per hectare.

Considering the importance of the beta carotene in human organism, it was suggested that further research works be carried out to study the genotypic differences of bioavailability of the beta carotene content in yellow cassava and other factors affecting the bioavailability.

Beside beta carotene content it was suggested to initiate research works be carried out to study the iron and zinc content of the yellow root cassava genotypes.

In this study it was planned in collaboration with Ghana Atomic Energy Centre (GAEC) to use the facilities for determination of mineral components of the yellow root cassava genotypes using instrumental neutron activation analysis. At each harvest samples were sent to GAEC but for various reasons beyond our control including unavailability of liquid nitrogen and lack of electricity that part of the study could not be completed It will be recommended that mineral components of the yellow root cassava be studied to know mainly the genotypic variation in iron and zinc content.

Because of the importance of Cassava in Ghana and the nutritional problems caused by vitamin A deficiency in the country, it was suggested that a research task force be set up between the Agricultural Research Institutes (CRI, SARI etc.), the Universities (Legon, Cape Coast, Kumasi etc), the central nutritional Labs (Noguchi) and the Ministry of Agriculture (MoFA) for sustainable management of the yellow root cassava root research

REFERENCES

Adams, C D. 1957. Activities of Danish Botanists in Guinea 1738-1850. Transactions of the Historical Society of Ghana III Part1

Adewusi Steve R. A. and Bradbury J. Howard 1993. Carotenoids in Cassava: Comparison of Open-Column and HPLC Methods of Analysis. *J. Sci. Food Agric* 62: 375-383.

Aina O. O., A. G. O. Dixon, and E. A. Akinrinde 2001: Trait association and path analysis for yield of cassava genotypes grown in various agroecologies in Nigeria. In Root Crops: The small processor and development of local food industries for market economy M. O Akoroda 2003. (ed) Proceedings of the eighth Triennial Symposium of the International Society of Tropical Root Crops – Africa Branch (ISTRC-AB) Pp 399-404

Akobundu, I O. 1980. Weed science research at International Institute of Tropical Agriculture and research needs in Africa. *Weed Sci.* 28: 439-444

Akoroda M. O., C Ocitti-P'Obwoya and S. K. Hahn 1997. Screening cassava genotypes for field establishment ability. *Discovery* 9 (1-2): 25-31

Akoroda M. O., A. G. O. Dixon and R. U. Okechukwu 1998. Relating early growth traits to root productivity for cassava breeding schemes. In Akoroda M. O. & Ngeve J. M. 1998. Proceedings of the 7th Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch (ISTRC-AB) Cotonou, Benin pp. 391-394

Al-Hassan, R. 1989. Cassava in the Economy of Ghana. In Status of Cassava research in Africa. CISCA working paper No. 3. Eds, F. I Nweke, J. Lynam and C. Y. Prudencio, International Institute of Tropical Agriculture, Ibadan, Nigeria

Almazan, A.M. and Theberge, L.R. (1989). Influence of cassava mosaic virus on cassava leaf-vegetable quality. Tropical Agriculture (Trinidad) 66: 305-308.

Almeida -Muradian L B., Penteado M V C. 1992. Carotenoids and provitamin A value of some Brazilian sweet potato cultivars (Ipomea batatas Lam). Rev Farm Bioquim Univ. Sao Paulo 28. 145-154.

Arima H K Rodriguez-Amaya D. B. 1988. Carotenoid composition and vitamin A value of commercial Brazilian squashes and pumpkins. *J Micronutr Anal* 4: 177-191.

Asafu-Agyei J. N. 1992. Managing cassava in a triple cropping system involving maize/cassva/cowpea In Akoroda M. O. (ed) Root crops for food security in Africa. Proceeding of the 5th Symposium of the International Society for Tropical Root Crops- Africa Branch, Kampala, Uganda 22 -28 November 1992. ISTRC-AB, IITA, Ibadan pp 233-236.

Asante I.K 2007: Additive Main Effects and Multiplicative Interactions Analysis of harvest Index Performances in Cassava Genotypes across Environments. Abstract of 7 pages Department of Botany, University of Ghana, Legon.

Asante, I. K. and Dixon, A. G. O. 2002 Heritability studies of some cassava genotypes. *West African Journal of Applied Ecology* 3: 49-53.

Aslam, M.; Lowe, S. B. and Hunt, I A. 1977. Effect of leaf age on photosynthesis and transpiration of cassava (Manihot esculenta Crantz). *Can. J. Bot.* 55: 2288-2295.

Astrog P. 1997: Food carotenoids and prevention: An overview of current research. *Trends Food Sci. technol* 81 406-413.

Basford, K E and Cooper, M 1998. Genotype x environmental interactions and some considerations of their implications for wheat breeding in Australia Australian *J. Agric. Res.* 49: 154-174

Beck, B D. A. and Chant, S. R. 1958. A preliminary investigation on the effect of mosaic virus on Manihot utilissima Pohl In Nigeria. *Trop. Agric.* (Trinidad) 35, 59-64.

Becker, H C and Leon, J 1988 Stability analysis in plant breeding. *Plant Breeding* 101 1-23

Bendich A 1994: Recent advances in clinical research involving carotenoids *Pure Appl. Chem.* 66:1017-1024.

Birader, R. K , Rajendran, P G and Hrishi, N. 1978: Genetic variability and correlation studies in cassava (Manihot esculenta Crantz). *J. Root Crops* 4. 7 -10.

Boateng, E.A. 1960. *A Geography of Ghana* Cambridge University Press. 205 pp.

Bodlaender, K B A 1960. The influence of temperature on the development of the potato. Jaarb. *Inst. Biol. Scheik. Ondors. Landbouwgew* Pp 69-83.

Boerboom, B. W. J 1978. Growth and development of cassava (*Manihot esculenta* Crantz) and the effect of growth regulators. Ph.D dissertation Univ West Indies, Kingston, Jamaica. 80 pp.

