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FACULTY OF AGRICULTURE, DEPARTMENT OF CROP AND SOIL SCIENCES

Influence of age and Cultivar on Yield and Quality of Starch/Flour Extracted from Cassava (*Manihot esculenta* Crantz)

A thesis submitted to the school of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfilment of the requirements for the degree of MSC. AGRONOMY (Plant Breeding option).

Agordjo Samuel Mawutor

February, 2012

CERTIFICATION

I declare that, with the exception of references to other people's work which have been duly cited, this work submitted as a thesis to the Department of Crop and Soil Sciences, Faculty of Agriculture, College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and Technology Kumasi, for the Degree of Master of Science in Plant Breeding, is the result of my own investigation.

....

SAMUEL MAWUTOR AGORDJO

(STUDENT)

DATE..

....

PROF. RICHARD AKROMAH

(MAIN SUPERVISOR/HEAD OF DEPARTMENT)

DATE..

....

DR. JOSEPH MANU-ADUENING

(CO. SUPERVISOR)

DATE..

ABSTRACT

The work aimed at evaluating the effects of age at harvest and cultivar on the yield and physico-chemical properties of cassava starch and flour. Ten cassava cultivars (Ampong, Sika bankye, Ahwengyanka, Nkabom, Sisipe 290, Bankye hemaa, Bensere, Tuaka, Doku-duade and Nyamebekyere) were used. Agronomic data were collected on plant height, canopy width, and height at branching at 4, 6, 8 and 10 Months After Planting (MAP). Data were also collected on Root yield, Harvest index, Starch content, Starch and Flour yields at 8 and 11 MAP. Physico-chemical analysis was carried out on Solubility, Swelling power and Water-binding capacity of flour and starch. The results showed that starch yield ranged from 2.52 – 5.99 at 8 MAP and 6.29 – 8.56 t/ha 11 MAP. Flour yield also ranged from 5.70 – 9.46 t/ha at 8 MAP, and from 10.82 – 12.53 t/ha at 11 MAP. Swelling power of flour ranged from 10.00 – 15.84 g/g at 8 MAP and 12.04 – 18.31 g/g at 11 MAP. Swelling power of starch also ranged from 7.20 – 12.69 g/g at 8 MAP and from 7.78 – 11.97 g/g at 11 MAP. Water-binding capacity was high and the range was 176.3 – 244.0 % at 8 MAP and 183.1 – 215.7 % at 11 MAP for flour whiles that of starch ranged from 68.01 – 77.70 % at 8 MAP and 62.61 – 76.01 % at 11 MAP. Solubility was also high for both starch and flour and the values ranged from 66.44 – 78.26 % at 8 MAP and 45.08 – 72.78 % at 11 MAP for flour whereas the values for starch were 37.68 – 76.31 % at 8 MAP and 53.04 – 74.06 % at 11 MAP. From the results obtained it was inferred that age at harvest significantly ($p < 0.05$) affected starch and flour yields, but not solubility, swelling power and water-binding capacity. Cultivar effect was however not significantly different.

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DEDICATION

I dedicate this work to my loving parents Mr Johannes Kwame Agordjo and Mrs Rosemond Awaitey Agordjo.

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LIST OF ABBREVIATIONS

AGDP	Agricultural Gross Domestic Product
°C	Degrees Celsius
CAD	Cassava Anthracnose Disease
CBSD	Cassava Brown Streak Disease
CBB	Cassava Bacterial Blight
CGM	Cassava Green Mite
CGIAR	Consultative Group on International Agricultural Research
cm	Centimetre
CMD	Cassava Mosaic Disease
CRI	Crops Research Institute
DAP	Days After Planting
DRC	Democratic Republic of Congo
FAO	Food and Agriculture Organisation
FAOSTAT	Food and Agriculture Organisation Statistics
g	Gram
g/g	Gram per gram
IITA	International Institute of Tropical Agriculture
ISI	International Starch Institute

kg	Kilogram
l	Litre
MAP	Months after planting
MoFA	Ministry of Food and Agriculture
m	Meter
ml	Millilitre
mm	Millimetre
MW	Molecular weight
N	North
PSI	Presidential Special Initiative
%	Percentage
RCSA	Research Center for Southern Africa
RCBD	Randomized Complete Block Design
rpm	Revolution per minute
µm	Micrometre
USAID	United States Aid
SRID	Scientific Research Information Directorate
SSA	Sub-Saharan Africa
t/ha	Tonnes per hectare

CHAPTER ONE

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is one of the most important food crops in the humid tropics, being particularly suited to conditions of low nutrient availability and able to survive drought (Burrell, 2003).

It is mainly grown in tropical areas including Asia (annual root production of 48 million tonnes with 37.5% from Thailand, 31.2% from Indonesia, 12.5% from India and 8.3% from China), Africa (annual root production of 84 million tonnes with 35.7% from Nigeria, 20% from the Democratic Republic of Congo and 8.4% from Ghana) and Latin America (annual root production of 32 million tonnes with 75% from Brazil and 9.7% from Paraguay) (Vilai *et al.*, 2001).

Compared with other root and tuber crops, cassava ranks very high in-terms of its conversion of solar energy into soluble carbohydrates per unit area (Cock, 1982). Other advantages of cassava include flexibility in planting, and harvesting time as well as ease of incorporating into various cropping systems (Fregene *et al.*, 2000; Nassar, 2005).

As food the leaves of cassava are used as a vegetable in Africa and are rich source of proteins, vitamins A, B C, and minerals (Hahn, 1988; FAO, 1993; Moyo *et al.*, 1998; Fregene *et al.*, 2000; IITA, 2001) and also as feed for livestock.

The starchy tuberous roots also provide more than half of the calories consumed by over 800 million people in Sub-Saharan Africa, Latin America and Asia (Shore, 2002). In Ghana, a mean per capita production of 465 kg per annum provides about 20% of calories in diet, which is more than any single crop or animal source

(FAOSTAT, 2005). It has therefore been described as the last line of food security in Ghana (Arku-Kelly, 2001).

Cassava starch and flour are used in food, textiles, plywood, paperboard, pharmaceutical, petroleum and brewery industries. This diverse usage is due to its many remarkable characteristics, such as high paste viscosity, high paste clarity, and high freeze-thaw stability, which are advantageous for industrial purposes (Oyewole and Obieze, 1995).

In a study by FAO in (2000a) it was suggested that global demand for cassava starch could increase at an annual rate of 3.1 %, while regional growth rates are expected to be 4.2 % for Asia, 3.4% for Latin America and 2.3 % for Africa. This coupled with the fact that opportunities for product and market diversification are excellent in several countries, such as Nigeria, Uganda, Malawi, and lately South Africa (CGIAR Research, 2001; Benesi *et al*., 2004) means cassava cultivation can improve these countries' fortune if taken seriously. This is evident in the FAO report of 2006 which observed that with the world's cassava root production now standing at 200 million tonnes a year many developing countries' could strengthen their rural economies and boost cassava farmers' incomes by converting more of the relatively low cost raw material into high value starches. However this is not the case in Ghana though it is evident that locally manufactured starch has the possibilities of a ready market in Ghana as revealed by a study conducted by Dziedzoave *et al*., (2000) in four paper board factories. The study showed that three out of the four factories preferred the locally manufactured starch due to its low price and ready availability. However all users complained about the low quality of the product, saying locally produced starch based absorbents form weaker bonds, have short shelf life, contain too many contaminants and are not finely milled. These therefore provide evidence that there is less information on the physico-chemical or functional properties of starch/flour used in the country, though this property determines the final usage of starch and flour.

The physico-chemical or functional properties of starch and flour which determines quality are affected by variety, age and the environment. According to Asaoka *et al*., (1991) starch functionalities display unpredictable variations depending on the environmental conditions at the time of harvest.

Moorthy and Ramanujam (1986) also observed a number of physicochemical properties such as swelling power, solubility and water-binding capacity to increase with age.

With the emerging markets for starch and allied products as well as the launched Presidential Special Initiative (PSI) on cassava in Ghana, there is the need for studies to identify cultivars with high starch content as well as the effect of factors such as age, cultivar and condition at harvest on their functional or physico-chemical properties. Knowledge in this area can help plant breeder's select suitable cultivars with good functional properties to meet the standard requirements. The problem of low starch/flour yield as well as quality reported by Dziedzoave *et al*., (2000) can also be curtailed with such a study as the precise age and condition for harvesting each cultivar in order to optimize yield and improve quality can be determined.

The objectives of the study were therefore to:

1. Determine the effect of age and cultivar differences on starch and flour yield of cassava.

2. Determine the effect of age and cultivar differences on the functional properties of cassava starch and flour.

CHAPTER TWO

LITERATURE REVIEW

2.1 Cassava

2.1.1Taxonomy of cassava

Cassava (*Manihot esculenta* Crantz), belongs to the family Euphorbiaceae. Of the 98 species that belong to the genus Manihot, cassava is the only species that is widely cultivated for food production (Rogers and Appan, 1973; Onwueme, 1978; Mkumbira, 2002; Nassar, 2005). Cassava cultivars have been classified according to morphology, e.g. leaf shape and size, plant height, stem and petiole colour, inflorescence and flower colour, root shape and colour, and content of cyanogenic glucoside in the roots (Onwueme, 1978; Mkumbira, 2002; Nassar, 2005).

Cyanogenic glucoside has been used to place cassava cultivars into two major groups: bitter cultivars, in which the cyanogenic glucoside is distributed throughout the tuberous root, at levels higher than 100mg/kg fresh root weight, and sweet/cool varieties, in which the cyanogenic glucoside at low levels is confined mainly to the peel. The flesh of sweet/cool varieties is therefore relatively free of cyanogenic glucoside (Mkumbira, 2002; Nassar, 2005).

Early literature on cassava therefore described the genus as having two edible species, *Manihot utilissima* Phol and *Manihot aipi* Phol delineating cultivars with low and high cyanogenic glucoside concentration respectively. Cassava has recently been classified as being one species, *Manihot esculenta* Crantz (Onwueme, 1978).

