KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI.

FACULTY OF SCIENCE

DEPARTMENT OF BIOCHEMISTRY

TIME OF HARVESTING AND ITS EFFECT ON THE QUALITY OF GARI AND FLOUR FROM FOUR CASSAVA VARIETIES.

BY

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A THESIS SUBMITTED TO THE DEPARTMENT OF BIOCHEMISTRY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE MASTER OF SCIENCE DEGREE IN FOOD SCIENCE AND TECHNOLOGY

BY

FRANKLIN BRIAN APEA BAH

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Certified as the original work of the author, FRANKLIN BRIAN APEA BAH

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SUPERVISORS:

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DR. (MRS.) IBOK ODURO DR. WILLIAM O. ELLIS

DEDICATION

To Horace Apea Bah in memoriam, dad, mentor and friend.

ABSTRACT

Four varieties of cassava (*Afisiafi, Tek bankye, Abasafitaa* and *Gblemoduade*) were each harvested at 9, 10, 11, 12, 13, 14 and 15 months after planting and processed into gari and flour. The yields of gari and flour obtained from processing 100kg of fresh, whole roots were determined. Selected physicochemical properties of the gari and flour samples at different ages were also studied. The properties of gari studied were moisture, ash, pH, total titratable acidity, swelling capacity and crude fibre, while that of flour were moisture, ash, crude protein, crude fibre, pH, swelling power, solubility, starch yield, amylose content and pasting characteristics. The data obtained were statistically analyzed to determine whether age and variety each affected the yields and physicochemical properties of the gari and flour.

Age and variety both had significant effects ($p<0.05$) on flour yield, but gari yield was not significantly affected by either age or variety. Moisture, pH and bulk density of gari were significantly affected by age while crude fibre of gari was affected significantly by variety. Also, age significantly affected moisture, ash and crude protein of flour, while solubility and all pasting characteristics of the flour were affected significantly by variety. Afisiafi and Tek bankye had optimum flour yields at 13 months after planting while Abasafitaa and Gblemoduade had their optimum flour yields at 12 months after planting. However, Afisiafi and Tek bankye had optimum gari yields at 14 months after planting while Abasafitaa and Gblemoduade had optimum gari yields at 13 and 12 months after planting respectively.

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CHAPTER 1

1.0 INTRODUCTION

Cassava is one of the most important root crops in the world and it provides a lot of energy to consumers. It is a tropical plant since it cannot survive very low temperatures. Due to its high resistance to drought and its ability to survive on depleted soil, it is the first choice crop for food security and poverty alleviation. This is because poor farmers may not need to irrigate and apply fertilizer during cassava cultivation, both of which are costly. The roots are rich in starch and therefore find wide application in the industry. It may be used in the textile and paper industry for sizing, as well as in commercial production of ethanol (Toyin, 2000). In the food industry, cassava starch may be used in the production of high fructose syrup, glucose-fructose syrup, as thickener in soups and sauces, as a binder in many food and feed products such as formulated fish feed and as a malt adjunct in the breweries (Nweke *et al.*, 2002). Recently, there has been an increase in the production of high quality cassava flour that is suitable for use, in composite with wheat flour, for baking and in pastry preparation. This reduces over dependence of African countries on wheat flour and saving of foreign exchange. It also enhances cassava production since farmers will have ready market for their produce. In Ghana, work has started on cassava processing by the Root and Tuber Improvement Programme (RTIP), the Biochemistry Department of KNUST and the Food Research Institute. With the release of four improved cassava varieties under the names *Afisiafi, Tek bankye, Abasafitaa* and *Gblemoduade,* there is the need to study their physical and chemical properties in relation to their suitability for various applications.

Generally, cassava roots mature within 6-18 months after planting, depending on the cultivar. Age affects the quality and suitability of cassava roots for various uses, especially in preparing high quality starch and flour. Young plants have roots that are low in starch yield since most of their carbohydrates are in the form of simple sugars. Bulking of roots and the conversion of sugars into starch increase with age. Over aged roots, however, are fibrous and give products of poor quality (Nweke *et al.*, 1994). There is the need to study the effect that age has on the physical and chemical properties of products from cassava such as flour, starch and gari that are common dry forms into which cassava is processed to enhance storage.

The objective of this study is to determine whether age has an effect on yield and selected physicochemical properties of gari and high quality flour prepared from four cassava varieties.

CHAPTER 2

2.0 LITERATURE REVIEW

Cassava (*Manihot esculenta*, Crantz) is a perennial, woody shrub with an edible root that grows in tropical and sub-tropical areas of the world. It is known variously as *yucca*, *manioc* and *mandioca* (Microsoft Encarta Encyclopaedia 2002). 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. Because cassava roots can be stored in the soil for up to 24 months, and in some varieties up to 36 months, harvest may be delayed until market, processing, or other conditions are favourable (www.iita.org/crop/cassava/htm#).

2.1 TAXONOMY.

The genus *Manihot* is a member of the economically important family *Euphorbiaceae* with several thousand species. Cassava is the most important species of this genus (Microsoft Encarta Encyclopaedia 2002).

2.2 ORIGIN AND DISTRIBUTION.

Cassava was introduced at a number of points along the West African coast, from the Gambian river to present day Nigeria. It is believed to have originated from Brazil and Mexico, and might have been brought to West Africa by the released slaves from Brazil around 1800. However, as early as 1785, cassava was known to have been cultivated around Accra widely. Around the 18th century, Portuguese at Ouidah (present-day Benin) had factories run by Brazilians, who are thought to have introduced cassava to Nigeria, possibly with the intention of supplying slave ships with farinha. The slaves who returned to West Africa from Brazil after the 18th century were instrumental in the spread of cassava since they created a local demand for the crop and also introduced processing techniques that helped to detoxify bitter and high cyanide varieties. The cassava product *gari* is thought to have been introduced to West Africa by slaves from Brazil.

In West Africa, colonial governments played a major role in encouraging cassava cultivation in the 20th century, particularly in the savannah areas, since the plant is able to withstand drought and other adverse environmental conditions such as low soil fertility.

Source: www.iita.org/info/trn-mat/irg49/irg493.html

2.3 GROWTH REQUIREMENTS.

Cassava is very resistant to drought and it is the one crop that provides food security in drought-stricken areas. During the drought period, it loses its leaves but quickly re-grows them with the first rains. It is therefore invaluable in the tropical regions with low and uncertain rainfall.

Cassava grows well on sandy and loamy soils of reasonable fertility. However, it can grow on almost all soil types provided they are not waterlogged, too shallow or too stony, since these conditions prevent the formation of roots. Cassava will produce an economic crop on exhausted soils unsuitable for growing other crops and consequently, it is the last crop taken in rotation in shifting cultivation. If soil fertility is too high, there is excessive vegetative growth at the expense of root and starch formation (Purseglove, 1968). Cassava can tolerate pH of 5.5-8.0. It has unsatisfactory growth at low temperatures such as less than 16°C; since it cannot withstand chills and frost, it is purely a tropical crop. Long periods of exposure to drought, increases cyanide accumulation in roots (Githunguri *et al.* 1998). Cassava does not usually require irrigation, but occasional irrigation during drought is helpful.

Usually during cultivation of cassava, fertilizers are not essential, however, application of NPK fertilizers and farmyard manure gives positive response, since cassava requires considerable amount of nitrogen, phosphorus and potassium. Nitrogen application increases the number of tuberous roots formed (Kasele *et al.*, 1984; Odwukwe and Oji, 1984). Nitrogen deficiency can be easily recognized by stunted growth and leaf discolouration. Excessive application of nitrogen without simultaneous application of phosphate or potash may enhance vegetative growth at the expense of tuber yield (Githunguri *et al.* 1998). Phosphorus is important for the development of the root system and its deficiency is recognized by stunted growth and violet discolouration of the leaves. Although cassava removes large quantities of potassium from the soil, an adequate supply of nitrogen and phosphorus seems to be more important in producing good yield than is a large supply of potassium. Symptoms of potash deficiency begin with stunted growth, followed by development of dry, brown spots at the tips and margins of the leaves. Potash deficiency may also affect root quality (IITA, 1990). If applied correctly, however, it results in significant increase in tuberization, root diameter and weight, storage cell size and number, and dry-matter of roots.

2.4 GENERAL CULTIVATION.

After clearing the land, the weeds may be burned to increase the mineral content of the soil. The cleared piece of land can be left flat or made into ridges.

Planting can be done in any month of the year, but is usually preferred at the beginning of the rainy season (Nweke *et al.*[1], 1994). About 25cm of stem cuttings from mature, selected virus-free plants are inserted to about half their length in ridges, about 75-90cm apart with 30-40cm between cuttings, in desirable rows. Cuttings that are inserted into soil slanted give better yield than those inserted vertically. The undergrowth should be cleared one month after planting. If fertilizer is to be applied, it is advisable to do so in the first and third months after planting.

In Africa, cassava is grown on small farms, usually intercropped with vegetables, sweet potato, cereals or legumes (Sauti *et al.*, 1994). Small-scale farmers hardly apply fertilizer due to its high cost or non-availability in some instances.

2.5 STAGE OF GROWTH OF CASSAVA AT HARVEST.

Cassava roots mature between 6-18 months depending on cultivars but can remain in the soil for two years after maturation. The stage of growth of cassava at which it is harvested is determined by the following factors:

1. Market pressure- the distance to the nearest urban centre, the number of farm tasks performed by hired labour and market access infrastructure.
2. Demographic pressure- This is represented by the population density within the farming communities or neighbouring communities where the produce will be sold; the higher the population density, the greater the demand for cassava and hence the shorter the period allowed for roots to stay in the soil before harvest.
3. Environmental pressure- Different climates and altitudes result in different bulking periods for cassava due to their effects on soil fertility and rainfall pattern.
4. Varietal effect- Different varieties of cassava may have different physiological and morphological characteristics, one of which is bulking period (Nweke *et al.*[1], 1994).
5. Level of processing- The mean proportion of cassava output that is processed per harvest or commercialization of production, has an effect on the desired age at which the roots are harvested for two reasons. One is that a commercial producer is interested in a rapid turnover and the shorter the bulking period, the higher the rate of turnover. Secondly, a middleman who is either a trader or a processor is particular about the

quality of product he purchases for further selling or processing. Such a person would not buy old cassava because it might produce a processed product of poor quality (Nweke *et al.* 1994).

6. Other factors such as short-term variations in price of cassava products and in household food needs also affect age at harvest.

The modal harvest age for cassava reported by Nweke *et al.* (1994) was 12 months after planting, at which age more than 70% of villages studied in Nigeria reportedly harvested their cassava; 25% reported less than 12 months and only 5% reported over 12 months as the usual harvest age. Fresco (1986) reported that early harvesting leads to yield losses because the plant has insufficient time to accumulate dry matter.

Harvesting is usually by hand. Losses through harvesting, handling, rotting, sprouting and streaking may be as much as10%.

2.6 WORLD PRODUCTION.

According to FAO estimates, 172 million tonnes of cassava were produced world wide in 2000. Africa accounted for 54%, Asia for 28%, and Latin America and the Caribbean for 19% of the total world production. In 1999, Nigeria produced 33 million tonnes of cassava, becoming the world's largest producer.

In terms of area, a total of 16.8 million tonnes was planted with cassava throughout the world in 2000; about 64% of this was in sub-Saharan Africa. The average yield that year was 10.2 tonnes per hectare, but this varied from 1.8

tonnes per hectare in Sudan to 27.3 tonnes per hectare in Barbados. In Nigeria, the average yield was 10.6 tonnes per hectare (www.iita.org/crop/cassava.htm#).

2.7 PESTS AND DISEASES.

In Africa, the major pests are the cassava green mite, the cassava mealy bug and the variegated grasshopper. The main diseases that affect cassava are the mosaic disease, bacterial blight, anthracnose and root rot. Pests and diseases, together with poor cultural practices, combine to cause yield loses up to about 50% in Africa. (Source: www.iita.org/crop/cassava.htm#; http://www.iita.org/research/high2000/proj10.htm#; http://www.iita.org/research/high2000/proj6.htm#).

2.8 WOMEN IN CASSAVA PRODUCTION.

Women are involved in planting, weeding, harvesting and transporting of crops from the field, as well as processing, storing and marketing of root crops. However, they lack adequate improved technology and extension services to improve upon their production. Generally, women are solely responsible for food processing for both the family and the market. All other agricultural activities apart from land acquisition and preparation are dominated by women, sometimes with their children helping them (Haleegoah *et al.*, 1992; Nweke *et al.*, 2002).

2.9 CONSTRAINTS TO CASSAVA PRODUCTION.

The major constraint to cassava production is the slow multiplication rate of good quality vegetative planting materials, compared to grain crops, which are propagated by true seeds. In addition, cassava stem cuttings are bulky, increasing transport cost; they are also highly perishable and dry up in few days. As a root crop, cassava requires considerable labour to harvest. Because they are highly perishable, roots must be processed soon after harvest, to storable forms. Most cassava varieties are known to contain cyanogenic glucosides, and inadequate processing before consumption can lead to chronic cyanide toxicity. Various processing methods such as grating, fermentation and sun drying are used to reduce the cyanide content (Source: www.iita.org).

2.10 RESEARCH ON CASSAVA IN AFRICA.

A lot of work has been done on cassava by research institutes such as IITA. IITA has, for example, played a leading role in the development of improved cassava varieties that have the following desirable qualities:

1. disease and pest resistance,
2. low cyanogenic potential ,
3. drought resistance,
4. early maturation,
5. high yield.

Currently, 60% of the area cultivated in Nigeria has improved cassava varieties, resulting in Nigeria leading in cassava production worldwide.

In the area of post harvest, IITA scientists have been developing simple machines, which reduce processing time and labour, as well as production losses. With these machines, losses can be reduced by 50% and labour by 70%. During the past three decades, over 9000 scientists and technicians have been trained by IITA in various fields. For example in about 10 African countries, researchers were trained in the processing and utilization of high quality cassava flour. Such flour was used for preparation of products such as biscuits and noodles. Source: www.iita.org.

2.11 VARIETAL CHARACTERISTICS OF FOUR IMPROVED CASSAVA VARIETIES.

Cassava contributes significantly to the economy of Ghana. Its multiplication in the formal planting material sector started in the 1990s, when four high yielding varieties namely *Afisiafi, Tek bankye, Abasafitaa* and *Gblemoduade* were released. The new varieties were found to be acceptable to the consuming public, including food processors and industrialists. They were also superior in yield, disease resistance and pest resistance to the existing local varieties. It is required that for new varieties to be released, they must be very distinct in their characteristics from all other varieties. Varietal characterization also facilitates ease of identification by quality control personnel and farmers. The distinguished characteristics of the four improved varieties are as shown below (RTIP Fact sheet 2002):

Afisiafi

The clone (*TMS 30572*) was introduced from IITA to Ghana in 1988 under the code *GC/88-07*. The morphological characteristics are:

- Light green petiole
- Brownish grey mature stem
- Light brown outer skin of root with cream inner skin
- Can be grown in both major and minor seasons
- Highly tolerant to major pests and diseases
- Suitable for the preparation of *gari, agbelima* and *kokonte*
- Not suitable for *fufu* and *ampesi*
- Suitable for industrial uses- starch and flour

Yield

Average yield (12 months maturity)

- Fresh roots: 27-30 ton/ha
- Dry roots: 9-10 ton/ha

Cyanogenic potential	mg HCN/100g (FWB)
- unpeeled fresh root:	13.0-25.5
- peeled fresh root:	15.3
- *kokonte* (dried unfermented chips):	8.2
- *agbelima* (roots milled into dough):	2.7
- *gari* (grated, fermented, sieved and fried mash):	1.1-5.2

Tek bankye

Tek bankye was received as an open pollinated seed from IITA in 1984. It was named then as *Isunikankiyan*. One segregant of *Isunikankiyan* was selected and coded *Isu-White* (*Isu-W*). Cuttings were irradiated in 1987 to induce variation for cooking quality. Mutant with acceptable cooking quality was identified and released as a variety.

The identified morphological characteristics are:

- red petiole
- grey mature stem
- moderately tolerant to the African Cassava Mosaic Virus Disease (ACMVD)
- moderately tolerant to major diseases and pests of cassava
- pale brown outer skin of root
- suitable for the preparation of all the important food items (*fufu, ampesi, gari, kokonte* and *agbelima*)
- may be grown sole or intercropped in both the major and minor season
- suitable for industrial uses- starch, flour

Yield

Average yield (12-18 months maturity)

- fresh roots: 26-31 ton/ha
- dry roots: 8 ton/ha

Cyanogenic potential	mg HCN/100g (FWB)
- unpeeled fresh root	44.22
- peeled fresh root	-
- *ampesi* (boiled roots)	6.22
- *fufu* (pounded boiled roots)	6.22
- *kokonte* (dried unfermented chips)	8.89
- *agbelima* (roots milled into dough)	-
- *gari* (grated, fermented, sieved and fried mash)	0.32

(Source: RTIP Fact sheet, 2002)

Abasafitaa

The clone (*TMS (4)1425*) was introduced to Ghana from IITA in 1988 under the code *GC/88-03*. It has these morphological characteristics:

- short low branching variety
- yellow petiole with pinkish tip
- brownish-white mature stem
- brownish-white outer skin of root
- cream inner skin colour of the root

- may be grown sole or intercropped in both the major and minor seasons

- moderately tolerant to the ACMVD

- highly tolerant to other major cassava diseases and pests

- suitable for the preparation of all the important food items (*ampesi, fufu, gari, agbelima* and *kokonte*)

- suitable for industrial uses-starch, flour

Yield

Average yield (12 months maturity)

- fresh roots: 26-31 ton/ha
- dry roots: 8-10 ton/ha

Cyanogenic potential	mg HCN/100g (FWB)
- unpeeled fresh root:	8.4-24.0
- peeled fresh root:	17.5
- *ampesi:*	4.6
- *fufu:*	2.1
- *kokonte:*	3.5
- *agbelima:*	3.8

- *gari:* 0.4-2.3

(Source: RTIP Fact sheet, 2002)

Gblemoduade

The clone (*TMS 50395*) was introduced to Ghana from IITA and coded *GC/88-05*. Major identifiable morphological characteristics are:

- light green petiole colour with purplish tip
- brownish-grey matured stem
- dark brown outer skin colour of roots
- milky white inner skin colour
- suitable for intercropping and sole cropping
- can be planted in both major and minor seasons
- has medium to high tolerance to major pests and diseases
- suitable for the preparation of *gari*, *agbelima* and *kokonte*
- not suitable for *fufu* and *ampesi*
- suitable for industrial uses-starch, flour

Yield

Average yield (12 months maturity)

- fresh roots: 33-38 ton/ha
- dry roots: 9-11 ton/ha

Cyanogenic potential	mg HCN/100g (FWB)
- unpeeled fresh root:	19.8-23.8
- peeled fresh root:	18.8
- *kokonte*	4.2
- *agbelima*	2.1
- *gari*	0.5-2.0

(Source: RTIP Fact sheet, 2002)

2.12 EFFECT OF PLANTING TIME AND VARIETY ON ROOT YIELD.

Yield of harvested roots of cassava have been reported (Nembozanga Sauti, 1984) to depend significantly on variety since varieties differ in terms of moisture content and dry matter. Time of planting has also been reported to affect root yield in some cases. In trials conducted at Bvumbwe and Baka research stations in Malawi, 3 cassava varieties (Chitembwema, Mbundumali and Gomani) planted at monthly intervals in an attempt to determine the effect of different planting dates on yield, revealed that at both sites, yields were highest for crops planted in January. At Bvumbwe, there were highly significant differences between varieties, whereas time of planting had a marked effect at Baka (Nembozanga

Sauti, 1984). It is worth noting that Malawi has distinct dry (April – October) and wet (November – March) seasons. Ezedinma *et al.*, (1981) found that yields of fresh cassava were not affected significantly by planting dates but that late plantings produced the highest dry-matter yields. Okigbo (1971) also reported that cassava planted later than June in Nsukka, Nigeria, produced higher yields of storage roots than did that planted earlier. The findings above agree with that of Ngendahayo and Dixon (1998).

2.13 FUNCTIONAL PROPERTIES OF FLOUR.

2.13.1 Occurrence of Starch.

Starch exists as a major reserve carbohydrate of higher plants especially in the roots and tuber crops. Of all the polysaccharides, only starch is produced and stored in small packets called granules. Since they are biosynthesized in plant cells, they assume size and shape prescribed by the biosynthetic system of the host plant and by the physical constraints imposed by the tissue environment. Different plants will therefore have starch granules of different sizes and shapes, when examined under the microscope (Whistler and Daniel 1984). There could even be differences in the size and shapes of starch granules from the same plant but different varieties. Starch granules of root and tuber crops therefore vary in shape, size, amylose content and functional properties, depending on the source of the crop.

Starch in root crops exists relatively free from lipids and proteins, and hence its extraction and purification are relatively simple. The high starch content of cassava, which can be grown on marginal soils, makes it an important industrial crop in addition to being a calorie-rich food crop (Balagopalan *et al.*, 1988).

2.13.2 Chemical Structure of Starch.

Starch is a polysaccharide made up of D-glucose units joined by both α-(1,4)-linkages and α-(1,6)-linkages (Moorthy, 1994). It is found in layers in a granule that is surrounded by a thin protein layer. Starch is made up of two polymers, amylose and amylopectin. Amylose is the linear polymer component of starch consisting of α-D-glucopyranosyl units joined to each other by α-(1-4)-glucosidic linkages. It has a degree of polymerization (DP) of several thousand glucose units (molecular weight of 1.5-10.0 x 10^4).

Amylopectin on the other hand, is made up of linear glucosyl chains, just like amylose chains, joined to each other by α-1,6-glycosidic linkages; these form branched points in the amylopectin structure. The molecular weight of amylopectin (10^7) is higher than that of amylose. The degree of polymerization ranges from 10^4 to 10^5, making amylopectin one of the largest naturally occurring macromolecules. Starches consisting of almost only amylopectin, such as waxy corn, waxy barley or waxy rice, produce clear pastes that are fairly stable and resistant to retrogradation.

The functional properties of starch (gelatinization, pasting, viscosity, retrogradation, swelling and solubility) which control the sensory attributes and stability of processed starch products depend on the composition and molecular structure of the starch granules. These include the amylose/amylopectin ratio, the characteristics of each fraction in terms of molecular weight, degree/length of branching, and the physical manner in which the constituents are organized in the granules (Rickard *et al.*, 1991).

2.13.3 Amylose Content.

The functional properties of many starch-based food products can be attributed to the water-soluble or water-dispersible fraction found in the starch granule, amylose (Ihekoronye *et al.*, 1985). The linear amylose chain is made up of several glycosyl units which have hydroxyl hydrogen and oxygen atoms that undergo hydrogen bonding either with similar groups on adjacent molecules or with water molecules in aqueous solution. When they hydrogen bond with water molecules, it results in dissolution of the starch. On the other hand, when similar linear amylose chains lie parallel and close to each other, they associate through hydrogen bonds along their length, creating junction zones or crystalline forms that exclude water. When the ambient temperature is not sufficiently high to energetically pull the combined chain segments apart, the junction zones will remain and may even grow by extending in length as neighbouring chain segments move together in a zipper-like manner. This results in aggregation and consequent particle formation whose size may increase to a point where gravitational effects cause it to precipitate (Whistler and Daniel, 1984). This insolubilization effect may result in retrogradation and the exclusion of water (syneresis). High amylose starches therefore are more susceptible to retrogradation. For steric reasons, linear polysaccharides require more space for gyration and their solutions are more viscous than those of branched polysaccharides.

Amylose molecules exist as helical structures both in starch granules and in solution, and entrap other molecules such as fatty acids or hydrocarbons (Whistler and Daniel, 1984). It has a high affinity for iodine and produces a dark blue colour with it. The colour is due to the formation of a complex in which the iodide ions fit into the helical structure of amylose in solution. This forms the basis for the determination of amylose using the blue value method (Balagopalan, 1988). Other methods for determining amylose are the potentiometric and amperometric iodine titration methods. The amylose content of cassava starch using different methods have been reported by Rickard *et al.* (1991) to be in the range 13.6 and 23.8%. Values ranging from 22.6 to 26.2% and 17-26% have also been reported by Moorthy *et al.* (1992) and Fernandez *et al.* (1996) respectively.

2.13.4 Gelatinization and Pasting of Starch.

When granular starches are heated in aqueous environment, they undergo a series of changes known as gelatinization and pasting. Starch gelatinization is the collapse or disruption of molecular order within the starch granule manifested by irreversible changes in properties such as granules swelling, native crystallite melting, and loss of birefringence and starch solubilization. Gelatinization of starch takes place over a definite range of temperature known as gelatinization temperature. This series of events is one of the most important in food industry, since they affect the texture and digestibility of starchy foods. An empirical rheological test of the gelatinization properties of starches is the measurement of viscosity of starch dispersions in a temperature/time profile using Brabender

Visco–amylograph (Rickard *et al.*, 1991). The initial point of gelatinization and the range over which it occurs is governed by starch concentration, method of observation, granule type and heterogeneities within the granule population under observation (Atwel *et al.*, 1988). Starch granules are made of amylose and amylopectin molecules and these are linked either intermolecularly or intramolecularly by hydrogen bonding; the linkages may either be direct or through hydrate bridges to form micellar regions. The strength of the micellar network decides many of the properties of the starch granules (Balagopalan *et al.*, 1988). Starch heated in water to its gel temperature takes up more than 10 times its weight of water. As the temperature rises after the onset of gelatinization, the granules continue to swell and take up water but retain some air due to residual bonds.

Starch gelatinization depends on other factors such as pH and moisture content of the sample, rate of heating of sample suspension and presence of other components such as sugars, salts, proteins and lipids which compete with starch for water (Whistler and Daniel, 1984).

2.13.5 Swelling Power and Solubility.

Swelling power is the maximum increase in volume and weight, which starch undergoes when allowed to swell freely in water (Balagopalan *et al.*, 1988). As temperature of the aqueous suspension of starch is increased above the gelatinization temperature range, intermolecular and intramolecular hydrogen bonds become disrupted while water molecules get attached to the hydroxyl groups that are liberated, resulting in continued swelling of granules. Granular swelling occurs with corresponding increase in starch solubility due to starch-water hydrogen bonding. The swelling behaviour of starch is dependent on the strength and nature of the micellar network within the starch granules, which correspondingly depends on the nature and strength of associative forces within the granules. The various factors that determine the associative forces include:

(1) ratio of amylose to amylopectin,

(2) molecular weight of the fractions,

(3) molecular weight distribution,

(4) degree of branching,

(5) structural conformation of amylose and amylopectin, and

(6) length of the outer branches of amylopectin molecules that can partake in associative linkages.

The presence of naturally occurring non-carbohydrates such as lipids (fats, oils and fatty acids), affect both swelling power and solubility, since they have hydroxyl groups that can interact with the hydroxyl groups of helical amylose. Such amylose–lipid complexes are less easily leached from the granule and they resist entry of water into the granule, hence reducing swelling and solubilization of starch (Whistler and Daniel, 1984). Normal starches fall into three groups, depending on their degree of association. The cereal starches, with the highest degree of association, have lowest swelling power and solubility, followed by root starches and then tuber starches (Balagopalan *et al.*, 1988). Moorthy (1994) reported that cassava starch had swelling power lying in between those of cereals and potato starches.

Starches that swell greatly give shiny and cohesive paste. This sort of consistency is desirable in foods. However, greatly swollen granules are quite fragile and break down with stirring, resulting in subsequent decrease in viscosity (Rickard *et al.*, 1991).

2.13.6 Viscosity Profile or Pasting Characteristics.

An important property of starch is that it provides a viscous paste when heated in the presence of water. This viscosity accounts for the use of starch in textiles, paper, adhesives and the food industry. Cassava flour, which contains a lot of starch, also shows this phenomenon. Viscosity profile of starch paste can be studied using the Brabender amylograph or viscograph. The transition from a suspension of starch granules to paste when heat is applied is accompanied by a large increase in viscosity. Changes in viscosity also accompany the formation of gels upon cooling of starch paste. The extent of this increase reflects the retrogradation or setback tendency of the starch, which is greater with increasing amylose content. When an aqueous concentrated suspension of starch is heated above its gelatinization temperature, the individual granules swell and gelatinize rapidly and freely until they absorb almost all the available water, causing the viscosity to increase. The temperature at which the viscosity begins to rise is termed pasting temperature, and the temperature corresponding to a rise in viscosity of 20BU (Brabender Units) is the gelatinization temperature. Highly swollen granules are very susceptible to thermal or mechanical breakdown and the peak viscosity is obtained when the increase in viscosity caused by swelling is counter balanced by the granule disintegration and starch solubilization. As heating continues, granule rupture increases and the viscosity gradually decreases; the drop in viscosity on holding at 95°C indicates stability of the hot paste. On cooling the paste to 50°C the viscosity usually increases slightly. The extent of this increase reflects the retrogradation tendency of the sample.

Typically, an amylogram contains the following significant points (ISI 19-6e):

1. Pasting temperature = temperature at which viscosity starts rising,
2. Gel temperature = temperature at which viscosity has increased by 20BU,
3. Peak temperature = temperature at which viscosity reaches its peak value,
4. Peak viscosity = viscosity at peak temperature,
5. Visc 95 = viscosity when temperature reaches 95°C,
6. Visc 95/20 = viscosity after 20 min at 95°C (1st holding period),
7. Visc 50 = viscosity when cooled down to 50°C,
8. Visc 50/20 = viscosity after 20 min at 50°C (2nd holding period/ end of test),
9. Hot Paste Breakdown = peak visc – visc 95/20,
10. Setback (Retrogradation) = visc 50 – visc 95/20.

BU = Brabender Units

(Source: http://home3.inet.tele.dk/starch/isi/methods/19brabenderNotes.htm)

Viscosity values vary with temperature programme, speed of stirring (rev/min) and concentration of suspension. Fernandez *et al.* (1996) reported the pasting characteristics of starch from six cassava varieties as shown in table 2.1 below:

Table 2.1: Values of Total Cyanogens in Parenchyma, Amylose content, Starch Crystallinity and Starch Functionality Characteristics for six Cassava Cultivars harvested in October 1992 at CIAT.