Bokanga, M. 1994. The cyanogenic potential of cassava. In Root Crops and Food Security in Africa Proceedings of the Fifth Triennial Symposium of the International Society for Tropical Root Crops African Branch, Kampala, Uganda, 24-28 November 1992, (M. O, Akoroda, ed.), International Institute of Tropical Agriculture, Ibadan, Nigeria

Bokanga M., Ekanayake I. J. and Dixon A. G. O. 1994. In International Workshop on Casssava Safety Proceedings of the International Society for Horticulture Science (ISHS), Ibadan Nigeria 1-4 march 1994 (M. Bokanga, A J. A. Essers, N. Poulter, H. Rosling, O. Tewe eds.). ISHS, IITA, ISTRC *Acta Horticulture* N° 375, Nov 1994 pp 131-139

Bolhuis, G. G. 1966 Influence of length of the illumination period on root formation in cassava. Neth *J. Agric. Sci.* 14 251-254.

Borgemeister, C , F Djossou, C. Adda, H. Schneider, B Djomamou, K. Azoma, and R. H Markham, 1997. Establishment, spread and impact of Teretriosoma nigrescens Lewis (Coleoptera Histeridae), an exotic predator of the larger grain borer Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae), in south-western Benin Environmental Entomology

Bradbury J. H , Holloway W. D 1988 Chemistry of Tropical Root Crops. Significance for nutrition and agriculture in the Pacific. ACIAR, Canberra, Australia, pp 53-77.

Braima, J., Yaninek, S. J; Tumanteh, A, Maroya, N., Dixon, A.; Salanon, R., Kwarteng, J. (2000). Starting a cassava farm. Wordsmithes Printers, Lagos, pp.20.

Britton G. 1995: UV/visible spectroscopy. In Britton G. Liaaen-Jensen S , Pfander H. (eds). Carotenoids: Spectroscopy, vol 1B Birkauser Verlag, Basel 1995, pp 13-63

Burri B J. 1997 Beta-carotene and human health: A review of current research. *Nutr. Res.* 17: 547-580.

Cereda M. P , Sarmento S B. S., Wosiaki G., Abbud N S., Takeda I. J. M. 1990b. A madioca (Manihot esculenta C.) cultivar Pioneira 1. Caracteristicas culinarias. *Arquiros de Biologia eTecnologia, Curitiba*, 33(3) : 511-525.

Chandraratna, M. F. and Nanayakkara K. D. S. S. 1948. Studies in cassava, II: the production of hybrids. *Trop. Agric.* (Colombo) 104(2) 59-74.

Chavez, A. L; Sanchez, T.; Ceballos, H.; Rodriguez-Amaya, D. B.; Nestel, P.; Tohme, J.; Ishitani, M. 2007. Retention of carotenoids in cassava roots submitted to different processing methods. *J. Sci. Food and Agric.*, (87),3 388-393.

CIAT (Centro International de l'agricultura Tropical) 1976. Annual report. Cali, Colombia

CIAT (Centro International de l'agricultura Tropical) 2005. Annual report. Output 1 Genetic base of cassava and related Manihot species evaluated and available for cassava improvement: higher nutritional quality Pp 1-45 Cali, Colombia.

Cock, J H., Franklin, D., Sandoval, G. and Jury, P. 1979. The ideal cassava plant for maximum yield. *Crop Sci.* 19: 271-270.

Cock, J H. 1983. Cassava In: Smith, W. H. and Banta, S. J. (eds.). Symposium on the potential productivity of field crops under different environments, 1980. International Rice Research Institute (IRRI), Los Banos, Laguna, Philippines. Pp 341-359.

Cours G. 1951. Le Manioc à Madagascar. Mem. Inst. Rech. Sci. Madagascar Ser. B Biol. Veg. Pp 203 - 400.

Coursey, D G 1973. Cassava as food: toxicity and technology. In Nestel, B and MacIntyre, R. (eds.). Chronic cassava toxicity: proceedings of a workshop. Report N° IDRC-010e IDRC (International Development Research Centre), Ottawa, Canada Pp 27-36.

Coursey, D. G., and Haynes, P. H. 1970. Root crops and their potential as food in the tropics. *World Crops Prod. Util. Descr.* 22: (4) 261-265.

Craft N E 1992. Carotenoid reversed-phase high performance liquid chromatography methods. Reference compendium *Meth Enzymol* 213: 185-205

Craft N.E. and Soares J.H. Jr 1992. Relative solubility, stability, and absorptivity of lutein and beta-carotene in organic solvents *J Agric Food Chem* 40 431-434

Crossa, J. P., Fox, N, Pfeiffer, W. H Rajaram, S and Gauch, G. Jr. 1991. AMMI adjustment for statistical analysis of an international wheat yield trial. *Theoretical and Applied Genetics*, 81, 27-37.

Crossa, J., Gauch, H. G. and Zobel, R. W 1990 Additive Main Effects and Multiplicative Interaction analysis of two international maize cultivar trials. *J. Crop Sci.* 30:493-500

d'Almeida, Y. A., J. A. Lys, P. Neuenschwander and O. Ajuonu, 1997: Impact of two accidentally introduced Encarsia species (Hymenoptera Aphelinidae) and other biotic and abiotic factors on the spiralling whitefly, Aleurodicus dispersus (Russell) (Homoptera Aleyrodidae), in Benin, West Africa. Biocontrol Science and Technology

Dahniya M. T. and A. Jallow 1992 Effect of plant population on the performance of cassava in Sierra Leone. In M. O. Akoroda (Eds.) 1994. Proceedings of the fifth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch held at Kampala, Uganda 22-28 November 1992 Pp 166-170.

Dapaah S K 1996 The way forward for accelerated agricultural growth and development A paper presented to the Government of Ghana on behalf of the Ministry of food and Agriculture 6 pp

de Vries, C A., Farwerda, J D. and Flach, M. 1967. Choice of Food Crops in Relation to Actual and Potential Production in the Tropics Neth. *Agric. Sci.* 15, 241-8

de Bruijn, G. H 1971 Etude du caractère cyanogenique du *Manihot esculenta* Crantz. Meded. Landbouwhogesch Wageningen 73 1-140.

de Bruijn, G. H 1982. Performance and dry matter distribution of cassava at different ages and ecological conditions in Ivory Coast In Belén, E H. and Villanueva, M (eds.) Proceedings 5th Symposium International Society of Tropical Root Crops (ISTRC), Los Banos, Laguna, Philippines, 1979 Philippine Council for Agriculture and Resources Research. Pp 323-329.

