KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

DEPARTMENT OF CROP AND SOIL SCIENCES

GROWTH, YIELD AND NUTRITIONAL QUALITY OF FIVE BAMBARA GROUNDNUT (*Vigna subterranea* (L) Verdc.) LANDRACES TO DIFFERENT PLANT POPULATION DENSITIES

THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES OF KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF SCIENCE (AGRONOMY).

BY

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JUNE, 2010

DECLARATION

I do hereby declare that this thesis entitled “Growth, Yield and Nutritional Quality of Five Bambara Groundnuts Landraces to Different Population Densities” was written by me and that it is the record of my own research work. It is neither in part nor in whole been presented for another degree elsewhere.

Mercy Marilyn Akpalu ………………………….. ………………………
(Student Name) **(Signature)** **(Date)**

The above declaration is affirmed

Dr. Joseph Sarkodie-Addo ………………………….. ………………………
(Supervisor’s Name) **(Signature)** **(Date)**

Dedication

THE LORD IS MY SHEPERED I SHALL NOT WANT.

This thesis is dedicated to my husband Mr. Stephen Edem Akpalu and my lovely children; Stephanie and Elsie Akpalu.

ACKNOWLEDGEMENT

I am most grateful to the Almighty God who gave me good health, guidance, protection and abundant blessings throughout my studies.

My dream would not have been realized had it not been for the continued guidance and advice of my supervisor, Dr. Joseph Sarkodie-Addo of the Department of Crop and Soil Sciences Faculty of Agriculture, KNUST Kumasi, and Mr. Joseph Nketia Berchie at Crop Research Institute, Fumesua. Their encouragement, tireless support and constructive criticisms provided me with the motivation needed most to successfully complete this work. Words are not enough to express my gratitude!

I am greatly indebted to the Human Resource Development Directorate of the Ministry of Food and Agriculture for giving me the opportunity to be part of this programme and providing the financial support without which it would have been difficult to complete. I am also grateful to the students of Kwadaso Agriculture College, especially, those who helped in diverse ways during my data collection, and God richly bless you.

The assistance of technical staff and field staff at the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, in providing the require technical assistance in field and laboratory work is highly appreciated.

I also appreciate the assistance of the staff of the Legumes Division CSIR- Crop Research Institute, Fumesua for their cooperation and assistance during the data collection. The assistance of Mrs. Adelaide Agyemang of Forestry Research Institute, Fumesua in analyzing the data in a very special way is highly appreciated.

The contribution of my family to this accomplishment was enormous. I wish to thank my husband, Stephen for his patience, encouragement and taking care of the children during my absence. I do not have the right words to thank my mother Augusta Tay, my siblings

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Mathias Dzikunu and Rophina Tay for their immense support and help during data collection.

I acknowledge the invaluable contribution of my friends and course mates especially, Mr. Daniel Oppong-Sekyere, Stephen, Osman, just to mention a few, towards the success of this work.
I have also drawn liberally from the published works of many authors. To those people, too numerous to list here, I am especially grateful.

In a long journey like this one, you meet many people who were supportive and very helpful in making your dreams come true. Although it is practically impossible to name them all, I sincerely appreciate their effort. May the Almighty God richly bless you.

ABSTRACT

A field experiment to study the effect of plant population density on the growth, yield and nutrient quality of five bambara groundnut landraces was conducted at Kwame Nkrumah University of Science and Technology, Kumasi; at the Department of Crop and Soil Sciences in 2008 cropping season.

The experimental design was a split plot with bambara groundnut landraces; Nav 4, Nav Red, Black eye, Mottled cream and Burkina as the main plot factor and the population densities (5,6.7 and 10 plants m^{-2}) as the subplot factor. Two seeds per hill were planted on the 17^{th} of May and thinned to one seed per hill 21 days after sowing. Weeding was done when necessary. Growth analysis were carried out at six different sampling periods during which number of leaves, leaf area, petiole length, canopy spread, total dry matter, petiole internode ratio and leaf area index were measured. Yield and components of yield-number of pods per plant, number of seeds per pod, mean seed weight as well as harvest index were also measured during harvest. At final harvest, proximate analysis was carried out on air dried seed samples of the five landraces.