Characteristics	CULTIVAR					
	CM 3306	CGI-37	MVEN 77	CG 165-7	M Tai 1	MVEN 25
Total Cyanogen (HCN, mg/kg DB)	82	182	223	402	629	1629
Amylose	26	22	23	22	22	22
Crystallinity (%)	43	44	40	44	43	43
Gelatinization temperature (°C)	64.0	64.0	65.0	62.5	62.5	62.5
Maximum Viscosity	975	775	610	800	780	730
Viscosity at 95°C	415	320	330	350	340	310
Viscosity after 20min at 95°C	260	225	195	220	230	190
Viscosity at 50°C after cooling	520	460	380	435	410	330
Ease of cooking[a]	4	4	7	5	5	5
Gel instability[b]	715	550	415	580	550	540
Gelatinization index[c]	260	235	185	215	180	140

(Source: Fernandez *et al.*, 1996)

a: Ease of cooking = time to maximum viscosity – time to gelatinization

b: Gel instability = maximum viscosity – viscosity after 20 min at 95°C

c: Gelatinization index = viscosity at 50°C after cooling – viscosity after 20 min at 95°C

Safo-Kantanka and Asare (1993) in their study on cooking quality of different cassava varieties, reported the following values for the pasting characteristics of six varieties.

Viscosity Changes of Starch and Flour during Gelatinization.

Table 2.2: Sample: 7% suspension of Cassava Starch.

Variety	Pasting Temp.	Peak Temp.	Peak Viscosity	Viscosity At 95°C	Viscosity at 95°C/30min	Viscosity At 50°C
Ankra	74	82	560	460	260	480
91934	74	77	500	380	145	280
60142	69	77	440	390	200	430
30474	71	85	340	290	140	280
Isu-W	75	83	300	260	160	260
30001-W	68	83	400	360	240	420

(Source: Safo-Kantanka and Asare, 1993).

Table 2.3: Sample: 7% suspension of Cassava Flour.

Variety	Pasting Temp.	Peak Temp.	Peak Viscosity	Viscosity At 95°C	Viscosity at 95°C/30min	Viscosity At 50°C
Ankra	68	76	490	320	150	130
91934	68	72.5	380	40	0	0
60142	69.5	74	300	210	80	60
30474	71	78.5	90	60	30	20
Isu-W	69.5	76.3	300	210	80	60
30001-W	68	78.5	300	200	60	60

(Source: Safo-Kantanka and Asare, 1993).

2.13.7 The Brabender Amylograph.

(a) Application.

The Brabender amylograph offers the most information at a lower cost. It is a standard instrument that may be used to test the gelatinization properties of wheat and rye flour, as well as any pure sample of starch. Over five decades, it has been used world wide as an essential tool in the milling and baking industry. By measuring the viscosity of a flour-water suspension and its dependence on temperature, the amylograph gives information concerning the α-amylase and diastatic activity of the sample. In the amylograph test, heating is done in such a way that it gives good correspondence to the baking process (Brabender Amylograph Manual).

(b) Principle of Operation.

The suspension prepared from the sample (starch or flour) and distilled water is heated in a rotating bowl at a constant rate of 1.5°C/min, and the heating is controlled by a thermoregulator. This heating causes an increase in viscosity of the suspension and gelatinization of starch granules, followed by liquefaction. Depending on the viscosity of the sample inside the rotating bowl a sensor, which reaches into the sample, is deflected against the force or torque of a measuring spring. This deflection is recorded on a line or chart recorder. In this way, viscosity is recorded over time depending on the rising temperature (Brabender Amylograph Manual).

2.14 UTILIZATION OF CASSAVA FOR HUMAN CONSUMPTION.

Cassava is the basis of many products, including food. In Africa and Latin America cassava is mostly used for human consumption, while in Asia and parts of Latin America it is also used commercially for the production of animal feed and starch-based products. In Africa, cassava provides a basic daily source of dietary energy. Roots are processed into a wide variety of granules, pastes and flours, or consumed freshly boiled or raw. In most of the cassava-growing countries in Africa the leaves are also consumed as green vegetables, which provides protein and vitamins A and B. Work done and published on the internet (www.specialfoods.com/cassava.html) suggests that one pound of cassava flour contained about 1550 calories. Cassava flour produced and advertised at this electronic webpage is said to have the following composition approximately; 80.4% carbohydrates, 1.7% protein, 1.6% fat, 12% fiber, 0.1% water and 4.2% minerals. The flour is reportedly used to make quick breads, loaf breads, cookies, doughnuts, pancakes, dumplings and so on.

In Southeast Asia and Latin America, cassava has taken on an economic role. Cassava starch is used as a binding agent, in the production of paper and textiles, and as monosodium glutamate, an important flavoring agent in Asian cooking. In Africa, cassava is beginning to be used in partial substitution for wheat flour used for baking.

2.15 CASSAVA FLOUR PREPARATION.

In most cases, cassava flour is made from dry cassava chips. The methods of drying may vary according to the type of product to be made. In Nigeria, fermented cassava flour (lafun) is obtained by soaking roots for 3-4 days in water to ferment, followed by drying in the sun, and milling into flour. In Cote d'Ivoire, cassava flour is obtained by peeling, washing, chipping and drying at a slow rate, then milling into flour. Bokanga (1995) proposed a method for the production of high quality cassava flour suitable for baking. The method involves peeling, washing and grating the fresh harvested roots into mash and pouring the mash into porous, woven polythene sacks, and pressing mechanically to dewater. The pressed mash is then pulverized and spread on raised wooden platforms lined with black polyethylene films and exposed to the sun. The sun-dried granules are then milled and sieved to obtain the flour. Bokanga (1995) reported that cassava flour preparation, from harvesting to drying should be completed within a day.

2.16 WHEAT SUBSTITUTION POTENTIAL OF CASSAVA.

Cassava products could be used as partial or total substitutes for imported cereals such as wheat, thus saving foreign exchange and reducing the vulnerability of African economies to fluctuation in world market conditions. The extent to which such benefits are realized depends on government policies with respect to trade, foreign exchange rates and market prices. The major factors affecting wheat consumption and imports by developing countries include rising income, rising value of human time, increased urbanization, lagging production of staple foods, food aid, changing relative prices, consumer pricing policies, market promotion and institutional arrangements in the wheat processing industry. Consumption of wheat products is closely related to income levels and it is significantly higher in urban areas where people are ready and willing to pay a premium for convenience foods consumed away from home, and that require little or no processing. This reflects the higher opportunity cost of food preparation time at home due to working outside the home and to the high cost of transportation in the cities. These favour bread consumption even though the price of bread is nearly double that of wheat flour and it is usually higher than the price of traditional staple foods (Bokanga *et al.*, 1994).

2.17 GARI PREPARATION.

Gari is a toasted food product made from cassava and common in Ghana and Nigeria. Its preparation involves peeling, washing and grating fresh cassava roots into a mash or pulp. The pulp is put into porous, plastic sack and weighted down with a heavy object for 3 to 4 days to express effluent from the pulp while it is fermenting. The dehydrated, fermented pulp is pulverized and sieved after which it is toasted in a pan. Palm oil is sometimes added during toasting to prevent pulp from burning. The toasted granules may be sieved through a cane mesh to obtain grains of fine sizes.

Grating, effluent expression, pulverization, toasting and addition of palm oil reduce cyanogens to safe levels (Hahn, 1989). Fermentation imparts sour taste to gari. Duration of fermentation varies depending on consumer preference and ethnic locality. Toasting extends shelf life so that gari can easily be transported to urban markets. If stored in a dry environment, *gari* can store better than other grains since it is not attacked by weevils (Okigbo, 1980).

Gari preparation is labour-intensive and women provide the manual labour for these tasks. It is a convenient product because it is stored and marketed in a ready to eat form. It can be soaked or suspended in hot or cold water, depending on the type of meal being prepared. Because of its long shelf life, it is an attractive product to urban consumers.

2.18 ECONOMIC ASPECTS OF DRIED CASSAVA PRODUCTS.

2.18.1 Food Industry

Suitability of dried cassava products such as cassava flour as raw material base for bakeries, biscuit factories, noodles, animal feed, starch industries and other industrial products has proven the viability of cassava as a good business for Africans (Onabolu *et al.*, 1998). High quality cassava flour (HQCF) has reportedly been used increasingly as a partial substitute for wheat flour in biscuits (5-25%), bread baking (5-20%), and in noodles (10%) in Nigeria. Home caterers also substitute HQCF for wheat in chin-chin (25-100%), fish pies (12.5%), fish rolls (12.5%) and puff-puff (12.5%). This resulted in the income of manufacturers of such products increasing because HQCF (21.1naira/kg) was cheaper than wheat flour (38.34naira/kg) (Abass *et al.*, 1998).

Processors make traditional products when the market is prosperous or when HQCF is difficult to produce, for instance during the rainy season. This justifies the need to improve the sun drying method currently being used by African processors to cater for continuous usage during both the rainy and dry seasons.

Even though there are several small-scale starch producers in villages in West Africa, they produce on only small scale (200-2000kg/day of dried starch) for domestic purposes. Due to the small-scale production, food, adhesive and textile industries import large quantities of starch for their production since the small-scale farmers cannot provide as much as they need. The imported starch is usually extracted from maize, and it is not superior in quality to that extracted locally from cassava. There is the need therefore for governments and other agencies to help mechanize such starch processing to enable the small scale producers meet the demand of the large scale industries that utilize starch (Sanni, 2000).

2.18.2 Ethanol Production

Nigeria Yeast and Alcohol Manufacturing Plc. (NIYAMCO) produce ethanol from cassava due to inadequate supply of molasses from cane sugar as raw material. They produce 400-450litres ethanol per ton of cassava starch (typically 441litres/ton), thus producing a total of 3.969 million litres of ethanol per annum which is 88% efficiency of its installed capacity, using Novo Nordisk enzymes for liquefaction and saccharification. Table 2.3 below shows the respective costs of ethanol production from sugar cane molasses and cassava, as well as the yield and output of ethanol.

Table 2.4: Cost and Yield Comparison of Ethanol Production from Sugar Cane Molasses and Cassava in Nigeria.

MOLASSES AS RAW MATERIAL		CASSAVA AS RAW MATERIAL	
Description	**Amount**	**Description**	**Amount**
Total cost of production per litre	83.42 naira	Total cost of production per litre	30.83 naira
Quantity of molasses used	3000 tons	Quantity of cassava used	3000 tons
Yield of ethanol	260 litres/ton	Yield of ethanol	400 litres/ton
Ethanol output per 100 days of production	780,000 litres	Ethanol output per 100 days of production	1,080,000 litres

(Source: Toyin, 2000).

The results of shifting from molasses to cassava as a raw material for ethanol production were:

1. Farmers being empowered by developing potential for cassava multiplication using modern practices. The financial returns from the multiplication and industrial supplies were reinvested.
2. Rural dwellers in the farming communities were employed to assist in transporting, harvesting and processing of cassava.
3. Cassava production and yield increased through sponsored training programmes in better agronomic practices in collaboration with IITA. Such training helped the farmers to improve farm management and apply the correct fertilizer to their farms in the right proportions.

4. Release of new, improved cassava varieties with more desirable characteristics by Scientists.
5. Farmers developed ways to deliver cassava promptly to the ethanol-producing factory.

All the above factors helped farmers to achieve cassava yield of 30 to 40 tons per hectare (wet basis) (Toyin, 2000).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 SOURCE OF RAW MATERIALS.

Cassava varieties were obtained from experimental plots at the Wenchi Agricultural Research Station (WARS). The four varieties studied are *Afisiafi (AF), Tek bankye (TEK), Abasafitaa (AB)* and *Gblemoduade (GB).* The varieties were harvested at 9, 10, 11, 12, 13, 14 and 15 months after planting and processed into gari and flour. The varieties were not all planted in the same month and therefore reached maturity in different months. *Afisiafi* and *Tek bankye* reached 9 months after planting in March while *Abasafitaa* and *Gblemoduade* reached 9 months after planting in April.

3.2 PROCESSING OF CASSAVA ROOTS INTO GARI.

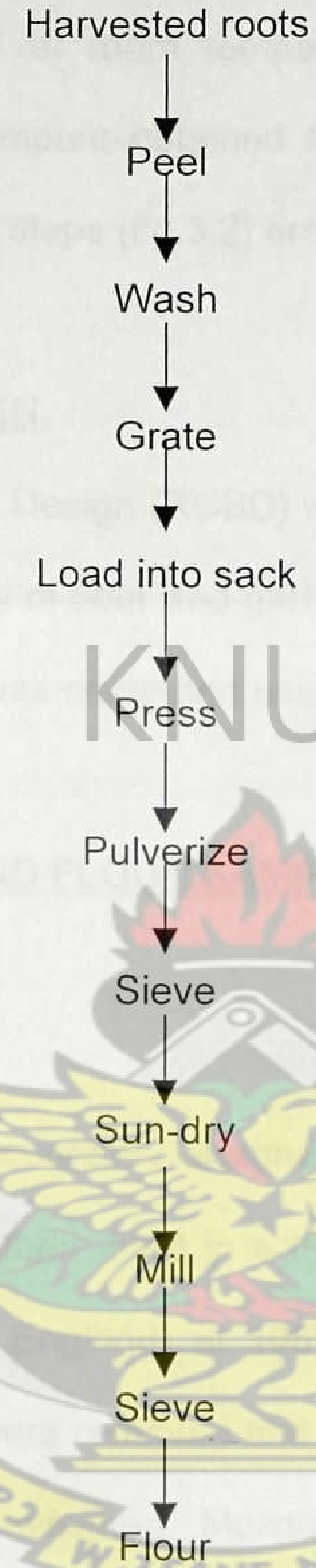
Fresh roots harvested from the farm were peeled the following day, washed with water and grated with a commercial mechanical grater. The grated mash was loaded into plastic woven sacks and pressed using manual screw-press to dehydrate it. It was then allowed to ferment for 2 days after which it was sifted to remove larger chunks. The fermented mash was roasted in an open pan greased with palm kernel oil, while stirring continuously with a broken piece of calabash. The roasted granules (gari) were then sieved through a cane mesh and packed into woven polyethylene sacks for storage. The yield of gari was then determined by weighing the amount obtained from processing 100kg of fresh cassava roots. The processing steps are shown in fig.3.1 below.

Fig 3.1. Flow diagram showing processing of cassava roots into Gari.

3.3 PROCESSING OF CASSAVA ROOTS INTO FLOUR.

Fresh roots were peeled a day after harvesting and washed. They were grated finely and the mash packed into porous woven polyethylene sacks and dehydrated manually by pressing with a screw-press. The cakes obtained from

Fig 3.2. Flow diagram showing processing of cassava roots into Flour.



pressing were stored in a freezer to prevent fermentation. The frozen cakes were thawed and pulverized the following day, sieved and spread thinly on raised wooden platforms lined with black polyethylene film, and allowed to dry in the sun while stirring intermittently. The dry granules obtained after 2 days of sun drying were milled and sieved to give the fine flour, which was packaged in transparent polyethylene bags and stored at room temperature. The yield of flour was determined by weighing the amount obtained from processing 100kg of fresh roots. The essential processing steps (fig.3.2) are shown above.

3.4 EXPERIMENTAL DESIGN.

A Randomized Complete Block Design (RCBD) was used to determine the effect of harvesting time on the quality of flour and gari from the four cassava varieties. Statistical analysis of the data was computed using Microsoft Excel programme.

3.5 ANALYSIS OF GARI AND FLOUR SAMPLES

3.5.1 MOISTURE CONTENT.

Two grams of sample was accurately weighed into a dried and previously weighed glass crucible. It was then dried in a thermostatically controlled forced convection oven (Gallenkamp, England) at 105°C until a constant weight was obtained. The glass crucibles were removed and transferred into a desiccator for cooling after which they were weighed. Moisture content was determined by difference and expressed as a percentage.

3.5.2 ASH CONTENT.

Two grams of sample was weighed into a pre-ignited and previously weighed porcelain crucible and placed in a muffle furnace (Gallenkamp, England) that was preheated to 600°C, and ignited for 2hr. After ashing, the crucibles were cooled to about 105°C in forced convection oven before cooling it further to room temperature in a desiccator. The crucible and content were weighed and the percent ash calculated.

3.5.3 pH DETERMINATION.

3.5.3.1 pH of Flour

Ten grams of flour was weighed into a dry beaker and 25ml of distilled water added. It was stirred thoroughly and the pH measured using a pH meter (HANNA Instruments, model 8521, U.K.) at room temperature.

3.5.3.2 pH of Gari

Ten grams of gari was weighed into a dry beaker and 100ml of distilled water added. It was stirred thoroughly and the pH measured using a pH meter (HANNA Instruments, model 8521, U.K.).

3.5.4 TOTAL TITRATABLE ACIDITY.

The gari suspension used for pH determination was filtered through a Whatmann's No.1 filter paper and 25ml of the filtrate titrated with 0.1M NaOH solution using phenolphthalein as indicator. The total titratable acidity was determined and expressed as percent lactic acid.

3.5.5 SWELLING CAPACITY OF GARI.

The swelling capacity of the gari samples was determined based on the method of the Natural Resources Institute (Bainbridge and Tomlins, 1996). A 50ml glass-measuring cylinder was filled with gari to the 10ml mark. Distilled water was added at room temperature (27-29°C) to give a total volume of 50ml. The top of the cylinder was tightly covered and the contents mixed by inverting the cylinder. After 2 minutes, the cylinder was inverted again for the contents to mix. The cylinder was left to stand for 3 minutes, giving a total of 5 minutes. The final volume occupied by the swollen gari after 5 minutes was recorded and the swelling capacity determined by dividing the swollen gari volume by the initial gari volume.

3.5.6 CRUDE PROTEIN.

The Kjeldahl method for protein determination was used. 2g of each flour sample was weighed and digested with 25ml of concentrated H_2SO_4 solution, in the presence of 0.5g Selenium catalyst. The digested solution was diluted with little distilled water, transferred into a 100ml volumetric flask and topped with more distilled water to the 100ml mark. 10ml of the diluted solution was distilled with about 17ml of 40% NaOH solution through the Kjeldahl apparatus and the distillate collected directly into 25ml of 2% boric acid solution stained with two drops of phenolphthalein indicator. When the pink colour of the boric acid solution turned green, the distillate collection was continued for five extra minutes. The ammonia distillate in boric acid solution was titrated with 0.1N HCl solution to a colourless end-point. The percent nitrogen and crude protein content were then calculated (AOAC, 1990).

3.5.7 CRUDE FIBRE.

Two grams of sample and 0.5g of asbestos catalyst were weighed into a flat-bottomed flask and 200ml of boiling 1.25% H_2SO_4 poured on them. They were boiled under reflux for 30 minutes after which they were washed with hot water on cheesecloth until they tested negative for acid using litmus paper. They were transferred back to the flat-bottomed flask and 200ml of boiling 1.25% NaOH poured on them. They were again boiled under reflux for 30 minutes and washed on cheesecloth with hot water until they tested negative for base using litmus paper. The residue was further washed with 15ml alcohol and transferred into porcelain crucible. It was dried in a hot-air oven and weighed, after which it was ignited at 600°C for 30 minutes in a muffle furnace. It was weighed after cooling and the fibre content calculated by difference and expressed as a percentage (AOAC, 1990).

3.5.8 STARCH YIELD OF FLOUR.

Ten grams of flour was weighed into a beaker and water added to form a slurry. The starch in the flour was extracted by washing it several times with water through cheesecloth until the flour showed no signs of containing any more starch. The starch suspension collected was allowed to stand until the starch settled at the bottom of the collecting vessel. It was decanted and dried in a hot-air oven at 50°C overnight and weighed. The starch yield was then expressed as a percentage.

3.5.9 AMYLOSE CONTENT.

The amylose content of the flour was determined spectrophotometrically by the method of McCready and Hassid (1943), as described below.

3.5.9.1 Preparation of the Amylose Standard Curve.

10, 30, 50, 70 and 90mg of pure corn amylose were weighed individually into 100ml volumetric flasks and made wet by adding 1ml of ethanol and 10ml of distilled water to them. They were made to dissolve by the addition of 2ml of 10% NaOH solution. Each flask with its contents was topped up to the 100ml mark with distilled water. A 5ml portion of this solution was dispensed into a 500ml volumetric flask and about 100ml distilled water added. It was slightly acidified with 3 drops of 6M HCl and 5ml of iodine solution was then added. The content was uniformly mixed by swirling the flask, after which it was topped with more distilled water to reach the 500ml mark. The absorbance of each standard solution was read in a UV-visible spectrophotometer (M259 Sherwood Scientific Ltd., U.K.) at 640nm and these values were used to plot a standard curve.

3.5.9.2 Determination of Amylose Content in Flour.

100mg of flour was weighed into a 100ml capacity volumetric flask and 1ml ethanol, 10ml distilled water and 2ml of 10% NaOH added to it. It was shaken and warmed to dissolve and more distilled water added to make up to the 100ml mark. A 5ml portion of the clear solution obtained was transferred into a 500ml volumetric flask and 100ml distilled water added. It was then acidified with 3 drops of 6M HCl, and 5ml iodine solution was added. The mixture was shaken and then made up with more distilled water to reach the 500ml mark. The absorbance of the solution was read at 640nm using a UV-visible spectrophotometer. Amylose concentration in the flour was determined from the equation of the standard curve.

3.5.10 SWELLING POWER AND SOLUBILITY.

The swelling power and solubility determinations were carried out based on a modification of the method of Leach *et al.,* (1959). One gram of flour was weighed into a previously weighed 40ml capacity centrifuge tube and 40ml distilled water added to it. The suspension was stirred uniformly and gently, avoiding excess force that might rupture starch granules in the flour. It was heated in a thermostatically controlled water bath at 85°C for 30 minutes, with constant stirring. The tube was removed from the water bath, wiped dry and allowed to cool to room temperature. It was then centrifuged in a refrigerated centrifuge (Centrikon T-42K, Italy) at 2200rpm for 15 minutes. The supernatant was poured into a weighed glass crucible and evaporated to dryness in an oven at 105°C. The dried supernatant was weighed after cooling and used to calculate the solubility. The sedimented paste was also weighed and used to calculate the swelling power.

3.5.11 PASTING CHARACTERISTICS.

Pasting characteristics of the flour was determined using the Brabender Amylograph (Brabender OHG Duisburg, model 486045, Germany, with 700cmg cartridge). A modification of the CRA Standard analytical method (B-9, draft ICC-standard No. 169) was used. A 6% aqueous suspension was made by dissolving 30g of flour in 500ml of distilled water. It was transferred into the amylograph vessel and heated uniformly at a rate of 1.5°C/min by means of an automated thermo regulator inside the amylograph. At a peak temperature of 95°C, the temperature of the paste formed was automatically held constant for 20 minutes (first holding period) while being stirred uniformly and constantly by the rotational movement of the amylograph vessel. The paste was then cooled gradually to 50°C and held constant at this temperature for another 20 minutes (second holding period). The following parameters were then recorded from the amylogram obtained; pasting temperature, gelatinization temperature (temperature at 20BU), peak temperature, peak viscosity, viscosity at 95°C, viscosity at 95°C after 20 minutes, viscosity at 50°C and viscosity at 50°C after 20 minutes.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 GARI RESULTS AND DISCUSSION

4.1.1 Moisture content of gari.

Moisture content of gari ranged between 9.54-11.57% (Fig 4.1). Statistical analysis showed significant difference ($p<0.05$) existing between ages but not among varieties. Other factors such as processing method or the extent of roasting affect the moisture content of gari. Codex standards for gari (Codex stan 151-1989) gave a maximum value of 12.0% for moisture. Moisture content of the gari samples was therefore within specification.

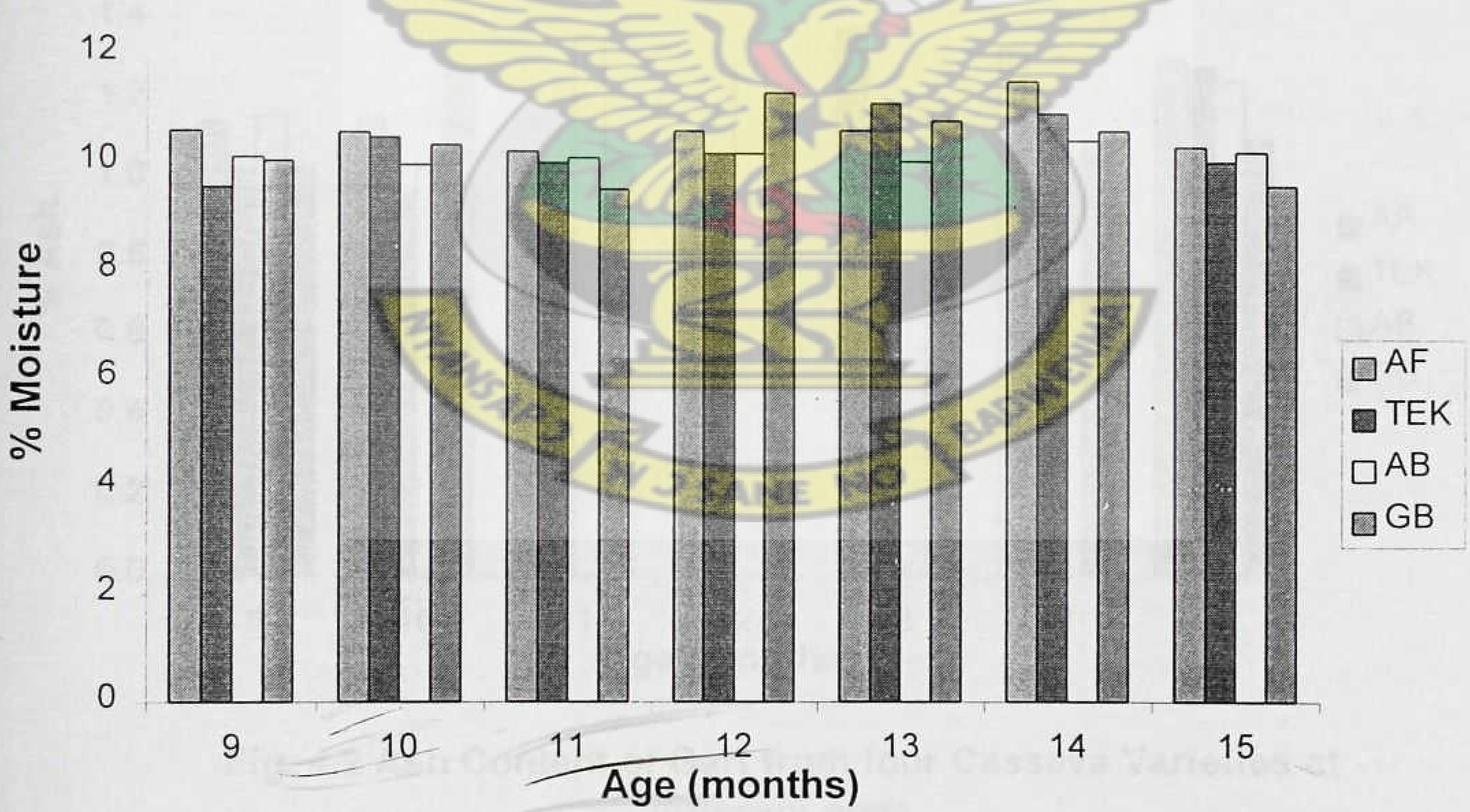


Fig. 4.1 Moisture Content of Gari from four Cassava varieties at different ages

4.1.2 Ash content of gari.

Ash content for *Afisiafi* was between 1.03-1.39% with the lowest at 12 months and the highest at 13 months while it was between 0.88-1.29% for *Tek bankye* with the lowest value at 11 months and the highest at 15 months. *Abasafitaa* had ash between 0.90-1.36% with 14 months having the lowest value and 11 months the highest while *Gblemoduade* had values between 1.03-1.28%, with the lowest at 9 months and the highest at 10 months. There was no significant difference ($p>0.05$) for both age and variety. Ash content, which is a measure of the mineral element content in the plant, depends on the mineral content of the soil. *Tek bankye* had lowest ash content except at both 14 and 15 months when it rose above that of *Abasafitaa* and *Gblemoduade*. *Afisiafi* had highest ash content from

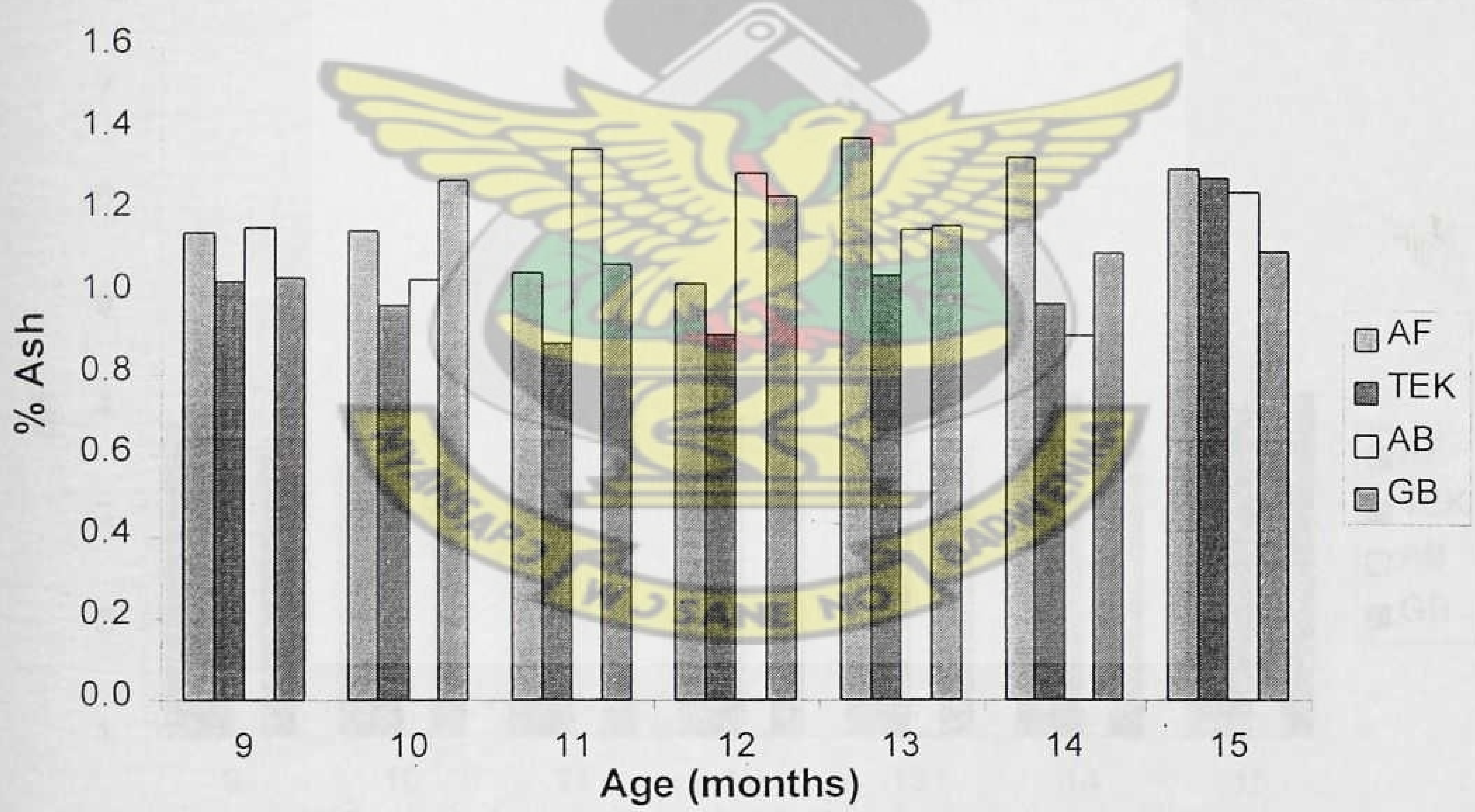


Fig. 4.2 Ash Content of Gari from four Cassava Varieties at different ages

13 to 15 months while *Abasafitaa* was highest at 9, 11 and 12 months after planting. *Gblemoduade* was highest only at 10 months after planting (Fig. 4.2). All the samples had values lower than the maximum of 2.75% specified by Codex Alimentarius (Rev.1-1995). This indicates less likelihood of heavy metal contamination during processing.