Dickson K. B , and Benneh G. 1988 A New Geography of Ghana, Longman Group, UK Limited, Harlow 70 pp

Dixon, A. G. O., R. Asiedu, S. K. Hahn 1991. Genotypic stability and adaptability. Analytical methods and implications for cassava breeding for low-input agriculture. In Ofori F. and S. K. Hahn (eds). Proceeding of the 9th symposium of the International Society for Tropical Root Crops (ISTRC), 20 -26 October 1991, Accra, Ghana pp. 130-137.

Dixon, A. G. O., R. Bandyopadhyay, D. Coyne, M. Ferguson, S. B. Ferris, R. Hanna, J. d'A. Hughes, I. Ingelbrecht, J. Legg, N. Mahungu, V. Manyong, D. Mowbray, P. Neuenschwander, J. Whyte, P. Hartmann, and R. Ortiz. 2003. Cassava: from poor farmers' crop to pacesetter of African rural development. *Chronica Horticulturae* 43: 8–15.

Dudley, J. W. and Moll, R. H. 1969. Interpretation and use of estimates of heritability and genetic variances in plant breeding. *Crop Sci.* 9: 257-262.

Doku, E. V. 1969. *Cassava in Ghana*. Ghana University Press, Accra, 41 pp.

Dulong, R. 1971. *Le manioc à Madagascar*. Agronomie Tropicale. 26(8):291 – 377.

Dunstan, W. R., and I. A. Magazine, 1981. Tanzania: the larger grain borer on stored products. *FAO Plant Protection Bulletin* 29: 80-81.

Eberhart, S. A. and Russel W. A. 1966. Stability parameters for comparing varieties. *Crop Sci.* 6:36-40.

Epler K. S., Sander L. C., Ziegler R. G., Wise S. A. Craft N. E. 1992: Evaluation of reversed-phase liquid chromatographic columns for recovery and selectivity of selected carotenoids. J. Chromatogr. 595:89-101.

Ermans, A. M., Bourdoux, P., Kinthaert, J., Lagasse, R. Luvivila, K., Mafuta, M., Thilly, C. H. and Delange, F., 1983. Role of Cassava in Etiology of Endemic Goitre and Cretinism. In: Delange, F. and Ahluwalia, R. (eds.). Cassava Toxicity and Thyroid: Research and Public Health Issues. Proceedings of a Workshop held in Ottawa, Canada, 31st May-2nd June, 1982. IDRC Memographs, IDRC 207e 9-16.

Evenson, R. E., J. C. O'Toole, R. W. Coffman and H. E. Kauffman 1978 Risk and uncertainty as factors in crop improvement research IRRI Paper Series 15, Manila, Philippines

Fargette, D., Fauquet, C. and Thouvenal, J. C. 1988. Yield losses induced by African Cassava Mosaic Virus in relation to the mode and the date of infection. Tropical Pest Management 34, 89-91

Finlay, K. W. and Wilkinson, G.N. 1963 The analysis of adaptation in a plant breeding programme Aust. *J. Agric. Res.* 14 742-754.

Finne, M. A.; Rognli, O. A. and Schjelderup, I. 2000. Genetic variation in a Norwegian germplasm collection of white clover (*Trifolium repens* L). *Euphytica*, 112: 45-56.

Francis, T. R. and Kannenberg, L. W. 1978. Yield stability studies in short-season maize I. A descriptive method for grouping genotypes. *Can. J. Plant Sci.* 58.1029-1034.

Freeman G. H. 1985.The analysis and interpretation of interaction. *J. Appl. Stat.* 12: 3 - 10

Fresco, L. 1986 Cassava in shifting cultivation. A Systems Approach to Agricultural Technology Development in Africa Royal Tropical Institute, Amsterdam, 290p

Gauch, H. G. 1988. Model selection and validation for yield trials with interaction. *Biometrics* 44:705-715.

Gaziano J. M. Hennekens C. H. 1993: The role of Beta-Carotene in the prevention of cardiovascular disease *Ann. New York Acad. Sci.* 691 148-155.

Ghuman, B. S. and Lal. R. 1983 Mulch and irrigation effect on plant-water relations and performance of cassava and sweet potato *Field Crops Res.* 7 13-29.

Gomez, K A. and Gomez, A. A. 1984. Statistical procedures for agricultural research (2nd ed.) John Wiley and Sons, New York, pp. 20-299

Gomez, G. and Valdivieso, M. 1985. Cassava foliage chemical composition, cyanide content and effect of drying on cyanide elimination. Journal of the Science of food and Agriculture 36: 433-441.

Greathead, D. J., 1989. Present possibilities for biological control of insect pests and weeds in tropical Africa. In: The Search for Sustainable Solutions to Crop Protection in Africa, edited by J. S. Yaninek and H. R. Herren, IITA Publication Series, pp. 173-194

Gross J. 1987: *Pigments in fruits*. Academic Press, London.

Gross J. 1991: *Pigments in vegetables*. Chlorophylls and carotenoids. Avi: Van Nostrand Reinhold Company Inc, New York.

Hagenimana V., Carey E. E., Gichuki S. T., Oyunga M. A., Imungi J. K. 1999: Carotenoid contents in fresh, dried and processed sweet potato products. *Ecol. Food Nutr.* 37: 455-473.

Hagenimana V., Oyunga, M. A., Low J., Njoroge S. M. Gichuki S., and Kabira J. 1999: The effects of women farmers' adoption of orange-fleshed sweet potatoes: raising vitamin A intake in Kenya. ICRW/OMNI Research program, Research Report Series 3. International Center for Research on Women, Washington DC, 24p.

Hahn, S. K., Howland A. K., and Terry E. R. 1977. Cassava breeding at IITA. In: Leakey, C. L. A. (ed). Proc. 3rd Symp. Int. Soc. Trop. Root Crops, Ibadan, Nigeria, 2-9 Dec. 1973. IITA (international Institute of Tropical Agriculture), Ibadan, Nigeria pp. 4-10.