Results indicated that increasing plant population density resulted in higher pod yield. The highest density of 10 plants m^{-2} produced significantly ($P < 0.05$) the greatest pod and grain yield of 3399 kg/ha and 1684.7 kg/ha respectively. Similarly, density of 10 plants m^{-2} produced significantly higher number of pods than the lowest population density treatment. However, the number of seeds per pod and mean seed weight were not affected by plant population. Although, most vegetative data were not significantly affected by varying plant population, crop growth rate, net assimilation rate and leaf area index were also significantly higher in the low population density treatment than other treatments.

Yield data among the landraces were statistically similar, except with the number of pods per plant, where the Mottled Cream landrace produced significantly lower pods than the other landraces. However, the mean seed weight, pod and seed harvest indices of this landrace were superior to those of other landraces. Therefore Mottled Cream is recommended for sole cropping, Nav 4, Nav Red, Black Eye in intercropping situations and Burkina for subsistence farming. The spacing of 50 cm x 20 is recommended for cultivation bambara groundnut.

Seed analysis showed that the landraces contain 26.88-33.75% protein; 54.89-63.67% carbohydrate; 2.45-4.29% fat; 1.59-3.13% fibre and 2.45-4.28% ash. The mineral composition (mg/100g) was Fe = 1.71-4.56, Ca = 88-144, K = 1700-2200 and Na = 4.20-5.00.

The results indicated that the landraces contained protein, carbohydrate, fat and fibre in levels that provide balanced nutrition. Cultivation and use of these landraces therefore should be encouraged because the legume has great potential to contribute to food security in Ghana.

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List of Abbreviations

BAMNET	Bambara Groundnut Network
CGR	Crop Growth Rate
DM	Dry Matter
DAP	Days after plating
DAS	Days After Sowing
FAO	Food and Agriculture Organization
HI	Harvest Index
IITA	International Institute of Tropical Agriculture
KNUST	Kwame Nkrumah University of Science and Technology
LAI	Leaf Area Index
LSD	Least Signifinicant Deference
NAS	National Academy of Sciences
NAR	Net Assimilation Rate
Nav 4	Navrongo number 4
NFE	Nitrogen Free Extractives
PIR	Petiole Internode Ratio
RCBD	Randomized Complete Block Design

CHAPTER ONE

1.0 INTRODUCTION

1.0 Introduction

Given the rapid rate at which the world's population is currently increasing in relation to agricultural production, the goal of agronomic research must be to improve the productivity not only of our main crops, but also certain neglected crops.

Animal protein is very expensive and therefore not easily affordable by the average Ghanaian whose income is very low. The need to find alternative sources of protein which are cheaper and more affordable cannot be overemphasized. Research priorities needs to be reorganized in order to attend adequately to the development of our local underutilized crops, like bambara groundnut, which have a lot to offer in terms of their nutritional value. Bambara groundnut also known as bambaranut, has numerous agronomic and nutritional attributes which make it an excellent crop to develop. The legume is adapted to both the poor and fertile soils of Africa, and produces seeds that are high in protein (14-24%) and carbohydrate (60%) content (NAS 1979).

The seed protein is richer in essential amino acid, methionine, than most other legumes. From agronomic standpoint, the bambara groundnut is disease free, drought tolerant and produces yield in poor soils where no other crops can grow.

The high carbohydrate and relatively high protein content makes it a complete food. In northern Ghana the fresh immature beans are boiled with little salt and eaten as snacks.

The dry beans are also boiled and used to prepare stews. In southern Ghana the dry beans are usually used to prepare a kind of porridge/blancmange called aboboi which is served with gari and fried ripe plantain.

In the early 1960s, bambara groundnut was canned in Ghana, which competed favourably with Heinz baked beans but the state-owned cannery has now collapsed (Doku, 1996). Coudert (1984) estimated that of the total annual production of 300 000t, approximately half is produced in West Africa. Studies conducted by the International Trade Centre UNCTAD/GATT in early 1980s showed that the demand for bambara groundnut in West Africa exceeded supply. This has not changed; therefore, increase production will increase the income of farmers. Information on the crop is scarce. Review by Linnemann (1991) and Linnemann and Azam-Ali (1993) highlighted the lack of research and the need for reliable agronomic information. Although Bambara groundnut is known to be productive under various growing conditions, there is need to establish the conditions under which it can achieve reliable and predictable yields.