2.1.2 Morphology, agronomy and climatic requirements of cassava

Cassava is a perennial woody shrub of one to three metres high with edible tuberous roots arising from stem cutting, but farmers mostly grow it as an annual crop (Onwueme, 1978; Lozano *et al*., 1980; IITA, 1990; 2001; Benesi, 2002; Nassar, 2005). It is propagated mainly from stem cuttings but during plant breeding and under natural conditions, propagation is by sexual seed in the first cycle (Onwueme, 1978; IITA, 1990; Nassar, 2005). Cassava seeds germinate slowly and normally display dormancy. The germination period can be shortened by filing the micropylar end until the white embryo is just visible. A wet treatment of cassava seed has also been reported to improve seed germination (Onwueme, 1978). The best scarifying method is thermal treatment, by exposing seeds to temperatures of 18°C for 16 hours or 26°C for 8 hours (Nassar, 2005).

Cassava tuberous roots are composed of a peel which represents about 10-20% of the tuberous root. The cork layer represents 0.5-2.0% of the total tuberous root weight. The fleshy edible portion makes up 80-90% of the tuberous root and is composed of 60-65% water, 30-35% carbohydrate, 1–2% protein, 0.2-0.4% fat, 1.0-2.0% fibre, and 1.0-1.5% mineral matter (Nassar and Costa, 1976; Onwueme, 1978; Nassar, 1986). Most of the carbohydrate fraction contains starch which makes up 20-25% of the tuber flesh (Purseglove, 1968). The root is relatively rich in vitamin C (35mg/100g fresh weight), and contains traces of niacin and vitamins A, B1 and B2 but the amounts of thiamine and riboflavin are negligible (Onwueme, 1978).

Cassava grows in tropical and subtropical areas of the world between latitudes 30° N and S of the equator under diverse ecological and agronomic conditions (Onwueme, 1978; Lozano *et al*., 1980; IITA, 2001; Benesi, 2002; Nassar, 2005). Cassava is a lowland tropical plant and needs a warm moist climate with mean temperature of 24° - 30°C (Onwueme, 1978; IITA, 1990; Nassar, 2005). The ideal soils for cassava are light sandy loam with medium fertility. Cassava has the ability to grow on marginal lands where cereals and other crops do not grow well, it can tolerate drought and can grow in low nutrient soils but does not tolerate high concentrations of salts with a pH above 8, excess soil moisture, and temperatures of 10°C and below (Onwueme, 1978; Lozano *et al*., 1980; IITA, 2001; Benesi, 2002; Mkumbira, 2002; Nassar, 2005).

Cassava tuberous root formation commences by the end of the second month after planting. With time, the tuberous roots continue to increase in size by swelling due to the deposition of large amounts of starch within the tuberous root tissues. Hence, very young tuberous roots contain much less starch than old ones, so harvesting must be delayed until an appreciable amount of starch has accumulated in the roots. However, as the tuberous roots become older, it tends to become more lignified and fibrous, so that the starch content, as a percentage of the total dry weight of the tuberous root, tends to decrease or remain constant (Onwueme, 1978; ISI, 1999-2001).

It is therefore best to harvest cassava at the time when the tuberous roots are old enough to have stored sufficient starch, but not too old to have become woody or fibrous (Onwueme, 1978).

The exact time in terms of months after planting, when it is best to harvest cassava depends on the cultivar. Some cultivars are ready for harvest at seven months after planting (MAP) while others require up to 18 MAP (Onwueme, 1978). Corbishley and Miller (1984) reported that starch yield of cassava tuberous roots depends on many factors such as variety, soil type and climate, in addition to the age of the plant.

Cassava tuberous roots formation is photo-periodically controlled. Under short day conditions tuberisation occurs readily, but when the day length is 12 hours or longer, growth is delayed, and yield reduced (Bolhuis, 1966).

2.2 Growth and development of cassava

This can be described under the sub headings emergence or sprouting, beginning of leaf development and formation of root system, development of stems and leaves, high carbohydrate translocation to roots and dormancy.

2.2.1 Emergence or sprouting: 5 – 15 days after planting (DAP)

Emergence or sprouting normally starts with the arising of first adventitious root at 5 – 7 DAP from the basal cut surface of the stake and occasionally from buds under the soil. First sprouting occurs at 10 – 12 DAP followed by small leaves, which starts to emerge (Conceicao, 1979). Emergence is fully achieved at 15 DAP.

2.2.2 Beginning of leaf development and formation of root system: 15 – 90 DAP

True leaves in cassava starts to expand around 30 DAP when the photosynthetic process starts to contribute positively to plant growth.

Until 30 DAP shoot and root growth depend on the reserves of the stem cutting. The fibrous roots also start to grow, replacing the first adventitious roots in this phase. The new fibrous root normally penetrates the soil to a depth of 40 – 50cm deep and function in water and nutrient absorption (Conceicao, 1979).

According to Cock *et al*., (1979) only few of this fibrous roots (3 – 14) becomes storage root, which can be distinguished from fibrous root at 60 – 90 DAP.

2.2.3 Development of stems and leaves (canopy establishment): 90 – 180 DAP

This phase is characterized by maximum growth rate of leaves and stems, in the growing cycle of the cassava plant. Branching habit and plant architecture is normally defined during this phase. Cassava leaves are able to intercept most of the incident light on canopy from 120 – 150 DAP (Veltkamp, 1985). According to Howler and Cadavid (1983) Ramanujam, (1985) and Tavora *et al*., (1995), maximum canopy size and maximum dry matter partition to leaves and stems also occur during this phase. Storage root also continues to bulk throughout this phase.

2.2.4 High carbohydrate translocation to roots: 180 – 300 DAP

This phase is characterized by accelerated bulking of storage root as photoassimilate partition from leaves to root. Leaf senescence also increase during this phase whereas stems also become lignified (Conceicao, 1979).

Boerboom (1978) and Tavora *et al*., (1995) all agreed that the highest rate of dry matter accumulation in storage root occur within this phase.

2.2.5 Dormancy: 300 – 360 DAP

The dormancy phase is characterized by a decrease in the rate of leaf production and falling of leaves. Only translocation of starch to root and maximum dry matter partition to the root is kept and attained during this phase. This phase normally occurs in regions with significant variation in temperature and rainfall. After this phase the cassava plant begins a new period of vegetative growth, dry matter accumulation and dormancy all over again.

2.3 Constraints to cassava research, production and utilization

A lot of constraints hinder the growth and development of the cassava industry some include the ones as discussed below.

2.3.1 Biotic and Abiotic constraints to cassava production and expansion

In Sub Saharan Africa (SSA), a number of biotic (diseases, insects, mites, and weeds) and abiotic, (soil, climate, and agronomic factors) constraints hamper increased production of cassava. Cassava is a long season crop and the diverse agro-ecologies in which it is grown contribute largely to its exposure to a number of these constraints (Dixon *et al*., 1992; Mahungu *et al*., 1994).

Nichols (1950), Storey (1936) Onwueme (1978) Sauti (1981), IITA (1985) and Raji *et al.,* (2001) pointed out that the economically most important diseases include Cassava Mosaic Disease (CMD), Cassava Bacterial Blight (CBB) and Cassava Anthracnose Disease (CAD), while the most important arthropod pest is Cassava Green Mite (CGM), Variegated Grasshopper, whiteflies, and termites. The important mammal pests are rodents, wild pigs and monkeys. Diversification of resistance to diseases and pests is necessary because diseases and pests may continue to evolve into new races or biotypes which can increase in prevalence and cause economic losses (Raji *et al*., 2001).0248955618

There exist differences in the types of diseases or even strains in Africa and the Americas. Even within Africa, the diseases which are problematic in East and South Africa are not the same as those in West Africa. Cassava Brown Streak Disease (CBSD) is a serious problem in the coastal areas of South-East Africa and of late CBSD-like symptoms were observed in 2002 in the western part of Democratic

Republic of Congo (DRC), namely Bas-Congo and Kinshasa provinces, which were previously unaffected areas such as DRC and the whole West Africa (Mahungu *et al*., 2003).

In the case of pests, Cassava Mealy Bug is the most important pest in cassava production in East and South Africa as reported by Sauti *et al*., (1994) and Nassar (2005) compared to CGM which is a big problem in West Africa as highlighted by Raji *et al*., (2001). This emphasises the need to use local germplasm in breeding programmes since landraces are already adapted to local conditions. Only useful exotic genes should be introgressed into local cultivars to stabilise yield and add value to the local varieties. Unfortunately as pointed out by Raji *et al*., (2001) local cultivars of cassava have been used to a lesser extent in African breeding programmes.

2.3.2 Limitations in amount of knowledge available on local germplasm

The diversity of African local genotypes is yet to be fully exploited. There exists a need to exploit genes of resistance to major diseases and pests as well as preferred food quality traits of local cultivars in tropical Africa (Raji *et al*., 2001).

The study of Raji *et al*. (2001) showed that out of 11 selected landraces, some of the local cultivars were superior to improved checks in terms of pest and disease resistance as well as quality traits. Some of the cultivars were comparable to the improved checks in terms of yield in addition to combining resistance and quality traits, although it was widely reported that local Nigerian genotypes were low yielding (Raji *et al.*, 2001).

2.3.4 Environmental constraints

Rainy season for most of Ghana is between June – November and slightly within March. There are few areas where rain continues for more than six months, and most of the areas have up to nine months of dry weather. Although cassava is drought tolerant, inception of drought at the time of planting and establishment affects performance (Sauti, 1981; Sauti *et al*., 1994).

2.4 Importance of cassava

Cassava (*Manihot esculenta* Crantz) is the most important tropical root crop (Onwueme, 1978, Roa *et al*., 1997; Mkumbira, 2002) and is primarily grown for its starchy tuberous roots, which are major sources of dietary energy (Onwueme, 1978; Cock, 1985; Lynam, 1993; Nassar, 2005). It was estimated that in 2002, more than 700 million people in the world consumed cassava in one form or the other globally (Dixon *et al*., 2003). Cassava accounts for approximately one-third of the total staples produced in Sub Saharan Africa (SSA) and is grown exclusively as food in 39 African countries stretching through a wide environments from Madagascar in the south-east to Senegal in the north-west (Raji *et al*., 2001). Cassava leaves are an important vegetable rich in protein, minerals and vitamins (Jones, 1957; Onwueme, 1978; Hahn, 1988, FAO, 1993; Nweke, 1994; Chiwona-Karltun *et al*., 1998; Fregene *et al*., 2000; IITA, 2001; Benesi *et al*., 2001a; 2001b). Shore (2002) said that cassava has all indicators to be a food security crop for Africa. This is because of its high calorie production, year-round availability, and tolerance to extreme environmental conditions.