Hahn, S. K. and Keysen, J. 1985. Cassava: A basic food of Africa. Outlook on Agriculture 14 (2) 95-100

Hahn, S. K., E. R. Terry, K. Leuschner, I. O. Akobundu, C. Okali and R. Lal 1979. Cassava improvement in Africa. *Field crops Res.* 2: 193-226.

Hart D. J. and Scott K. J. 1995. Development and evaluation of an HPLC method for analysis of carotenoids in foods, and measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. *Food Chem.* 54:101-111.

Helbig, J., and F. A. Schulz, 1996. The potential of the predator Teretriosoma nigrescens Lewis (Coleoptera: Histeridae) for the control of Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae) on dried cassava chips and cassava wood. *Journal of Stored Product Research* 20(1): 91-96.

Herren, H. R., and F. D. Bennett, 1984. Cassava pests, their spread and control. In: Advancing Agricultural Production in Africa, Proceedings of CAB's First Scientific Conference Arusha, Tanzania, 12-18 February 1984, edited by D. L. Hawksworth, pp. 110-114.

Herren, H. R. and P. Neuenschwander 1991. Classical biological control of cassava insects and mites in Africa. *Annual Review of Entomology* 36:257-283.

Hershey Clair H. 1985. Cassava Germplasm Resources. In Clair H. Hershey (Ed) Cassava Breeding. A Multidisciplinary Review. Proceedings of a workshop held in the Philippines, 4-7 March 1985. pp. 1-24.

Hodges, R. J., J. Meik and H. Denton, 1985. Infestation of dried cassava (Manihot esculenta Crantz) by Protesphanus truncatus (Horn) (Coleoptera: Bostrichidae). *Journal of Stored Product Research* 21: 73-77.

Horton, D.E. and Fano, H. 1985. Potato Atlas, 19 pp. 52.

Huang A. S., Tanudjaja L., Lum D., 1999: Content of alpha-, beta-carotene, and dietary fiber in 18 sweet potato varieties grown in Hawalii. *J. Food Comp. Anal.* 12: 147-151.

Hunt, R 1990 *Basic growth analysis: Plant growth analysis for beginners*. Unwin Hyman, London pp 112.

Indira, P. and Sinha, S. K 1970. Studies on initiation and development of tubers in Manihot esculenta Crantz. Indian *J. Plant Physiol.* 13: 24-39

International Institute of Tropical Agriculture (IITA) 1981. Annual report, 1980 Ibadan, Nigeria. 185pp.

International Institute of Tropical Agriculture (IITA) 1982. *Tuber and Root Crops production Manual.* Manual Series No 9

International Institute of Tropical Agriculture (IITA) 1987. Annual Report of Root, Tuber and Plantain Improvement Program. Ibadan, Nigeria. 90 pp.

International Institute of Tropical Agriculture (IITA), 1989: Terminal Report: Africa Project Findings and Recommendations of the Ecologically Sustainable Cassava Plant Protection in South America and Africa (UNDP/IITA/CIAT; Project GI.O/91/013) Biological Program for Africa. Cotonou, Benin 99 pp

International Institute of Tropical Agriculture (IITA), 1990. *Cassava in Tropical Africa.* A Reference Manual, IITA, Ibadan, Nigeria 173 pp.

Irikura, Y Cock, J H., Kwano, K 1979. The physiological basis of genotype temperature interaction in cassava. *Field Crops Res.*, 2:227-229.

Ivory D. A., Kaewmeechai S , DeLacy I. H. & Basford K E. 1991. Analysis of the environment components of genotype x environment interaction in crop adaptation evaluation. *Field Crops Res.* 28 71-84

Janssens, M J. J 2001. Cassava. In: Raemaekers, R H. (ed) Crop Production in Tropical Africa, Directorate General for International Co-operation, Brussels, Belgium, pp. 165-187

Jennings, D. L. 1960. Observations on virus diseases of cassava in resistant and susceptible varieties II Brown Streak Diseases. *Empire Journal of Experimental Agriculture* 28, 261-270.

Jennings, D. L. 1995. Cassava In: Smartt, J and Simmonds, N.W (eds). Evolution of Crop Plants (2nd Edition) Longman, London, pp. 81-83.

Jones, W. O. 1959. *Manioc in Africa* Stanford Univ. Press, Stanford, CA, USA. 135pp.

Kang, M. S and Gorman, D. P. 1989 Genotype x environment interaction in maize. *Agron. J.* 81 662-664

Kang, M. S. and Magari, R. 1996 New developments in selecting for phenotypic stability in crop breeding. In: Kang M. S. and Zobel (Jr.), H. G. (eds.). Genotype-by-environment interaction. CRC press, Boca Raton, New York. pp. 51-84.

Kapinga R , Ewell P T , Hagenimana V , Collins W. and Zhang D. 2001. Promotion of orange-flesh sweet potatoes as a dietary source of pro-vitamin A: Lessons and strategies in Eastern and Southern Africa. In M. O. Akoroda (ed) Root Crops: The small Processor and Development of local Food Indrustries for Market Economy. Proceedings of the eighth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch, (ISTRC-AB) 12-16 November 2001 Ibadan, Nigeria

Kawano K. Fukuda W. M. G & Uthai C 1987. Genetic and environment effects on dry matter content of cassava root. *Crop Sci.* 27: 69-74.

Kay, D E 1987 Crop and Product Digest No. 2-Root Crops (2nd edition), London, Tropical Development and Research Institute, pp. 30-56

Keating, B. A. 1981 Environmental effects on growth and development of cassava (Manihot esculenta, Crantz) With special reference to photoperiod and

temperature, Ph.D. Thesis Department of Agriculture, University of Queensland, Australia, pp 84-120

Keating, B. A. and Evenson, J. P. 1979 Effect of soil temperature on sprouting and sprout elongation of stem cuttings of cassava (Manihot esculenta Crantz). *Field Crops Res.* 2: 241-251

Kempton R. A. 1984. The use of biplots in interpreting variety by environment interactions *J. Agric. Sc.* 103: 123-135.