Bambara groundnut yields vary considerably among sites, seasons and genotypes (Linnemann and Azam-Ali, 1993), with yields averaging 650-850 kg/ha as reported by Stanton *et. al*, (1966). However, Collinson *et al.* (1996) have reported yields of up to 4.1 t/ha and Sessey *et al*. (2004) obtained seed yield of 2.6 t /ha in field trials in Swaziland. This suggests that bambara groundnut has a potential for high yield, and conducting more research on the crop can place it among the leading legumes. Field observations suggest that bambara groundnut production by subsistence farmers is characterized by low and unpredicted yields, and that crop failures are common. There is general lack of field experimental evidence on which to base reliable extension recommendations. Subsistence farmers thus cultivate the crop with little guidance on improved practices, and the crop is grown without any recommended spacing. Different landraces may respond differently to different spacing, and also vary genetically in terms of yield and there is dearth of information on nutritional composition of the landraces. In this regard, identifying the degree of variability could be a useful step for improvement of the crop.

It is in view of this, that this experiment was conducted with the following objectives.

i) To determine the optimum population density for cultivation of bambara groundnut.

ii) To study growth forms and development of the landraces. iii) To determine the yield and nutritional composition of the landraces.

CHAPTER TWO

2.0 LITRATURE REVIEW

2.1 Taxonomy and Origin

Bambara groundnut belongs to the family *Legminosae* and subfamily *Papilinoideae.*

In 1963, Linnnaeus described it in species *Plantarum* and named it *Glycine subterranean*. Du Petit Thoaurs (1806) had proposed the name *Voandzeia subterranean* (L.) Thouars and this was used widely by subsequent researchers over a century. Later, detailed botanical studies were undertaken by Marechal *et. al*. (1978) who found great similarities between bambara and plant species of the genus *Vigna*. This confirms studies done by Verdcourt, who seized the opportunity in 1980 to propose the current name *Vigna subterranean* (L) Verdc. (Goli, 1997).

Investigators interested in origin of bambara groundnut agreed that the crop originated from the African continent. The common name actually appears to be derived from a tribe, the Bambara, who now live mainly in Mali. However, no spontaneous or wild form was found in Mali. The exact area of origin of the crop has been a matter of debate, although Guillemin *et. al*. (1832) reported the probable occurrence of wild forms in nearby Senegal.

Begemann (1988) carried out detailed analysis of seed-pattern diversity within the large collection of bambara groundnut at IITA and his conclusion confirmed the hypothesis that the centre of origin of bambara groundnut is in the region of Northern Nigeria and

Northern Cameroon (Goli, 1997).

2.2 Botany / Morphological Description of Bambara groundnut

Bambara groundnut is a herbaceous, intermediate annual plant, with creeping stems at ground level. Differences in internodes length result in bunched, intermediate (semibunched), and spreading types. The general appearance of the plant is bunched leaves arising from branched stems which form a crown on the soil surface. Stem branching begins very early, about 1 week after germination, and as many as 20 branches may be produced and each branch is made up of internodes. The plant has a well developed tap root with profuse geotropic lateral roots. The roots form nodules for nitrogen fixation, in association with appropriate rhizobia. Leaf and flower buds arise alternately at each node. Leaves are pinnately trifoliate with erect petiole, thickened at the base. The flowers are borne on hairy peduncle which arises from nodes of the stem. The pods develop first, and reach its matured size about 30 days after fertilization. The seeds develop in the following 10 days (Doku and Karikari, 1971).

The pods usually develop underground and may reach up to 3.7cm long, depending on the number of seeds they contain. Most varieties have single seeded pods, but pods with three seeds were frequently found in ecotypes collected in Congo (Goli and Ng, 1988). Matured pods are indehiscent, often wrinkled, ranging from a yellowish to a reddish dark brown colour. Seed colour also varies from white to creamy, yellow, brown, purple, red or black. Various testa patterns are found, including mottled, blotched or striped, in addition to the predominantly uniformly coloured seeds (Goli, 1997).

2.3 Climatic requirements and soil requirement

The climatic requirement is as a rule those required for groundnut: bright sunshine, frequent rains from sowing to flowering and higher temperatures. However, it survives in conditions which are more arid, that is, in the drier savanna areas with short periods of scanty rainfall of up to 750mm per annum, excessive rainfall especially during fruiting, reduces yield (F.A.O.,1982). Zulu (1989) found that, maximum fractional germination of bambara groundnut occurred between 22^0C and 36^0C in contrasting bambara groundnut landraces from Zimbabwe and Zambia. Linnemann and Azam-Ali (1993) stated that mean temperatures during the growing seasons influences the time taken to reach physiological maturity.