In Africa, people are starting to use cassava in industries like textile, wood, as binding agent, and partial substitution for wheat flour. This provides income to resource-poor farmers and saves foreign exchange for nationals. Opportunities for product and market diversification are excellent in several countries, such as Nigeria, Uganda, Malawi, and of late South Africa (CGIAR Research, 2001; Benesi *et al*., 2004).

Although cassava has a wide range of uses, it is mainly used as a food crop in Africa and the rest goes to waste. In most cases cassava is used as a fresh product for home consumption.

In Africa, there exists a need for increased production of cassava to meet food requirements and have surplus for industry, feed and export. Processing adds value at farm level and reduces perishability and bulkiness, thereby facilitating the sale of cassava products in the off-season and in distant markets (Chiwona-Karltun, 2001). Processing can also help by generating employment and income for non-growers, thereby enhancing income generation of both rural and urban dwellers (Benesi, 2002).

2.5 Cassava as animal feed

As the standard of living improves, the demand for meat and dairy products also increases. It is therefore expected that livestock production will increase rapidly and significantly in many African and other developing countries. This will certainly call for corresponding increase in demand for livestock feed in the right quantities, quality and at affordable prices.

Though this need varies among countries, where surplus cereals are available, they may provide the major energy component in animal ration.

However, in less developed countries where cereal production is inadequate for human consumption, cassava must occupy the first position in terms of energy source in meeting the increasing animal ration need. The use of well-balanced compound feedstuffs has proved to be the most efficient way to meet the shortage of home-grown natural fodder to increase efficiency in raising milk cows, beef cattle, broilers, layers, and pigs. Many feeding experiments show that cassava provides a good quality carbohydrate source, which could be substituted for maize or barley (Balagoplan, 2004).

Global cassava utilization as feed is estimated at 34 million tonnes, most of which is concentrated in Latin America and the Caribbean and in the European Commission (FAO, 2004a). Even though cassava is an important food staple in a number of these countries, a large share is used as feed (FAO, 1999). In Ceara State in Brazil, feeding livestock with fresh cassava at the farm level represents another important use of the cassava crop, accounting for 25% of total production (FAO, 2004b). When George (1989) predicted animal feed shortage of 5.8 million metric tonnes in India by the year 2000, cassava was identified as a top – ranking crop to compensate for the deficit.

Even though research in Cameroon has shown that poultry breeders could lower their production costs 40% by incorporating cassava into their chicken feed (FAO, 2000b), this potential of cassava has not been seriously tapped in Africa compared to other regions of the world. For example, based on FAO (2000b) report, more than 30% of the cassava produced in Latin America is used for domestic animal feed, compared to less than 2% in Africa.

According to FAO (2004b), till up to the 1960's, the animal feed industry in Brazil was relatively small in scale and it was directed mainly to dairy cattle. In the early sixties, the use of balanced feed for pig production started to grow, stimulating a fast development of the animal feed industry. The demand for balanced feed rations increased from 2.4 million metric tonnes in 1971 to 10 million metric tonnes in 1985. As a consequence, a strong demand for corn evolved, since corn represented the main animal feed raw material in Brazil, accounting for an average of 65% of rations. Hence, the demand for corn in Brazil went up from 8.4 million metric tonnes to 15 million metric tonnes a year. Due to that, Brazil, a traditional corn exporting country, had to import more than 4 million metric tonnes of corn from 1977 to 1980 (Balagoplan, 2004).

The aforementioned scenario offered the opportunity for the use of dried cassava in animal feed in Brazil. At the same time, it offered an opportunity to place cassava in the overall context of rural development, which produced favourable effects on small – farmer income and employment opportunities (Balagoplan, 2004).

This clearly shows that there is a great need to utilize cassava as animal feed in Africa to ease the pressure on maize consumption.

Africa can benefit from the inclusion of the leaves, which contains 22% protein (dry weight basis) as reported by Nweke *et al*, (2002). Nweke *et al*, (2002), also indicated that 4:1 ratio of cassava root and leaves successfully replaced maize in poultry feed and reduced feed cost without a loss in weight gain or egg production. Cassava leaves and other by – product are known extensively to be used to produce silage to be fed to livestock during the dry season. For example, there was 19% increase in milk yield when cassava silage was incorporated in feed up to 28% in India (Padmaja, 2000).

2.6 Starch.

Starch is the major carbohydrate reserve in plant roots and seed endosperm where it is found as granules. By far the largest source of starch is maize with other commonly used sources being wheat, potato, cassava and rice. Starch consists primarily of D-glucopyranose polymers linked by α-1, 4 and α-1, 6 glucosidic bonds called amylose and amylopectin respectively (Wurzburg, 1986a; Thomas and Atwell, 1999). These bonds are formed when carbon number 1 (C1) on a D-glucopyranose molecule reacts with carbon number 4 (C4) or carbon number 6 (C6) from the adjacent D-glucopyranose molecule. Since the aldehyde group on the end of the starch polymer is always free, starch polymers have at least one reducing end (Wurzburg, 1986a; Thomas and Atwell, 1999). Starch polymers contain only α-linkages which allow some starch polymers to form helical structures unlike the β configuration of cellulose which forms the sheeted ribbon-like structure (Thomas and Atwell, 1999).

2.7 Cassava starch and its uses

The fresh root of cassava contains 30% to 40% dry matter of which 85% is starch. Since the roots are rich in starch, they are increasingly used as raw materials for starch based products. About 25% starch may be obtained from mature, good quality roots. About 60% starch may be obtained from dry cassava chips and about 10% dry pulp may be obtained per 100kg of cassava roots (Oyewole and Obieze 1995).

Its unique properties also include high paste viscosity, high paste clarity, and high freeze-thaw stability, which are advantageous to many industries. (Oyewole and Obieze 1995).

Cassava starches are potential substitutes for wheat and maize – based starches (Rickard *et al*., 1991, Tian *et al*., 1991). A survey by Dziedzoave *et al*., (2000) indicates that 5000t of starch is used in Ghana per annum which includes textiles (40%), plywood (27%), pharmaceuticals (20%), paper (10%), and food (3%).

In the textile industry, starch is used in the sizing operation to coat yarn; in the finishing operation, to modify appearance, change stiffness and add weight to fabric and in the printing operation to prepare the paste of dyestuff (Balagoplan *et al*., 1998).

Starch hydrosates are also a basic input in the manufacture of industrial chemicals such as alcohol, Gluconic acid and acetic acid (Balagoplan *et al*., 1998). It is used in the making of adhesives for use in the packaging industry, for lamination in plywood, paperboard and footwear.

In the cable industries, starch is used in the production of paper tubes, cans and cones; as printing, publishing and library paste and as label adhesive for envelopes, postage stamps, gummed tapes, safety matches and many other items (Balagoplan *et al*., 1998).

Starch hydrosates which are obtained by starch hydrolysis with acid or enzyme treatment are used to impart sweetness, texture and Cohesiveness to drinks such as soft drinks, fruit juice and dairy drinks and to a variety of foods such as soup, cake and cookies (Balagoplan *et al*., 1998).

2.8 Flour

Cassava flour is a potential substitute for wheat and maize based flour (Rickard *et al*., 1991, Tian *et al*., 1991).

A preliminary study indicated a potential substitute of local cassava flour for imported materials in areas of plywood glue extenders and paperboard adhesives in Ghana (Graffam *et al*., 2000). In Ghana 250,000 t of wheat flour is imported per annum and this is mainly used by bakeries with about 1,200 t/annum used by the plywood industry (Dziedzoave *et al*., 2000). Much of this can be replaced by cassava flour.

In Malawi a manufacturing company, Raiply used cassava and wheat flour as binders, along with wood and synthetic adhesive in the production of plywood, block boards for domestic and export markets. Using cassava flour enabled Raiply to reduce its wheat imports by 40% and save US$54,000. Now Raiply and other industries in Malawi are using cassava flour as filler material for adhesives, as starch in the manufacture of textiles, as a partial substitute for wheat flour in biscuits and as a source of glucose (USAID / Malawi, 2002). It is reported that a 15% substitution of cassava flour for wheat flour could save Nigeria close to US$ 15 million a year in foreign exchange (USAID / RCSA, 2002).

2.9 Amylose and amylopectin content

Amylose is essentially a linear polymer in which the anhydroglucose units are predominantly linked through α-1, 4 glucosidic bonds. Amylose content varies considerably among starches and genetic modifications have been done to obtain amylose content varying from 0-75% and part of it can exist as soluble amylose in the amorphous region of the starch granules (Moorthy, 2002). The molecular weight (MW) for amylose ranges between 243000µ and 972000µ. Although amylose from potato starch has been reported to have a MW of up to 1000000µ, the MW for amylose is typically less than 500000µ (Thomas and Atwell, 1999). The average MW of amylose from cassava starch seems to vary greatly, possibly due to the variety of cassava from which starch is extracted and extraction methods. For instance, three MWs of 232000µ (Ciacco and D'Applonia, 1977), 431000µ (Takeda *et al*., 1984) and 522000µ (Suzuki *et al*., 1985) for cassava amylose have been reported in literature. The average degree of polymerisation is 960 for maize, 3280 for cassava, 2000 for potato and 2600 for sweetpotato (Jarowenko, 1977; Takeda *et al*., 1984; Wurzburg, 1986b).

Amylopectin, like amylose, is a polymer with α-1, 4 glucosidic bonds. However, unlike amylose, it has periodic branches linked to C6 by α-1, 6 glucosidic bonds. The MW of amylopectin ranges from 10 million to 500 million (Thomas and Atwell, 1999). The relatively high amylopectin content of cassava probably accounts for the high MW. The average degree of polymerisation of amylopectin is 1450 for maize, 1300 for cassava and 2000 for potato (Jarowenko, 1977; Wurzburg, 1986a).

The level of amylose and amylopectin found in starch depends upon crop and variety from which starch was extracted (Wurzburg, 1986a). Maize and wheat starch have an average amylose content of 28% and 26%, respectively, while potato, sweetpotato and cassava have 20%, 18% and 17%, respectively (Onwueme, 1978; Young, 1984).