4.1.3 pH of gari.

The pH of the gari samples ranged between 3.58 and 4.59 as shown in Fig. 4.3 below. Even though pH depends on the extent of fermentation, statistical analysis showed it to be significantly affected ($p<0.05$) by age but not variety. Both *Afisiafi* and *Tek bankye* had their lowest pH values at 10 months after planting, which coincided with the onset of rains in April. This may be attributed

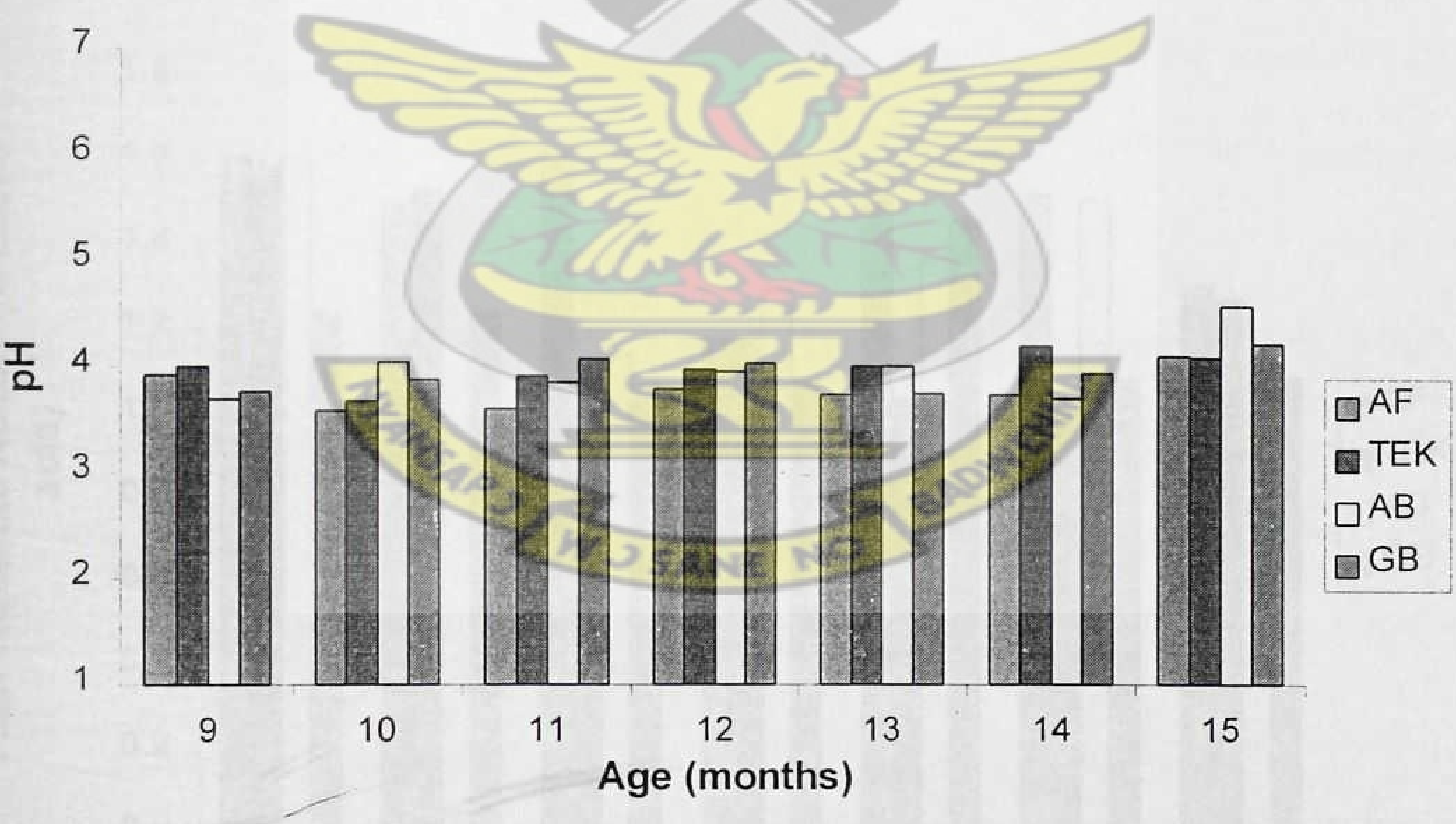


Fig. 4.3 pH of Gari from four Cassava Varieties at different ages

to starch hydrolysis or mobilization by the plants for germination at the onset of rains, resulting in most of the carbohydrates in the roots being in the form of fermentable sugars. They were thus readily fermented, giving low pH. *Abasafitaa* and *Gblemoduade* also had their lowest pH at 9 months after planting for the same reason since their 9 months old samples were harvested at the onset of rains in April. With the exception of *Tek bankye* that had its highest pH at 14 months after planting, all the other varieties had their highest pH values at 15 months after planting.

4.1.4 Total titratable acidity of gari.

Total titratable acidity of the samples ranged between 0.85-1.62% (Fig. 4.4). Age and variety did not significantly affect ($p>0.05$) the total titratable acidity.

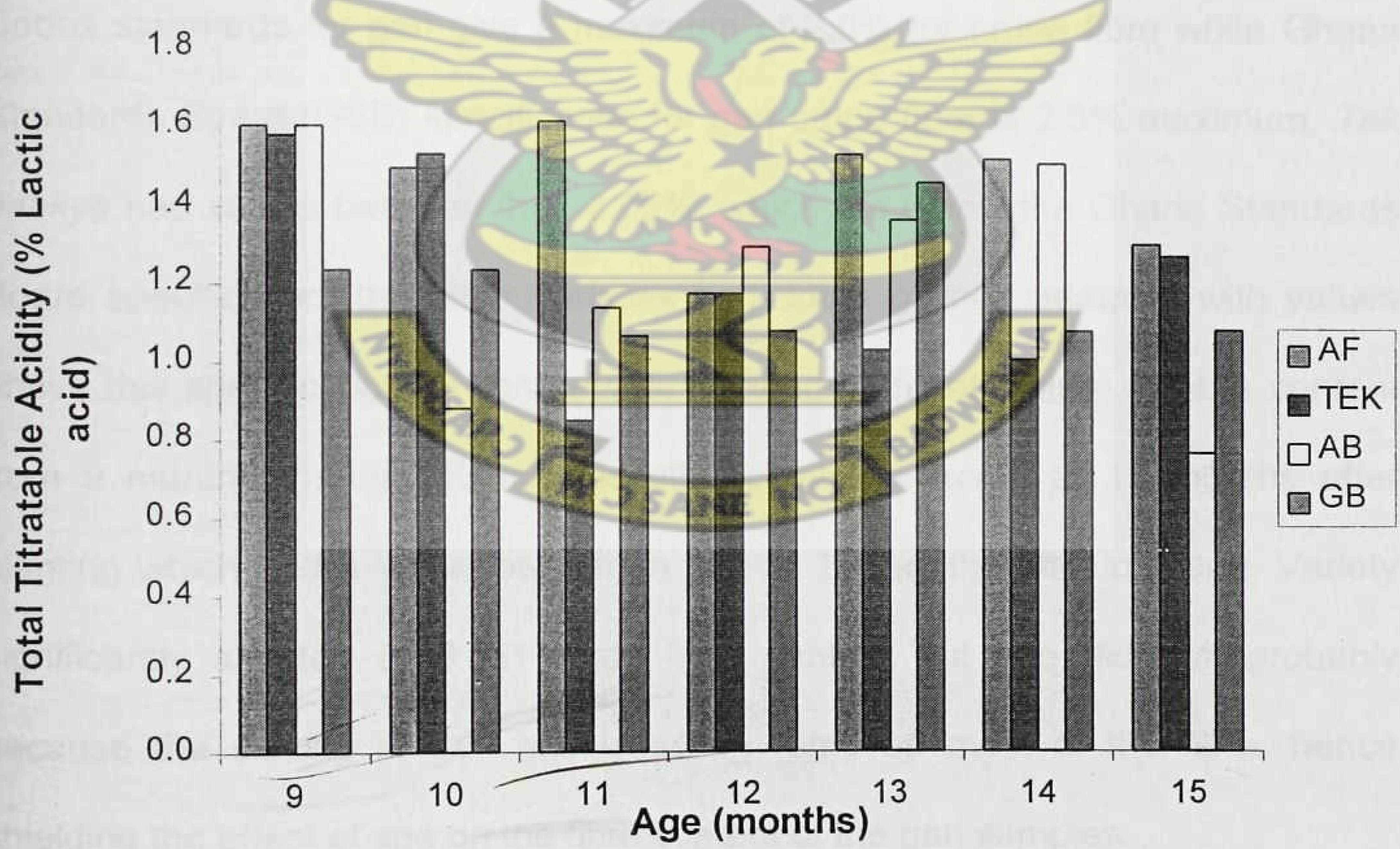


Fig. 4.4 Total Titratable Acidity Of Gari from four Cassava Varieties at different ages

This is probably due to the fact that titratable acidity depends more on the extent or duration of fermentation of the mash than on age or variety.

The codex standard of total acidity for gari is between 0.6-1.0%; most of the samples, however, had values above the codex upper limit. All the *Afisiafi* and *Gblemoduade* samples had values above 1.0% while *Tek bankye* 11 months and *Abasafitaa* 10 and 15 months old had values below 1.0%. *Abasafitaa* had its total acidity sequentially increasing from 10 months until 14 months, after which it fell to a minimum at 15 months after planting. The reason for this trend is unclear.

4.1.5 Crude fibre of gari.

Crude fibre content of the gari samples was in the range of 1.61% and 3.63%. Codex standards for gari give a maximum of 2.0% for crude fibre while Ghana Standards Board (GSB) specification for gari crude fibre is 2.5% maximum. *Tek bankye* had values between 1.61-2.25%, which are below the Ghana Standards Board specification; the other varieties had some of their samples with values above this specification. *Gblemoduade* showed sequential drop in fibre content from 9 months through 15 months after planting, except at 13 months after planting which had a value lower than that at 14 months after planting. Variety significantly affected ($p<0.05$) crude fibre content but age did not, probably because the sieving of gari after roasting removed most of the fibre, hence shielding the effect of age on the fibre content of the gari samples.

Fig. 4.5. Crude Fibre of Gari from four Cassava Varieties at different ages

4.1.6 Swelling capacity of gari.

Swelling capacity is a very important criterion for determining gari quality; the higher the swelling capacity, the greater is its suitability for use in foods such as '*eba*', which is a typical delicacy of Nigerians and most Ghanaians. Swelling capacity of gari also indicates its starch content since it is the starch component of gari that enables it to swell. The swelling capacity of *Afisiafi* ranged between 2.77-2.93 with the lowest at 14 months and the highest at 13 months; *Tek bankye* had values between 2.60-2.87 with the lowest value at 13 months and the highest at 11 months (Fig. 4.6). *Abasafitaa* had values ranging from 2.53-2.90 with the lower limit at 13 months and the upper limit at 15 months, while *Gblemoduade* had values between 2.63-2.93 with the lower limit at 13 months and the higher limit at 9 months. Apart from *Afisiafi* that had its lowest value at 14 months after planting, the other three varieties had their lowest values at 13 months after planting. For good quality gari, it should be able to swell to about 3 times its initial volume, as Codex Alimentarius Commission (1986) recommends

Fig. 4.6 Swelling Capacity of Gari from four Cassava Varieties at different ages

a value of 3. The samples studied had values below 3, indicating low starch content. Time of harvesting (age) and varietal differences had no significant effect ($p>0.05$) on the swelling capacities of the gari samples.

4.1.7 Bulk density of gari.

Determination of bulk density of gari is essential since gari is made up of granules of different sizes, and the granule sizes affect swelling capacity. Bulk density ranged between 0.49g/ml and 0.58g/ml (Fig. 4.7). Bulk density was significantly affected ($p<0.05$) by age but not by variety. Bulk density also depends on the processing method since some gari producers grind the granules

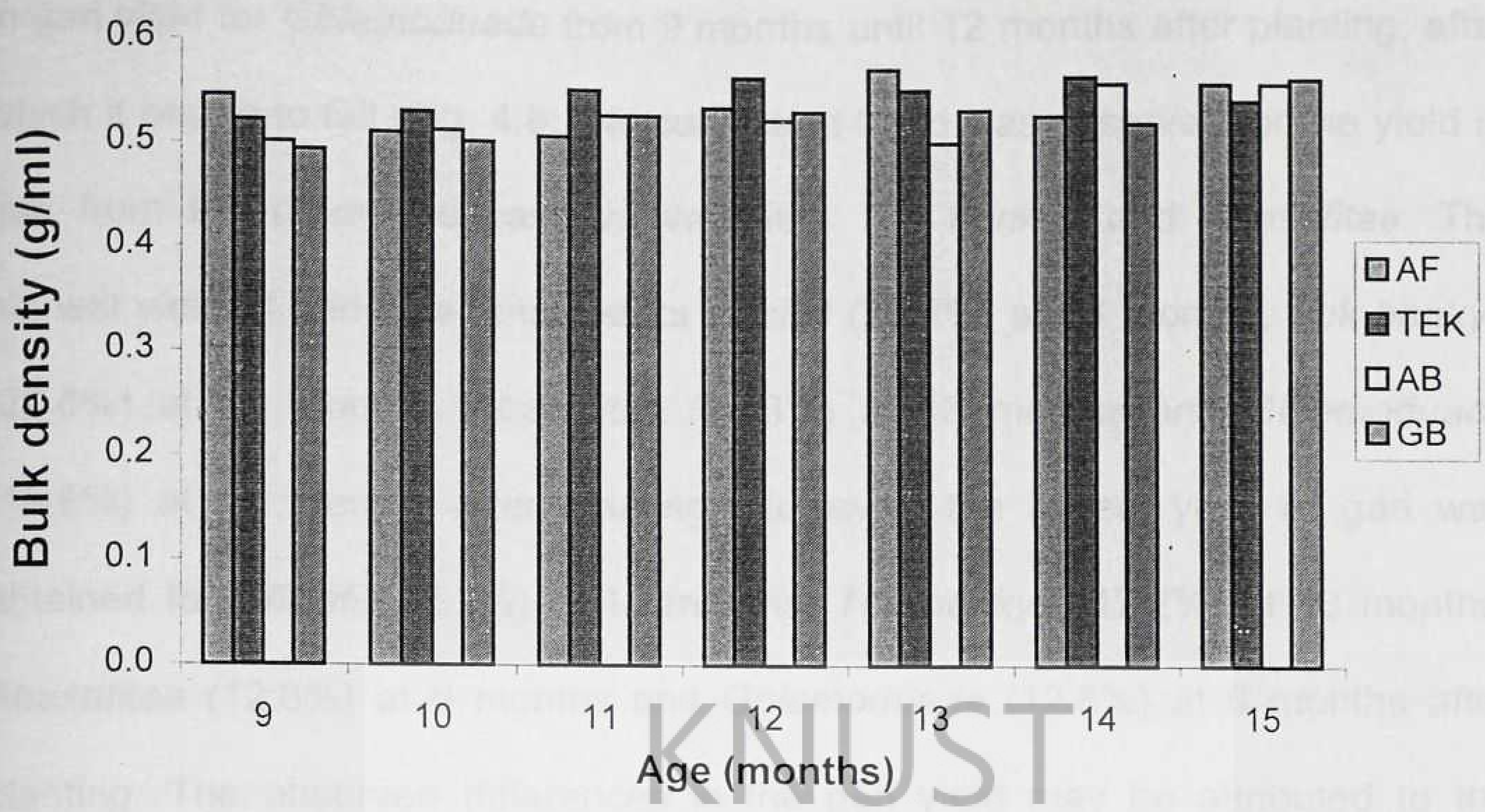


Fig. 4.7 Bulk Density of Gari at different Ages for four Cassava Varieties

after roasting to fine particles while others leave them coarse. The fine granules have higher bulk density than coarse ones.

4.1.8 <u>Yield of gari (kg gari/100kg whole roots)</u>.

Yield of gari from whole roots is a very important parameter to determine, since it reveals the age at which harvesting of each cassava variety gives the highest yield. Young cassava plants may have most of the carbohydrates in their roots in the form of reducing sugars, and these carbohydrates may be lost through leaching during gari preparation. Over-aged cassava roots, on the other hand, are fibrous and sometimes woody, hence reducing the net amount of gari obtained from them.

There was a general decrease in the yield of gari for the first four months of harvest (9 to 12 months after planting) for *Afisiafi*. However, there was increase in gari yield for *Gblemoduade* from 9 months until 12 months after planting, after which it began to fall (Fig. 4.8). No consistent trend was observed for the yield of gari from the other two cassava varieties, *Tek bankye* and *Abasafitaa*. The highest yield of gari was obtained for *Afisiafi* (26.2%) at 14 months, *Tek bankye* (22.6%) at 14 months, *Abasafitaa* (20.6%) at 13 months and *Gblemoduade* (18.8%) at 12 months after planting. However, the lowest yield of gari was obtained for *Afisiafi* (12.2%) at 12 months, *Tek bankye* (17.2%) at 13 months, *Abasafitaa* (12.6%) at 9 months and *Gblemoduade* (12.8%) at 9 months after planting. The observed differences in the gari yield may be attributed to the planting and harvesting times. The cassava varieties were not planted in the same month, so they reached maturity in different months. *Afisiafi* 9 months and

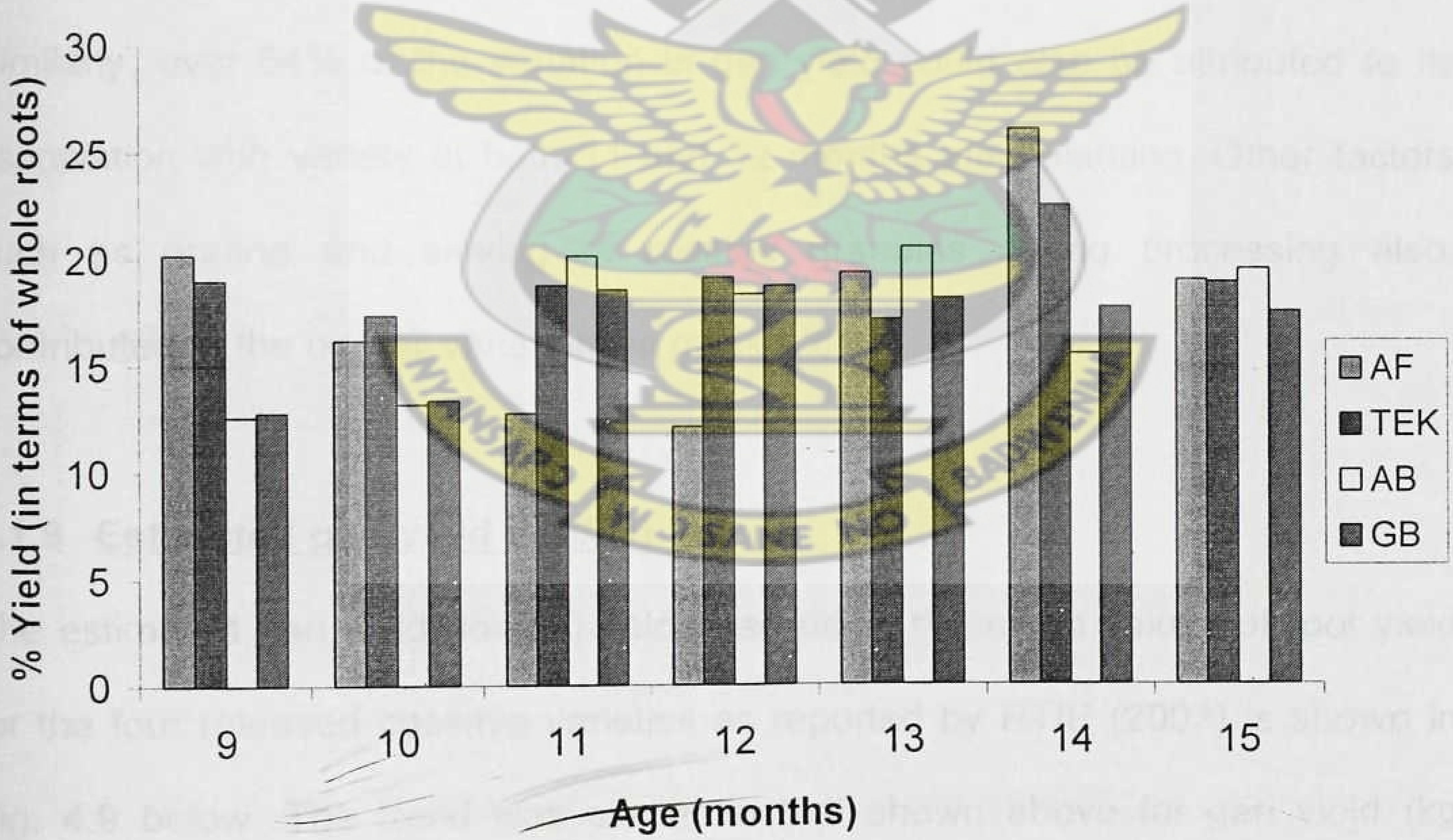


Fig. 4.8 Yield of Gari from four Cassava Varieties at different ages

Tek bankye 9 months old samples were harvested in March, while *Abasafitaa* 9 months and *Gblemoduade* 9 months old samples were harvested in April. Month of harvest therefore became a factor that affected yield and the selected physicochemical properties.

Regression analysis revealed a relationship between gari yield and age for all four varieties even though correlation was weak ($0.139<r^2<0.484$). Variety showed relationship with gari yield at all the ages except 13 months after planting. Correlation between gari yield and variety was strong (r^2=0.846, 0.611 & 0.760 respectively) at 9, 10 and 14 months after planting, but moderate at 11 months (r^2=0.548) and 12 months after planting (r^2=0.547). This means that 84.6%, 76% and 61.1% of the variation in gari yield could be attributed to its association with variety at 9, 14 and 10 months after planting respectively. Similarly, over 54% of the variation in gari yield could also be attributed to its association with variety at both 11 and 12 months after planting. Other factors such as grating and sieving of roasted granules during processing also, contributed to the overall variations in gari yield.

4.1.9 Estimated gari yield (ton/ha).

The estimated gari yield (ton/ha) calculated using the mean values of root yield for the four released cassava varieties as reported by RTIP (2002) is shown in Fig. 4.9 below. The trend was similar to that shown above for gari yield (kg gari/100kg whole roots). Both *Afisiafi* and *Tek bankye* had estimated peak yields at 14 months after planting while *Abasafitaa* and *Gblemoduade* respectively had their estimated peak yields at 13 and 12 months after planting. Regression analysis revealed a relationship between estimated gari yield and age for all four varieties. Correlation, however, was weak ($0.139<r^2<0.484$). Another relationship existed between estimated gari yield and variety at all the ages except 10 months after planting. Correlation between them was weak ($r^2=0.311$) at 14 months, moderate ($r^2=0.529$ & 0.556 respectively) at both 9 and 13 months and strong ($r^2=0.926$, 0.840 & 0.711 respectively) at 11, 12 and 15 months after planting.

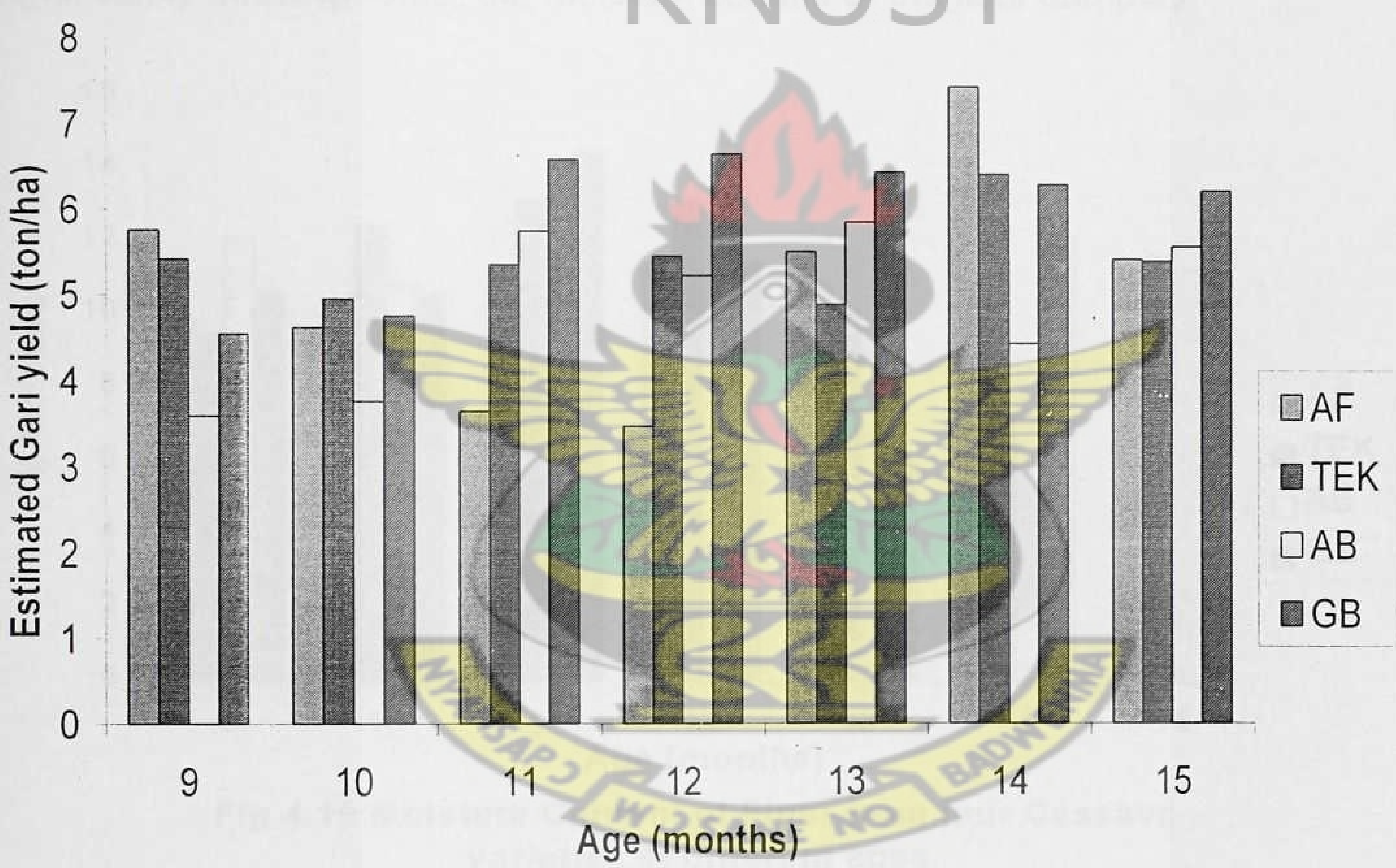


Fig. 4.9 Estimated Gari Yield (ton/ha) of four Cassava Varieties at different ages

Since neither age nor variety had any significant effect ($p>0.05$) on estimated gari yield, it means that harvesting can be done at any age from 9 to 15 months after planting if the roots are to be processed into gari.

4.2 FLOUR RESULTS AND DISCUSSION

4.2.1 Moisture content of flour.

Moisture content of the flour samples ranged between 6.34-14.58% (Fig. 4.10). Flour samples were sun dried from March to December, when rainfall and sunshine patterns were unpredictable and non-uniform. It is worth noting that moisture content of flour is influenced by the extent of drying and the rainfall pattern during the period of sun drying. Statistical analysis revealed age to significantly affect ($p<0.05$) the moisture content of the flour samples.