The crop prefers averagely day temperatures of $20\text{-}28^0$C and full sun. The optimum temperature for germination of bambara groundnut is $30^0\text{-}35^0$C; below 15^0C and above 40^0 C, germination is very poor (Brink and Belay, 2006)

Bambara groundnut is adapted to a wide range of soils, especially light or sandy loam, and does better on very poor soils where other crops fail. It is best suited for conditions of the savanna ochrosol. Nitrogen rich soils tend to encourage vegetative growth at the expense of fruit production. However, Mullin (1962) recommended that, whatever the soil texture, it should have a reasonable amount of organic matter. A pH preferably within the range of 5.0 to 6.5 and should be very well drained.

2.4 Water management in bambara groundnut

The amount of moisture available to a crop greatly influences its productivity. Excess or insufficient amount of water can be detrimental to crop growth and yield. However, since bambara groundnut is the most adaptable of all plants and has extended flowering period, it tolerates relatively reasonable periods of moisture stress, particularly if the stress does not occur during germination and early pod filling.

According to Ameyaw and Doku (1983), yield under available moisture of 40% was more than ten times that under 75% available moisture, indicating a low optimum water requirement. The crop requires average annual rainfall of 600-750 mm/year but optimum yields are obtained at higher rainfall of 900-1200 mm/year. It is also grown in humid conditions e.g. in northern Sierra Leone, where the annual rainfall exceeds 2000 mm (Brink and Belay, 2006).

2.5 Effect of photoperiod on bamara groundnut

The performance of bambara groundnut is also determined by the day-length. For this crop, photo- regulation is an important trait with specific day-length requirements for successive stages of development.

In field study in Botswana, Harris and Azam-Ali (1993) confirmed the evidence from controlled-environment experiments at Wagneningen Agricultural University in Netherlands (Linnemann, 1991) that, although the flowering behaviour in some landraces of bambara groundnut is unaffected by daylength, the filling of pods is more rapid at daylength of less than approximately 12 hours.

Nishitani *et al*. (1993) tested the response of 21 varieties of bambara groundnut from Indonesia and Africa to photoperiods of 8 to 24 hours. The results indicated that even though 19 varieties flowered under both photoperiods, there were fewer matured pods per plant under long day conditions. Other studies by Linnemann (1993) have indicated that if exposed to continuous long day of 14 and 16 hours, some bambara groundnut accessions fail to produce pods. These results apparently indicate the stronger effect of photoperiod on the beginning of fruit set than on the beginning of flowering.

2.6 Growth habit, landraces and yield

Two growth habits occur in bambara groundnut landraces in Botswana: bunch and spreading. Local red and black landraces are spreading type. Under various spacing and irrigation condition, Zimbabwe Red had a bunch growth habit. The spreading types were also found to produce a few tillers. In actual field measurement, the spreading types could attain a canopy spread of 120 cm or more, but at average spacing of 30 cm x 30 cm, the bunch types did not form close canopies (Karikari *et. al*., 1997).

Karikari (2000), studied variability within local and exotic landraces and observed that, three of the local landraces namely DIPC, GABC and TSHC had characteristic bunch growth habit and were early maturing and high yielding. Another three local landraces namely OM1, OM2 and OM3 were semi bunch and medium yielding while two of the exotic and one other local landraces were late maturing with spreading growth habit.

Begemann (1987) reported that the yield potential of bambara groundnut range between 500-2600 kg/ha, depending on variety, cropping system and management. Karikari *et. al* (1997), reported that yields were very variable in bambara ground nut landraces, the highest yield obtained was 1.7 t/ha for Zimbabwe Red and all other red seeded landraces had low yields. They also stated that, lower yields have always been recorded for the cream-landraces, and on some occasions, no yields were obtained from these landraces at all.

2.7 Nutritional and mineral content

The bambara groundnut seed is regarded as a completely balanced food because it is rich in iron 4.9-48 mg/100g, compared to a range of 2.0-10.0 mg for most legumes, protein 18.0-24.0% with high lysine and methionine contents, fat 5.0-12.0 mg/100g, fibre 5.0-12.0%, potassium 1144-1435 mg/100g, sodium 2.9-12.0 mg/100g, calcium 95.8-99 mg/100g, carbohydrate 51-75%, oil 6-12%, and energy 367-414 kal/100mg.