2.10 Granule Shape and size.

Amylose and amylopectin do not exist free in nature, but as components of discrete, semi crystalline aggregates called starch granules. The diameters of starch granules generally range from 1µm to more than 100µm, and shapes can be regular (spherical, ovoid or angular) or quite irregular. The diameter for cassava starch granules ranges from 4-35µm (Onwueme, 1978; Moorthy, 1994; Thomas and Atwell, 1999).

The study of Moorthy and Ramanujam (1986) revealed that cassava starch granules increase in size two to six months after planting, then remain steady for the rest of the growing cycle of the plant. Defloor *et al*., (1998) also concluded that the granule size was lower during the dry season based on the high percentage of small granule during the period. Cassava starch granules are mostly round or oval with a flat surface on one side containing a conical pit which extends into a well which Moorthy (1994) described as an eccentric hilum, while Thomas and Atwell (1999) described it as truncated or kettledrum. Some granules appear perfectly round (Moorthy, 1994; Thomas and Atwell, 1999). Although the major components of all types of starch granules are amylose and amylopectin polymers, there is great diversity in the structure and characteristics of native starch granules depending on environment and source in terms of the biochemistry of the chloroplast or amyloplast and the physiology of the plant, (Snyder, 1984; Thomas and Atwell, 1999; Singh *et al*., 2005).

Physicochemical properties, such as percentage light transmittance amylose content, swelling power and water-binding capacity are significantly correlated with the average granule size of starches extracted from different plant sources (Zhou *et al*., 1998).

2.11 Physicochemical and functional properties of cassava starch and flour

This includes swelling power, water-binding capacity, gelatinization, viscosity, solubility etc. This determines the quality of any starch and flour as well as its final usage.

2.11.1 Swelling power.

This occurs as a result of increase in temperature of aqueous suspension above gelatinization temperature range. When this occurs, inter and intra molecular hydrogen bonds become disrupted giving way for water molecules to get attached to the liberated hydroxyl groups. It provides evidence for non-covalent bonds between starch molecules. Factors like amylose and amylopectin ratio, chain length and molecular weight distribution, degree or length of branching and conformation (Rickard *et al*., 1991) are related to swelling power. The swelling power of cassava is between those of potato and cereal starches (Moorthy, 2002). Asaoka *et al*., (1992) found in the work involving some cassava genotypes that swelling power was higher in the dry season than in wet season.

2.11.2 Solubility

It is defined as a solute ability to dissolve in solvent. This occurs when the adhesive force between the solute and the solvent becomes greater than the cohesive force between the solute molecules. It depends on a number of factors such as source, inter associative force, swelling power, presence of other components etc (Moorthy, 2002).

Cassava starch has higher solubility than the other root crop starches and the higher solubility may be attributed partly to the high swelling cassava starch undergoes during gelatinization (Moorthy, 2002). Even though solubility values reported for cassava starch range from 25-48 %, Moorthy, (2001) observed a range of 17.2 – 27.2 % and found no direct correlation between swelling power and solubility.

2.11.3 Water – binding capacity

Water – binding capacity measures the water holding capacity of starch granules at room temperature. It is related to the viscosity of the starch and thus it is important in determining the bulking and consistency of products as well as in baking applications (Niba *et al*., 2001). This makes it important in determining starch use in products like sauces.

2.12 Contribution and importance of starch and flour to Ghana's economy

Root and tuber crops contribute more than any sub-sector (46%) in Ghana to the Agricultural Gross Domestic Product (AGDP) (MOFA, SRID, 2004). This is an indication that the sector has an immense potential to propel the country's economy. However this is not the case even in the wake of the Presidential Special Initiative (PSI) on cassava. This suggests that studies and investigations on how to improve and add value to cassava and other root crops are key in developing the sector. The need for cultivars with high starch and flour yield as well as good physico-chemical properties as this determines the final usage of any flour and starch cannot be over emphasised. It's in this light that this study is important since it seeks to add to the information database of cassava flour and starch in Ghana. The market for starch comprises a number of end users who use maize, cassava and potato starch, in textiles, pharmaceuticals, paper, food and adhesive industries. The market size in 1996 was estimated at around 4,200 tonnes per annum, with the potential to grow to

6,000 tonnes by the year 2000. Most users have very high quality specifications with 60% of the market being for modified starches. The market for flour in Ghana is also currently dominated by wheat flour. In 1996, approximately 300,000 tonnes of wheat equivalents (grain and flour) were imported. Most of this flour was used by the food industry in the preparation of bread and snack foods, but some was used as a glue extender by the plywood industry (Graffam *et al.,* 2000). Hence with such a study the high specifications of these users are more likely to be met. This will help boost the economy and increase farmers livelihood thereby reducing poverty since cassava is one of the most widely cultivated crop in Ghana. This also implies that the use of starch and flour from locally produced cassava would mean that less material has to be imported which will save the country lots of money.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of study

The study was conducted at the Crops Research Institute, (CRI) experimental field at Fumasua in the Ashanti region from June 2009 to May 2010 (01° 36' W; 06° 43' N), in the semi-deciduous forest zone with an elevation of 286m above sea level. The area has a bimodal rainfall distribution pattern.

The major rains start in late March and end in mid July in the semi-deciduous forest zone of Ghana. This zone is characterized by short dry spell from August to mid-September followed by minor rainy season from mid-September to mid-November. The mean annual rainfall is 1500mm.The mean minimum and maximum temperatures are 21°C and 31°C, respectively. The mean annual relative humidity is about 60% at noon and 95% in the morning. The soil at the experimental site at Fumesua is *Asuansi* series, a *ferric Acrisol* (FAO/UNESCO legend). The predominant cropping systems practised in the zone are sole maize, sole cassava, maize-cassava intercrop and plantain/cocoyam intercrop.

3.2 Planting material and land preparation

Ten cassava cultivars were used. The cultivars were obtained from the Crops Research Institute (CRI) Fumasua. The cultivars were Sika bankye, Ahwengyanka, Doku-duade, Nkabom, Ampong, Bensere, Sisipe 290, Bankye hemaa, Tuaka, and Nyamebekyere.

The land was slashed, burned and later sprayed with a pre-emergent herbicide to control early weeds emergence and to ensure better crop establishment. Planting distance was 1m×1m between and within rows with a total of 30 plots, 10 within each replication. The plot size was 5m×10m with 50 plants per each plot and a plant population of 1500.

3.3 Agronomic practices

There were three weeding at 3 months interval (i.e. 3, 6, and 9 months after planting). Re-filling was done for cuttings that failed to sprout. Harvesting was carried out twice at 8 Months after Planting (MAP) and 11 (MAP). A total of 300 plants were harvested for both harvest thus 150 plants for each harvest.

3.4 Meteorological information

Meteorological information was obtained from the Metrological Services Department in Kumasi and covers the study location and the duration of the study. The parameters obtained were total monthly rainfall, relative humidity, and temperature readings during the period of the study.

3.5 Experimental design and data collection

Randomised Complete Block Design in 2 x 10 factorial designs (RCBD) with three replications was used. Age at harvest and cultivar were considered as factors. Agronomic data were collected on parameters such as plant height, canopy width, and height at branching from five middle plants at 4, 6, 8 and 10 MAP. Canopy width was determined by measuring the top growth in a horizontal manner.

Fresh root weight, fresh shoot weight, number of roots and starch content were also taken at each harvest. 1 kg of (fresh roots) from each cultivar was sent to the laboratory for physico-chemical analysis.

3.6 Harvest Index (H.I)

The five middle stands selected from each genotype at each harvest was used to determine the harvest index. The weight of the above ground parts and that of the roots from those stands were recorded and the H.I calculated as below:

$$Harvest\ index = \frac{Weight\ of\ roots}{Total\ biomass}$$

3.7 Root Yield (t/ha)

Fresh root yield was calculated as:

$$Yield = \frac{10{,}000\ \times Weight\ of\ roots\ from\ harvested\ stands}{No\ of\ stands\ harvested}$$

3.8 Starch content

Starch content determined by the gravimetric method. Fresh roots were weighed into a bucket containing water attached to the gravimetric machine until stable at the 5kg mark. The cassava roots were removed afterwards and placed in a hanging basket also attached to the gravimetric machine and readings were taken after being balanced at the 5kg mark of the weighing rod.

3.9 Starch Yield (t/ha)

The cassava roots were peeled, washed with tap water and grated. 500g of the grated roots was weighed and blended into dough by adding 1000 ml of water. The dough was then sieved with 5000 ml of tap water to extract the starch through a piece of muslin cloth. This was done till dough was completely fibrous. The slurry was allowed to stand for 24 hours for the starch to settle after which the supernatant was poured away and the starch sun dried.

The starch yield was calculated as:

$$Yield\ of\ starch = \frac{Weight\ of\ wet\ processed\ product\ \times Weight\ of\ roots}{Weight\ of\ fresh\ roots\ used}$$

3.10 Flour Yield (t/ha)

The cassava roots were peeled, washed with tap water and grated. This was followed by dewatering. 500g of the grated cassava was weighed and dried in oven at 60°C till a constant weight was attained before milling.

Flour yield was calculated as:

$$Yield\ of\ flour = \frac{Weight\ of\ dried\ processed\ product\ \times\ Weight\ of\ roots}{Weight\ of\ fresh\ roots\ used}$$

3.11 Functional Properties Determination

Detailed laboratory analyses were carried out on starch and flour at each harvest. Each analysis was carried out in triplicates.

The parameters determined were solubility for flour and starch, swelling power for flour and starch and water binding capacity for flour and starch.

3.11.1 Solubility (%) and Swelling Power (g/g) of Flour and Starch

The method of Leach *et al*., (1959) was used for the determination of solubility and swelling power of both starch and flour. 1g of each sample was weighed into a 50ml centrifuge tube. 40ml of distilled water was added. The centrifuge tube was then heated at 85°C for 30 minutes in a water bath with constant stirring in water bath. The sample was cooled to room temperature and then centrifuged at 2200 rpm for 15min. The supernatant was poured into a glass crucible and evaporated in the oven at 105°C for 24hrs and the weight of the residue noted. The weight of the sediment paste was also noted. The solubility and swelling power was calculated as below.

$$Solubility = \frac{Weight\ of\ residue\ \times 100}{Weight\ of\ sample}$$

$$Swelling\ power = \frac{Weight\ of\ sediment\ paste\ \times 100}{Weight\ of\ sample\ \times (100 - \%\ solubility)}$$

3.11.2 Water Binding Capacity (WBC) (%) of Starch and Flour

The methods of Yamazaki (1953) as modified by Medcalf and Gilles (1985) were used. 2g of sample was dissolved in 40ml of distilled water to form an aqueous suspension. The suspension was agitated for 1hr on a Haake slop 20 shaker at 100 rpm after which it was centrifuged for 10 minutes at 2200 rpm. The free water was decanted from the wet starch, which is allowed to drain for 10 minutes and the wet sample weighed.