Kennedy, E T. and R. Oniang'o, 1993. Household and pre-schooler vitamin A consumption in South-western Kenya *J. Nutrition* 123: 841-846

Khachik F., Beecher G. R., Whitaker N F 1986 Separation, identification and quantification of the major carotenoid and chlorophyll constituents in extracts of several green vegetables by liquid chromatography. *J. Agric Food Chem.* 34: 603-616.

Khachik F., Beecher G. R., Goli M. B., Lusby W. R 1992 *Separation and quantification of carotenoids in foods.* Meth. Enzymol. 213:347-359.

Kimura A. M., Rodriguez-Amaya J. B 2003 Carotenoid composition of hydroponic leafy vegetables *J. Agric. Food Chem.* 51: 2603-2607.

Kock B., V. S. Nielsen, B. A. Halkier, C. E Olsen and B L. Møller, 1992 The biosynthesis of cyanogenic glucosides in seedlings of cassava (Manihot esculenta Crantz). *Archives of Biochemistry and Biophysics*, 292(1):141-150

Korang_amoakoh S., Cudjoe R. A and Adams E 1987. Biological Control of cassava pest in Ghana Prospects for integration of other strategies. In Hahn S. K. and F. E. Caveness (Eds) Integrated Pest Management for Tropical Root and Tuber Crops. IITA, pp 164-169

K'osambo L M , Carey E. E , Misra A. K., Wilkes J., Hagenimana V 1998 Influence of age, farming site and boiling on pro-vitamin A content in sweet potato (Ipomea batatas (L.) Lam) storage roots. J. Food Comp Anal 1998; 11: 305-321.

Krinsky N I. 1993: Actions of carotenoids in biological systems *Annu. Rev. Nutr.* 13: 561-587.

Kumar, C R M and Hrishi 1979. Intercropping systems with cassava in Kerala Sate, India In Weber, E , Nestel, B. and Campbell, M (eds.). Intercropping with cassava : proceedings of an international workshop held at Trivandrum, India, 27 Nov 1 Dec. 1978 Report no IDRC-142e. IDRC (Internatioonal Development Research Centre), Ottawa, Canada pp. 122-124.

Lal, R. 1974. Soil temperature. In: Role of Mulching Techniques in Tropical Soil and water management IITA. Technical Bulletin N° 1

Lian T. S. 1985. Selection for yield potential in cassava. In: Clair H Hershey (ed.). Cassava Breeding A Multidisciplinary Review. Proceedings of a workshop held in the Philippines, 4-7 March 1985. Pp. 67-88.

Lin, C. S., and Binns, M R 1988. A method of analyzing cultivar x location x year a new stability parameter. *Theor. Appl. Genet.* 76, 425-430

Lin, C. S , M. R Binns and L. P. Lefkovitch 1986 Stability analysis. Where do we stand? *Crop Sci.* 26: 894-900.

Lowe, S. B., Mahon, J. D. and Hunt, L. A. 1976. The effects of day length on shoot growth and formation of root tubers in young plants of cassava (*Manihot esculenta* Crantz). *Plant Sci. Lett.* 6:57-62.

Lutalado, N B. and Ezumah, H C 1981. Cassava leaf harvesting in Zaire In: Tropical Root Crops Research Strategies for the 1980s. Proceedings First Triennial Sumposium ISTRC African Branch, pp 134-136. Terry, E R, Oduro, K A and Caveness, F , eds. Ibadan, IDRC

Mahungu, N. M. 1983. Relationships among selected agronomic characters and their effects on tuberous root yield of cassava (*Manihot esculenta* Crantz) Ph.D. Thesis. University of Ibadan 193 pp.

Mahungu, N. M. 1998. Cassava germplasm enhancement in Southern Africa. In: Food security and crop diversification in SADC Countries: The role of cassava and sweet potato. Akoroda M. O. and Teri, J.M. (eds.), pp. 100-109. Proceedings of the Scientific Workshop of the Southern Africa Root Crops Research Network held in Lusaka, Zambia, 17-19, August 1998.

Mahungu, N. M., Chheda H. R., Aken'Ova M. E. and S. K. Hahn 1991: Correlated response and use of selection index in cassava. In: Ofori F. and Hahn S. K. (eds.). Proceeding of the 9th symposium of the International Society for Tropical Root Crops (ISTRC), 20 -26 October 1991, Accra, Ghana pp 114-117.

Makame M. 1995: Genetic variation, stability of performance of cassava clones and their responses to intercropping with sweet potato in Zanzibar. Ph. D. thesis, University of Ibadan. 288 pp.

Mariani B. M. & Manmana P. N. 1986. Combination of results from several data sets: Some possibilities for a better understanding of the genotype-environment interaction. *Genetica Agraria* 40:83-96.

Mantoura R. F. C., Repeta D. J. 1997: Calibration methods for HPLC. In Jeffrey S. W., Mantoura R. F. C., Wright S. W. (eds), phytoplankton pigments pigments in oceanography Guidelines to modern methods. UNESCO Publishing, Paris , 1997, pp 407-428.

Maroya G. N., Bah S. Somana K. et Akakpo K. 2001: Evaluation participative des clones améliorés de manioc en milieu paysan en Afrique de l'Ouest : cas du Bénin, de la Guinée et du Togo. In M. O. Akoroda 2003 (eds.). Proceedings of the eight

Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch (ISTRC-AB) held in IITA-Ibadan, Nigeria from 12 to 16 November 2001 on Root Crops the small processor and Development of Local Food Indiustries for Market Economy, pp 392-398

Maroya N G and Dixon A. G O. 1992 Utilisation des paramètres de stabilité dans la sélection des clones de manioc pour le rendement en racine. In. Root crops for food securitv in Africa. M. O. Akoroda 1994 (eds.). Proceedings of the 5th Symposium of ISTRC-AB held in Kampala, Uganda 22-28 November 199. pp 111-115

Mayne S. T 1996 Beta-carotene, carotenoids, and disease prevention in humans. FASEB J 10: 690-701

Mba R. E. C and Dixon A. G O. 1995 Genotype x environment interaction, phenotypic stability of cassava yields and heritability estimates for production and pests resistance traits in Nigeria In Root Crops and Poverty Alleviation. Akoroda M. O. and Ekanayake I. J. 1998 (eds.) pp 255-261. Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops –Africa Branch held from 22 to 28 October 1995 in Lilongwe, Malawi.