In another study Brink and Belay (2006), indicated that the raw immature bambara groundnut seeds contain per 100 g edible portion: water 57.3 g, energy 152 kcal, protein 7.8 g, fat 3.1, carbohydrate 30.0 g, fibre 3.0 g, ash 1.8g, calcium 14 mg, phosphorus 258 mg and iron 1.2 mg. They again stated that, the matured dry seeds per 100 g contains; 10.3 g water energy 367 kcal, protein 18.8, fat 6.2 g carbohydrate 61.3 g, fibre 4.8 g, ash 3.4 g, Ca 62 mg, P 276, and Fe 12.2 mg.

Ijarotumi and Esho (2009) in their study on nutritional and mineral composition of bambara groundnut also reported that processed bambara groundnut contains; fat 6.02-6.57 g/100 g; protein 20.00-20.49 g/100 g; ash 1.17-3.46 g/100 g; carbohydrate 65.8268.74 g/100 g and energy 400.2-412.18 kcal. And for the minerals composition; calcium ranged between 14.12-18.26 mg/100 g, potassium 57.61-80.62 mg/100 g, magnesium 50.47-69.34 mg/100 g, sodium 19.05-25.97 mg/100 g, iron 0.15-0.48 mg/100g, and phosphorus 164.73-187.13 mg/100 g.

2.8 Plant density effect on the growth and yield of bambara groundnut An important aspect of crop management is spacing and its relationship to yield. The essence of this relationship is that in any environment there is an optimum density for crop yield beyond which no significant increase would occur with further increases in plant density.

Several researchers have attempted to establish quantitative relationships between plant population density and crop yield. Holliday (1960), for example, studied the relationship between plant density and yield on soybean and observed two relationships:

a) an asymptotic relationship, where yield rises to a maximum and remains constant with further increase in density, and

b) a parabolic relationship, where yield rises to maximum and then declines with increase in density.

Willey and Heath (1969) established further that total dry matter yield conforms to the asymptotic relationship, while the economic yield, that is grain or seed yield conforms to the parabolic relationship. Crop yield increases in direct proportion to increase in plant density when there is hardly any interplant competition owing to wider spacing; but at high densities which exacerbate interplant competition, yield decrease with increasing density (Funnah and Matsebella, 1985; Egli, 1988).

Studies from different parts in Africa reported large variation in seeding rate of bambara groundnut (Linnermann, 1992). Dunbar (1969) indicated that farmers sow bambara nut at an average spacing of 30cm x 30cm in North-western Tanzania. In Ghana, Ameyaw and Doku (1983) recommended a spacing of 60 cm x 30 cm. Duke *et. al*. (1977) similarly reported seed rate variation from 25-75 kg ha^{-1}, with inter-row and intra-row spacing of 30 cm -75 cm and 10-50cm, respectively. Bambara groundnut reaction to population density also varies with location and cropping systems. At Chitala in Malawi, a population density of 167,400 plants ha^{-1} gave the highest yield while in

Thuchila, also in Malawi high yields were obtained at a lower population density of 83,720 plants ha^{-1} (Malawi Agriculture Research Council, 1975, cited by Linnerman, 1992). Matelerkamp (1988) reported that under conditions of moisture stress, high population density can depress yield. In another development, Cumberland (1978) reported higher pod yields of bambara groundnut at densities of 7 and 14 plants m^{-2}. Similarly, Eliesen and Freira (1992) working with groundnuts and Edje *et al*. (1971) with beans reported a decrease in number of pods $plant^{-1}$ with increase in plant population. Based on the studies conducted in Botwana, Harris and Azam-Ali (1993) indicated the need to investigate the relationship between population density and yield of bambaranut. They again reported that the wide variation in yield response to planting densities suggests need to establish optimum plant density under different agro-climatic conditions in order to enhance bambara groundnut production.

2.9 Effect of time of planting on growth and yield

Differences in time of planting may relate to different climatic conditions, especially with respect to rainfall, temperature and photoperiod.