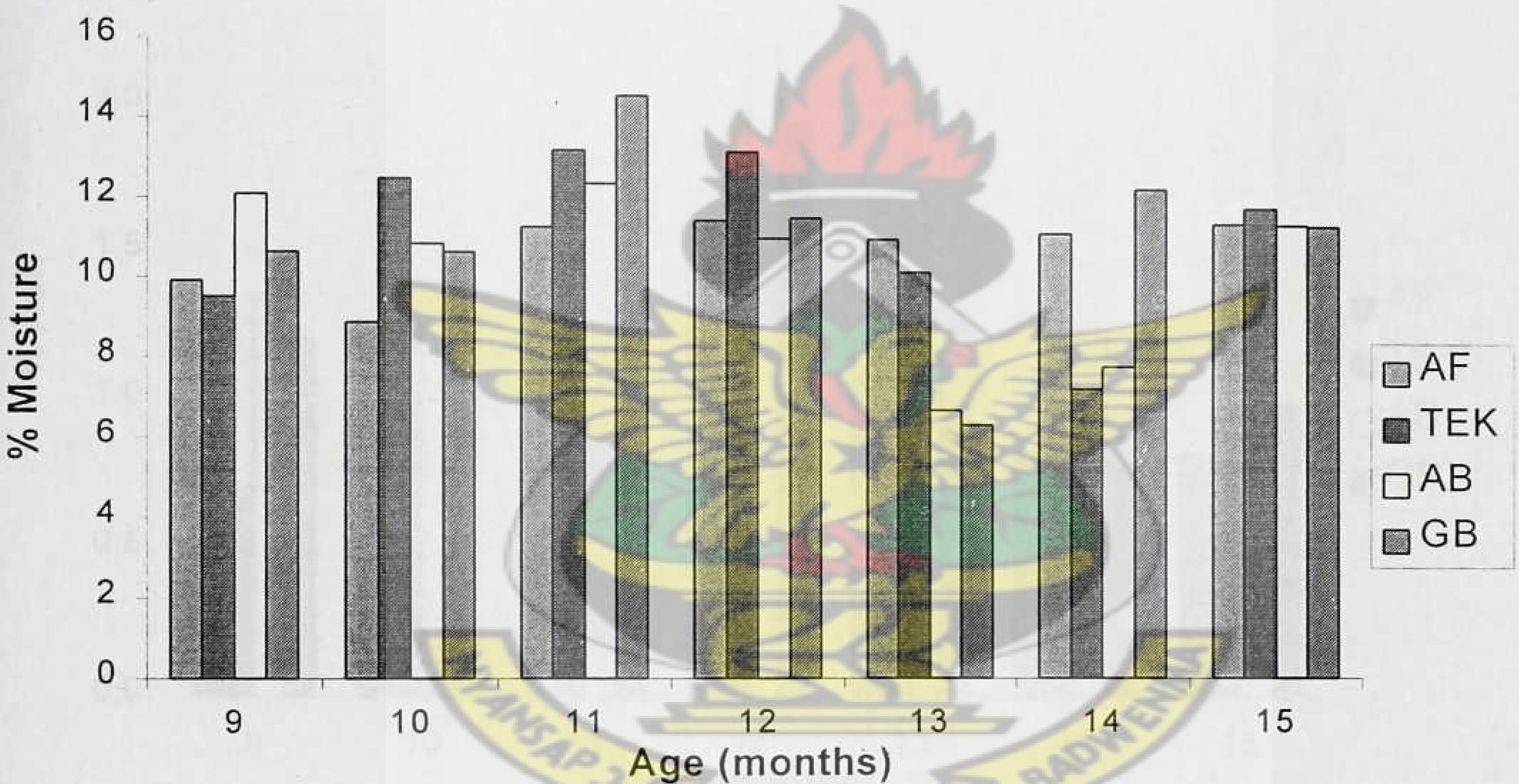


Fig 4.10 Moisture Content of Flour from four Cassava Varieties at different ages

4.2.2 Ash content of flour.

Ash content of *Afisiafi* was between 0.80-1.47% representing 9 months and 12 months respectively. *Tek bankye* had values between 0.70-1.26% with the lowest limit at 9 months and the highest at 10 months after planting. *Abasafitaa* had ash content between 0.87-2.21%, representing 15 months and 12 months after planting respectively, while *Gblemoduade* had ash values in the range of 0.88-1.94% with the lowest value at 14 months and the highest at 12 months after planting. With the exception of *Tek bankye*, which had its highest value at 10 months after planting, all the other varieties had peak ash content at 12 months after planting (Fig. 4.11). The ash content of *Tek bankye* fell sequentially from 10 months after planting until 15 months after planting. There was inconsistent trend in ash content for the other three varieties. Age significantly affected ($p<0.05$) ash content of the cassava flour samples.

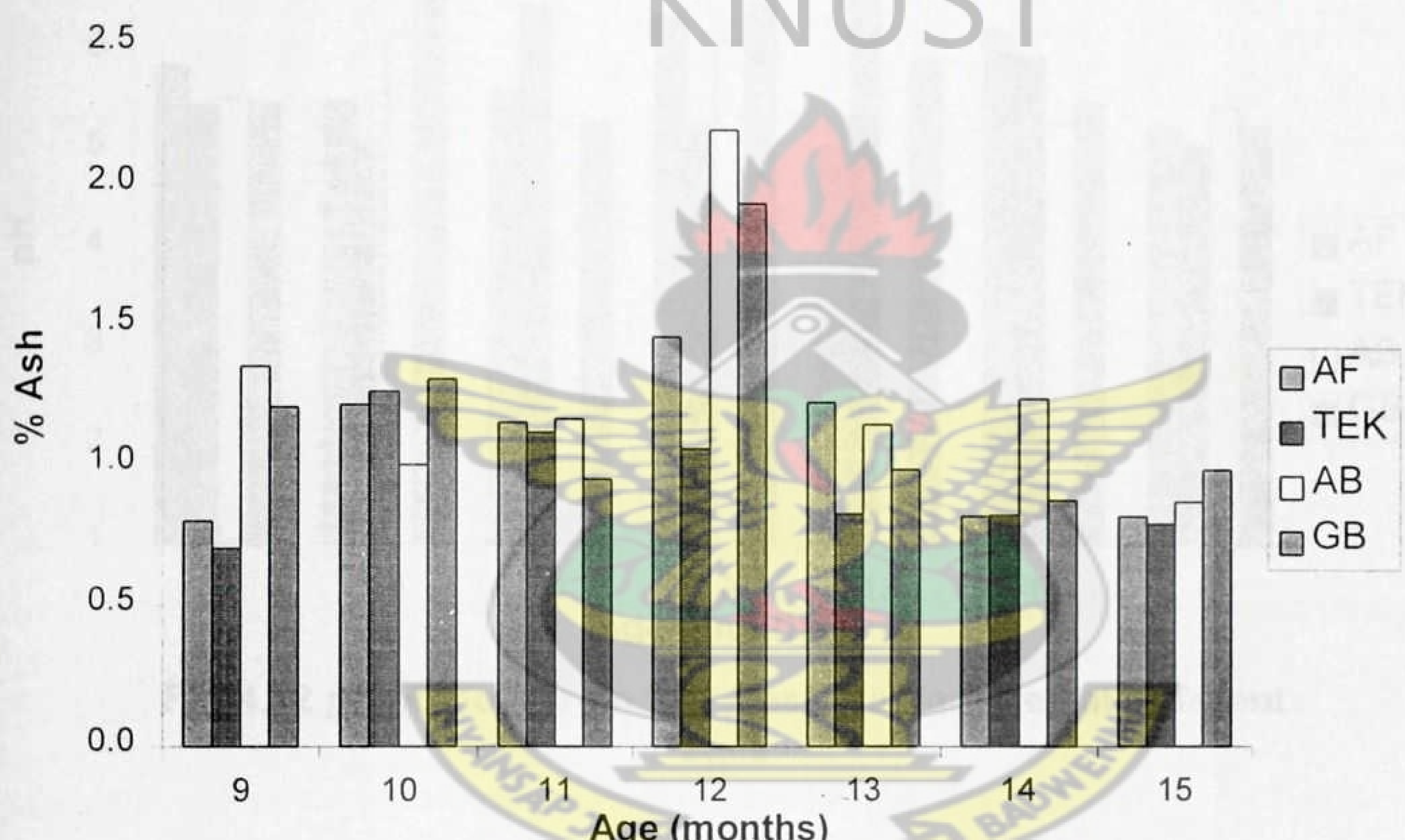


Fig 4.11 Ash Content of Flour from four Cassava Varieties at different ages

Other factors such as mineral content in the soil, rate of mineral absorption by the plants, as well as leaching of minerals out of cassava mash during processing, also affect ash content of the flour.

4.2.3 pH of Flour.

pH is an important parameter in determining the quality of cassava flour since pH of 4 or less indicates appreciable level of fermentation, and hence some starch breakdown. Such fermentation also imparts undesirable flavour to the cassava flour making it less preferred when used in baking. The flour samples had pH between 5.07 and 6.65 (Fig. 4.12), indicating that they were of good quality. pH was neither significantly affected ($p>0.05$) by age nor by variety.

Fig 4.12 pH of Flour from four Cassava Varieties at different ages

4.2.4 Crude fibre of flour.

Afisiafi had crude fibre content of between 0.77-2.62%, with the lower limit at 14 months and the upper limit at 11 months; *Tek bankye* had values in the range of 1.45-2.07% with the lower and the upper limits at 9 and 10 months respectively. *Abasafitaa* on the other hand, had crude fibre values between 1.27-2.11% with the lowest value at 12 months and the highest at 9 months, while *Gblemoduade* had its fibre content in the range of 1.62-2.56% with the lower and upper limits at 13 and 9 months respectively (Fig. 4.13).

Fig 4.13 Crude Fibre of Flour from four Cassava Varieties at different ages

There was no significant difference ($p>0.05$) in crude fibre content between ages and also varieties. This may be due to the fine sieving of the flour after milling that removed most of the fibre and therefore shielded the effects of age and variety on the fibre content.

4.2.5 Crude protein of flour.

Crude protein content of *Afisiafi* ranged between 0.22% and 1.53% representing 12 months and 9 months after planting respectively while *Tek bankye* had values between 0.22-1.68% with the lower limit at 11 months and the upper limit at 9 months after planting. *Abasafitaa* had protein content ranging between 0.22% and 1.68% with the lowest value at 13 months and the highest at 15 months after planting, while *Gblemoduade* had values between 0.22% and 1.53% with the lowest value at 12 and 13 months after planting and the highest at 15 months after planting. Age significantly affected ($p<0.05$) crude protein content but variety

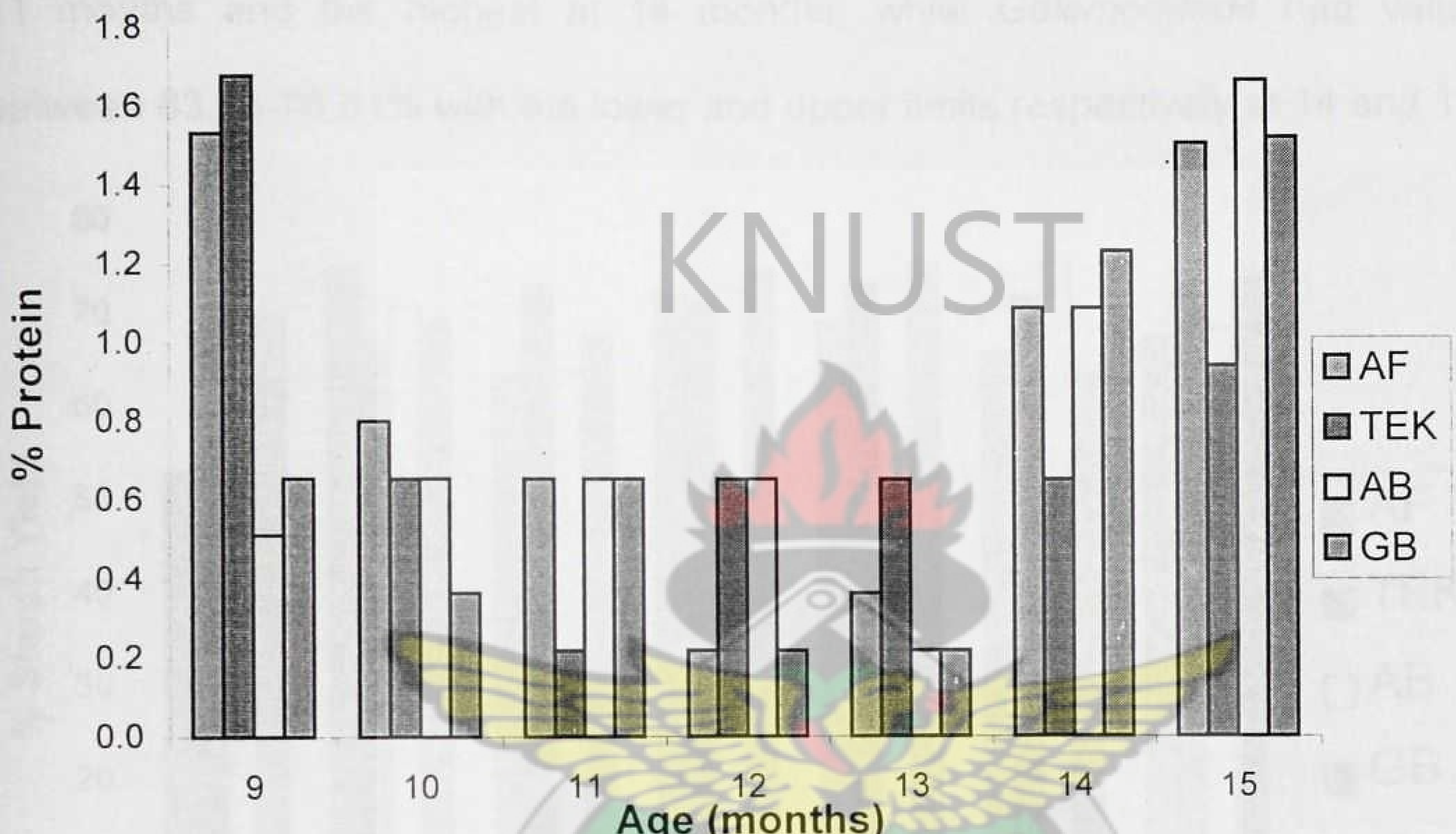


Fig. 4.14 Protein Content of Flour from four Cassava Varieties at different ages

did not. Other factors such as nitrogen content of the soil and the differing rates of nitrogen metabolism in the growing plants may be responsible for the differing trends in crude protein content (Fig. 4.14) among the four varieties. It is important to note that both *Afisiafi* and *Tek bankye* had maximum crude protein content at 9 months after planting while *Abasafitaa* and *Gblemoduade* had maximum crude protein at 15 months after planting. All varieties had a minimum value of 0.22%.

4.2.6 Starch yield of flour.

Starch yield of *Afisiafi* was between 53.60-75.50% with the lowest value at 9 months and the highest at 10 months, while *Tek bankye* had values between 67.33-73.83%, with the lower limit at 10 months and the upper limit at 13 months. *Abasafitaa* had starch yield ranging from 64.06-75.69% with the lowest value at 11 months and the highest at 14 months, while *Gblemoduade* had values between 63.75-76.01% with the lower and upper limits respectively at 14 and 13

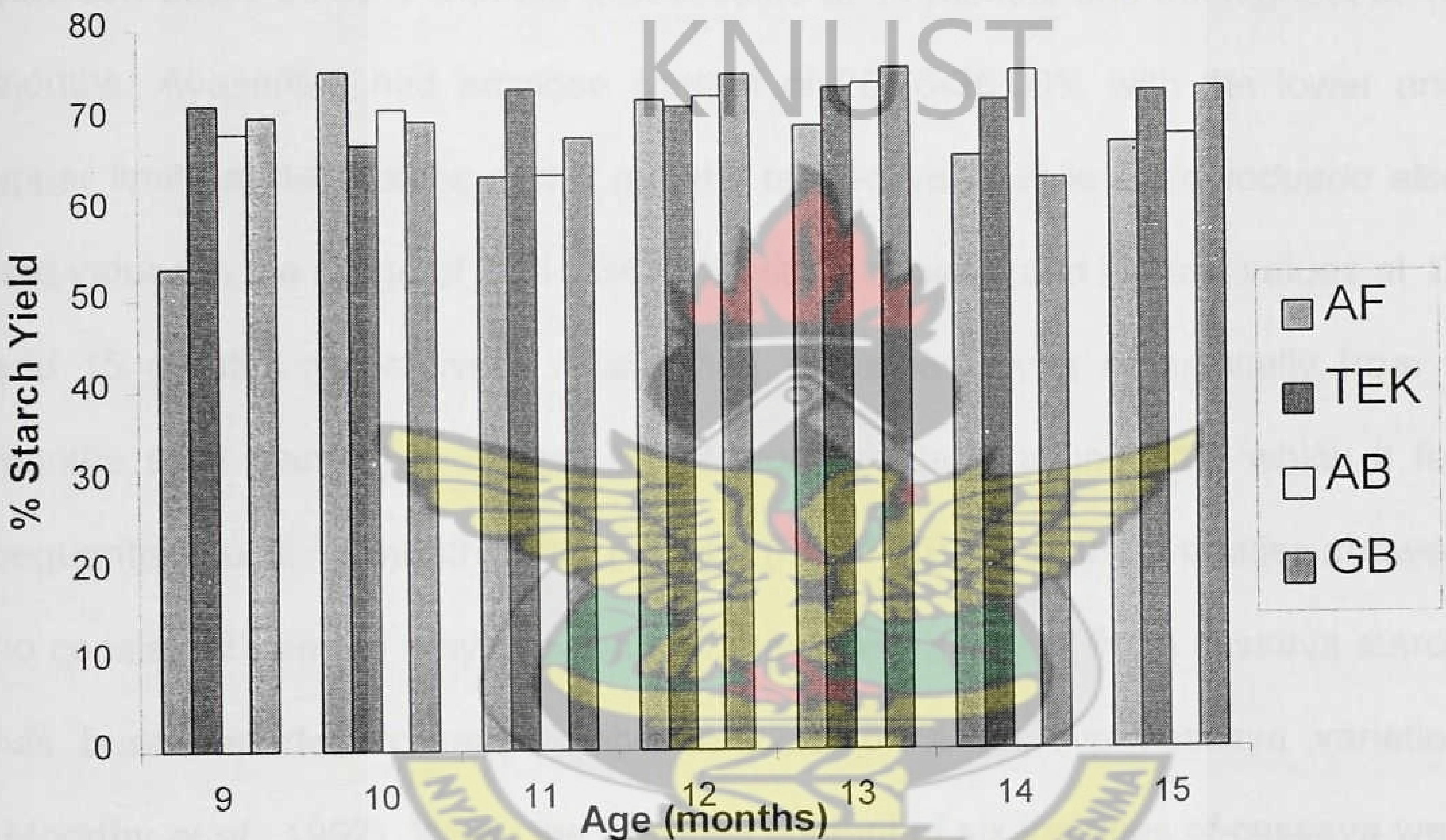


Fig. 4.15 Starch Yield of Flour from four Cassava Varieties at different ages

months after planting (Fig. 4.15). Niba *et al.* (nd) reported starch content of eleven cassava genotypes to be in the range of 62.84-75.72g/100g; these values compare well with those obtained in this study. Starch yield was neither significantly affected ($p>0.05$) by age nor by variety. This may be due to the effect of processing on the starch yield. During processing, the mash obtained from grating the peeled roots was dehydrated by manual pressing using a screw press. This caused most of the starch to leach out of the mash. The effects of age and variety on starch yield were thus shielded.

4.2.7 Amylose content of flour.

Amylose content of *Afisiafi* ranged between 16.48-34.57% with the lower and upper limits respectively at 9 and 12 months, while *Tek bankye* had values between 20.29-36.00% with the lowest value at 14 months and the highest at 10 months. *Abasafitaa* had amylose content of 20.76-36.00% with the lower and upper limits at 14 months and 9 months respectively, while *Gblemoduade* also had values in the range of 23.14-34.57% with the lowest and highest values at 13 and 15 months respectively. *Afisiafi* had its values rising sequentially from 9 months after planting to a peak at 12 months after planting after which it fell sequentially until 14 months after planting (Fig. 4.16). The other varieties showed no consistent trend in amylose content. Amylose content of fresh cassava starch has been reported to range between 22.6-26.2% for five cassava varieties (Moorthy *et al.*, 1992). When the amylose content of six varieties of cassava was compared during growth period, there were only insignificant differences among the varieties (Moorthy, 1994). Barimah (1999) reported amylose content of starch from dry chips ranging between 22.3-24.5% for the varieties *Afisiafi*, *Abasafitaa*, *Gblemoduade* and Isu-white. These values were obtained for varieties at one particular age. Rickard *et al.* (1991) also reported amylose content of 13.6-23.8%. Amylose content obtained in this study were higher than the reported values above, probably due to differences in harvesting time, variety and growing

Fig. 4.16 Amylose Content of Flour from four Cassava Varieties at different ages

conditions. Neither age nor variety significantly affected (p>0.05) amylose content.

4.2.8 Swelling power of flour.

Swelling power of *Afisiafi* ranged between 17.15-28.95 with the lower and upper limits at 13 and 9 months respectively while *Tek bankye* had values between 18.13-31.07, with the lowest value at 12 months and the highest at 9 months after planting. *Abasafitaa* had swelling power in the range of 20.71-28.45 with the lower and upper limits at 11 and 15 months respectively, while *Gblemoduade* had values between 18.74-31.97 with the lowest value at 11 months and highest value at 13 months. *Tek bankye* had its swelling power falling sequentially from a peak at 9 months after planting till 12 months after planting, after which it rose uniformly until 15 months after planting (Fig. 4.17). *Afisiafi* had its values falling in a similar trend to that of *Tek bankye*, except at 12 months after planting where the swelling power was unusually high. It, however, had its lowest value at 13 months after planting, from where it rose sequentially through 15 months after planting. The swelling power of *Abasafitaa* fell sequentially from 9 months to 11 months after planting, from where it rose uniformly until 13 months after planting. *Gblemoduade* showed no consistent trend.

The sequential drop in swelling power may be attributed to the onset of rains in late March (9 months for *Afisiafi* and *Tek bankye*) and early April (9 months after planting for *Abasafitaa*). This caused starch within the plants to be mobilized for germination. For *Tek bankye* and *Abasafitaa*, their lowest values were obtained in June, while for *Afisiafi* it was in July. From then on, swelling power rose with age as a result of possible starch biosynthesis within the plants. This clearly indicates that month of harvest and rainfall pattern affected the swelling power of flour from these varieties. No significant difference ($p>0.05$), however, was found to exist between ages and varieties. There was a positive correlation between swelling power and peak temperature for *Abasafitaa* ($r^2=0.509$) and *Gblemoduade* ($r^2=0.883$). Barimah (1999) reported a strong correlation between swelling power and peak viscosity for starch from dried cassava chips, while Balagopalan *et al.* (1988) also reported that starches capable of high swelling are less resistant to break down. Even though there was a relationship between swelling power and peak viscosity for *Afisiafi* and *Tek bankye*, correlation between them was weak ($r^2=0.378$ & 0.135 respectively). Similarly, a weak correlation existed between swelling power and paste breakdown for *Afisiafi*, *Tek bankye* and *Abasafitaa*. There was also a weak correlation (r^2=0.134) between starch yield and swelling power for *Gblemoduade*. The weak correlation may be

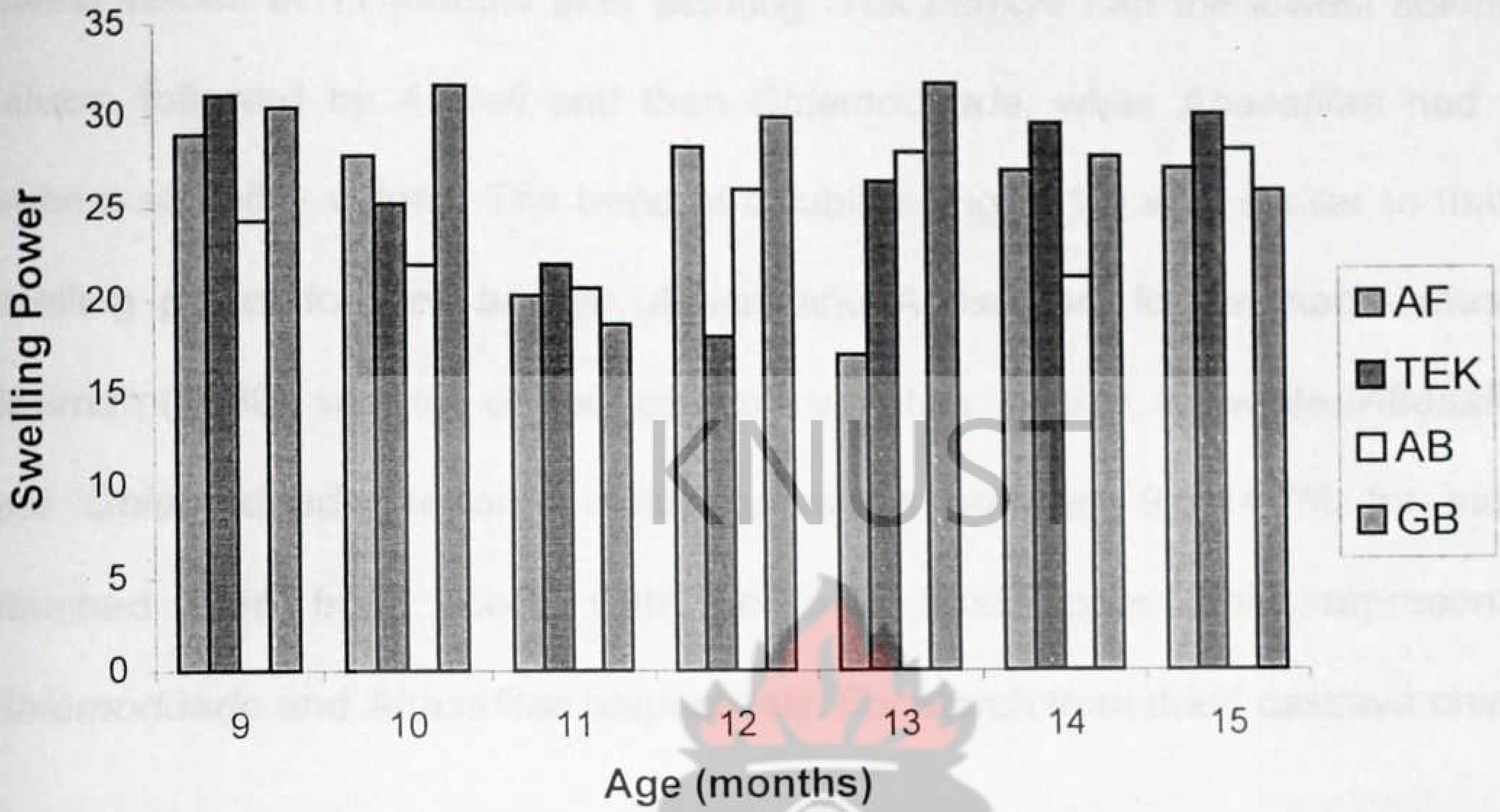


Fig. 4.17 Swelling Power of Flour from four Cassava Varieties at different ages

attributed to starch loss during dehydration of the cassava mash in the course of processing, resulting in only a small amount of starch left in the flour to cause swelling.