Water-Binding Capacity was determined as:

$$WBC = \frac{Weight\ of\ wet\ sample - Weight\ of\ sample\ \times 100}{Weight\ of\ dry\ sample}$$

3.12 Statistical analysis

All data collected were entered into excel. Variation among the cultivars, age and their interactions were analysed with the statistical software Statistix version 9 using Factorial design in RCBD. Significance was tested at 5% level ($p < 0.05$) while least significant difference (LSD) was use to compare the means.

CHAPTER FOUR

RESULTS

4.1 Climatic information for study area

Table 1 presents the rainfall, relative humidity and temperature data for Fumesua during the period of the study. The highest rainfall (367.9 mm) was recorded in June 2009 and the lowest (4.2 mm) was in January 2010. Mean rainfall figure during the period was 118.9 mm. The maximum temperature (35.5°C) was recorded in February whilst the minimum temperature (21.1°C) occurred in June and October 2009. Mean maximum temperature was 35.1°C and mean minimum temperature was 24.6°C. August also recorded the highest relative humidity of 90% and 74% whereas February recorded the lowest relative humidity of 81% and 46%. Mean relative humidity was 93.6% and 67.1%. The rainfall values for the two harvest dates (8 and 11 MAP) were 56.7 mm for February and 132.6 mm for May. The maximum and minimum temperatures were also 35.5°C and 23.3°C for 8 MAP and 33.1°C and 23.4°C for 11 MAP respectively. The mean maximum and minimum relative humidity at 8 and 11 MAP were also 81% and 46% for 8 MAP to 84% and 63% at 11 MAP.

Table 1: Mean Rainfall, temperature and relative humidity of study area from June 2009 – May 2010.

Months	Rainfall (mm)	Temperature (°C)		Relative humidity (%)	
		Max	Min	09.00	15.00
June	367.9	31.7	22.1	87	66.0
July	226.1	29.6	21.4	88	72.0
August	19.0	28.6	21.7	90	74
September	59.7	30.0	21.9	88	69
October	201.7	31.1	22.1	88	65
November	40.4	31.8	22.4	85	61
December	30.0	32.9	23.1	87	55
January	4.2	33.4	22.7	87	52
February	56.7	35.5	23.3	81	46
March	41	34.5	23.4	83	55
April	129.1	34.4	23.4	82	60
May	132.6	33.1	23.4	84	63
Mean	118.9	35.1	24.6	93.6	67.1

4.2 Genotypic differences in plant height

There were highly significant differences ($p < 0.001$) among the cultivars for plant height at 4, 6, 8 and 10 MAP (Appendix 1, 2, 3 and 4). The range of values produced were 67.1 – 114.9cm at 4 MAP, 118.3 – 188.4cm at 6 MAP, 128.5 – 193.8cm at 8 MAP and 148.2 – 212.9 cm at 10 MAP. In general plant height increased rapidly from 4 MAP to 6 MAP. Plant height at 8 MAP was characterised by slow growth with a little or no growth observed by most of the cultivars, plant height picked up again at 10 MAP. Ahwengyanka and Tuaka were the best cultivars in terms of height (Fig 1).

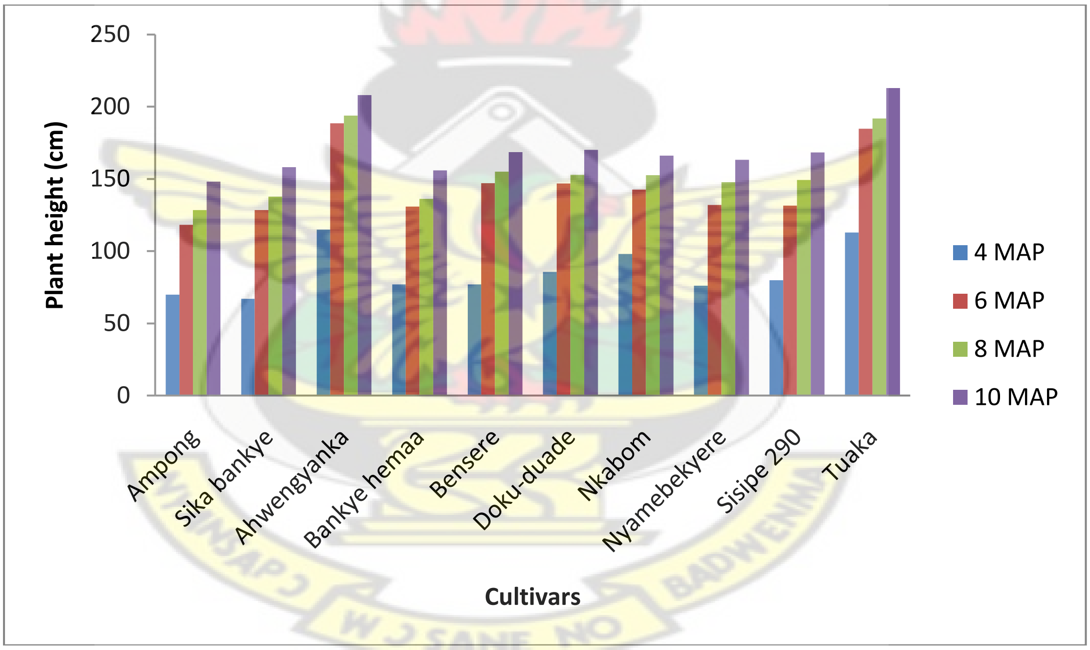

Figure 1: Plant height of different cultivars at 4, 6, 8 and 10 MAP

4.3 Genotypic differences in canopy spread over time

Result of canopy width at 4, 6, 8, and 10 MAP showed highly significant differences ($p < 0.001$) among the cultivars (Appendix 5, 6, 7 and 8) (Fig 2). The range of values produced were 54.07 – 80.20cm at 4 MAP, 87.5 – 131cm at 6 MAP, 58.7 – 110.5cm at 8 MAP and 82.7 – 128.8cm at 10 MAP. In general canopy width increased from 4 MAP to 6 MAP. However all the cultivars reduced in canopy width drastically at 8 MAP but increased at 10 MAP. The highest canopy width was recorded at 6 MAP. Ampong, Sika bankye and Nyamebekyere were the best cultivars in terms of canopy spread across the ages.

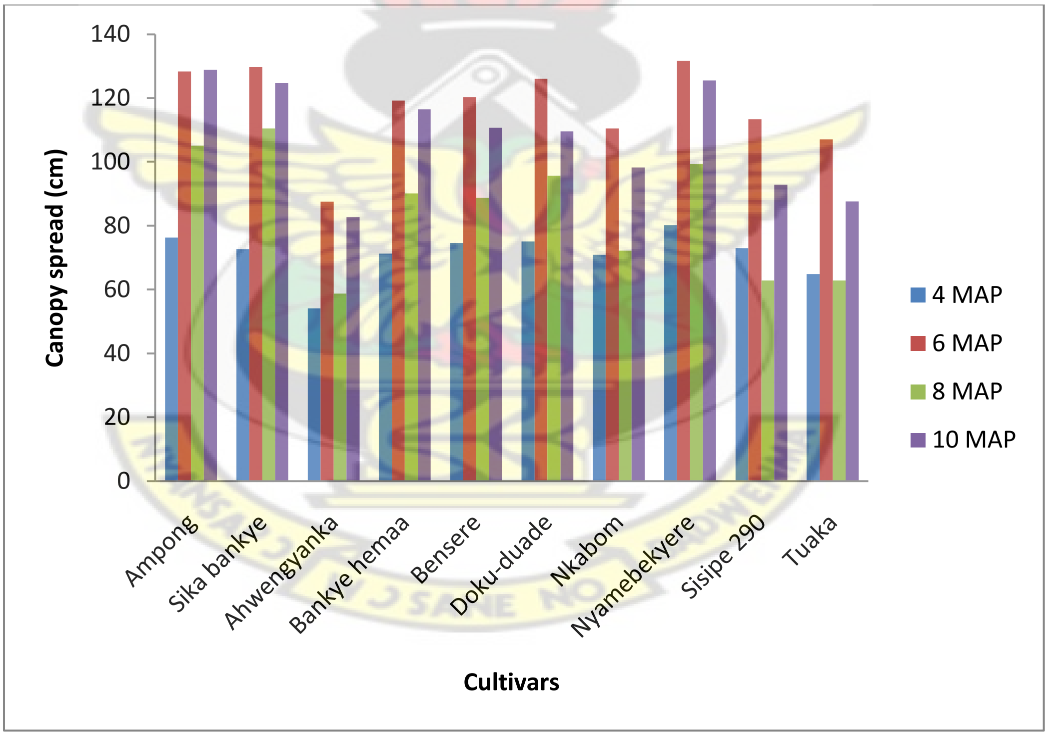

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Figure 2: Canopy spread of the different cultivars at 4, 6, 8 and 10 MAP.

4.4 Height at branching

Differences in height at branching among the cultivars were highly significant ($p < 0.001$) (Appendix 9). Some cultivars branched early while others branched late. The range of values was 48.67 – 156.33cm. Ahwengyanka was significantly higher than the rest of the cultivars. Sika bankye and Ampong were also significantly lower than Tuaka, Sisipe 290, Bensere and Nkabom but were not different from each other (Fig 3).