In Ghana, the main cultivated areas are in the Guinea savanna, the transition and the coastal savanna zones. In Guinea savanna and transition zones, planting occurs between early April and early May, and between late August and early September. There is only one cropping season in the coastal savanna, between early April and early May. These planting periods correspond to different rainfall and temperature regimes hence bambara groundnut yield may vary among locations and planting periods. (Kumaga *et. al*., 2002).

Mkandawire and Sibuga (2002) reported that in long rain season, bambara groundnut generally yield higher than the short rain season regardless of seed bed type or plant density. Nevertheless, Doku and Karikari (1970) found out that high rains adversely affected seed yield of bambara groundnut.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site / location

The experiment was conducted during the major season (May-September) of 2008, at the Plantation Research Farm of the Department of Crop and Soil Sciences of the Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi (6°43'N, 1°36'W) located in the forest zone of Ghana.

The soil belongs to the Kumasi series or Ferric Acrisol (FOA/UNESCO, 1988) developed over deeply weathered granite. Soil samples from the experimental area were taken from 0-30 depth and analysed for pH and other chemical properties.

3.2 Experimental Design and Treatments

The experiment was a split plot in a randomized complete block design with three replicates. The main plot treatments were the five landraces and the subplot treatments were the population densities randomized in three blocks giving a total of 45 plots in all.

Each plot in a block measured 4m x 3m and was contiguous to one another; the distance between the blocks was 1meter.

Main-plot-Landraces

(i) Nav 4 (ii) Nav Red (iii) Black Eye (iv) Mottled Cream (v) Burkina

Sub-plot- population densities used

S 1 = 50 cm x 20 cm =10 plants/m^2 = 100,000 plants/ha

S 2 = 50 cm x 30 cm = 6.7 plants/m^2 = 67,000 plants/ha

S 3 = 50 cm x 40 cm = 5.0 plants/m^2 = 50,000 plants/ha

Landraces

The landraces planted were:-

L1: Nav 4

L2: Nav Red

L3**: Black Eye** **L4: Mottled Cream**

L5: Burkina

Plate 1: Seeds of the five bambara groundnut landraces planted

3.3 Management / Cultural Practices

The land was ploughed and harrowed and harrowed, lined and pegged before planting. Seeds of four of the landraces were obtained from CSIR-Crop Research Institute, Fumesua. The Mottled Cream was bought from the open market at Navrongo. Two seeds were planted per hill at a depth of 5 cm on May 17, 2008.

Thinning was done 21 days after sowing (DAS) bringing plants to one seedling stand per hill was done 21 days after sowing to obtain the desired plant population densities. Weeds were controlled by hand hoeing two weeks after germination and subsequent weddings' were done when necessary.

3.4 Data Collected 3.4.1

Soil Analysis

a. pH pH was determined using Pye Unicom pH metre (model 290) at a soil water ratio of

1:2.5.

b. Carbon

Organic carbon was determined by the Walkley-Black wet oxidation method (Piper 1944).

c. Phosphorus

d. This was determined using the Bray P1 method (Piper 1944).

e. Exchangeable bases (Ca, Mg, K and Na) Using the 1.0 ammonium acetate extract (Black, 1965)

f. Total Nitrogen

Total nitrogen was determined by the macro-Kjeldahl digestion, distillation and titration method (Black, 1965).

3.4.2 Growth Parameters

Number of leaves

The trifoliate leaves were counted as one as one leaf; three plants were uprooted at random and the leaves were counted.

Petiole Length

Three plants were tagged randomly from each plot and measurements were taken by using a ruler to measure the tallest petiole length from the ground level to beneath the leaf blade.

Canopy spread

The canopy spread was measured by putting 4 sticks at the four crossed sides of each of the three plants tagged. Tape measure was used to measure across to obtain the average length of the canopy.

Petiole Internodes Ratio (PIR)

Three plants were sampled and their petioles and internodes were counted. The average number of petioles and average number of internodes were used to calculate the PIR by dividing the average number of petioles with the average number of internodes.

Leaf Area Index

Leaves from three randomly selected plants from each plot were passed through the leaf area meter and the values read were used to compute the leaf area index by dividing the leaf area obtained by the area covered by the plant (the spacing).

Dry Matter Accumulation

Sampling begun 27 days after sowing (DAS) and continued at 20 days interval. In all six samplings was taken. Three plants were randomly harvested from the sampling area. For each plant sampled, the roots were cut and discarded and the whole plants weighed fresh and dried in the oven to a constant weight at 700C for 48 hrs. The dry weights were determined and recorded.