4.2.9 Solubility of flour.

The solubility of *Afisiafi* ranged between 8.02-17.42% with the lowest value at 12 months and the highest at 14 months, while for *Tek bankye* it was between 7.81-11.89%, with the lower and upper limits respectively at 11 and 14 months. *Abasafitaa* also had solubility values ranging between 13.11-18.65%, with the lowest value at 11 months and the highest at 9 months, while *Gblemoduade* had solubility between 11.72-18.80% with 11 and 12 months having the lowest and highest values respectively. With the exception of *Afisiafi*, all other varieties had lowest values at 11 months after planting. *Tek bankye* had the lowest solubility values, followed by *Afisiafi* and then *Gblemoduade*, while *Abasafitaa* had the highest solubility values. The trend of solubility (Fig. 4.18) was similar to that of swelling power for *Tek bankye*, *Afisiafi* and *Abasafitaa*, for the same reason. Barimah (1999), working on four cassava varieties: *Afisiafi*, Isu-white, *Abasafitaa* and *Gblemoduade*, reported solubility values between 9.6-14.7% for starch obtained from fresh roots, with the lower and upper limits representing *Gblemoduade* and *Abasafitaa* respectively. For starch from dried cassava chips,

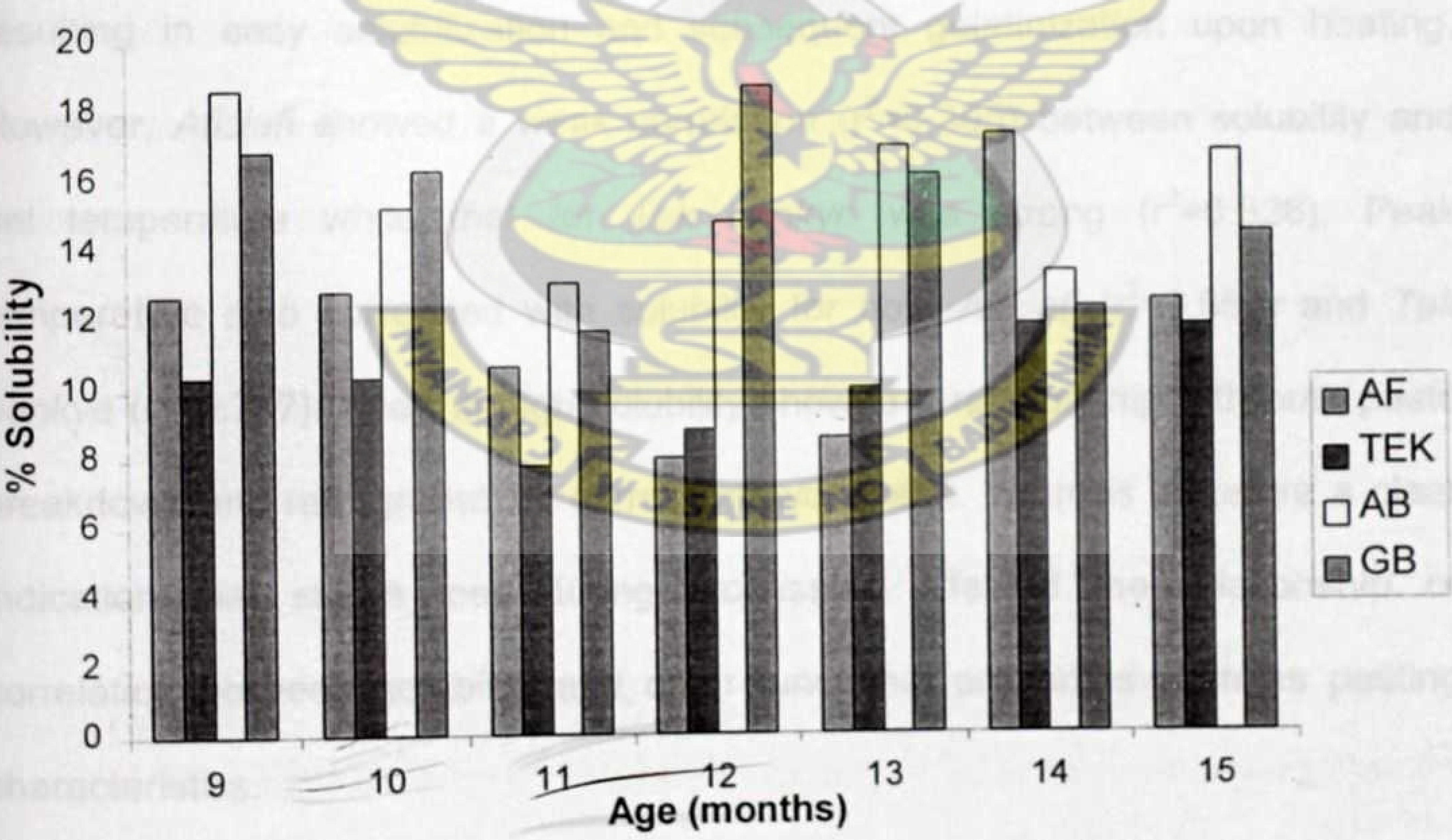


Fig. 4.18 Solubility of Flour from four Cassava Varieties at different ages

Barimah (1999) reported values between 11.4-19.7%, representing *Gblemoduade* and *Abasafitaa* respectively. The values obtained in this study compare well with those reported by Barimah (1999). There was no significant difference ($p>0.05$) in solubility between ages, but significant difference ($p<0.05$) existed among varieties.

There was weak correlation ($r^2=0.447$ & 0.285 respectively) between moisture content and solubility for *Tek bankye* and *Gblemoduade*. *Gblemoduade* showed correlation ($r^2=0.502$) between starch yield and solubility while *Afisiafi* showed correlation ($r^2=0.518$) between amylose content and solubility. Swelling power also correlated ($r^2=0.658$, 0.428 & 0.568 respectively) with solubility for *Tek bankye*, *Abasafitaa* and *Gblemoduade*. It is expected that high solubility flour will gelatinize at low temperature since water readily enters its starch granules resulting in easy solubilization and subsequent gelatinization upon heating. However, *Afisiafi* showed a weak correlation ($r^2=0.305$) between solubility and gel temperature while that for *Tek bankye* was strong ($r^2=0.828$). Peak temperature also correlated with solubility for both *Afisiafi* ($r^2=0.664$) and *Tek bankye* ($r^2=0.787$). Even though solubility showed a relationship with both paste breakdown and retrogradation, correlation was weak. There is therefore a clear indication that starch loss during processing affected the relationship or correlation between solubility and other functional properties such as pasting characteristics.

4.2.10 Pasting characteristics of flour.

Pasting characteristics of flour depend to a large extent on the ability of starch granules to imbibe water and swell in the cold, as well as its gelatinization when heated. Non-carbohydrate components such as protein, fibre and minerals, which interact with water molecules, also affect the gelatinization profile or pasting characteristics of the flour and similar food products.

4.2.10.1 Pasting Temperature.

Pasting temperature of *Afisiafi* ranged between 67.69-69.95°C with the lower limit at 15 months and the upper limit at 13 months; *Tek bankye* had values between 68.7-73.2°C representing 10 months and 11 months respectively. *Abasafitaa* had values between 68.95-71°C, representing 15 and 11 months respectively, while *Gblemoduade* also had pasting temperatures in the range of 68-71°C, representing 15 and 11 months respectively (Fig. 4.19). There was no significant difference ($p>0.05$) in pasting temperature between ages but significant difference ($p<0.05$) existed among varieties. Pasting temperatures ranging from 66-68.7°C has been reported for flour from roots of the cassava varieties *Afisiafi*, *Abasafitaa*, *Gblemoduade* and Isu-white, while values between 65.3-66.9°C were reported for starch from dried chips of the same varieties (Barimah, 1999). Moorthy *et al.* (nd) reported pasting temperatures of starch from 5 Indian cassava varieties between 65.0-71.0°~~C, while~~ Rickard *et al.* (1991) reported pasting temperatures of 59-62°C for cassava starch. The values obtained in this study for

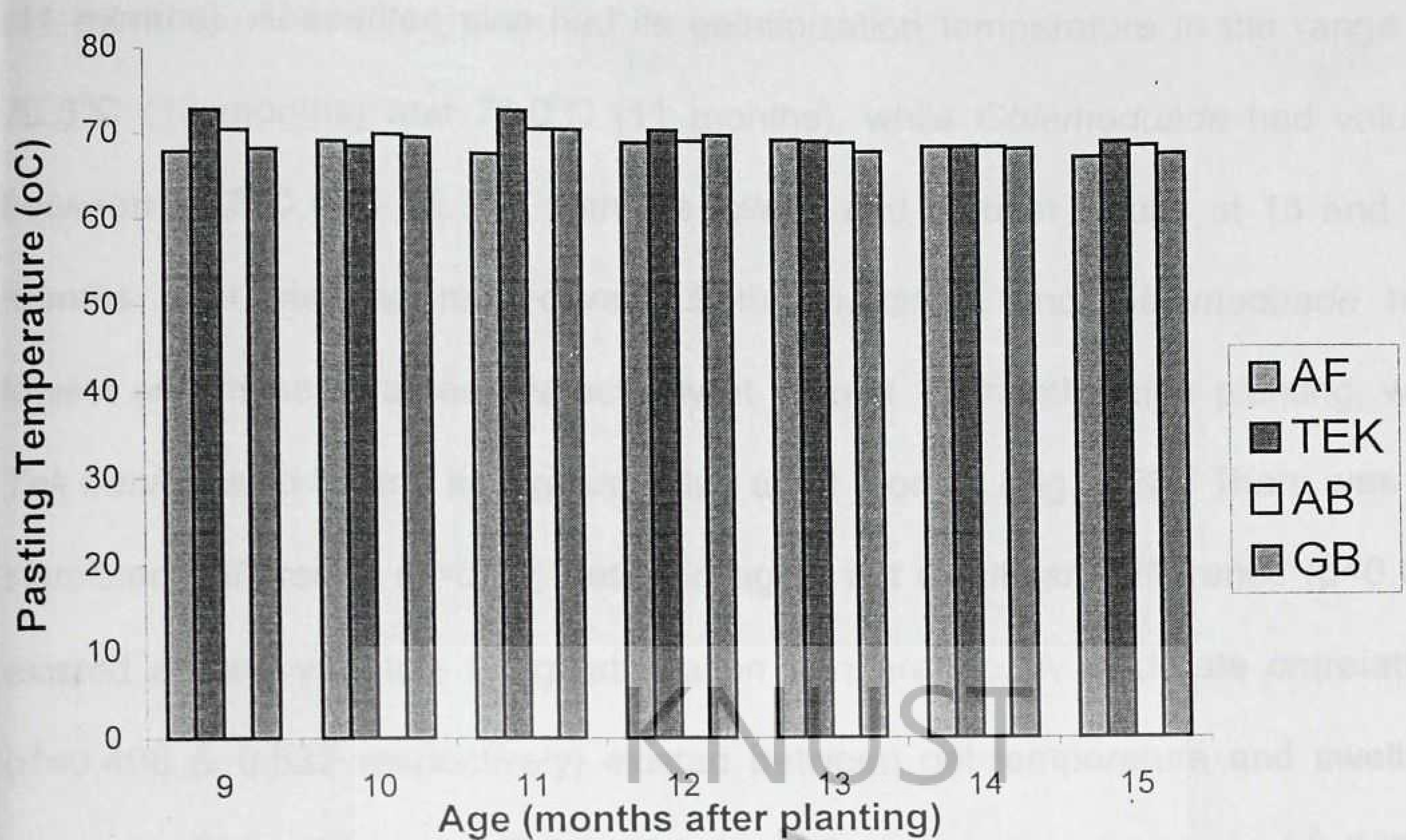


Fig. 4.19 Pasting Temperatures of Flour from four Cassava Varieties at different Ages

cassava flour therefore compare well with those obtained for cassava starch by different workers. Even though there was relationship between starch yield and pasting temperature for *Afisiafi*, *Tek bankye* and *Abasafitaa*, correlation was weak. This may be attributed to starch loss through leaching during processing of high quality cassava flour.

4.2.10.2 Gelatinization Temperature.

Gelatinization temperature was recorded as the temperature at which paste viscosity rose from 0 to 20BU. This temperature was attained after pasting temperature had been recorded. Gelatinization temperature of *Afisiafi* ranged between 69.7-75.25°C with the lower and upper limits respectively at 9 and 13 months, while *Tek bankye* had values between 70.15°C (14 months) and 78.6°C

(11 months). *Abasafitaa* also had its gelatinization temperature in the range of 70.8°C (13 months) and 76.0°C (11 months), while *Gblemoduade* had values between 69.3°C and 75.3°C, with the lowest and highest values at 13 and 11 months after planting respectively. Both *Abasafitaa* and *Gblemoduade* had lowest and highest values respectively at 13 and 11 months after planting, with *Tek bankye* also having its highest value at 11 months (Fig. 4.20). There was no significant difference ($p>0.05$) between ages, but significant difference ($p<0.05$) existed among varieties for gelatinization temperature. A moderate correlation (r^2=0.498 & 0.532 respectively) existed between gel temperature and swelling power for *Tek bankye* and *Gblemoduade*, while correlation was strong (r^2=0.828) between gel temperature and solubility for *Tek bankye*. This indicates that 82.8% of the variation in gel temperature could be attributed to its association with solubility for *Tek bankye*. Starch gelatinization, which is the collapse or disruption of the molecular order within the starch granule, is manifested by irreversible changes in starch properties such as swelling of the granules and solubilization. Solubility of the starch in water depends on the amylose/amylopectin ratio since it is the amylose component of starch that hydrogen bonds with water molecules, resulting in its solubilization. Flour with low solubility in water such as that of *Tek bankye* (Fig. 4.18), require higher temperature to disrupt the molecular order in its starch granule and thus to gelatinize. Other factors such as presence of sugars, proteins, salts and moisture content of the sample, affect starch gelatinization and solubility, since they compete with starch molecules for water

(Whistler and Daniel, 1984). Starch yield correlated strongly (r^2=0.637) with gel temperature for *Abasafitaa*.

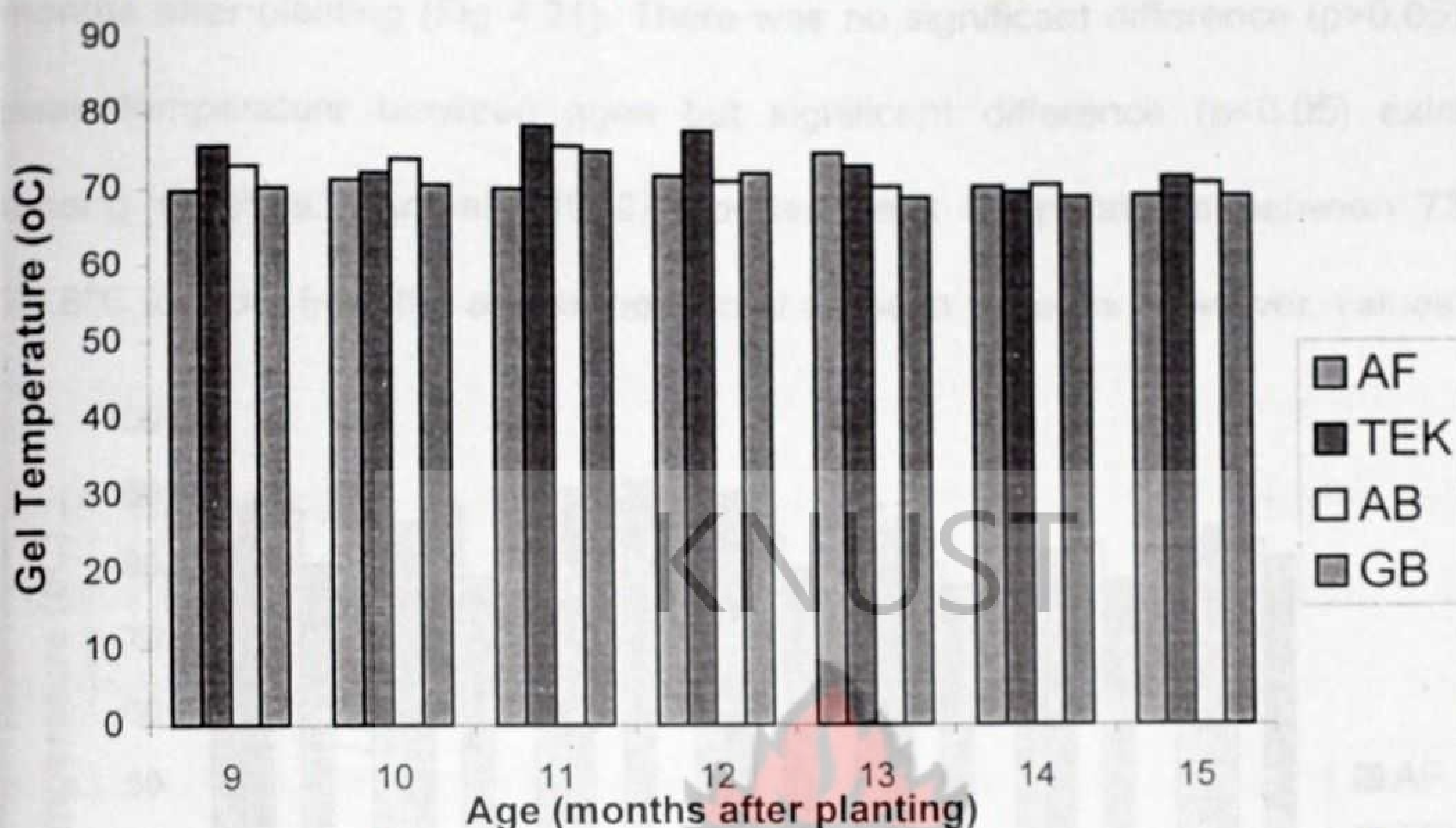


Fig. 4.20 Gel Temperatures of Flour from four Cassava Varieties at different Ages

4.2.10.3 Peak Temperature.

Peak temperature for *Afisiafi* was between 82.2-89.2°C with 14 and 13 months having the lowest and highest values respectively, while *Tek bankye* had values between 82.6-91.1°C with the lower and upper limits at 14 and 11 months after planting respectively. *Abasafitaa* had peak temperatures ranging from 80.7-90.7°C with 13 and 11 months having the lowest and highest values respectively, while *Gblemoduade* also had values ranging from 77.6-92.1°C with the lowest value at 13 months and the highest at 11 months old. Both *Afisiafi* and *Tek bankye* had their lowest peak temperatures at 14 months after planting, while *Abasafitaa* and *Gblemoduade* had their lowest and highest values at 13 and 11 months after planting respectively. Apart from *Afisiafi* whose upper limit for peak temperature was at 13 months, all the other varieties had their upper limits at 11 months after planting (Fig 4.21). There was no significant difference ($p>0.05$) in peak temperature between ages but significant difference ($p<0.05$) existed among varieties. Barimah (1999) reported peak temperatures between 73.7-74.8°C for flour from the above-mentioned cassava varieties. However, values

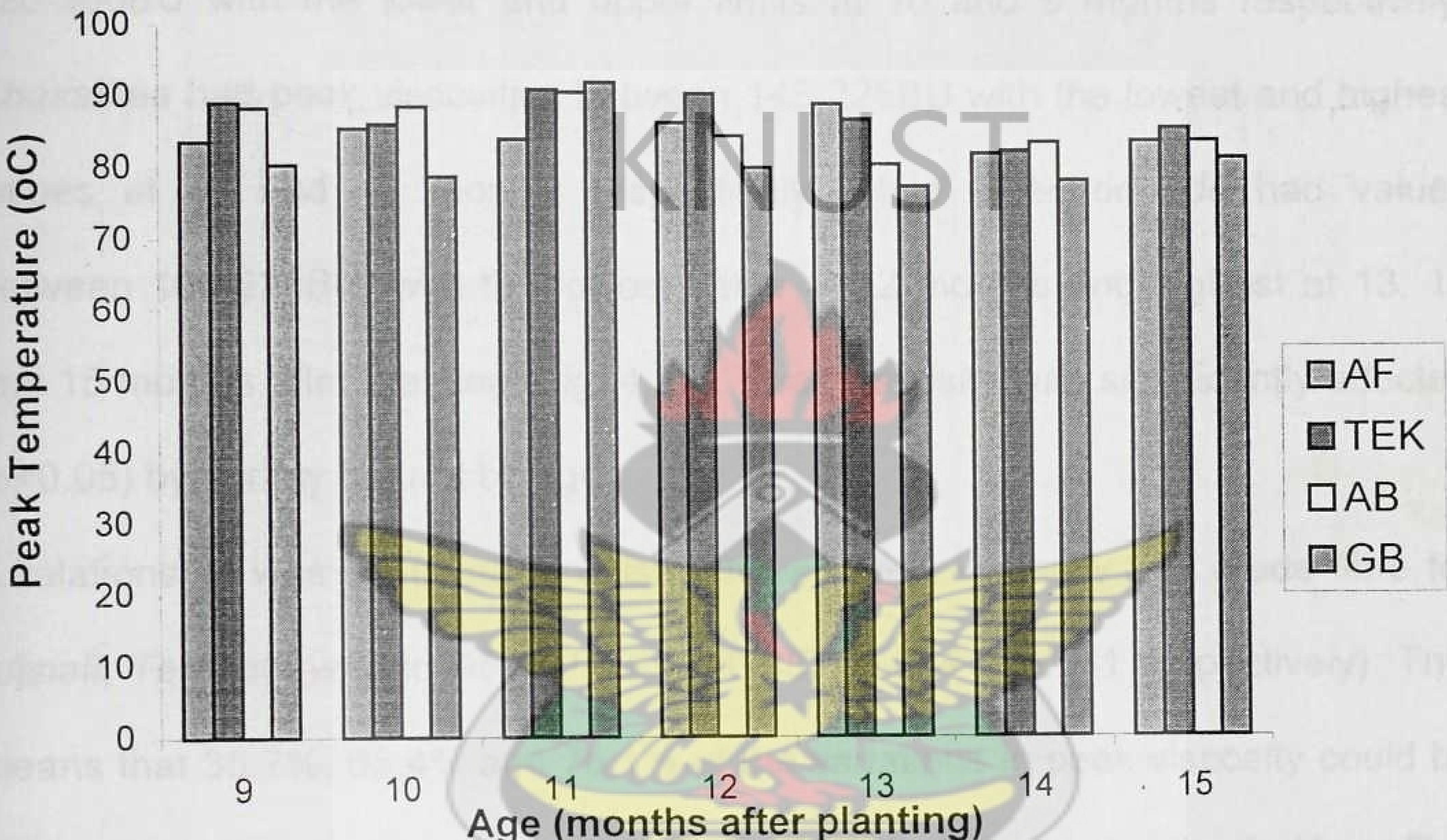


Fig. 4.21 Peak Temperature of Flour from four Cassava Varieties at different ages

reported by Barimah (1999) are lower than that obtained in this study. The reason may be due to a difference in processing method; Barimah's flour was produced from dry chips while that used in this study were from dried, grated mash. Aryee (2001) reported peak temperatures of cassava flour from thirty-one varieties to range between 73.1°C to 84.5°C; the age at harvest, however, was not reported. Other factors such as size and shape of starch granules may also affect the pasting, gelatinization and peak temperatures of flour.

4.2.10.4 Peak Viscosity.

Peak viscosity of *Afisiafi* was between 210-305BU with the lowest and highest values at 14 and 10 months respectively, while *Tek bankye* had values between 220-300BU with the lower and upper limits at 10 and 9 months respectively. *Abasafitaa* had peak viscosities between 145-225BU with the lowest and highest values at 10 and 12 months respectively, while *Gblemoduade* had values between 160-220BU, with the lowest value at 12 months and highest at 13, 14 and 15 months after planting (Fig. 4.22). Peak viscosity was significantly affected ($p<0.05$) by variety but not by age.

A relationship was observed to exist between peak viscosity and crude fibre for *Afisiafi*, *Tek bankye* and *Abasafitaa* (r^2=0.357, 0.654 & 0.761 respectively). This means that 35.7%, 65.4% and 76.1% of the variations in peak viscosity could be attributed to the crude fibre content of *Afisiafi*, *Tek bankye* and *Abasafitaa* respectively. Similarly, a relationship was observed between peak viscosity and amylose content for *Tek bankye* and *Abasafitaa* (r^2=0.569 & 0.608 respectively), since it is the amylose molecules that uncoil along their length and hydrogen bond with water molecules in an aqueous solution when heated. This results in an increase in the viscosity of the solution.

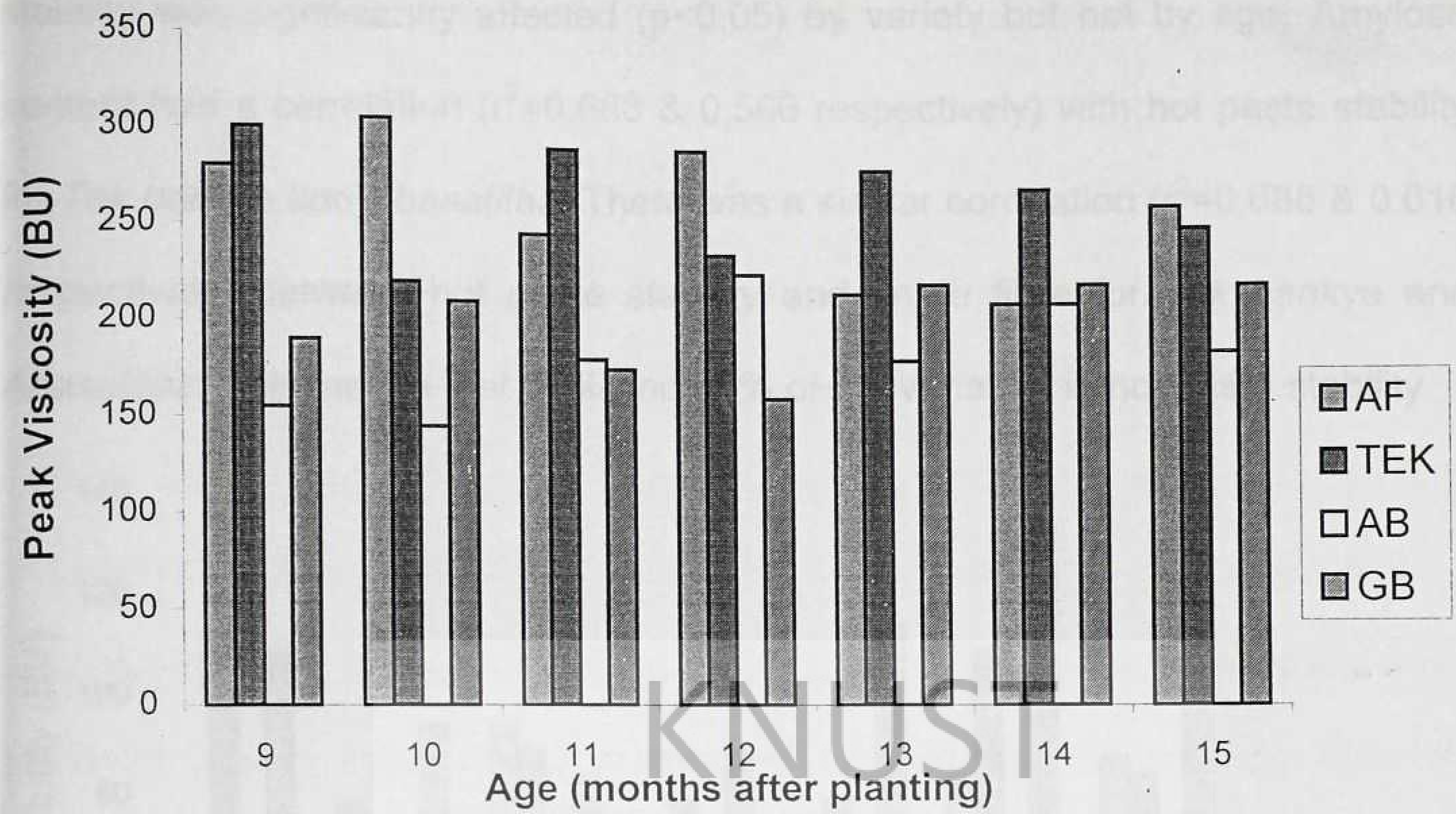


Fig. 4.22 Peak Viscosity of Flour from four Cassava Varieties at different Ages

4.2.10.5 Hot Paste Stability.

The hot paste stability of *Afisiafi* was lowest at 9, 12 and 13 months after planting with a value of 70BU and highest at 11 months after planting with a value of 95BU, while *Tek bankye* had values ranging between 65BU (10 months) and 110BU (14 months). *Abasafitaa* also had values between 10BU and 80BU with the lowest at 9 months and the highest at 13 months after planting, while *Gblemoduade* had hot paste stability values between 85BU and 135BU with the lowest at 11 months and the highest at 14 months after planting. The hot paste stability of *Abasafitaa* rose sequentially from 9 months to a peak at 13 months after which it began to fall, while that of *Gblemoduade* fell from 9 months through 11 months, after which it rose sequentially through 14 months after planting. *Afisiafi* and *Tek bankye* did not have consistent trend (Fig. 4.23). Hot paste stability was significantly affected ($p<0.05$) by variety but not by age. Amylose content had a correlation ($r^2=0.688$ & 0.566 respectively) with hot paste stability for *Tek bankye* and *Abasafitaa*. There was a similar correlation ($r^2=0.685$ & 0.616 respectively) between hot paste stability and crude fibre for *Tek bankye* and *Abasafitaa*. This means that 56% and 69% of the variation in hot paste stability

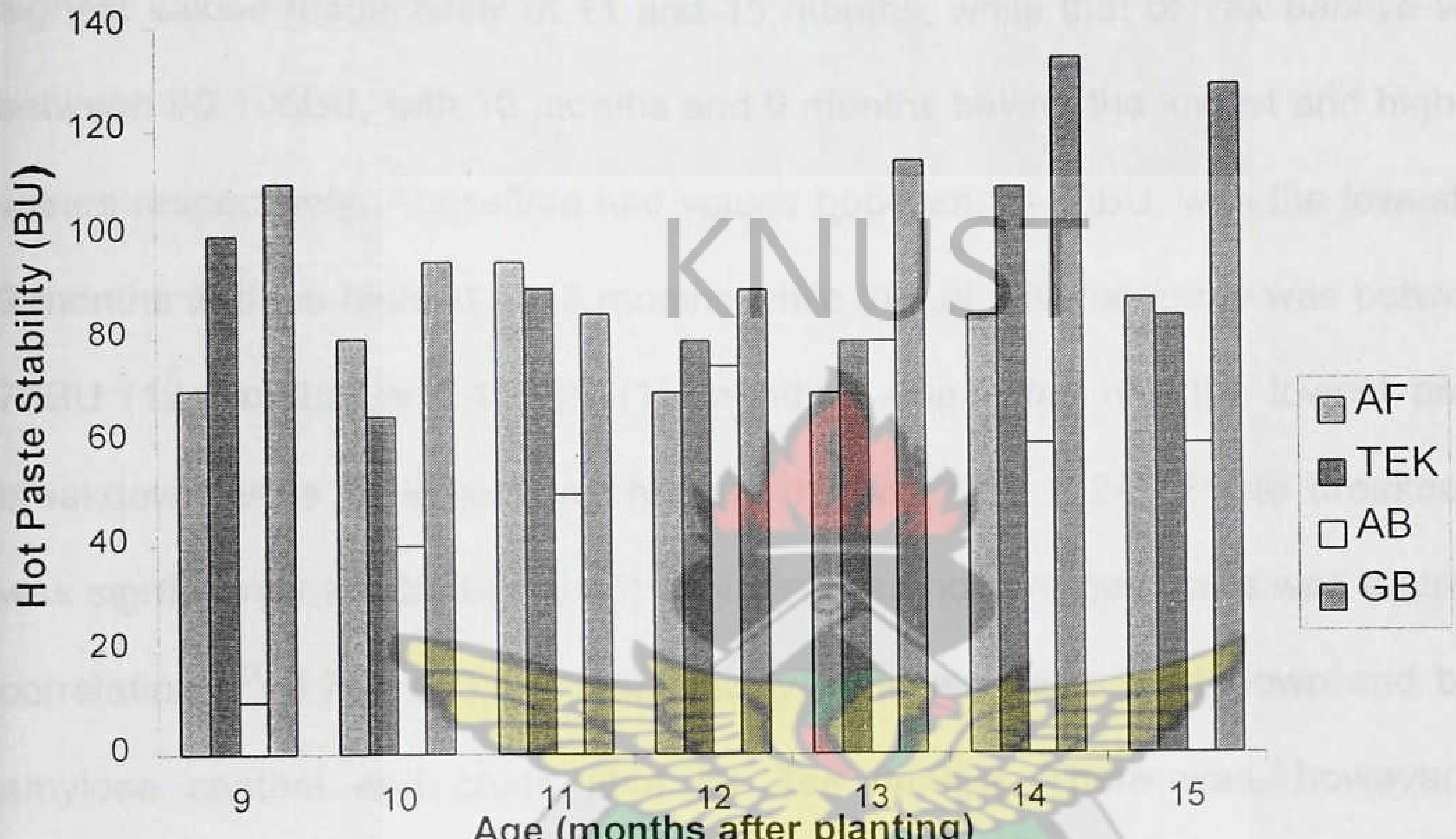


Fig. 4.23 Hot Paste Stability of Flour from four Cassava Varieties at different Ages

could be attributed to its association with amylose content for *Abasafitaa* and *Tek bankye* respectively, while 69% and 62% of the variations in hot paste stability could be attributed to its association with crude fibre for *Tek bankye* and *Abasafitaa* respectively. There is therefore an evidence to suggest from this study that crude fibre complements the effect of amylose on the stability of the hot paste. This may be as a result of the fibre molecules (cellulose and hemicelluloses) interacting with the excess water molecules present in the aqueous suspension, hence preventing syneresis at high temperature.