McDowell I., Oduro K A. 1983. Investigation of β-carotene content of yellow varieties of cassava (*Manihot esculenta* Crantz). *J. Plant Foods* 5: 169-171.

McGuire, J 1993. Addressing micronutrient malnutrition In United Nation Subcommittee on Nutrition (SCN) News No. 9, ACC/SCN, Geneva, Switzerland

Mercadante A Z., Rodriguez-Amaya J B. 1998: Effects of ripening, cultivar differences, and processing on the carotenoid composition of mango. *J. Agric Food Chem.* 46 1094-1097

Mercadante A Z., Rodriguez-Amaya J. B. 1991 Carotenoid composition of a leafy vegetable in relation to some agricultural variables. *J. Agric. Food Chem.* 39.128-130

Ministry of Food and Agriculture (MOFA), 2002a. Root Tubers: A Newsletter of the Ghana Root and Tuber Improvement Programme, MOFA, IFAD, December 2000, No. 1, 2.

Ministry of Food and Agriculture (MOFA), 2002b Sixteenth National Farmers' Day, 30 pp

Ministry of Food and Agriculture (MOFA 2004 Statistics, Research and Information Directorate (SRID), September 2004

Miranda Lilian Azevedo, Adelaide del Pino Beleia and Nelson Fonseca Jr. 2007: Cassava Cooking Time. In Ortiz, R. and N.M.A. Nassar (eds.) 2007 *Cassava Improvement to Enhance Livelihoods in Sub-Saharan Africa and Northeastern Brazil*. First International Meeting on Cassava Breeding, Biotechnology and Ecology, Brasilia, Brazil, 11-15 November 2006. Universidade de Brasilia, Brasilia, Brazil. Pp 59-65

Mlingi, N., Poulter, N. H. and Rosling, H. 1992. An outbreak of acute intoxications from consumption of insufficiently processed cassava in Tanzania, *Nutri. Res.* 12: 677-687

Modder, W. W D., 1994. Control of the variegated grasshopper, Zonocerus variegatus (L.), on cassava. *African Crop Sci. J.* 2: 391-406.

Nassar, N. M. A. 1978 Conservation of the genetic resources of cassava (Manihot esculenta). determination of wild species location with emphasis on probable origin *Econ. Bot.* 32:311-320

Neuenschwander P., 1996 Spiralling whitefly, Aleurodicus dispersus a recent invader and new cassava pest in Africa. African Crop Sci. J. 2. 419-421

Ntawuruhunga P. 1992 Assessment of dry matter determination and its accumulation in cassava. M Sc thesis Department of Agronomy, University of Ibadan.

Ntawuruhunga P., H. Ojulong and A. G. O. Dixon 1995. Genetic variability among cassava genotypes and its growth performance over time. In Akoroda M. A. and I. J. Ekanayake 1998 (eds.). Root Crops and Poverty Alleviation: Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch held from 22 to 28 October 1995 in Lilongwe, Malawi. pp 242-248

Nweke, F. I. 1996. Cassava production prospects in Africa. Collaborative study of cassava in Africa Working Paper No. 13. International Institute of Tropical Agriculture, Ibadan, Nigeria. Pp. 39-41

Nweke, F. I., Dixon, A. G. O., Asiedu, R. and Foloyan, S. A. 1992. Attributes of cassava varieties desired by farmers in Sub-Saharan Africa. In: Akorada, M.O. (ed.). Root Crops for Food Security in Africa. Proceedings of the Fifth Triennial Symposium of the International Society for Tropical Root Crops - Africa Branch held at Kampala, Uganda, 22-28 November, 1992, pp. 65-92

Nweke, F.I., D.S.C. Spenser, J.K. Lyman. 2002. The cassava transformation: Africa's best kept secret. Michigan State University Press, East Lansing

Ofori F., Al-Hassan R., Afuakwa J. J. and Noamesi R. K. 2000. A case study of cassava development in Ghana. Document submitted of behalf of the Ministry of Food and Agriculture of Ghana to the International Fund for Agricultural Development (IFAD) in the framework of the Global Cassava Development Strategy 40 pp.

Ojulong H., P. Ntawuruhunga, A. G. O. Dixon and G. Ssemakula 1995. Genetic stability analysis and its application to cassava regional trials. In: Root Crops and Poverty Alleviation. Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch held from 22 to 28 October 1995 in Lilongwe, Malawi. Edited by Akoroda M. A. and I. J. Ekanayake 1998 pp 237-241.

Okai E., Kissiedu A. F K., Otoo J. A.; Afuakwa J. J.; Asare-Bediako A., Missah A., Sagoe R.; Okoli O. O.; Dixon A. G. O. 1995 In Root Crops and Poverty Alleviation Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch held from 22 to 28 October 1995 in Lilongwe, Malawi Edited by M. A Akoroda and I. J Ekanayake 1998 pp 231-235.

Olson J A. 1999: Carotenoids In Shils M E., Olson J A., Shike M., Ross A. C. (eds), Modern nutrition in health and disease, 9th Edition Williams & Wilkins, Baltimore, pp 525-541

Olson J. A. 1999b: *Carotenoids and human health*. Arch Latinoamer Nutr. 49: 75-115.

Olson J. A., Krinsky N. I 1995. The colorful, fascinating world of the carotenoids: important physiologic modulators. FASEB J 9: 1547-1550.

Onwueme, I. C. 1978 *The tropical root crops*. Wiley, New York, NY, USA. 234 pp.

Onwueme, I. C. 1982. *The tropical tuber crops: Yams, Cassava, Sweet Potatoes and Cocoyams*. John Wiley and Sons Ltd., New York, 45, 15 pp

Onwueme, I C and Sinha, T D. 1991. Field Crop Production in Tropical Africa Technical Centre for Agricultural and Rural Co-operation, CTA, Ede, The Netherlands, pp. 233-241.