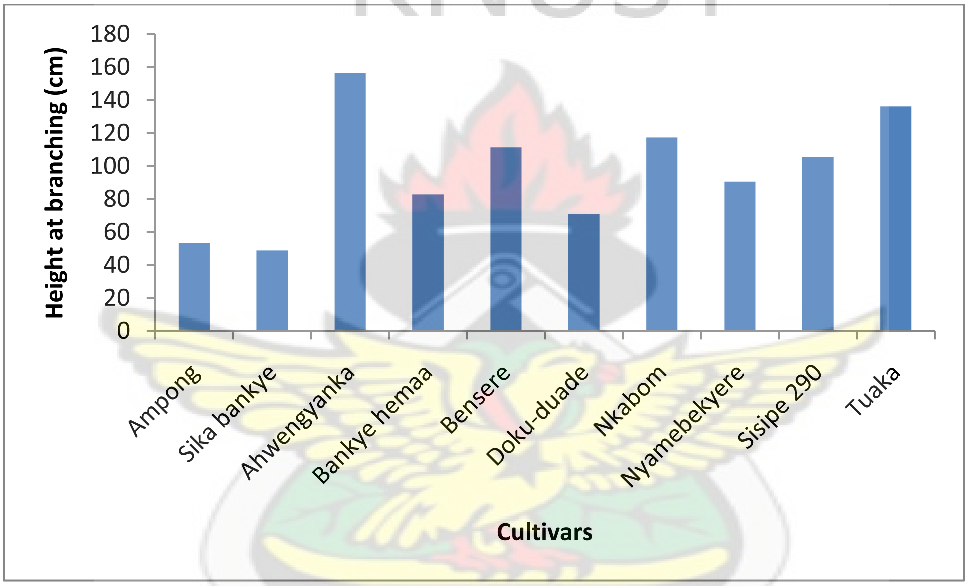

Figure 3: Height at branching for the cultivars studied

4.5 Correlation between Plant height, Canopy width, and Height at branching.

The correlation between plant height, canopy width and height at branching indicated plant height showed a significant positive correlation with height at branching with a correlation co-efficient (r) of 0.832. Hence height at branching increased with increasing plant height. However the relation between plant height and canopy width was negatively correlated (-0.832) indicating that canopy width increased with decreasing plant height.

A significant negative correlation was also observed between canopy width and height at branching with a correlation co-efficient (r) of -0.880 also implying that canopy width increased with decreasing height at branching.

Table 2, Correlation between growth and yield parameters

	CW	FY	HB	PH	SY	RY
CW	—					
FY	-0.330	—				
HB	-0.880*	0.473	—			
PH	-0.832*	0.161	0.832*	—		
SY	-0.372	0.360	0.454	0.111	—	
RY	-0.381	0.277	0.280	0.344	-0.276	—

CW = Canopy width, FY = Flour yield, HB = Height at branching, PH= Plant height SY = Starch yield, RY= Root yield.

4.6 Harvest Index

Harvest index ranged from 0.35 – 0.56 among the cultivars with Sika bankye and Sisipe 290 as the lowest and highest respectively. Harvest indices for growth duration were from 0.40 – 0.52 with the best being 11 MAP (Table 3). While differences among the cultivars as well as ages were highly significant ($p < 0.001$), the interaction between age and cultivar was not ($p > 0.05$) (Appendix 10). In general harvest index increased with age for all the cultivars.

Table 3: Harvest index of the cassava cultivars at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	0.36	0.53	0.44
Sika bankye	0.24	0.47	0.35
Ahwengyanka	0.43	0.54	0.48
Bankye hemaa	0.42	0.59	0.50
Bensere	0.48	0.49	0.48
Doku-duade	0.40	0.54	0.47
Nkabom	0.42	0.53	0.47
Nyamebekyere	0.31	0.44	0.37
Sisipe 290	0.54	0.58	0.56
Tuaka	0.41	0.55	0.48
Mean	0.40	0.52	0.46

Lsd (5%): Cultivar (C) = 0.08; Age (A) = 0.03; C × A = 0.11

4.7 Root yield

Results of root yield indicated no significant differences ($p > 0.05$) among the cultivars (Appendix 11). The range of values produced were 15.36 – 26.26 t/ha for Sika bankye and Bensere (Table 4). Highly significant differences ($p < 0.001$) were recorded between the ages. Root yield was higher at 11 MAP (22.9t/ha) compared to 8 MAP (15.91t/ha). The interaction between age and cultivar was also highly significant. In general root yield increased with age but declined with Ahwengyanka, Sika bankye and Doku-duade.

Table 4: Root yield (t/ha) of the cassava cultivars at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	15.53	24.30	19.91
Sika bankye	18.33	12.40*	15.36
Ahwengyanka	20.67	16.30*	18.48
Bankye hemaa	15.00	23.60	19.30
Bensere	13.93	38.80	26.36
Doku-duade	17.80	16.50*	17.15
Nkabom	14.93	31.10	23.01
Nyamebekyere	15.20	21.30	18.25
Sisipe 290	13.47	24.10	18.78
Tuaka	14.20	20.80	17.50
Mean	15.91	22.90	19.41

Lsd (5%): Cultivar (C) = 6.85; Age (A) = 3.06; C × A = 9.68

*Due to rotting of roots.

4.8 Starch yield

The cassava cultivars showed no significant differences ($p > 0.05$) in starch yield. However differences between the ages were highly significant (Appendix 12). Bensere recorded the highest starch yield and was significantly higher than Sika bankye (Table 5). In general starch yield increased with age and there was no significant interaction ($p > 0.05$) between age and cultivar.

Table 5: Starch yield (t/ha) of the cassava cultivars at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	5.52	6.39	5.95
Sika bankye	2.52	7.08	4.80
Ahwengyanka	4.55	7.94	6.24
Bankye hemaa	5.99	6.43	6.21
Bensere	5.73	8.56	7.14
Doku-duade	4.38	6.63	5.50
Nkabom	5.71	8.47	7.09
Nyamebekyere	5.10	6.40	5.75
Sisipe 290	5.47	7.18	6.32
Tuaka	4.90	6.29	5.59
Mean	4.98	7.14	6.05

Lsd (5%): Cultivar (C) = 2.13; Age (A) = 0.95; C × A = 3.01

4.9 Flour yield

Results of flour yield across the ages were highly significant ($p < 0.001$) (Table 6) (Appendix 13). But results of flour yield among the cultivars were not significant ($p > 0.05$). The mean flour yields ranged between 8.81 – 10.74 t/ha among the cultivars and 8.14 – 11.54 t/ha between the ages. Significant interaction was not found between age and cultivar. In general flour yield increased with age for all the cultivars.

Table 6: Flour yield (t/ha) of the cassava cultivars at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	8.85	11.14	9.99
Sika bankye	6.94	10.82	8.88
Ahwengyanka	8.79	11.69	10.24
Bankye hemaa	8.22	11.18	9.70
Bensere	7.32	12.39	9.85
Doku-duade	8.30	11.08	9.69
Nkabom	9.46	11.26	10.36
Nyamebekyere	5.70	11.93	8.81
Sisipe 290	8.96	12.53	10.74
Tuaka	8.84	11.41	10.12
Mean	8.14	11.54	9.83

Lsd (5%): Cultivar (C) = 2.84; Age (A) = 1.27; C × A = 4.02

4.10 Percentage starch

Starch content was not significantly affected by age and cultivar ($p > 0.05$) (Appendix 14). Values ranged between 25.01 – 26.21g/g across the ages and 24.45 – 27.35g/g among the cultivars (Table 7). Starch content was better at 8 MAP compared to 11 MAP. The interaction between age and cultivar was however highly significant (Appendix 14).

Table 7: Starch content (g/g) of the cassava cultivars at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	26.83	23.90	25.36
Sika bankye	26.27	24.47	25.37
Ahwengyanka	23.67	25.23	24.45
Bankye hemaa	29.50	21.90	25.70
Bensere	21.60	27.73	24.66
Doku-duade	25.13	27.83	26.48
Nkabom	26.87	24.10	25.48
Nyamebekyere	29.17	25.53	27.35
Sisipe 290	30.30	21.53	25.91
Tuaka	22.77	27.90	25.33
Mean	26.21	25.01	25.60

Lsd (5%): Cultivar (C) = 3.32; Age (A) = 1.48; C × A = 4.70

4.11 Solubility of starch

Solubility of starch showed no significant differences ($p > 0.05$) among the cultivars (Appendix 15). Age at harvest was also not significant ($p > 0.05$) though solubility increased with age (56.7% at 8 MAP to 60.8% at 11 MAP). The interaction between age and cultivar were not significant. Bensere (67.44%) recorded the highest solubility whereas Tuaka (51.58%) recorded the least among the cultivars (Table 8).

Table 8: Solubility (%) of starch at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	50.08	58.46	54.27
Sika bankye	50.78	65.72	58.25
Ahwengyanka	67.81	57.77	62.79
Bankye hemaa	61.73	56.96	59.34
Bensere	76.31	58.58	67.44
Doku-duade	44.99	74.06	59.52
Nkabom	51.14	60.39	55.76
Nyamebekyere	60.26	53.04	56.65
Sisipe 290	65.73	57.54	61.63
Tuaka	37.68	65.48	51.58
Mean	56.7	60.8	58.72

Lsd (5%): Cultivar (C) = 19.6; Age (A) = 8.76; C × A = 27.7

4.12 Swelling power of starch

Although swelling power increased with age (9.03g/g at 8 MAP – 9.41g/g at 11 MAP), the differences were not significant ($p > 0.05$). There were no significant differences among the cultivars as well. The interaction between age and cultivar was also not significant (Table 9) (Appendix 16).

Table 9: Swelling power (g/g) of starch at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	8.59	9.39	8.99
Sika bankye	7.81	10.05	8.93
Ahwengyanka	9.30	8.34	8.82
Bankye hemaa	9.35	9.42	9.38
Bensere	12.69	8.55	10.62
Doku-duade	7.51	11.97	9.74
Nkabom	8.89	9.95	9.42
Nyamebekyere	9.78	8.12	8.95
Sisipe 290	9.16	7.78	8.47
Tuaka	7.20	10.51	8.85
Mean	9.03	9.41	9.21

Lsd (5%): Cultivar (C) = 3.27; Age (A) = 1.46; C × A = 4.63

4.13 Water-Binding Capacity of starch

No significant differences ($p > 0.05$) were established among the cultivars for water-binding capacity of starch (Table 10). Water-binding capacity generally declined with age and there were no significant differences between the ages at harvest. The interaction between age and cultivar was not significant (Appendix 17).