4.2.10.6 Hot Paste Breakdown.

Hot paste breakdown for *Afisiafi* ranged between 60-85.3BU, with the lowest and highest values respectively at 11 and 15 months, while that of *Tek bankye* was between 60-105BU, with 10 months and 9 months having the lowest and highest values respectively. *Abasafitaa* had values between 10-80BU, with the lowest at 9 months and the highest at 13 months while that of *Gblemoduade* was between 70BU (12 months) and 115BU (15 months). *Abasafitaa* had the lowest paste breakdown while *Gblemoduade* had the highest (Fig. 4.24). Paste breakdown was significantly affected ($p<0.05$) by variety but not by age. There was a strong correlation ($r^2=0.717$ & 0.807 respectively) between paste breakdown and both amylose content and crude fibre for *Tek bankye*. There was, however, a moderate correlation ($r^2=0.594$ & 0.593 respectively) existing between paste breakdown and both amylose content and crude fibre for *Abasafitaa*. As stated in the previous section, both amylose and fibre molecules (cellulose and hemicelluloses) interact with water molecules through hydrogen bonding, in an aqueous suspension of starch or flour when heated. This results in gelatinization and subsequent increase in the viscosity of the paste. When the hot paste is agitated for a long period at high temperature, as is caused by the rotation of the Brabender amylograph bowl, the weak hydrogen bonds between some of the amylose molecules and water molecules break and the amylose molecules coil

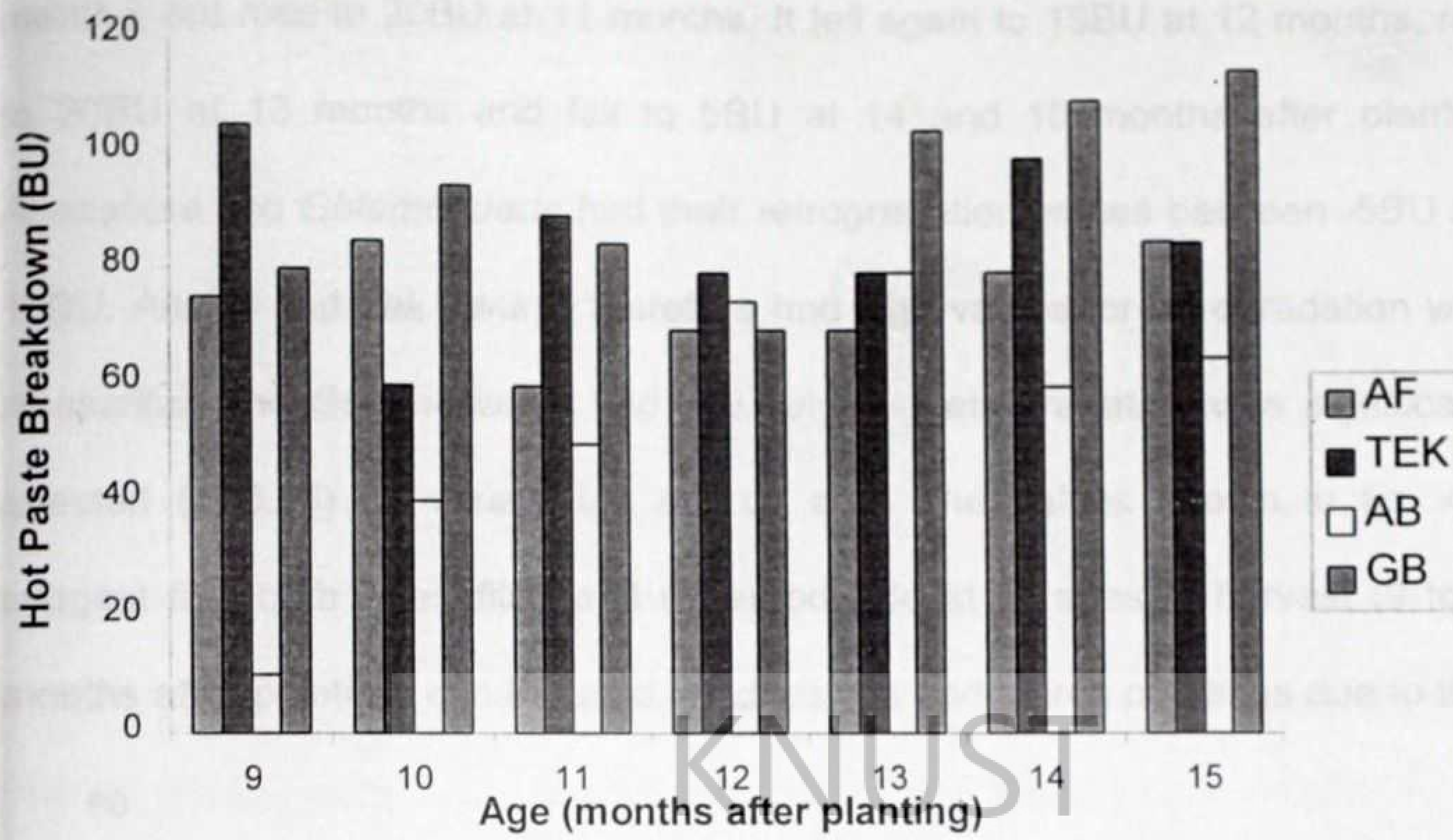


Fig. 4.24 Hot Paste Breakdown of Flour from four Cassava Varieties at different Ages

up forming intramolecular and intermolecular hydrogen bonds within and between its molecules. This causes a sharp decrease in viscosity and a consequent breakdown of the hot paste. The hydrogen bonds between cellulose or hemicellulose and water molecules may also break in a similar manner causing hot paste breakdown.

4.2.10.7 Retrogradation.

Retrogradation profile of *Afisiafi* started at 9 months with a value of 40BU and rose to 50BU at 10 months from where it fell to 0 (zero) at 11 months. It then rose to 30BU at 12 months but fell again to 5BU at 13 months and remained there till 14 months, from where it rose to 12.2BU at 15 months after planting. *Tek bankye*, on the other hand, started from 45BU at 9 months and fell to 10BU at 10 months, but rose to 20BU at 11 months. It fell again to 15BU at 12 months, rose to 20BU at 13 months and fell to 5BU at 14 and 15 months after planting. *Abasafitaa* and *Gblemoduade* had their retrogradation values between -5BU and 10BU. *Afisiafi* and *Tek bankye* therefore had high values for retrogradation while *Abasafitaa* and *Gblemoduade* had low values. Retrogradation was significantly affected ($p<0.05$) by variety but not by age. The values shown in fig. 4.25 suggest that both Abasafitaa and Gblemoduade at all ages at harvest (9 to 15 months after planting) can be used in adhesives and starch puddings due to their

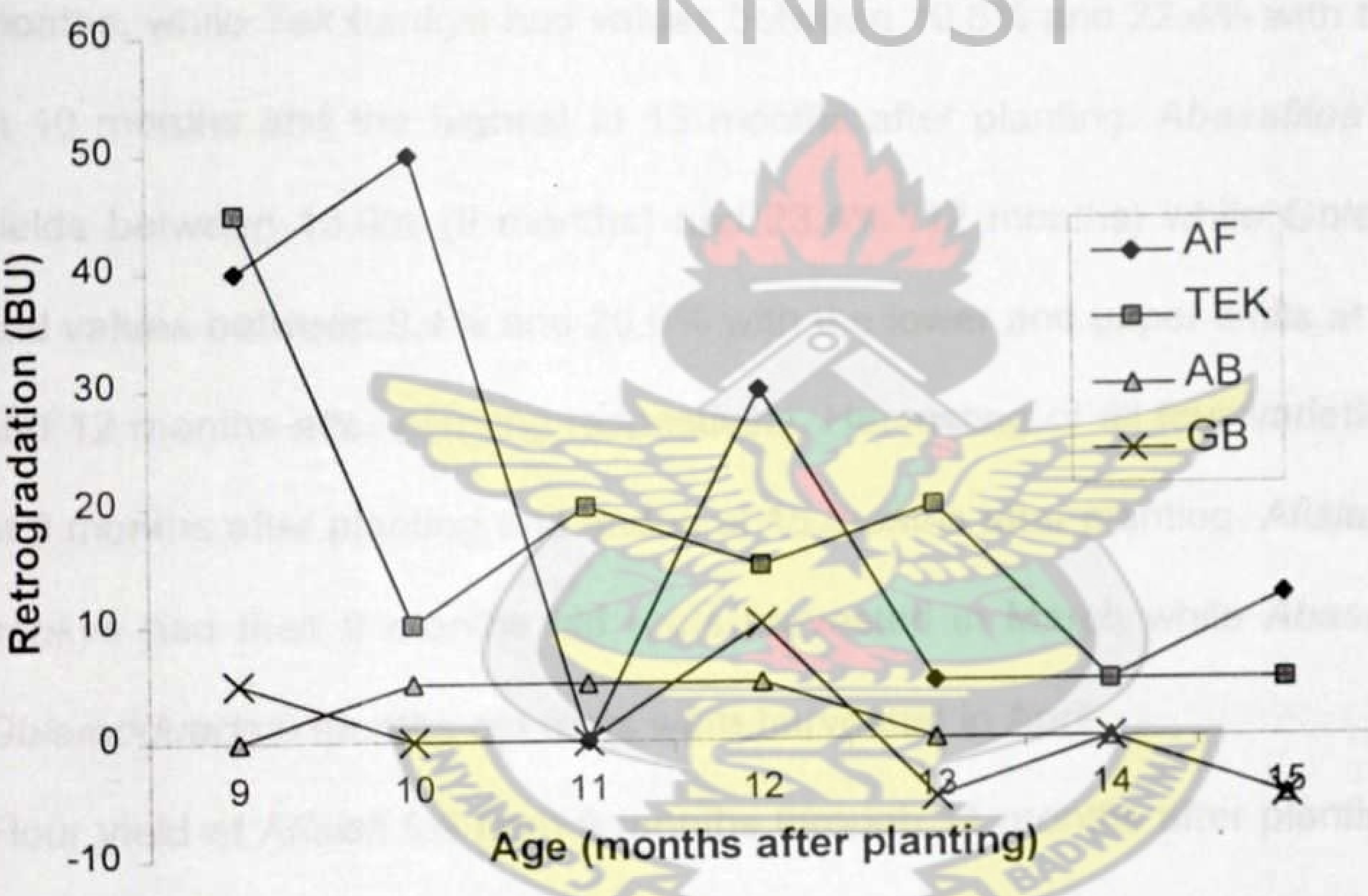


Fig.4.25 Retrogradation of Flour from four Cassava Varieties at different Ages

low retrogradation tendency. Afisiafi and Tek bankye, which had higher retrogradation values, can be used for baked products and pastries. However, Afisiafi harvested from 13 to 15 months after planting, as well as Tek bankye harvested at 14 and 15 months after planting, have low retrogradation values and therefore can be used for adhesives and starch puddings.

4.2.11 <u>Flour yield (kg flour/100kg whole roots)</u>.

Flour yield determination is important in ascertaining the age at which each cassava variety should be harvested to give optimum yield of flour, hence making processing of the roots into flour economical. Flour yield of *Afisiafi* ranged between 8% and 23% with the lowest at 11 months and the highest at 13 months, while *Tek bankye* had values between 10.6% and 22.4% with the lowest at 10 months and the highest at 13 months after planting. *Abasafitaa* had flour yields between 13.0% (9 months) and 23.4% (12 months) while *Gblemoduade* had values between 9.4% and 20.0% with the lower and upper limits at 9 months and 12 months after planting respectively. Harvesting of all four varieties started at 9 months after planting and ended at 15 months after planting. *Afisiafi* and *Tek bankye* had their 9 months old roots harvested in March while *Abasafitaa* and *Gblemoduade* 9 months old roots were harvested in April.

Flour yield of *Afisiafi* fell from 9 months through 11 months after planting (March to June), after which it rose uniformly reaching a peak at 13 months after planting, from where it fell again through 15 months after planting. *Tek bankye* had its flour yield falling from 9 months to 10 months after planting, after which it rose uniformly until 13 months after planting; it then fell uniformly until it reached 15 months after planting. *Abasafitaa* and *Gblemoduade* had similar trend for flour yield. They both rose sequentially from a minimum yield at 9 months old until they reached a peak at 12 months after planting, after which their yields fell uniformly until 15 months after planting. All the cassava varieties had low flour yield in April. This is because the rains started in late March, and by April the plants had mobilized most of the starch stored in their roots for germination or new shoots formation, following the onset of rains (Githunguri *et al.,* 1998). This clearly shows that apart from the age of plant at harvest, the month in which harvesting of the roots occurred also affects yield of the flour. Soil fertility and other environmental factors such as rainfall pattern (Ngendahayo and Dixon, 1998) also affect flour yield just as they affect root yield and starch yield. Even though cassava thrives well on depleted soil, it gives better yield of tuberous roots when cultivated on nutrient-rich soil (IITA, 1990). No fertilizer was applied during the planting season.

Afisiafi and *Tek bankye* had optimum flour yields at 13 months after planting (Fig.4.26) while *Abasafitaa* and *Gblemoduade* had optimum yields at 12 months after planting. Regression analysis showed a moderate correlation (r^2=0.578) existing between flour yield and age for *Tek bankye.* There was also a relationship between flour yield and variety at 9, 11, 12 and 13 months after planting. The respective correlation coefficients (r^2) for the ages at harvest are: 0.707, 0.728, 0.429 and 0.853. Correlation between flour yield and variety was strong, except at 12 months after planting. This means that 70% to 85% of the variations in flour yield could be attributed to its association with variety at 9, 11 and 13 months after planting.

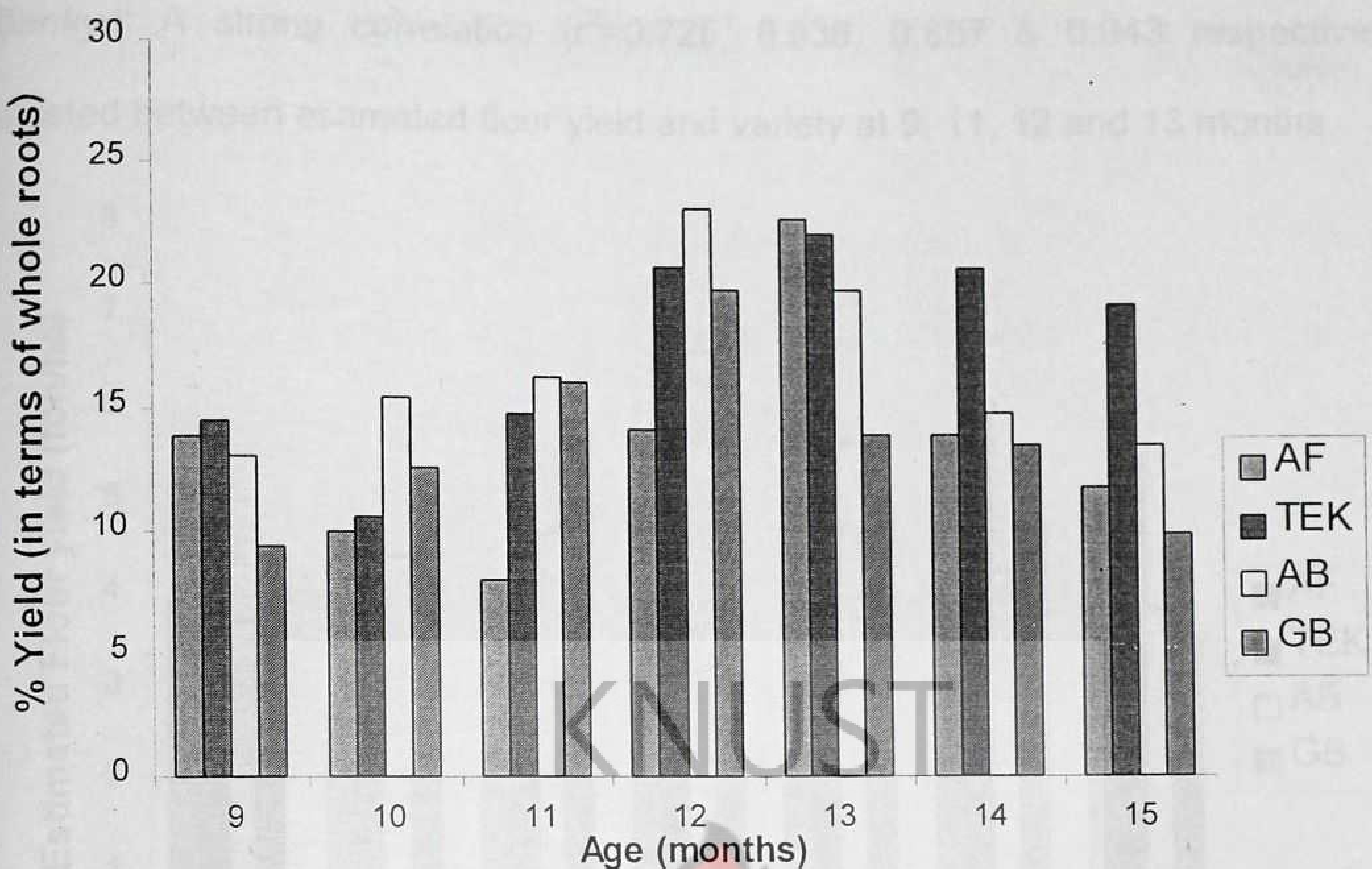


Fig.4.26 Yield of Flour from four Cassava Varieties at different ages

4.2.12 Estimated flour yield (ton/ha).

The estimated flour yield (ton/ha) calculated using the mean values of root yield for the four cassava varieties as reported by RTIP (2002) is shown below in Fig.4.27. The trend was similar to that shown above for flour yield (kg/100kg whole roots). Both *Afisiafi* and *Tek bankye* had estimated peak yields at 13 months after planting while *Abasafitaa* and *Gblemoduade* had their estimated peak yields at 12 months after planting. Regression analysis revealed a moderate correlation (r^2=0.578) between estimated flour yield and age for *Tek* *bankye*. A strong correlation (r^2=0.725, 0.936, 0.887 & 0.943 respectively) existed between estimated flour yield and variety at 9, 11, 12 and 13 months

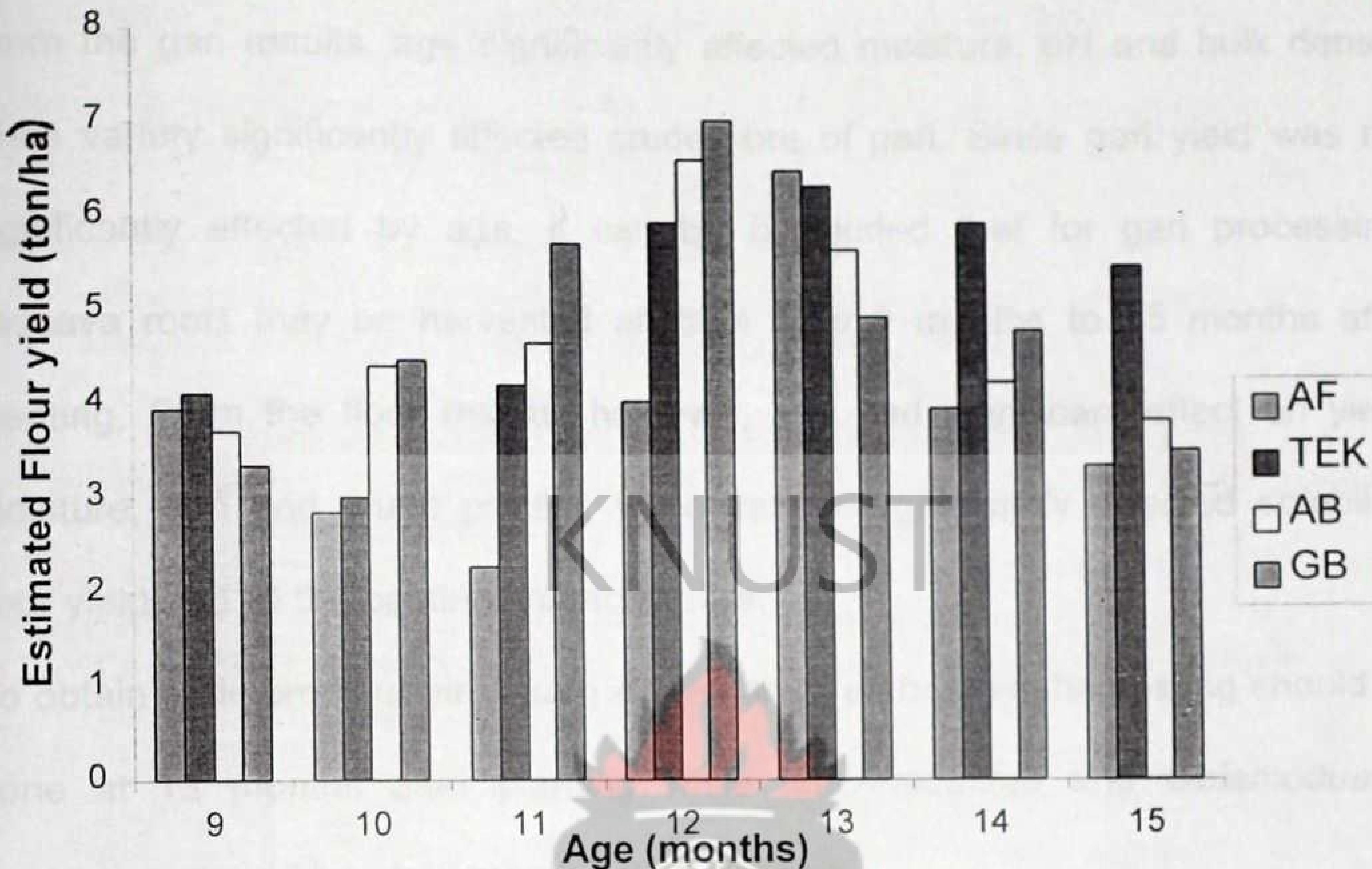


Fig. 4.27 Estimated Flour Yield (ton/ha) of four Cassava Varieties at different ages

after planting. 72% to 94% of the variation in the estimated flour yield could thus be attributed to variety at 9, 11, 12 and 13 months after planting.

4.3 CONCLUSION AND RECOMMENDATION

4.3.1 CONCLUSION

From the gari results, age significantly affected moisture, pH and bulk density while variety significantly affected crude fibre of gari. Since gari yield was not significantly affected by age, it can be concluded that for gari processing, cassava roots may be harvested anytime from 9 months to 15 months after planting. From the flour results, however, age had significant effect on yield, moisture, ash and crude protein, while variety significantly affected solubility, flour yield and all the pasting characteristics.

To obtain optimum flour yield from *Afisiafi* and *Tek bankye*, harvesting should be done at 13 months after planting while for *Abasafitaa* and *Gblemoduade*, harvesting should be at 12 months after planting.

4.3.2 RECOMMENDATION

Further studies should be conducted on:

1. The effects that month of harvest, soil fertility status and environmental factors such as rainfall pattern and altitudes have on the yield and physicochemical properties of cassava flour and starch.
2. The effects that different drying methods (sun drying both in open air and in solar drying cabinets) have on the physicochemical properties of cassava flour.
3. Relating pasting characteristics of flour from these four cassava varieties to their suitability for baking and in pastry preparation.

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APPENDICES

APPENDIX 1A: CALCULATIONS

$$\text{Moisture Content} = \frac{\text{Weight of fresh sample} - \text{Weight of dry sample}}{\text{Weight of fresh sample}} \times 100\ \%$$

$$\text{Ash content} = \frac{\text{Weight of Ash} \times 100\ \%}{\text{Weight of sample}}$$

$$\text{Titratable Acidity} = \frac{\text{Titre} \times \text{Conc. Alkali} \times \text{Total vol. filtrate} \times \text{Mol. Wt. Acid} \times 100}{\text{Pipetted filtrate vol.} \times \text{Weight of Sample} \times 1000}$$

$$\text{Swelling Capacity} = \frac{\text{Swollen gari volume}}{\text{Initial gari volume}}$$

$$\text{Crude Fibre} = \frac{\text{Weight of dry residue} - \text{Weight of ignited residue} \times 100\ \%}{\text{Weight of fresh sample}}$$

$$\%\ \text{Nitrogen} = \frac{A \times 14.007 \times \text{Conc. of HCl} \times 100\ \%}{\text{Weight of fresh sample}}$$

Where, A=ml of HCl used for sample - ml of HCl used for blank

Crude Protein = % Nitrogen X 6.25

$$\text{Starch Yield} = \frac{\text{Weight of Starch extracted}}{\text{Weight of Flour}} \times 100\%$$

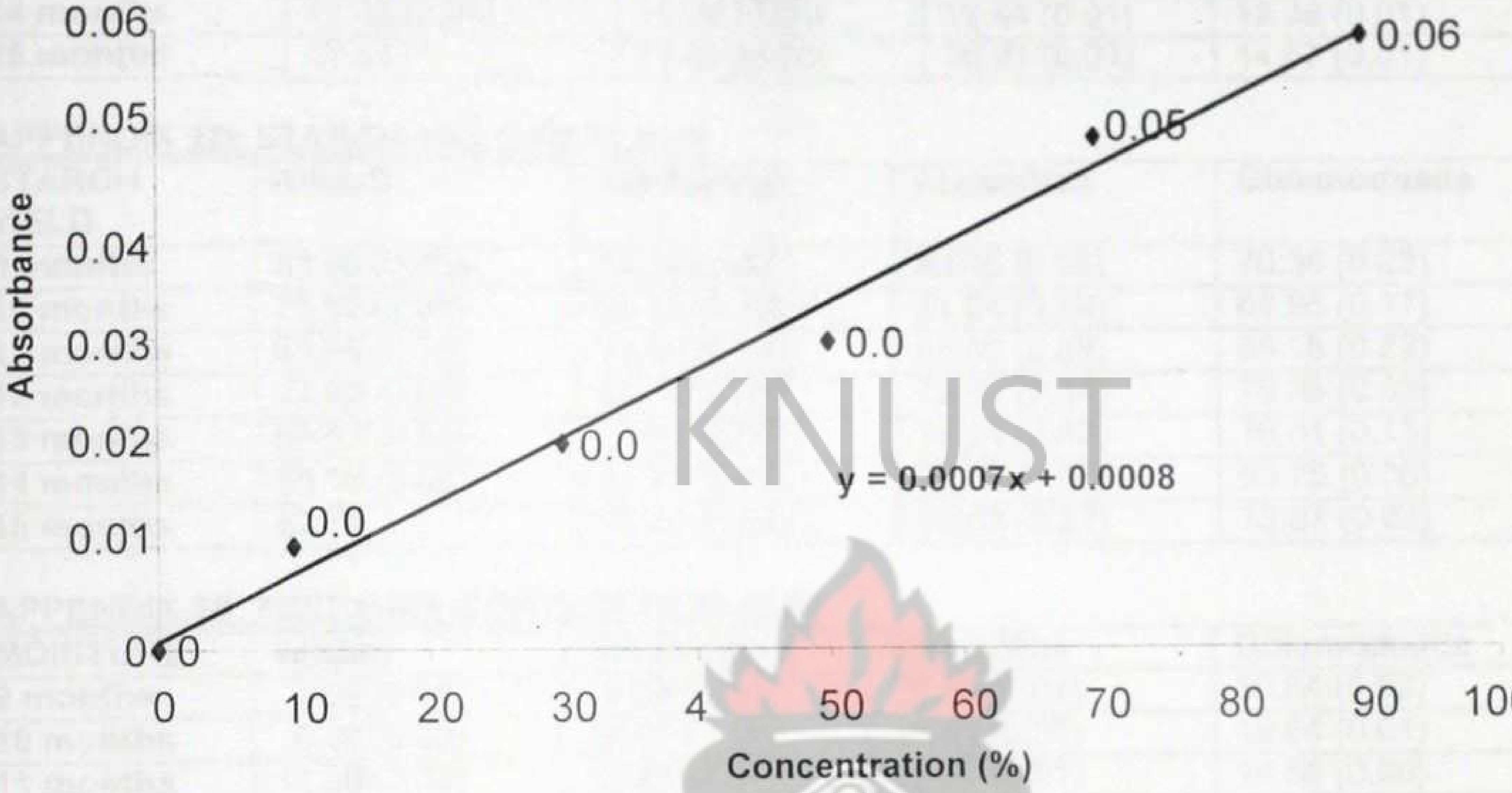
$$\text{Solubility} = \frac{\text{Weight of dry supernatant} \times 100\ \%}{\text{Weight of sample (dry basis)}}$$

$$\text{Swelling Power} = \frac{\text{Sedimented Paste} \times 100}{\text{Sample Wt} \times (100 - \%\ \text{Sol.})}$$

$$\text{Yield of Gari} = \frac{\text{Weight of gari} \times 100\ \%}{\text{Weight of whole roots}}$$

$$\text{Yield of Flour} = \frac{\text{Weight of flour} \times 100\ \%}{\text{Weight of whole roots}}$$