Oomen, H. A. P. C and Grubben, G J. H. 1978. Tropical leaf vegetables in human nutrition, Amsterdam, Konnikliyk Institute Voor de Troppen, 36 pp.

Osiru, D S O., Porto, M. C. M. and Ekanayake, I J. 1995. Physiology of cassava. IITA Research Guide 55 Training Programme, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 22 pp.

Osiru, D. S O, Hahn, S K and Osonubi, O. 1992 Varietal response to drought stress in Cassava Proceedings of the Fourth Triennial Symposium of the International

Society for Tropical Root Crops. African Branch, Kinshasa, Zaire, December 5-8, 1989. Akoroda, M. O. and Arene, O. B. (eds) pp 97-102.

Osuntokun, B O 1981 Cassava diet, chronic cyanide intoxication and neuropathy in the Nigerian Africans *World Rev. Nutr. Diet.* 36:141-173

Otim-Nape, G.W , Shaw, M.W and Thresh, J.M. (1994). The effects of African Cassava Mosaic Geminivirus on the growth and yield of cassava in Uganda *Trop. Sci.* 34:43-54

Otoo, J. A. 1983 The effect of daylength on the flowering, fruiting, seed-setting and other characteristics of cassava (Manihot esculenta Crantz) Ph D dissertation. Uni. Ghana. 170 pp.

Otoo J. A., Dixon A. G O., Asiedu R., Okeke J. E. Maroya G. N., Tougnon K., Okoli O. O. Tetteh J. P and Hahn S. K. 1991 Genotype by Environment interaction studies with cassava. In: Ofori F. and Hahn S. K. (eds.). Proceeding of the 9th symposium of the International Society for Tropical Root Crops (ISTRC) , 20 -26 October 1991, Accra, Ghana pp 146-148.

Otoo, J. A., R Al-Hassan, A. F K. Kissiedu and A. Y. Alhassan 1995. Cassava processing technology as a determinant of commercialization and farmers' varietal requirements in Ghana. In Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch held from 22 to 28 October 1995 in Lilongwe, Malawi. Edited by M. A. Akoroda and I. J. Ekanayake 1998 pp 113-115

Palozza P., Krinsky N I 1992 Antioxidant effects of carotenoids in vivo and in vitro: An overview. *Meth. Enzymol.* 213: 403-420

Piepho, H. P 1994. Partitioning genotype environmental interaction in regional yield trials via a generalized stability variance *Crop Sci.* 24: 1682-1685.

Plasteid, R L. (1960). A shorter method for evaluating the ability of selections to yield consistently over locations. *Am. potato J.* 37: 166-167

Plasteid, R. L and Peterson, L C (1959). A technique for evaluating the ability of selections to yield consistently over locations. *Am. Potato J.* 36:381-385.

Pfander H. 1987 *Key to carotenoids*, 2nd edition Birkhäuser Verlag, Basel, 1987.

Piepho, H P 1996 Analysis of genotype by environment interaction and phenotypic stability. In Kang, M S and Zobel (Jr.), H. G (eds). *Genotype by environment interaction*. CRC press Boca Raton, New York, pp. 51-84.

PPMED (Policy Planning Monitoring and Evaluation Department) 1991. Report of Ministry of Food and Agriculture 1991, Accra, Ghana

Purseglove, J W (1968) Tropical Crops Dicotyledons 1 Longmans, Green and Co. Ltd. London Pp. 172-180.

Rahmathullah, L , Underwood, B. A.; Thulasiraj, R. D.; Milton, R. C.; Ramaswamy, K.; Rahmathullah R.; and Babu, G 1990. Reduce mortality among children in Southern India receiving a small weekly dose of vitamin A. *N. Engl. J. Med.* 323: 929-935

Ramanujam, T and P. Indira, 1984 Effect of girdling on the distribution of total carbohydrates and hydrocyanic acid in cassava. *Indian Journal of Plant Physiology*, 27(4): 355-360.

Renvoise, B S 1973. The area of origin of Manihot esculenta as crop plant· a review of the evidence. *Econ. Bot.* 26 352-360.

Rikimaru Toru, Juliana E. Yartey, Kiyosu Taniguchi, Margaret Amar-Klemesu, and Francis K Nkrumah 1996 Present trends and characteristics of malnutrition in Africa. the case of Ghana *Environmental Sciences1996; 4(Suppl):S109-S121*

Rodriguez-Amaya D. B. 1993: Nature and distribution of carotenoids in foods. In Charalambous G. (ed), *Shelf-life studies of foods and beverages. Chemical, biological, physical and nutritional* aspects. Elsevier Science Publishers, Amsterdam, pp 547-589.

Rodriguez-Amaya D. B. 1989. Critical review of provitamin A determination in plants foods. J. Micronutr Anal 5:191-225.

Rodriguez-Amaya D. B. Kimura M. 2001: A Guide to Carotenoid Analysis in Foods. OMRI Research, International Life Sciences Institute (ILSI) Washington 20005-5802. ISBN 1-57881-072-8. 64 pp.

Rogers. D. J. 1963. Studies on *Manihot esculenta*, Crantz. (Cassava) and Related Species. *Bull. Torrey Bot.*, 90:43-54.

Rogers, D. J. and Appan, S. G. 1973. *Manihot and Manihotoides (Euphorbiaceae): a computer-assisted study*. Monograph 13. Organization for Flora Neotropica, New York, NY, USA. 272 pp

Romagosa, I. and Fox, P. N. 1993. Genotype by environment interaction and adaptation. In: Hayward, M. D.; Bosemark, N. O. and Romagosa, I. (eds). Plant Breeding: principles and prospects pp. 373-390.

Rosling H. 1988. Cassava toxicity and food security: a review of health effects of HCN exposure from cassava and ways to prevent these effects. A report for UNICEF African Household Food Security Programme. 2nd Ed. Tryck Kontakt, Uppsala Sweden.