Table 10: Water-binding capacity (%) of starch at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	71.72	73.10	72.41
Sika bankye	73.64	72.34	72.99
Ahwengyanka	69.05	66.69	67.87
Bankye hemaa	68.91	70.82	69.86
Bensere	73.68	76.01	74.84
Doku-duade	74.93	71.31	73.12
Nkabom	68.01	68.03	68.02
Nyamebekyere	74.90	73.08	73.99
Sisipe 290	70.07	74.39	72.23
Tuaka	77.70	62.61	70.15
Mean	72.2	70.8	71.54

Lsd (5%): Cultivar (C) = 8.37; Age (A) = 3.74; C × A = 11.84

4.14 Solubility of flour

There were no significant differences among the cultivars for solubility of flour (Table 11) (Appendix 18). The highest solubility was recorded by Doku-duade whereas Tuaka recorded the least. Solubility of flour decreased with age from 72.5% – 62.8% and differences were highly significant ($p < 0.001$). The interaction between age and cultivar was not significant.

Table 11: Solubility (%) of flour at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	78.26	64.02	71.14
Sika bankye	71.46	61.32	66.39
Ahwengyanka	76.08	59.43	67.75
Bankye hemaa	66.44	61.42	63.93
Bensere	68.31	72.78	70.54
Doku-duade	76.32	70.48	73.40
Nkabom	74.77	70.09	72.43
Nyamebekyere	68.12	61.19	64.65
Sisipe 290	74.66	61.82	68.24
Tuaka	70.12	45.08	57.60
Mean	72.5	62.8	67.61

Lsd (5%): Cultivar (C) = 11.53; Age (A) = 5.15; C × A = 16.3

4.15 Swelling power of flour

Differences in swelling power among the cultivars were not significant ($p > 0.05$) (Appendix 19). Bensere and Nkabom gave the lowest and highest values respectively (Table 12). Swelling power increased with age but with no significant differences between the ages. Differences between age and cultivar interactions were also not significantly different.

Table 12: Swelling power (g/g) of flour at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	13.58	13.19	13.38
Sika bankye	13.16	13.04	13.10
Ahwengyanka	13.25	18.31	15.78
Bankye hemaa	11.24	12.71	11.97
Bensere	10.00	12.04	11.02
Doku-duade	11.07	13.33	12.20
Nkabom	15.84	12.87	14.35
Nyamebekyere	11.87	13.83	12.85
Sisipe 290	13.90	13.68	13.79
Tuaka	12.68	13.83	13.25
Mean	12.66	13.68	13.17

Lsd (5%): Cultivar (C) = 2.77; Age (A) = 1.24; C × A = 3.92

4.16 Water-binding capacity of flour

Water-binding capacity of flour ranged from 176.3 – 244.6% at 8 MAP and 183.1 – 215.7% at 11 MAP. Sika bankye recorded the highest water-binding capacity (228.4%) whiles Doku-duade recorded the least (183.2%). Water-binding capacity was not significantly affected by age at harvest and cultivar (Appendix 20). In general water-binding capacity declined with age. The interaction between age and cultivar was also not significantly different.

Table 13: Water-binding capacity (%) of flour at 8 and 11 MAP.

	Age (Months After Planting)		
Cultivar	8	11	Mean
Ampong	199.6	205.5	202.5
Sika bankye	243.1	213.8	228.4
Ahwengyanka	176.3	197.4	186.8
Bankye hemaa	208.5	215.7	212.1
Bensere	244.0	183.1	213.5
Doku-duade	181.3	185.1	183.2
Nkabom	210.5	197.3	203.9
Nyamebekyere	194.3	186.0	190.1
Sisipe 290	182.7	210.1	196.4
Tuaka	199.3	207.2	203.2
Mean	204.0	200.1	202.0

Lsd (5%): Cultivar (C) = 34.36; Age (A) = 15.36; C ×A = 48.6

CHAPTER FIVE

DISCUSSION

5.1 Plant height, Height at branching and Canopy spread (Growth and Development)

Though not captured in the results, it was apparent that during the first two months after planting the cassava varieties mainly developed shoots (stems and leaves) from observation made on the field, as similarly was observed by (Cock, 1984).

The immense increase in plant height and canopy width from 4 MAP to 6 MAP can be attributed to the favourable climatic conditions. A total of 914.8mm of rainfall were recorded during that period (i.e. June to November 2009). This increase which represents the developmental phase was mainly characterised by rapid growth of leaves and stems. This supports similar observation by El-sharkawy *et al*., (2004) who reported that the distribution patterns of dry matter among the different organs of the cassava plant change markedly during the growth cycle, with shoots having the dominance in the first 3-5 months after planting while storage roots become the major sink for photo assimilates during the rest of the growth cycle. This explains why the highest canopy width was recorded at 6 MAP.

Slow growth in terms of height at 8 MAP can also be attributed to the dry climatic conditions, (34.2mm) of rainfall recorded for the month of December and January.

This trend was also observed in the canopy development which resulted in drastic decline in canopy width at 8 MAP. The slack in canopy development from 6 – 8 MAP due to changes in the environmental conditions significantly affected photosynthetic activities of the plants and as a result affected growth and development of the plants.

The gradual revival or increase in height and canopy at 10 MAP which coincided with the commencement of the rainfall season saw the growth of fresh new shoots.

Height at branching was also evenly spread throughout the growing period as some cultivars branched earlier especially the shorter cultivars whereas the taller cultivars branched late. This can be attributed to the genetic make-up of the cultivars.

The correlation between plant height, canopy width and height at branching showed that the negative correlation observed between plant height and canopy width was evident in Ahwengyanka and Tuaka as these two tallest cultivars recorded lower canopy spread whereas Ampong, Sika bankye and Nyamebekyere the three shortest cultivars also recorded the highest canopy widths.

The superior height at branching and superior plant height of Ahwengyanka and Tuaka as well as the inferior plant height and inferior height at branching recorded by Ampong and Sika bankye can also be explained by the positive correlation observed between the two parameters. This indicate that the shorter or taller the plant so will its height at branching be.

On the other hand the negative correlation between height at branching and canopy width was expressed in Ahwengyanka and Tuaka which is the reason why the two cultivars with the highest height at branching had lower canopy widths, whiles Ampong, Sika bankye and Nyamebekyere with lower height at branching obtained the highest canopy widths.

5.2 Root yield and Harvest index

The higher root yield obtained at 11 MAP compared to 8 MAP can be attributed to the age at harvest as well as genetic and environmental factors. Normally most cassava cultivars are harvested at 12 MAP hence at 11 MAP the cultivars are already matured. Climatic conditions before harvesting also showed it was more dryer at 8 MAP compared to 11 MAP (Table 1). This can hinder growth which will eventually affect the yield.

The excessive moisture in the soil could also have accounted for the yield difference at 11 MAP. This resulted in a lot of rotten roots especially for Ahwengyanka, Sika bankye and Doku-duade as was observed at the time of harvest. This explains why these cultivars declined in yield at 11 MAP.

The higher harvest index observed at 11 MAP compared to 8 MAP was expected. This was as a result of the drastic decline in canopy development at 8 MAP due to the dry environmental conditions. Differences in harvest index among the cultivars can also be attributed to varietal superiority especially in their ability to utilise moisture for growth and to withstand shock in this case drought as shown by Sisipe 290 and Bankye hemaa.

Harvest index of Sisipe 290, Nkabom, and Bensere and to some extent Bankye hemaa did not agree with the fact that cultivars with characteristically profuse branching, closed canopy architecture and excessive vegetative growth produces the highest harvest index as was observed by Baafi and Safo-Kantanka, (2005). This is because these cultivars produced non-profuse branching and open canopy architecture as well as less top growth. Hence these cultivars can be suitably use in various intercrop systems as well as deriving the best out of these cultivars.

5.3 Interaction of Age and cultivar on starch yield and quality

Starch content and starch yield are important parameters in determining the final usage of cassava, especially for food and industrial purposes. The higher starch yield recorded at 11 MAP compared to 8 MAP could be linked to the differences in age at harvest as well as genetic and climatic factors. This result corroborates what Corbishley and Miller (1984) reported that starch yield of cassava roots depends on many factors such as variety, soil type and climate in addition to age of the plant. The higher starch yield of Bensere and Nkabom can be attributed to their higher root yields. This might also be due to their starch content since the starch content of these cultivars was very good. This results suggest that in selecting cassava cultivars for starch production, it is important to consider the starch content in addition to potential root yield, and not only the age at harvest. This observation is in agreement with the findings of Wholey and Booth, (1979), who found age at harvest to obtain maximum fresh root yield not necessarily the same as that to obtain maximum starch yield.

Starch quality is defined in terms of solubility, swelling power and water-binding capacity. This influences the functional properties of starch and is important in the modification of starches to suit different uses. Solubility is a solute’s ability to dissolve in a solvent. This occurs when the adhesive force between the solute and the solvent becomes greater than the cohesive force between the solute and the solvent.

It depends on a number of factors such as source, inter-associative forces, swelling power, presence of other components etc (Moorthy, 2002).

Solubility values (37.68 – 76.31%) obtained from the study was far higher than the range (25 – 48%) reported for cassava, as well as (17.2 – 27.2%) both reported by (Moorthy, 2001).

These differences in solubility can be linked to the different analytical methods used, the age and different varieties of cassava studied. However solubility values obtained from the study agrees with that found by Aryee *et al*., (2005). The higher solubility of the cultivars makes starch from these cultivars suitable for use in industrial application, especially where starch is used in solutions like pharmaceuticals (Benesi, 2005).

Swelling power is also defined as the maximum increase in volume and weight, which starch undergoes when allowed to swell freely in water (Balagoplan *et al*., 1998). This occurs as a result of increase in temperature of the aqueous suspension above gelatinization temperature range. The swelling power of starch depends on the ability of certain components of starch, especially amylose to solubilise in water hence, allowing water to attach to starch molecules. Thus increases in swelling power are a function of increased solubility (Moorthy, 2001). However swelling power values (7.20 – 12.69g/g) obtained from the study were far lower than the range of 42 – 71 g/g reported by Moorthy, (2002) considering the higher solubility values recorded. These may be due to differences in variety, age and environment as highlighted by Moorthy and Ramanujam, (1986) as well as differences in laboratory procedures. These values did not also agree with Rickard *et al*., (1991) who observed a positive correlation between solubility and swelling power of starch, as the solubility values obtained from this study were rather high. The low swelling accompanied by the high solubility obtained was indicative of the weak associative forces in the starch granules of the cultivars. This may also be attributed to the damage caused by milling to the starch granules of the cassava samples. This implies that starch from these varieties can be hydrolysed easily to produce starch sugars without using much energy as compared to cultivars with strong associative forces (Moorthy and Ramanujam, 1986).