APPENDIX 1B: STANDARD CURVE FOR AMYLOSE



APPENDIX 2: RESULTS OF CASSAVA FLOUR SAMPLES

APPENDIX 2A: AMYLOSE CONTENT OF FLOUR

AMYLOSE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	16.48 (0.00)	21.71 (0.00)	36.00 (0.00)	34.57 (0.00)
10 months	22.19 (0.00)	36.00 (0.00)	30.29 (0.00)	34.57 (0.00)
11 months	30.29 (0.00)	26.48 (0.00)	32.19 (0.00)	28.86 (0.00)
12 months	34.57 (0.00)	31.71 (0.00)	23.14 (0.00)	23.62 (0.00)
13 months	26.00 (0.00)	23.62 (0.00)	27.43 (0.00)	23.14 (0.00)
14 months	20.29 (0.00)	20.29 (0.00)	20.76 (0.00)	34.57 (0.00)
15 months	23.49	22.67 (0.00)	23.14 (0.00)	34.57 (0.00)

( ) = standard deviation

APPENDIX 2B: SWELLING POWER OF FLOUR

SWELLING POWER	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	28.95 (0.15)	31.07 (0.35)	24.26 (0.54)	30.40 (0.25)
10 months	27.80 (0.35)	25.21 (0.07)	21.92 (0.28)	31.65 (0.07)
11 months	20.30 (0.31)	21.98 (0.21)	20.71 (0.14)	18.74 (0.23)
12 months	28.41 (0.09)	18.13 (0.13)	26.10 (0.14)	30.08 (0.27)
13 months	17.15 (0.17)	26.61(0.29)	28.23 (0.19)	31.97 (0.21)
14 months	27.24 (0.39)	29.85 (0.38)	21.41 (0.40)	28.03 (0.38)
15 months	27.40	30.39 (0.34)	28.45 (0.16)	26.16 (0.24)

APPENDIX 2C: SOLUBILITY OF FLOUR

SOLUBILITY	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	12.73 (0.03)	10.37 (0.01)	18.65 (0.01)	16.87 (0.01)
10 months	12.85 (0.01)	10.37 (0.01)	15.27 (0.03)	16.33 (0.00)
11 months	10.70 (0.01)	7.81 (0.00)	13.11 (0.01)	11.72 (0.01)
12 months	8.02 (0.01)	8.84 (0.02)	14.87 (0.01)	18.80 (0.04)
13 months	8.58 (0.00)	10.04 (0.00)	17.06 (0.01)	16.22 (0.00)
14 months	17.42 (0.01)	11.89 (0.01)	13.44 (0.01)	12.38 (0.01)
15 months	12.61	11.86 (0.00)	16.91 (0.01)	14.57 (0.01)

APPENDIX 2D: STARCH YIELD OF FLOUR

STARCH YIELD	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	53.60 (0.05)	71.55 (0.47)	68.46 (0.18)	70.36 (0.23)
10 months	75.50 (1.01)	67.33 (0.13)	71.24 (0.20)	69.95 (0.37)
11 months	63.94 (0.18)	73.65 (0.14)	64.06 (0.89)	68.16 (0.22)
12 months	72.40 (0.09)	71.72 (0.03)	72.93 (0.24)	75.35 (0.03)
13 months	69.63 (0.85)	73.83 (0.07)	74.24 (0.03)	76.01 (0.13)
14 months	66.19 (0.65)	72.45 (0.43)	75.69 (0.15)	63.75 (0.06)
15 months	67.71	73.45 (0.25)	68.63 (0.27)	73.87 (0.03)

APPENDIX 2E: MOISTURE CONTENT OF FLOUR

MOISTURE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	9.90 (0.01)	9.53 (0.03)	12.10 (0.01)	10.64 (0.02)
10 months	8.89 (0.02)	12.47 (0.11)	10.84 (0.00)	10.64 (0.01)
11 months	11.26 (0.02)	13.20 (0.01)	12.37 (0.01)	14.58 (0.00)
12 months	11.47 (0.01)	13.18 (0.00)	11.00 (0.04)	11.52 (0.01)
13 months	10.96 (0.00)	10.15 (0.01)	6.68 (0.01)	6.34 (0.01)
14 months	11.14 (0.01)	7.24 (0.01)	7.80 (0.02)	12.23 (0.00)
15 months	11.37	11.75 (0.00)	11.34 (0.00)	11.29 (0.00)

APPENDIX 2F: ASH CONTENT OF FLOUR

ASH	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	0.80 (0.00)	0.70 (0.00)	1.36 (0.00)	1.21 (0.00)
10 months	1.21 (0.00)	1.26 (0.00)	1.00 (0.00)	1.31 (0.00)
11 months	1.15 (0.00)	1.12 (0.00)	1.17 (0.00)	0.95 (0.00)
12 months	1.47 (0.00)	1.06 (0.00)	2.21 (0.00)	1.94 (0.01)
13 months	1.23 (0.00)	0.83 (0.00)	1.15 (0.00)	0.99 (0.00)
14 months	0.82 (0.00)	0.83 (0.00)	1.24 (0.00)	0.88 (0.00)
15 months	0.82	0.79 (0.00)	0.87 (0.00)	0.99 (0.00)

APPENDIX 2G: pH OF FLOUR

pH	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	5.86 (0.01)	5.46 (0.00)	5.53 (0.00)	5.47 (0.00)
10 months	5.49 (0.01)	5.13 (0.01)	6.21 (0.00)	6.61 (0.01)
11 months	5.63 (0.00)	6.51 (0.01)	5.27 (0.00)	5.30 (0.00)
12 months	6.40 (0.01)	5.31 (0.01)	6.15 (0.00)	6.54 (0.00)
13 months	5.07 (0.00)	6.65 (0.00)	5.67 (0.00)	5.97 (0.01)
14 months	6.27 (0.02)	6.02 (0.01)	5.32 (0.00)	5.55 (0.01)
15 months	5.28	5.11 (0.00)	5.49 (0.00)	5.31 (0.00)

APPENDIX 2C: SOLUBILITY OF FLOUR

SOLUBILITY	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	12.73 (0.03)	10.37 (0.01)	18.65 (0.01)	16.87 (0.01)
10 months	12.85 (0.01)	10.37 (0.01)	15.27 (0.03)	16.33 (0.00)
11 months	10.70 (0.01)	7.81 (0.00)	13.11 (0.01)	11.72 (0.01)
12 months	8.02 (0.01)	8.84 (0.02)	14.87 (0.01)	18.80 (0.04)
13 months	8.58 (0.00)	10.04 (0.00)	17.06 (0.01)	16.22 (0.00)
14 months	17.42 (0.01)	11.89 (0.01)	13.44 (0.01)	12.38 (0.01)
15 months	12.61	11.86 (0.00)	16.91 (0.01)	14.57 (0.01)

APPENDIX 2D: STARCH YIELD OF FLOUR

STARCH YIELD	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	53.60 (0.05)	71.55 (0.47)	68.46 (0.18)	70.36 (0.23)
10 months	75.50 (1.01)	67.33 (0.13)	71.24 (0.20)	69.95 (0.37)
11 months	63.94 (0.18)	73.65 (0.14)	64.06 (0.89)	68.16 (0.22)
12 months	72.40 (0.09)	71.72 (0.03)	72.93 (0.24)	75.35 (0.03)
13 months	69.63 (0.85)	73.83 (0.07)	74.24 (0.03)	76.01 (0.13)
14 months	66.19 (0.65)	72.45 (0.43)	75.69 (0.15)	63.75 (0.06)
15 months	67.71	73.45 (0.25)	68.63 (0.27)	73.87 (0.03)

APPENDIX 2E: MOISTURE CONTENT OF FLOUR

MOISTURE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	9.90 (0.01)	9.53 (0.03)	12.10 (0.01)	10.64 (0.02)
10 months	8.89 (0.02)	12.47 (0.11)	10.84 (0.00)	10.64 (0.01)
11 months	11.26 (0.02)	13.20 (0.01)	12.37 (0.01)	14.58 (0.00)
12 months	11.47 (0.01)	13.18 (0.00)	11.00 (0.04)	11.52 (0.01)
13 months	10.96 (0.00)	10.15 (0.01)	6.68 (0.01)	6.34 (0.01)
14 months	11.14 (0.01)	7.24 (0.01)	7.80 (0.02)	12.23 (0.00)
15 months	11.37	11.75 (0.00)	11.34 (0.00)	11.29 (0.00)

APPENDIX 2F: ASH CONTENT OF FLOUR

ASH	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	0.80 (0.00)	0.70 (0.00)	1.36 (0.00)	1.21 (0.00)
10 months	1.21 (0.00)	1.26 (0.00)	1.00 (0.00)	1.31 (0.00)
11 months	1.15 (0.00)	1.12 (0.00)	1.17 (0.00)	0.95 (0.00)
12 months	1.47 (0.00)	1.06 (0.00)	2.21 (0.00)	1.94 (0.01)
13 months	1.23 (0.00)	0.83 (0.00)	1.15 (0.00)	0.99 (0.00)
14 months	0.82 (0.00)	0.83 (0.00)	1.24 (0.00)	0.88 (0.00)
15 months	0.82	0.79 (0.00)	0.87 (0.00)	0.99 (0.00)

APPENDIX 2G: pH OF FLOUR

pH	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	5.86 (0.01)	5.46 (0.00)	5.53 (0.00)	5.47 (0.00)
10 months	5.49 (0.01)	5.13 (0.01)	6.21 (0.00)	6.61 (0.01)
11 months	5.63 (0.00)	6.51 (0.01)	5.27 (0.00)	5.30 (0.00)
12 months	6.40 (0.01)	5.31 (0.01)	6.15 (0.00)	6.54 (0.00)
13 months	5.07 (0.00)	6.65 (0.00)	5.67 (0.00)	5.97 (0.01)
14 months	6.27 (0.02)	6.02 (0.01)	5.32 (0.00)	5.55 (0.01)
15 months	5.28	5.11 (0.00)	5.49 (0.00)	5.31 (0.00)

APPENDIX 2H: CRUDE FIBRE OF FLOUR

CRUDE FIBRE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	1.90 (0.00)	1.45 (0.00)	2.11 (0.00)	2.56 (0.00)
10 months	2.22 (0.00)	2.07 (0.00)	1.84 (0.00)	2.54 (0.00)
11 months	2.62 (0.00)	1.57 (0.00)	1.92 (0.00)	1.82 (0.00)
12 months	2.52 (0.00)	1.67 (0.00)	1.27 (0.00)	1.69 (0.00)
13 months	1.89 (0.00)	1.52 (0.00)	1.69 (0.00)	1.62 (0.00)
14 months	0.77 (0.01)	1.46 (0.00)	1.47 (0.00)	1.78 (0.00)
15 months	1.98	1.58 (0.00)	1.76 (0.00)	1.99 (0.00)

APPENDIX 2I: CRUDE PROTEIN OF FLOUR

CRUDE PROTEIN	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	1.53 (0.00)	1.68 (0.06)	0.51 (0.06)	0.66 (0.00)
10 months	0.80 (0.06)	0.66 (0.00)	0.66 (0.00)	0.36 (0.06)
11 months	0.66 (0.00)	0.22 (0.00)	0.66 (0.00)	0.66 (0.00)
12 months	0.22 (0.00)	0.66 (0.00)	0.66 (0.00)	0.22 (0.00)
13 months	0.36 (0.06)	0.66 (0.00)	0.22 (0.00)	0.22 (0.00)
14 months	1.09 (0.00)	0.66 (0.00)	1.09 (0.00)	1.24 (0.06)
15 months	1.52	0.95 (0.06)	1.68 (0.06)	1.53 (0.00)

APPENDIX 2J: YIELD OF FLOUR

FLOUR YIELD	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	13.8	14.4	13.0	9.4
10 months	14.4	10.6	15.5	12.6
11 months	8.0	14.8	16.4	16.2
12 months	14.2	21.0	23.4	20.0
13 months	23.0	22.4	20.0	14.0
14 months	14.0	21.0	15.0	13.6
15 months	12.6	19.4	13.6	10.0

APPENDIX 2K: PASTING TEMPERATURE OF FLOUR

PASTING TEMPERATURE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	67.85 (1.20)	72.80 (2.69)	70.45 (0.49)	68.25 (0.35)
10 months	69.25 (0.78)	68.70 (0.28)	70.15 (1.63)	69.80 (0.14)
11 months	68.05 (0.07)	73.20 (1.84)	71.00 (0.71)	71.00 (0.00)
12 months	69.55 (0.92)	71.05 (0.64)	69.80 (0.42)	70.50 (0.42)
13 months	69.95 (0.92)	69.80 (1.41)	69.60 (0.57)	68.55 (0.49)
14 months	69.10 (0.00)	69.10 (0.14)	69.00 (0.14)	68.80 (0.28)
15 months	67.69	69.50 (0.00)	68.95 (1.34)	68.00 (0.00)

APPENDIX 2L: GELATINIZATION TEMPERATURE OF FLOUR

GELATINIZATION TEMPERATURE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	69.70 (1.13)	75.60 (0.99)	73.00 (0.85)	70.20 (0.00)
10 months	71.25 (0.64)	72.15 (0.49)	74.00 (0.71)	70.65 (0.21)
11 months	70.25 (0.07)	78.60 (0.57)	76.00 (0.71)	75.30 (0.14)
12 months	72.15 (0.07)	78.20 (0.28)	71.50 (0.28)	72.55 (0.92)
13 months	75.25 (1.34)	73.55 (1.06)	70.80 (0.28)	69.35 (0.07)
14 months	70.80 (0.42)	70.15 (0.07)	71.10 (0.28)	69.45 (0.07)
15 months	69.75	72.15 (0.07)	71.40 (0.99)	69.70 (0.00)

APPENDIX 2M: PEAK TEMPERATURE OF FLOUR

PEAK TEMPERATURE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	83.55 (0.35)	89.05 (0.49)	88.30 (2.69)	80.35 (0.07)
10 months	85.50 (0.85)	86.10 (0.00)	88.55 (0.07)	78.80 (0.00)
11 months	84.10 (0.42)	91.05 (0.35)	90.75 (1.91)	92.10 (0.42)
12 months	86.55 (0.92)	90.60 (1.70)	84.65 (1.20)	80.25 (1.91)
13 months	89.20 (0.14)	87.05 (0.78)	80.70 (1.56)	77.60 (0.71)
14 months	82.20 (0.00)	82.60 (0.00)	83.80 (0.85)	78.40 (0.57)
15 months	83.98	85.85 (0.21)	84.00 (1.41)	81.65 (0.21)

APPENDIX 2N: PEAK VISCOSITY OF FLOUR

PEAK VISCOSITY	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	280 (14.14)	300 (0.00)	155 (7.07)	190 (0.00)
10 months	305 (7.07)	220 (14.14)	145 (7.07)	210 (0.00)
11 months	245 (7.07)	290 (0.00)	180 (14.14)	175 (7.07)
12 months	290 (0.00)	235 (7.07)	225 (7.07)	160 (14.14)
13 months	215 (7.07)	280 (14.14)	180 (14.14)	220 (0.00)
14 months	210 (0.00)	270 (0.00)	210 (0.00)	220 (0.00)
15 months	261	250 (0.00)	185 (21.21)	220 (0.00)

APPENDIX 2O: VISCOSITY AT 95°C OF FLOUR

VISCOSITY AT 95°C	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	285 (7.07)	305 (7.07)	155 (7.07)	160 (14.14)
10 months	310 (0.00)	215 (7.07)	145 (7.07)	210 (0.00)
11 months	210 (0.00)	290 (0.00)	180 (14.14)	175 (7.07)
12 months	290 (0.00)	235 (7.07)	225 (7.07)	140 (14.14)
13 months	215 (7.07)	280 (14.14)	180 (14.14)	210 (0.00)
14 months	205 (7.07)	260 (0.00)	210 (0.00)	195 (7.07)
15 months	258	250 (0.00)	190 (28.28)	205 (7.07)

APPENDIX 2P: VISCOSITY AFTER 20 MINUTES AT 95°C OF FLOUR

VISCOSITY AT 95°C/20min	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	210 (0.00)	200 (0.00)	145 (7.07)	80 (14.14)
10 months	225 (7.07)	155 (7.07)	105 (7.07)	115 (7.07)
11 months	150 (0.00)	200 (14.14)	130 (0.00)	90 (0.00)
12 months	220 (14.14)	155 (7.07)	150 (0.00)	70 (14.14)
13 months	145 (7.07)	200 (14.14)	100 (14.14)	105 (7.07)
14 months	125 (7.07)	160 (0.00)	150 (0.00)	85 (7.07)
15 months	173	165 (7.07)	125 (21.21)	90 (0.00)

APPENDIX 2Q: VISCOSITY AT 50°C OF FLOUR

VISCOSITY AT 50°C	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	250 (0.00)	245 (21.21)	145 (7.07)	85 (7.07)
10 months	275 (7.07)	165 (21.21)	110 (0.00)	115 (7.07)
11 months	150 (0.00)	220 (0.00)	135 (7.07)	90 (0.00)
12 months	250 (0.00)	170 (0.00)	155 (7.07)	80 (14.14)
13 months	150 (0.00)	220 (14.14)	100 (14.14)	100 (14.14)
14 months	130 (14.14)	165 (7.07)	150 (0.00)	85 (7.07)
15 months	185	170 (14.14)	120 (14.14)	85 (7.07)

APPENDIX 2R: VISCOSITY AFTER 20 MINUTES AT 50°C OF FLOUR

VISCOSITY AT 50°C/20min	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	245 (7.07)	245 (21.21)	145 (7.07)	85 (7.07)
10 months	275 (7.07)	165 (21.21)	110 (0.00)	115 (7.07)
11 months	150 (0.00)	220 (0.00)	135 (7.07)	90 (0.00)
12 months	250 (0.00)	170 (0.00)	155 (7.07)	80 (14.14)
13 months	150 (0.00)	220 (14.14)	100 (14.14)	100 (14.14)
14 months	125 (7.07)	165 (7.07)	150 (0.00)	85 (7.07)
15 months	183	170 (14.14)	120 (14.14)	85 (7.07)

APPENDIX 2S: HOT PASTE STABILITY OF FLOUR

HOT PASTE STABILITY	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	70	100	10	110
10 months	80	65	40	95
11 months	95	90	50	85
12 months	70	80	75	90
13 months	70	80	80	115
14 months	85	110	60	135
15 months	88	85	60	130

APPENDIX 2T: HOT PASTE BREAKDOWN OF FLOUR

BREAKDOWN	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	75	105	10	80
10 months	85	60	40	95
11 months	60	90	50	85
12 months	70	80	75	70
13 months	70	80	80	105
14 months	80	100	60	110
15 months	85	85	65	115

APPENDIX 2U: SETBACK OR RETROGRADATION OF FLOUR

RETROGRADATION	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	40	45	0	5
10 months	50	10	5	0
11 months	0	20	5	0
12 months	30	15	5	10
13 months	5	20	0	-5
14 months	5	5	0	0
15 months	12	5	-5	-5

APPENDIX 3: RESULTS OF GARI SAMPLES

APPENDIX 3A: YIELD OF GARI

GARI YIELD	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	20.2	19.0	12.6	12.8
10 months	16.2	17.4	13.2	13.4
11 months	12.8	18.8	20.2	18.6
12 months	12.2	19.2	18.4	18.8
13 months	19.4	17.2	20.6	18.2
14 months	26.2	22.6	15.6	17.8
15 months	19.1	19.0	19.6	17.6

APPENDIX 3B: SWELLING CAPACITY OF GARI

SWELLING CAPACITY	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	2.80 (0.00)	2.67 (0.06)	2.80 (0.00)	2.93 (0.06)
10 months	2.80 (0.10)	2.73 (0.06)	2.63 (0.06)	2.73 (0.06)
11 months	2.80 (0.10)	2.87 (0.06)	2.80 (0.10)	2.73 (0.11)
12 months	2.87 (0.06)	2.77 (0.06)	2.57 (0.11)	2.73 (0.06)
13 months	2.93 (0.06)	2.60 (0.10)	2.53 (0.06)	2.63 (0.06)
14 months	2.77 (0.11)	2.80 (0.10)	2.87 (0.11)	2.80 (0.10)
15 months	2.90	2.70 (0.10)	2.90 (0.10)	2.83 (0.06)

APPENDIX 3C: BULK DENSITY OF GARI

BULK DENSITY	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	0.55 (0.01)	0.52 (0.00)	0.50 (0.01)	0.49 (0.01)
10 months	0.51 (0.00)	0.53 (0.01)	0.52 (0.01)	0.50 (0.01)
11 months	0.51 (0.01)	0.56 (0.01)	0.53 (0.03)	0.53 (0.02)
12 months	0.54 (0.01)	0.57 (0.02)	0.53 (0.03)	0.54 (0.01)
13 months	0.58 (0.01)	0.56 (0.01)	0.51 (0.01)	0.54 (0.00)
14 months	0.53 (0.01)	0.57 (0.02)	0.56 (0.00)	0.52 (0.02)
15 months	0.56	0.55 (0.00)	0.56 (0.00)	0.57 (0.00)

APPENDIX 3D: pH OF GARI

pH	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	3.91 (0.01)	4.00 (0.00)	3.69 (0.01)	3.76 (0.01)
10 months	3.58 (0.00)	3.68 (0.00)	4.05 (0.01)	3.89 (0.01)
11 months	3.60 (0.01)	3.92 (0.01)	3.85 (0.01)	4.08 (0.01)
12 months	3.79 (0.01)	3.99 (0.00)	3.96 (0.00)	4.05 (0.00)
13 months	3.75 (0.00)	4.02 (0.01)	4.03 (0.01)	3.76 (0.00)
14 months	3.75 (0.00)	4.21 (0.01)	3.72 (0.01)	3.95 (0.00)
15 months	4.12	4.10 (0.01)	4.59 (0.00)	4.24 (0.01)

APPENDIX 3E: TOTAL TITRATABLE ACIDITY OF GARI

TITRATABLE ACIDITY	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	1.61 (0.02)	1.61 (0.04)	1.61 (0.15)	1.24 (0.02)
10 months	1.50 (0.02)	1.56 (0.04)	0.87 (0.02)	1.24 (0.07)
11 months	1.62 (0.00)	0.85 (0.04)	1.14 (0.11)	1.07 (0.02)
12 months	1.18 (0.02)	1.17 (0.02)	1.30 (0.00)	1.08 (0.00)
13 months	1.54 (0.02)	1.03 (0.02)	1.37 (0.00)	1.46 (0.02)
14 months	1.52 (0.02)	1.01 (0.00)	1.51 (0.04)	1.08 (0.00)
15 months	1.30	1.27 (0.02)	0.77 (0.06)	1.13 (0.04)

APPENDIX 3F: CRUDE FIBRE OF GARI

CRUDE FIBRE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	2.03 (0.00)	1.81 (0.00)	2.56 (0.00)	2.72 (0.00)
10 months	2.49 (0.00)	2.25 (0.00)	2.14 (0.00)	2.32 (0.00)
11 months	3.33 (0.00)	2.07 (0.00)	2.18 (0.00)	2.08 (0.00)
12 months	2.77 (0.00)	1.61 (0.00)	3.63 (0.02)	1.91 (0.00)
13 months	2.00 (0.00)	1.61 (0.00)	1.87 (0.00)	1.87 (0.00)
14 months	2.19 (0.00)	1.62 (0.00)	2.02 (0.00)	1.90 (0.00)
15 months	2.15	1.89 (0.00)	2.33 (0.00)	1.80 (0.00)

APPENDIX 3G: MOISTURE CONTENT OF GARI

MOISTURE	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	10.60 (0.01)	9.57 (0.00)	10.11 (0.00)	10.04 (0.00)
10 months	10.57 (0.09)	10.49 (0.00)	10.03 (0.00)	10.35 (0.00)
11 months	10.24 (0.00)	10.03 (0.01)	10.11 (0.00)	9.54 (0.00)
12 months	10.62 (0.01)	10.22 (0.00)	10.22 (0.00)	11.33 (0.00)
13 months	10.65 (0.00)	11.15 (0.00)	10.08 (0.01)	10.83 (0.00)
14 months	11.57 (0.00)	10.97 (0.00)	10.46 (0.00)	10.64 (0.00)
15 months	10.35	10.08 (0.00)	10.25 (0.00)	9.62 (0.00)

APPENDIX 3H: ASH CONTENT OF GARI

ASH	Afisiafi	Tek bankye	Abasafitaa	Gblemoduade
9 months	1.15 (0.00)	1.03 (0.00)	1.16 (0.00)	1.03 (0.00)
10 months	1.15 (0.00)	0.97 (0.00)	1.03 (0.00)	1.28 (0.00)
11 months	1.05 (0.00)	0.88 (0.00)	1.36 (0.00)	1.07 (0.00)
12 months	1.03 (0.00)	0.90 (0.00)	1.30 (0.00)	1.24 (0.00)
13 months	1.39 (0.00)	1.05 (0.00)	1.16 (0.00)	1.17 (0.00)
14 months	1.34 (0.00)	0.98 (0.00)	0.90 (0.00)	1.10 (0.00)
15 months	1.31	1.29 (0.00)	1.25 (0.00)	1.11 (0.00)

APPENDIX 4: RESULTS OF TWO-WAY ANOVA WITHOUT REPLICATION FOR FLOUR

APPENDIX 4A: AMYLOSE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	141.6992	6	23.61654	0.664254	0.679355	2.661302
Variety	130.5781	3	43.52604	1.224241	0.329741	3.159911
Error	639.9628	18	35.55349			
Total	912.2402	27				
p>0.05 for both age and variety; no significant difference						

APPENDIX 4B: SWELLING POWER

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	173.9139	6	28.98564	1.834073	0.148728	2.661302
Variety	52.70686	3	17.56895	1.111679	0.37032	3.159911
Error	284.4716	18	15.80398			
Total	511.0923	27				
p>0.05 for both age and variety; no significant difference						

APPENDIX 4C: SOLUBILITY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	37.17046	6	6.195077	1.123449	0.387948	2.661302
Variety	147.9127	3	49.30425	8.941102	0.000765	3.159911
Error	99.25806	18	5.514337			
Total	284.3413	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4D: STARCH YIELD

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	182.8025	6	30.46709	1.538582	0.222155	2.661302
Variety	101.9456	3	33.98186	1.716077	0.19945	3.159911
Error	356.4371	18	19.80206			
Total	641.1852	27				
p>0.05 for both age and variety; no significant difference						

APPENDIX 4E: MOISTURE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	49.01891	6	8.169818	2.87062	0.038405	2.661302
Variety	2.67225	3	0.89075	0.312982	0.815761	3.159911
Error	51.22821	18	2.846011			
Total	102.9194	27				
p<0.05 for age; significant difference						
p>0.05 for variety; no significant difference						

APPENDIX 4F: ASH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	1.672941	6	0.278824	5.3404	0.002541	2.661302
Variety	0.452486	3	0.150829	2.888873	0.064045	3.159911
Error	0.939784	18	0.05221			
Total	3.065212	27				
p<0.05 for age; significant difference						
p>0.05 for variety; no significant difference						

APPENDIX 4G: pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	1.52248	6	0.253747	0.8753	0.532045	2.661302
Variety	0.090063	3	0.030021	0.103558	0.95692	3.159911
Error	5.218144	18	0.289897			
Total	6.830688	27				
p>0.05 for both age and variety; no significant difference						

APPENDIX 4H: CRUDE FIBRE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	1.596765	6	0.266128	2.097192	0.104412	2.661302
Variety	0.770614	3	0.256871	2.024249	0.146541	3.159911
Error	2.284148	18	0.126897			
Total	4.651527	27				
p>0.05 for both age and variety: no significant difference						

APPENDIX 4I: CRUDE PROTEIN

Source of Variation	SS	df	MS	F	P-value	F crit
Age	3.736967	6	0.622828	5.574935	0.002032	2.661302
Variety	0.1208	3	0.040267	0.360427	0.782286	3.159911
Error	2.010947	18	0.111719			
Total	5.868714	27				
p<0.05 for age; significant difference						
p>0.05 for variety; no significant difference						

APPENDIX 4J: FLOUR YIELD

Source of Variation	SS	df	MS	F	P-value	F crit
Age	245.2382	6	40.87304	4.318655	0.007182	2.661302
Variety	91.93961	3	30.64654	3.23812	0.046602	3.159911
Error	170.3574	18	9.464298			
Total	507.5352	27				
p<0.05 for both age and variety; significant difference						

APPENDIX 4K: PASTING TEMPERATURE

Source of Variation	SS	df	MS	F	P-value	F crit
Age	13.75844	6	2.293073	1.861231	0.143364	2.661302
Variety	12.82048	3	4.273493	3.46869	0.037972	3.159911
Error	22.17635	18	1.232019			
Total	48.75527	27				
p>0.05 for age; no significant difference						
P<0.05 for variety; significant difference						

APPENDIX 4L: GEL TEMPERATURE

Source of Variation	SS	df	MS	F	P-value	F crit
Age	61.62743	6	10.27124	2.509443	0.06075	2.661302
Variety	47.83544	3	15.94515	3.895677	0.026261	3.159911
Error	73.67464	18	4.093035			
Total	183.1375	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4M: PEAK TEMPERATURE