Safo-Kantanka O., Aboagye P., Amartey S. A., Oldham J. H. 1984. Studies on the nutrient content of yellow pigmented cassava. In Tropical Root Crops Production and uses in Africa. Proceedings of the Second Triennial Symposium of International Society of Tropical Root Crops Africa Branch. IDRC-221e, Ottawa, Canada, pp 103-104.

Safo-Kantanka O, Owusu-Nipah J 1992). Cassava varietal screening for cooking quality. relationship between dry matter, starch content, mealiness and certain microscopic observations of the raw and cooked tuber. *J. Sci. Food Agric.* 60:99-104

Sago R , A F K Kissiedu, J. A. Otoo, J. J Afuakwa, A Asare-Bediako, E Okai, O. O. Okoli and A. G O Dixon 1995. In Root Crops and Poverty Alleviation Akoroda M. O. and Ekanayake I. J. 1998 (eds.) pp 216-220. Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops –Africa Branch held from 22 to 28 October 1995 in Lilongwe, Malawi.

Seif, A. A 1982 Effect of Cassava Mosaic Virus on Yield of Cassava Plant Disease 66, 661-662

Schiedt K., Liaaen-Jensen S 1995: Isolation and analysis. In Britton G., Liaaen-Jensen S. Pfander H. (eds), Carotenoids, vol 1A: Isolation and analysis Birkhauser Verlag. Basel, 1996, pp. 81-108

Shukla, G K 1972. Some statistical aspects of partitioning genotype-environmental components of variability *Heredity* 29, 237-245

Silvestre, P 1989. *Cassava. The Tropical Agriculturist*, Macmillan Publishers Ltd London 82 pp.

Singh R K and Chadhary B. D 1985 *Biometrical methods in quantitative genetic analysis*. Kalyani Publishers, Ludhiana, New Delhi. Pp. 318.

Snedecor G. W. and Cochran W B 1980. *Statistical methods*. 7th ed. Iowa states Univ., Ames. USA

Spath, C D 1973. Plant domestication the case of *Manihot esculenta*. *J. Steward Anthropol. Soc* 5(1).

Ssemakula Gorrettie and Alfred Dixon 2007 Genotype X environment interaction, stability and agronomic performance of carotenoid-rich cassava clones. Scientific Research and Essay 2 (9):390-399

Takahata Y., Noda T., Nagata, T 1993 Varietal differences in chemical composition of the sweet potato storage root. *Acta Hort* 43 77-80

Takyi Etor E K 1999: Nutritional status and nutrient intake of preschool children in Ghana. *East African Medical Journal 76(9):508-513.*

Tan S. L. 1980. Growth parameters related to productivity in cassava (*Manihot esculenta* Crantz). M. Agr. Sc. thesis University Pertanian Malaysia, Serdang, Malaysia. 192 pp

Tan S. L. 1981: Heritability estimates and correlation studies on agronomic characters of cassava In Proceedings of a workshop on root crops and sugarcane, Serdang, Malaysia, 1981 pp.1-18.

Tan S. L 1984 G x E interactions, heritability estimates and varietal adaptability in important agronomic characters of cassava MARDI (Malaysian Agricultural Research and Development Institute) *Res. Bull.* 12: 136 - 147.

Tan S L., Cock J. H. 1979. Branching habit as a yield determinant in cassava. *Field crops Res.* 2: 281-289

Terry, E R and Hahn, S.K (1980) The effect of cassava mosaic disease on growth and yield of local and improved variety of cassava. *Tropical Pest Management* 26: 34-37

Thresh, J. M., Fargette, D. and Otim-Nape, G. W. 1994b Effects of African Cassava Mosaic Geminivirus on the Yield of Cassava *Trop Sci.* 34, 26-42.

Thresh J M., I. D. C Fishpool, G W Otim-Nape and D. Fargette, 1994a. African cassava mosaic virus disease. an under-estimated and unsolved problem *Trop Sci.* 34. 3-14

Tindall, H. D 1983. *Vegetables in the Tropics*. Macmillan Press, London, 533 pp.

Tylleskar, T., Bania, M., Bikangi, N., Cooke, R.D. Poulter, N.H. and Rosling, H 1992 Cassava cyanogens and Konzo, an upper motoneutron disease found in Africa. *Lancet* 399 (8787) 208-211.

Vines, A. E. and Rees, N. 1964. Plant and Animal Biology. Sir Isaac Pitman and Sons Ltd. London,. 2(2):342-344

Weikai Yan, 2006 Biplot analysis of Multi-Environment Trial Data. Statistical software used in data analysis training course held in may 2006 in IITA Ibandan, Nigeria

Welch Ross M , 2001. Breeding Strategies for Biofortified Staple Plant Foods to Reduce Micronutrient Malnutrition Globally. Presented as part of the symposium "Plant Breeding: A New Tool for Fighting Micronutrient Malnutrition" given at the Experimental Biology 2001 meeting, Orlando, Florida, on April 1, 2001.

Wholey D. W. 1974. Rapid propagation of cassava (*Manihot esculenta* Crantz) Ph.D Thesis St Augustine, Trinidal, University of West Indies 441p

Whyte James B. A., 1985. Breeding Cassava for Adaptation to Environmental Stress In: Hershey Clair H (ed.). Cassava Breeding A Multidisciplinary Review. Proceedings of a workshop held in the Philippines, 4-7 March 1985. pp. 147-176.

Wright A. J. 1971 The analysis and prediction of some two factor interactions in grass breeding. *J. Agric. Sci.* 76: 301 – 306.

Yaninek, J. S and Herren, H R 1988: Introduction and spread of the cassava green mite, Mononychellus tanajoa (Bondar) (Acari: Tetranychidae), an exotic pest in Africa and the search for appropriate control methods: a review Bulletin Entomological Research 78: 1-13.

Yanock, J Y., Lombin, G. and Owonubi, J. J. 1988. *Crop science and production in warm climates.* Macmillan Intermediate Agriculture Series, Macmillan Publishers Ltd London pp 185-189.

Zobel, R. W., Wright, M. J. and Gauch, H. G. 1988. Statistical analysis of a yield trial. *Agronomy Journal* 80: 388-393.