The high swelling observed at 11 MAP also support the assertion by Moorthy and Ramanujam (1986) that age of cultivar affect swelling of starch. Hence age at harvest must be considered when screening cultivars for swelling power.

The ability of starch granules to absorb water is very important in starch especially for food preparations. Hence the higher water-binding capacity obtained by the cultivars will be useful in the substitution of cassava starch for wheat in food applications since increase in water-binding capacity in food system enables bakers to make use of the functional properties of dough in bakery products as reported by (Achinewhu and Orafun, 2000; Iwe and Onadipe, 2001).

5.4 Interaction of Age and Cultivar on flour yield and quality

The results this study indicated that flour yield was higher at 11 MAP compared to 8 MAP which confirms that age at harvest has a bearing on starch and flour yield as observed by (Moorthy and Ramanujam, 1986). The higher flour yield at 11 MAP could also be linked to the environmental conditions prevailing prior to harvesting as explained earlier for starch yield.

The quality of flour is also defined in terms of solubility, swelling power, and water-binding capacity. Solubility values recorded (45.0 – 78.2 %) were in the range of 47 – 78% reported by Aryee *et al*., (2005) which is in the range acceptable for use of flour for industrial application.

Higher swelling observed at 11 MAP compared to 8 MAP as well as the differences observed among the cultivars is in agreement with the findings by Moorthy and Ramanujam (1986), who reported that swelling power of cassava flour is dependent on cultivar, environmental factors and age, as it was evident from the study that swelling power increased with age and environmental conditions were also more favourable at 11 MAP compared to 8 MAP. Swelling power values (10.0 – 18.3g/g) obtained from the study was also in the range of 5.87 – 13.48g/g and 14.88 – 26.58g/g reported by Aryee *et al*., (2005), and Appea Bah, (2003) which is very acceptable for most industrial uses.

The relatively high water-binding capacity observed for flour among the cultivars are again indicative of the weak associative forces between the flour granules, which allows for more molecular surfaces to be available for binding with water molecules (Rickard *et al*., 1991). This indicates that all the cultivars can produce higher viscosity and consistency in products making them very appropriate for baking applications. The relatively high water-binding capacity recorded (228.4 – 183.2%) is also not too far from the range observed by Aryee *et al*., (2005) for 31 cassava cultivars whose water-binding capacity for flour ranged between 113.66 – 201.99%.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

The findings of this study were.

1. Age significantly affected flour and starch yield but cultivar did not.
2. Physico-chemical properties of flour and starch were not significantly affected by age and cultivar.
3. The physico-chemical properties of the cassava cultivars showed most of the cultivars had very good physico-chemical properties hence would be good for industrial uses.
4. Values recorded for starch and flour yield shows most of the cultivars can be used for flour and starch production.
5. It was also evident from the study that environmental conditions had immense influence on the parameters investigated especially on growth.
6. Significant interactions were established. In the case of root yield and starch content farmers must know the precise age to harvest a cultivar in order to optimize yield and improve quality.

From the above conclusions it's hereby recommend that further studies be carried out in different ecological zones to ascertain the performance of these cultivars.

It's also recommended that Bensere, Nkabom, Bankye hemaa and Ahwengyanka is a suitable cultivar for starch and flour production considering its high root, starch and flour yields as well as good physico-chemical properties.

It’s also recommended that Bensere, Nkabom, and Bankye hemaa should be harvested at 11 MAP for good root yield whiles Ahwengyanka be harvested at 8 MAP for good root yield. However it’s important that Bensere, Ahwengyanka and Bankye hemaa be harvested at 8 MAP for good starch quality and at 11 MAP for good flour quality.

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APPENDICES

Appendix 1 Plant height at 4 MAP

Source	DF	SS	MS	F	P
Rep	2	3350.0	1675.0	7.18	
Variety	9	7850.7	872.3	3.74	0.0008
Error	18	4201.3	233.4		
Total	29	15402.0			

Appendix 2 Plant height at 6 MAP

Source	DF	SS	MS	F	P
Rep	2	4617.7	2308.9	10.18	
Variety	9	15068.0	1674.2	7.38	0.0001
Error	18	4081.9	226.8		
Total	29	23767.6			

Appendix 3 Plant height at 8 MAP

Source	DF	SS	MS	F	P
Rep	2	3198.7	1599.3	10.13	
Variety	9	12952.4	1439.2	9.11	0.0001
Error	18	2843.2	158.0		
Total	29	18994.2			

Appendix 4 Plant height at 10 MAP

Source	DF	SS	MS	F	P
Rep	2	3897.2	1948.6	9.11	
Variety	9	12392.1	1376.9	6.44	0.0001
Error	18	3849.7	213.9		
Total	29	20139.1			

Appendix 5 Canopy width at 4 MAP

Source	DF	SS	MS	F	P
Rep	2	115.38	57.69	1.36	
Variety	9	1416.11	157.35	3.70	0.0009
Error	18	765.85	42.55		
Total	29	2297.34			

Appendix 6 Canopy width at 6 MAP

Source	DF	SS	MS	F	P
Rep	2	332.8	166.4	1.48	
Variety	9	4852.4	539.2	4.78	0.0002
Error	18	2030.2	112.8		
Total	29	7215.4			

Appendix 7 Canopy width at 8 MAP

Source	DF	SS	MS	F	P
Rep	2	181.9	90.9	0.66	
Variety	9	9741.8	1082.4	7.81	0.0001
Error	18	2494.3	138.6		
Total	29	12418.0			

Appendix 8 Canopy width at 10 MAP

Source	DF	SS	MS	F	P
Rep	2	153.5	76.8	0.38	
Variety	9	7449.1	827.7	4.06	0.0006
Error	18	3670.0	203.9		
Total	29	11272.6			

Appendix 9 Height at branching

Source	DF	SS	MS	F	P
Rep	2	1084.7	542.4	1.51	
Variety	9	32695.5	3632.8	10.14	0.0001
Error	18	6451.2	358.4		
Total	29	40231.4			

Appendix 10 Harvest index

Source	DF	SS	MS	F	P
Rep	2	0.01630	0.00815		
Variety	9	0.17146	0.01905	3.75	0.0019
Map	1	0.28291	0.28291	55.67	0.0001
Variety*Map	9	0.03453	0.00384	0.75	0.6573
Error	38	0.19310	0.00508		
Total	59	0.69829			

Appendix 11 Root yield

Source	DF	SS	MS	F	P
Rep	2	1798.48	899.241		
Variety	9	535.00	59.445	1.73	0.1157
Map	1	739.21	739.206	21.51	0.0001
Variety*Map	9	1182.53	131.393	3.82	0.0016
Error	38	1305.68	34.360		
Total	59	5560.90			

Appendix 12 Starch yield

Source	DF	SS	MS	F	P
Rep	2	170.104	85.0522		
Variety	9	27.498	3.0554	0.92	0.5202
Map	1	69.682	69.6819	20.94	0.0001
Variety*Map	9	21.159	2.3510	0.71	0.6991
Error	38	126.449	3.3276		
Total	59	414.893			

Appendix 13 Flour yield

Source	DF	SS	MS	F	P
Rep	2	152.516	76.258		
Variety	9	20.008	2.223	0.37	0.9401
Map	1	173.162	173.162	29.18	0.0001
Variety*Map	9	24.882	2.765	0.47	0.8882
Error	38	225.467	5.933		
Total	59	596.035			

Appendix 14 Starch content

Source	DF	SS	MS	F	P
Rep	2	10.580	5.2902		
Variety	9	38.034	4.2259	0.52	0.8497
Map	1	21.480	21.4802	2.65	0.1118
Variety*Map	9	340.061	37.7846	4.66	0.0003
Error	38	307.946	8.1039		
Total	59	718.102			

Appendix 15 Solubility of starch

Source	DF	SS	MS	F	P
Rep	2	2061.5	1030.73		
Variety	9	1116.4	124.05	0.44	0.9039
Map	1	254.6	254.62	0.91	0.3475
Variety*Map	9	3579.8	397.76	1.41	0.2168
Error	38	10691.0	281.34		
Total	59	17703.4			

Appendix 16 Swelling Power of starch

Source	DF	SS	MS	F	P
Rep	2	15.509	7.75461		
Variety	9	20.227	2.24745	0.29	0.9746
Map	1	2.193	2.19299	0.28	0.6005
Variety*Map	9	88.287	9.80967	1.25	0.2965
Error	38	298.763	7.86219		
Total	59	424.980			

Appendix 17 Water-binding capacity of starch

Source	DF	SS	MS	F	P
Rep	2	261.50	130.752		
Variety	9	328.79	36.533	0.71	0.6950
Map	1	28.69	28.685	0.56	0.4595
Variety*Map	9	393.11	43.679	0.85	0.5758
Error	38	1951.76	51.362		
Total	59	2963.85			

Appendix 18 Solubility of flour

Source	DF	SS	MS	F	P
Rep	2	67.17	33.58		
Variety	9	1255.34	139.48	1.43	0.2089
Map	1	1409.32	1409.32	14.48	0.0005
Variety*Map	9	834.98	92.78	0.95	0.4925
Error	38	3698.82	97.34		
Total	59	7265.64			

Appendix 19 Swelling Power of flour

Source	DF	SS	MS	F	P
Rep	2	1.338	0.6688		
Variety	9	94.437	10.4930	1.86	0.0882
Map	1	15.710	15.7099	2.79	0.1031
Variety*Map	9	61.241	6.8046	1.21	0.3188
Error	38	214.056	5.6331		
Total	59	386.781			

Appendix 20 Water-binding capacity of flour

Source	DF	SS	MS	F	P
Rep	2	2560.8	1280.38		
Variety	9	10216.2	1135.13	1.31	0.2626
Map	1	226.5	226.50	0.26	0.6117
Variety*Map	9	9123.6	1013.73	1.17	0.3397
Error	38	32852.0	864.53		
Total	59	54979.0			