Source of Variation	SS	df	MS	F	P-value	F crit
Age	139.4238	6	23.2373	2.486194	0.062603	2.661302
Variety	142.7533	3	47.58442	5.091129	0.010006	3.159911
Error	168.2377	18	9.346537			
Total	450.4147	27				
p>0.05 for age: no significant difference						
p<0.05 for variety: significant difference						

APPENDIX 4N: PEAK VISCOSITY

Source of Variation	SS	df	MS	F	P-value	F crit
Age	378.0423	6	63.00705	0.053319	0.999209	2.661302
Variety	35080.99	3	11693.66	9.89561	0.000445	3.159911
Error	21270.63	18	1181.702			
Total	56729.66	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4O: VISCOSITY AT **95°C**

Source of Variation	SS	df	MS	F	P-value	F crit
Age	473.5284	6	78.92141	0.054389	0.999163	2.661302
Variety	38027.59	3	12675.86	8.735616	0.000863	3.159911
Error	26119	18	1451.055			
Total	64620.11	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4P: **VISCOSITY AT 95°C/20min**

Source of Variation	SS	df	MS	F	P-value	F crit
Age	2198.28	6	366.3801	0.456829	0.830838	2.661302
Variety	36962.73	3	12320.91	15.36261	3.31E-05	3.159911
Error	14436.11	18	802.0062			
Total	53597.12	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4Q: **VISCOSITY AT 50°C**

Source of Variation	SS	df	MS	F	P-value	F crit
Age	7217.857	6	1202.976	0.907499	0.511372	2.661302
Variety	56064.29	3	18688.1	14.09789	5.68E-05	3.159911
Error	23860.71	18	1325.595			
Total	87142.86	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4R: **VISCOSITY AT 50°C/20min**

Source of Variation	SS	df	MS	F	P-value	F crit
Age	7205.357	6	1200.893	0.896069	0.518646	2.661302
Variety	55028.87	3	18342.96	13.68695	6.81E-05	3.159911
Error	24123.21	18	1340.179			
Total	86357.44	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4S: HOT PASTE STABILITY

Source of Variation	SS	df	MS	F	P-value	F crit
Age	2338.69	6	389.7817	1.350636	0.286588	2.661302
Variety	10817.86	3	3605.952	12.49502	0.000118	3.159911
Error	5194.643	18	288.5913			
Total	18351.19	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4T: BREAKDOWN

Source of Variation	SS	df	MS	F	P-value	F crit
Age	1798.528	6	299.7547	1.053542	0.424942	2.661302
Variety	6258.54	3	2086.18	7.332252	0.002057	3.159911
Error	5121.379	18	284.5211			
Total	13178.45	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 4U: RETROGRADATION

Source of Variation	SS	df	MS	F	P-value	F crit
Age	1530.82	6	255.1367	2.107631	0.102968	2.661302
Variety	2219.874	3	739.9581	6.112639	0.004707	3.159911
Error	2178.968	18	121.0538			
Total	5929.663	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 5: LEAST SIGNIFICANT DIFFERENCE (LSD) OF ANOVA FOR FLOUR

APPENDIX 5A: LSD FOR SOLUBILITY

Varieties	Ma-Mb	LSD	Decision
AF-TEK	1.67563	2.176515	Not significant
AF-AB	3.769637	2.176515	significant
AF-GB	3.424201	2.176515	significant
TEK-AB	5.445267	2.176515	significant
TEK-GB	5.099831	2.176515	significant
AB-GB	0.345436	2.176515	Not significant

APPENDIX 5B: LSD FOR FLOUR YIELD (VARIETY)

Variety	Ma-Mb	LSD	Decision
AF-TEK	4.103968	2.851407	significant
AF-AB	3.146825	2.851407	significant
AF-GB	0.13254	2.851407	Not significant
TEK-AB	0.957143	2.851407	Not significant
TEK-GB	3.971429	2.851407	significant
AB-GB	3.014286	2.851407	significant

APPENDIX 5C: LSD FOR FLOUR YIELD (AGE)

Age	Ma-Mb	LSD	Decision	Age	Ma-Mb	LSD	Decision
9-10	0.475	3.772057	ns	**11-12**	5.8	3.772057	significant
9-11	1.2	3.772057	ns	**11-13**	6	3.772057	significant
9-12	7	3.772057	significant	11-14	2.05	3.772057	ns
9-13	7.2	3.772057	significant	11-15	0.131944	3.772057	ns
9-14	3.25	3.772057	ns	12-13	0.2	3.772057	ns
9-15	1.068056	3.772057	ns	12-14	3.75	3.772057	ns
10-11	1.675	3.772057	ns	**12-15**	5.931944	3.772057	significant
10-12	7.475	3.772057	significant	**13-14**	3.95	3.772057	significant
10-13	7.675	3.772057	significant	**13-15**	6.131944	3.772057	significant
10-14	3.725	3.772057	ns	14-15	2.181944	3.772057	ns
10-15	1.543056	3.772057	ns				

APPENDIX 5D: LSD FOR MOISTURE

Age	Ma-Mb	LSD	Decision	Age	Ma-Mb	LSD	Decision
9-10	0.168756	2.068485	ns	11-12	1.065413	2.068485	ns
9-11	2.310944	2.068485	significant	**11-13**	4.321634	2.068485	significant
9-12	1.245531	2.068485	ns	**11-14**	3.253455	2.068485	significant
9-13	2.010689	2.068485	ns	11-15	1.416543	2.068485	ns
9-14	0.94251	2.068485	ns	**12-13**	3.25622	2.068485	significant
9-15	0.894402	2.068485	ns	**12-14**	2.188041	2.068485	significant
10-11	2.142188	2.068485	significant	12-15	0.351129	2.068485	ns
10-12	1.076775	2.068485	ns	13-14	1.068179	2.068485	ns
10-13	2.179445	2.068485	significant	**13-15**	2.905091	2.068485	significant
10-14	1.111266	2.068485	ns	14-15	1.836912	2.068485	ns
10-15	0.725646	2.068485	ns				

APPENDIX 5E: LSD FOR ASH

Age	Ma-Mb	LSD	Decision	Age	Ma-Mb	LSD	Decision
9-10	0.181174	0.280164	ns	**11-12**	0.570184	0.280164	significant
9-11	0.083075	0.280164	ns	11-13	0.048945	0.280164	ns
9-12	0.653259	0.280164	significant	11-14	0.156918	0.280164	ns
9-13	0.03413	0.280164	ns	11-15	0.229737	0.280164	ns
9-14	0.073844	0.280164	ns	**12-13**	0.619129	0.280164	significant
9-15	0.146662	0.280164	ns	**12-14**	0.727102	0.280164	significant
10-11	0.0981	0.280164	ns	**12-15**	0.799921	0.280164	significant
10-12	0.472085	0.280164	significant	13-14	0.107973	0.280164	ns
10-13	0.147045	0.280164	ns	13-15	0.180791	0.280164	ns
10-14	0.255018	0.280164	ns	14-15	0.072818	0.280164	ns
10-15	0.327836	0.280164	significant				

APPENDIX 5F: LSD FOR CRUDE PROTEIN

Age	Ma-Mb	LSD	Decision	Age	Ma-Mb	LSD	Decision
9-10	0.474297	0.409825	significant	11-12	0.109453	0.409825	ns
9-11	0.547266	0.409825	significant	11-13	0.182422	0.409825	ns
9-12	0.656719	0.409825	significant	**11-14**	0.474297	0.409825	significant
9-13	0.729688	0.409825	significant	**11-15**	0.871571	0.409825	significant
9-14	0.072969	0.409825	ns	12-13	0.072969	0.409825	ns
9-15	0.324306	0.409825	ns	**12-14**	0.58375	0.409825	significant
10-11	0.072969	0.409825	ns	**12-15**	0.981024	0.409825	significant
10-12	0.182422	0.409825	ns	**13-14**	0.656719	0.409825	significant
10-13	0.255391	0.409825	ns	**13-15**	1.053993	0.409825	significant
10-14	0.401328	0.409825	ns	14-15	0.397274	0.409825	ns
10-15	0.798602	0.409825	significant				

APPENDIX 5G: LSD FOR PASTING TEMPERATURE

Variety	Ma-Mb	LSD	Decision
AF-TEK	1.815873	1.028783	Significant
AF-AB	1.073016	1.028783	Significant
AF-GB	0.494444	1.028783	Not significant
TEK-AB	0.742857	1.028783	Not significant
TEK-GB	1,321429	1.028783	Significant
AB-GB	0.578571	1.028783	Not significant

APPENDIX 5H: LSD FOR GEL TEMPERATURE

Variety	Ma-Mb	LSD	Decision
AF-TEK	3.035317	1.875158	Significant
AF-AB	1.235317	1.875158	Not significant
AF-GB	0.278968	1.875158	Not significant
TEK-AB	1.8	1.875158	Not significant
TEK-GB	3.314286	1.875158	Significant
AB-GB	1.514286	1.875158	Not significant

APPENDIX 5I: LSD FOR PEAK TEMPERATURE

Variety	Ma-Mb	LSD	Decision
AF-TEK	2.793651	2.833612	Not significant
AF-AB	1.143651	2.833612	Not significant
AF-GB	3.370635	2.833612	Significant
TEK-AB	1.65	2.833612	Not significant
TEK-GB	6.164286	2.833612	Significant
AB-GB	4.514286	2.833612	Significant

APPENDIX 5J: LSD FOR PEAK VISCOSITY

Variety	Ma-Mb	LSD	Decision
AF-TEK	5.555556	31.86171	Not significant
AF-AB	75.15873	31.86171	Significant
AF-GB	58.73016	31.86171	Significant
TEK-AB	80.71429	31.86171	Significant
TEK-GB	64.28571	31.86171	Significant
AB-GB	16.42857	31.86171	Not significant

APPENDIX5K: LSD FOR VISCOSITY AT 95°C

Variety	Ma-Mb	LSD	Decision
AF-TEK	8.849206	35.3067	Not significant
AF-AB	69.72222	35.3067	Significant
AF-GB	68.29365	35.3067	Significant
TEK-AB	78.57143	35.3067	Significant
TEK-GB	77.14286	35.3067	Significant
AB-GB	1.428571	35.3067	Not significant

APPENDIX 5L: LSD FOR VISCOSITY AT 95°C/20min

Variety	Ma-Mb	LSD	Decision
AF-TEK	1.825397	26.24847	Not significant
AF-AB	48.96825	26.24847	Significant
AF-GB	87.53968	26.24847	Significant
TEK-AB	47.14286	26.24847	Significant
TEK-GB	85.71429	26.24847	Significant
AB-GB	38.57143	26.24847	Significant

APPENDIX 5M: LSD FOR VISCOSITY 50°C

Variety	Ma-Mb	LSD	Decision
AF-TEK	5	33.74586	Not significant
AF-AB	67.85714	33.74586	Significant
AF-GB	107.1429	33.74586	Significant
TEK-AB	62.85714	33.74586	Significant
TEK-GB	102.1429	33.74586	Significant
AB-GB	39.28571	33.74586	Significant

APPENDIX 5N: LSD FOR VISCOSITY 50°C/20min

Variety	Ma-Mb	LSD	Decision
AF-TEK	3.333333	33.93098	Not significant
AF-AB	66.19048	33.93098	Significant
AF-GB	105.4762	33.93098	Significant
TEK-AB	62.85714	33.93098	Significant
TEK-GB	102.1429	33.93098	Significant
AB-GB	39.28571	33.93098	Significant

APPENDIX 5O: LSD FOR HOT PASTE STABILITY

Variety	Ma-Mb	LSD	Decision
AF-TEK	7.380952	15.74551	Not significant
AF-AB	26.19048	15.74551	Significant
AF-GB	28.80952	15.74551	Significant
TEK-AB	33.57143	15.74551	Significant
TEK-GB	21.42857	15.74551	Significant
AB-GB	55	15.74551	Significant

APPENDIX 5P: LSD FOR BREAKDOWN

Variety	Ma-Mb	LSD	Decision
AF-TEK	10.6746	15.63408	Not significant
AF-AB	20.75397	15.63408	Significant
AF-GB	19.24603	15.63408	Significant
TEK-AB	31.42857	15.63408	Significant
TEK-GB	8.571429	15.63408	Not significant
AB-GB	40	15.63408	Significant

APPENDIX 5Q: LSD FOR RETROGRADATION

Variety	Ma-Mb	LSD	Decision
AF-TEK	3.174603	10.19775	Not significant
AF-AB	18.88889	10.19775	Significant
AF-GB	19.60317	10.19775	Significant
TEK-AB	15.71429	10.19775	Significant
TEK-GB	16.42857	10.19775	Significant
AB-GB	0.714286	10.19775	Not significant

APPENDIX 6: RESULTS OF TWO-WAY ANOVA WITHOUT REPLICATION FOR GARI

APPENDIX 6A: **GARI YIELD**

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	81.74929	6	13.62488	1.346739	0.288098	2.661302
Variety	21.3725	3	7.124167	0.704182	0.561844	3.159911
Error	182.105	18	10.11694			
Total	285.2268	27				
p>0.05 for both age and variety; no significant difference						

APPENDIX 6B: SWELLING CAPACITY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	0.077808	6	0.012968	1.325986	0.296266	2.661302
Variety	0.053137	3	0.017712	1.811108	0.181244	3.159911
Error	0.176038	18	0.00978			
Total	0.306983	27				
p>0.05 for both age and variety; no significant difference						

APPENDIX 6C: BULK DENSITY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	0.00628	6	0.001047	2.952428	0.034693	2.661302
Variety	0.002332	3	0.000777	2.193156	0.124107	3.159911
Error	0.006381	18	0.000355			
Total	0.014993	27				
p<0.05 for age: significant difference						
p>0.05 for variety: no significant difference						

APPENDIX 6D: pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	0.576801	6	0.096133	3.245279	0.024278	2.661302
Variety	0.19376	3	0.064587	2.180318	0.125675	3.159911
Error	0.533206	18	0.029623			
Total	1.303767	27				
p<0.05 for age: significant difference						
p>0.05 for variety: no significant difference						

APPENDIX 6E: TOTAL TITRATABLE ACIDITY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	0.433723	6	0.072287	1.447434	0.25142	2.661302
Variety	0.371046	3	0.123682	2.47653	0.094365	3.159911
Error	0.898949	18	0.049942			
Total	1.703719	27				
p>0.05 for both age and variety: no significant difference						

APPENDIX 6F: CRUDE FIBRE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	1.455161	6	0.242527	1.428579	0.257927	2.661302
Variety	1.612649	3	0.53755	3.166381	0.049709	3.159911
Error	3.055822	18	0.169768			
Total	6.123632	27				
p>0.05 for age; no significant difference						
p<0.05 for variety; significant difference						

APPENDIX 6G: MOISTURE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	3.04005	6	0.506675	3.475207	0.018483	2.661302
Variety	0.856026	3	0.285342	1.957117	0.156634	3.159911
Error	2.624347	18	0.145797			
Total	6.520422	27				
p<0.05 for age: significant difference						
p>0.05 for variety: no significant difference						

APPENDIX 6H: ASH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Age	0.088835	6	0.014806	0.775705	0.599315	2.661302
Variety	0.140763	3	0.046921	2.458269	0.096028	3.159911
Error	0.343567	18	0.019087			
Total	0.573165	27				
p>0.05 for both age and variety :no significant difference						

APPENDIX 7: LEAST SIGNIFICANT DIFFERENCE (LSD) OF ANOVA FOR GARI

APPENDIX 7A: LSD FOR pH

Age	Ma-Mb	LSD	Decision	Age	Ma-Mb	LSD	Decision
9-10	0.04	0.211031	ns	11-12	0.085	0.211031	ns
9-11	0.024167	0.211031	ns	11-13	0.026667	0.211031	ns
9-12	0.109167	0.211031	ns	11-14	0.044167	0.211031	ns
9-13	0.050833	0.211031	ns	**11-15**	0.40125	0.211031	significant
9-14	0.068333	0.211031	ns	12-13	0.058333	0.211031	ns
9-15	0.425417	0.211031	significant	12-14	0.040833	0.211031	ns
10-11	0.064167	0.211031	ns	**12-15**	0.31625	0.211031	significant
10-12	0.149167	0.211031	ns	13-14	0.0175	0.211031	ns
10-13	0.090833	0.211031	ns	**13-15**	0.374583	0.211031	significant
10-14	0.108333	0.211031	ns	**14-15**	0.357083	0.211031	significant
10-15	0.465417	0.211031	significant				

APPENDIX 7B: LSD FOR MOISTURE

Age	Ma-Mb	LSD	Decision	Age	Ma-Mb	LSD	Decision
9-10	0.270037	0.468175	ns	**11-12**	0.615332	0.468175	significant
9-11	0.09879	0.468175	ns	**11-13**	0.696935	0.468175	significant
9-12	0.516541	0.468175	significant	**11-14**	0.931403	0.468175	significant
9-13	0.598145	0.468175	significant	11-15	0.09768	0.468175	ns
9-14	0.832613	0.468175	significant	12-13	0.081604	0.468175	ns
9-15	0.00111	0.468175	ns	12-14	0.316072	0.468175	ns
10-11	0.368827	0.468175	ns	**12-15**	0.517651	0.468175	significant
10-12	0.246505	0.468175	ns	13-14	0.234468	0.468175	ns
10-13	0.328108	0.468175	ns	**13-15**	0.599255	0.468175	significant
10-14	0.562577	0.468175	significant	**14-15**	0.833723	0.468175	significant
10-15	0.271146	0.468175	ns				

APPENDIX 7C: LSD FOR BULK DENSITY

Age	Ma-Mb	LSD	Decision	Age	Ma-Mb	LSD	Decision
9-10	1.68E-05	0.023086	ns	11-12	0.010983	0.023086	ns
9-11	0.01645	0.023086	ns	11-13	0.011992	0.023086	ns
9-12	0.027433	0.023086	significant	11-14	0.014383	0.023086	ns
9-13	0.028442	0.023086	significant	**11-15**	0.026305	0.023086	significant
9-14	0.030833	0.023086	significant	12-13	0.001008	0.023086	ns
9-15	0.042755	0.023086	significant	12-14	0.0034	0.023086	ns
10-11	0.016467	0.023086	ns	12-15	0.015322	0.023086	ns
10-12	0.02745	0.023086	significant	13-14	0.002392	0.023086	ns
10-13	0.028458	0.023086	significant	13-15	0.014313	0.023086	ns
10-14	0.03085	0.023086	significant	14-15	0.011922	0.023086	ns
10-15	0.042772	0.023086	significant				

APPENDIX 7D: LSD FOR CRUDE FIBRE

Age	Ma-Mb	LSD	Decision
AF-TEK	0.587139	0.381894	significant
AF-AB	0.033732	0.381894	ns
AF-GB	0.338625	0.381894	ns
TEK-AB	0.553407	0.381894	significant
TEK-GB	0.248514	0.381894	ns
AB-GB	0.304892	0.381894	ns

APPENDIX 8A: FLOUR YIELD REGRESSION ANALYSIS.

Age and Flour yield for Afisiafi.

Regression Statistics	
Multiple R	0.278783
R Square	0.07772
Adjusted R Square	-0.10674
Standard Error	5.012458
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	10.5862	10.5862	0.421346	0.544899
Residual	5	125.6237	25.12473		
Total	6	136.2099			

Age and Flour yield for Tek bankye.

Regression Statistics	
Multiple R	0.760025
R Square	0.577637
Adjusted R Square	0.493165
Standard Error	3.136468
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	67.27	67.27	6.838169	0.04738344
Residual	5	49.187143	9.837429		
Total	6	116.457143			

Age and Flour yield for Abasafitaa.

Regression Statistics	
Multiple R	0.090998
R Square	0.008281
Adjusted R Square	-0.190063
Standard Error	4.069609
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.691429	0.691429	0.041749	0.846156311
Residual	5	82.808571	16.56171		
Total	6	83.5			

Age and Flour yield for Gblemoduade.

Regression Statistics	
Multiple R	0.033928
R Square	0.001151
Adjusted R Square	-0.198619
Standard Error	3.983394
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.091429	0.091429	0.005762	0.942435934
Residual	5	79.337143	15.86743		
Total	6	79.428571			

Variety and Flour yield at 9 months.

Regression Statistics	
Multiple R	0.840971
R Square	0.707233
Adjusted R Square	0.560849
Standard Error	1.485261
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	10.658	10.658	4.831369	0.15902859
Residual	2	4.412	2.206		
Total	3	15.07			

Variety and Flour yield at 10 months.

Regression Statistics	
Multiple R	0.66118
R Square	0.43716
Adjusted R Square	0.155739
Standard Error	2.278486
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	8.0645	8.0645	1.553405	0.33882
Residual	2	10.383	5.1915		
Total	3	18.4475			

Variety and Flour yield at 11 months.

Regression Statistics	
Multiple R	0.853189
R Square	0.727932
Adjusted R Square	0.591898
Standard Error	2.532588
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	34.322	34.322	5.351107	0.146810612
Residual	2	12.828	6.414		
Total	3	47.15			

Variety and Flour yield at 12 months.

Regression Statistics	
Multiple R	0.654854
R Square	0.428834
Adjusted R Square	0.143251
Standard Error	3.613032
Observations	4

ANOVA	df	SS	MS	F	Significance F
Regression	1	19.602	19.602	1.501609	0.345145851
Residual	2	26.108	13.054		
Total	3	45.71			

Variety and Flour yield at 13 months.

Regression Statistics	
Multiple R	0.923542
R Square	0.852931
Adjusted R Square	0.779396
Standard Error	1.930285
Observations	4

ANOVA	df	SS	MS	F	Significance F
Regression	1	43.218	43.218	11.59903	0.076457511
Residual	2	7.452	3.726		
Total	3	50.67			

Variety and Flour yield at 14 months.

Regression Statistics	
Multiple R	0.269378
R Square	0.072564
Adjusted R Square	-0.391153
Standard Error	4.069889
Observations	4

ANOVA	df	SS	MS	F	Significance F
Regression	1	2.592	2.592	0.156484	0.730622218
Residual	2	33.128	16.564		
Total	3	35.72			

Variety and Flour yield at 15 months.

Regression Statistics	
Multiple R	0.362738
R Square	0.131579
Adjusted R Square	-0.30263
Standard Error	4.637481
Observations	4

ANOVA	df	SS	MS	F	Significance F
Regression	1	6.517014	6.517014	0.303029	0.637262
Residual	2	43.01245	21.50623		
Total	3	49.52947			

APPENDIX 8B: GARI YIELD REGRESSION ANALYSIS.

Age and Gari Yield for Afisiafi.

Regression Statistics	
Multiple R	0.373256
R Square	0.13932
Adjusted R Square	-0.03282
Standard Error	4.894479
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	19.38893	19.38893	0.809358	0.409544
Residual	5	119.7796	23.95593		
Total	6	139.1686			

Age and Gari Yield for Tek bankye.

Regression Statistics	
Multiple R	0.383203
R Square	0.146845
Adjusted R Square	-0.023786
Standard Error	1.792684
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.7657143	2.765714	0.860597	0.3961474
Residual	5	16.068571	3.213714		
Total	6	18.834286			

Age and Gari Yield for Abasafitaa.

Regression Statistics	
Multiple R	0.6027721
R Square	0.3633342
Adjusted R Square	0.236001
Standard Error	2.9311626
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	24.5157143	24.51571	2.853414	0.1519772
Residual	5	42.9585714	8.591714		
Total	6	67.4742857			

Age and Gari Yield for Gblemoduade.

Regression Statistics	
Multiple R	0.6955358
R Square	0.4837701
Adjusted R Square	0.3805241
Standard Error	1.9905491
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	18.565714	18.56571	4.685607	0.0827023
Residual	5	19.811429	3.962286		
Total	6	38.377143			

Variety and Gari Yield at 9 months.

Regression Statistics	
Multiple R	0.919714
R Square	0.845874
Adjusted R Square	0.768811
Standard Error	1.930285
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	40.898	40.898	10.97638	0.080286
Residual	2	7.452	3.726		
Total	3	48.35			

Variety and Gari Yield at 10 months.

Regression Statistics	
Multiple R	0.78172
R Square	0.611085
Adjusted R Square	0.416628
Standard Error	1.589339
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	7.938	7.938	3.142518	0.21828
Residual	2	5.052	2.526		
Total	3	12.99			

Variety and Gari Yield at 11 months.

Regression Statistics	
Multiple R	0.740364
R Square	0.548139
Adjusted R Square	0.322208
Standard Error	2.698889
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	17.672	17.672	2.426139	0.259636
Residual	2	14.568	7.284		
Total	3	32.24			

Variety and Gari Yield at 12 months.

Regression Statistics	
Multiple R	0.739686
R Square	0.547135
Adjusted R Square	0.320703
Standard Error	2.73313
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	18.05	18.05	2.416332	0.260314
Residual	2	14.94	7.47		
Total	3	32.99			

Variety and Gari Yield at 13 months.

Regression Statistics	
Multiple R	0.017528
R Square	0.000307
Adjusted R Square	-0.49954
Standard Error	1.803885
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.002	0.002	0.000615	0.982472
Residual	2	6.508	3.254		
Total	3	6.51			

Variety and Gari Yield at 14 months.

Regression Statistics	
Multiple R	0.871928
R Square	0.760258
Adjusted R Square	0.640387
Standard Error	2.859021
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	51.842	51.842	6.342305	0.128072
Residual	2	16.348	8.174		
Total	3	68.19			

Variety and Gari Yield at 15 months.

Regression Statistics	
Multiple R	0.586947
R Square	0.344507
Adjusted R Square	0.016761
Standard Error	0.850588
Observations	4

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.7605	0.7605	1.05114	0.413053
Residual	2	1.447	0.7235		
Total	3	2.2075			

APPENDIX 8C: Swelling power and Starch yield for Gblemoduade.

Regression Statistics	
Multiple R	0.366163
R Square	0.134076
Adjusted R Square	-0.03911
Standard Error	4.710546
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	17.17838	17.17838	0.774176	0.419202
Residual	5	110.9462	22.18924		
Total	6	128.1246			

APPENDIX 8D: Swelling power and Peak temperature for Abasafitaa.

Regression Statistics	
Multiple R	0.713557
R Square	0.509164
Adjusted R Square	0.410997
Standard Error	2.674855
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	37.11005	37.11005	5.186701	0.071768
Residual	5	35.77424	7.154847		
Total	6	72.88429			

APPENDIX 8E: Swelling power and Peak temperature for Gblemoduade.

Regression Statistics	
Multiple R	0.939835
R Square	0.883289
Adjusted R Square	0.859947
Standard Error	1.853114
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	129.947	129.947	37.84094	0.001651
Residual	5	17.17016	3.434031		
Total	6	147.1171			

APPENDIX 8F: Swelling power and Peak viscosity for Afisiafi.

Regression Statistics	
Multiple R	0.615052
R Square	0.378289
Adjusted R Square	0.253947
Standard Error	4.002092
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	48.7281	48.7281	3.042323	0.141572
Residual	5	80.08371	16.01674		
Total	6	128.8118			

APPENDIX 8G: Swelling power and Peak viscosity for Tek bankye.

Regression Statistics	
Multiple R	0.36686
R Square	0.134586
Adjusted R Square	-0.0385
Standard Error	4.900164
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	18.67103	18.67103	0.777583	0.418249
Residual	5	120.058	24.01161		
Total	6	138.7291			

APPENDIX 8H: Swelling power and Breakdown for Afisiafi.

Regression Statistics	
Multiple R	0.61337
R Square	0.376223
Adjusted R Square	0.251467
Standard Error	4.008737
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	48.46193	48.46193	3.015682	0.142975
Residual	5	80.34987	16.06997		
Total	6	128.8118			

APPENDIX 8I: Swelling power and Breakdown for Tek bankye.

Regression Statistics	
Multiple R	0.453491
R Square	0.205654
Adjusted R Square	0.046785
Standard Error	4.694652
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	28.53025	28.53025	1.29449	0.306787
Residual	5	110.1988	22.03976		
Total	6	138.7291			

APPENDIX 8J: Swelling power and Breakdown for Abasafitaa.

Regression Statistics	
Multiple R	0.469214
R Square	0.220162
Adjusted R Square	0.064194
Standard Error	3.127665
Observations	7

ANOVA	*df*	*SS*	*MS*	*F*	*Significance F*
Regression	1	13.80855	13.80855	1.411586	0.288147
Residual	5	48.91144	9.782289		
Total	6	62.71999			

Barimah (1999) reported values between 11.4-19.7%, representing *Gblemoduade* and *Abasafitaa* respectively. The values obtained in this study compare well with those reported by Barimah (1999). There was no significant difference ($p>0.05$) in solubility between ages, but significant difference ($p<0.05$) existed among varieties.

There was weak correlation ($r^2=0.447$ & 0.285 respectively) between moisture content and solubility for *Tek bankye* and *Gblemoduade*. *Gblemoduade* showed correlation ($r^2=0.502$) between starch yield and solubility while *Afisiafi* showed correlation ($r^2=0.518$) between amylose content and solubility. Swelling power also correlated ($r^2=0.658$, 0.428 & 0.568 respectively) with solubility for *Tek bankye*, *Abasafitaa* and *Gblemoduade*. It is expected that high solubility flour will gelatinize at low temperature since water readily enters its starch granules resulting in easy solubilization and subsequent gelatinization upon heating. However, *Afisiafi* showed a weak correlation ($r^2=0.305$) between solubility and gel temperature while that for *Tek bankye* was strong ($r^2=0.828$). Peak temperature also correlated with solubility for both *Afisiafi* ($r^2=0.664$) and *Tek bankye* ($r^2=0.787$). Even though solubility showed a relationship with both paste breakdown and retrogradation, correlation was weak. There is therefore a clear indication that starch loss during processing affected the relationship or correlation between solubility and other functional properties such as pasting characteristics.