Crop growth rate (C)

The crop growth rate, C, was calculated using the formula

$$C = \frac{W_2 - W_1}{t_2 - t_1}$$

Were W_2 = total plant dry weight at time t_2, and

W_1 = total plant dry weight at time, t_1

Net assimilaton rate (NAR)

The Net Assimilation Rate was calculated using

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{Log_e\ LAI_2 - Log_e\ LAI_1}{LA_2 - LA_1}$$

where LA_1 = natural log of leaf area index at harvest one and

LA_2 = natural log of leaf area index at harvest two

3.5 Final harvest and yield components

At the final harvest, plants were separated into leaves, petioles, stems and pods and their fresh weights recorded. Number of pods per m^2 was determined by harvesting ten, seven and five plants each from all the plots for densities S1, S2 and S3 repectively and the pods counted separately (Plate 2). The pods were air dried before oven drying to a constant weight at 70^0C for 48 hrs, and the dry weights recorded. The dried pods were hand shelled; the husk and seeds were weighed separately. Hundred random seeds were counted from each sample and weighed to determine the 100 seed weight. Number of seeds per pod was determined by counting fifty pods and shelled. The number of seeds obtained was divided by number of pods harvested. Shelling percentage was determined by dividing the weight of the extracted seed over that of the pod dry weight.

Harvest index was calculated by dividing the economic yield (seed) over the total biomass.

Plate 2: Sampling and record taking

3.6 Proximate analysis and mineral determination

Sampled seeds of the five landraces were sun dried for two weeks, ground in a laboratory mill and then sieved through a 500µg sieve. The ground samples were dried at 70^0 C to constant weight. Proximate analysis was carried out and was followed by mineral determination.

(i) Crude fat was determined by the ether extraction method by using Soxhlet extraction apparatus and extracting with petroleum ether for 2-3 hours. Crude fat was determined by the formula (A+B) –A = B % ether extract = B/C x 100

Where A = flask weight, B = ether extract, and C = sample weight.

(ii) Crude fibre was determined by digestion and filtration through a Cooch crucible, washing and drying the crucible and contents to a constant weight. The content of the crucible is then incinerated in muffle finance at 550^0 for 30 mins until the carbonaceous matter is consumed. After cooling and weighing the loss in weight was recorded as crude fibre.

$$\% \text{ crude fibre} = \frac{A - B}{C} \times 100$$

Where A = wt. of dry crucible and sample

B = wt. of incinerated crucible and ash, C = sample weight.

(iii) Digestible carbohydrate content was determined as:

NFE % on DM basis = 100 – [Ash on DM basis + % crude fibre on DM basis + % ether extracted on DM basis + % protein on DM basis}

Where NFE – Nitrogen free extractives or Digestible carbohydrate.

% Carbohydrate = % NFE + % Crude Fibre ((Maynard, 1970).

(iv) Crude Protein was determined by nitrogen content using the micro – Kjeldahl method. By this method the N in the protein is converted to ammonium sulphate digestion. The salt on steam distillation liberates ammonia which is collected in boric acid solution and titrated against standard acid. 1 ml of 0.1N acid is equivalent to 1.40 mg N, calculation is made to arrive at the N content of the sample. It is assumed that the N is derived from protein containing 16% N, and multiplying the N figure by 100/16 or 6.25, an approximate protein value is obtained (FAO, 1970).

(v) Minerals were determined by wet oxidation method; the powdered seeds were mixed in conc HNO_3, $HCLO_4$, H_2SO_4 and digested until production of red NO_2 fumes ceases. And heated until the volume was reduced and the mixture turned colourless. It was then allowed to cool and diluted with distilled water.

This digest was used to determine K, Na, Ca, Mg, and Fe (Piper, 1944).

CHAPTER FOUR

4.0 RESULTS

4.1 Weather conditions

Total monthly rainfall, mean number of hours of sunshine per day, and mean monthly maximum and minimum temperatures during 2008 are presented in Appendix 1.

4.2 Seedling Emergence and flowering

The number of days from sowing to seedling emergence varied from 7 to 14 days, the four landraces took much longer time, between 12-14 days, whiles the Mottled Cream took 7 days to emerge (Table 4.1).

Days to 50% flowering was related to the pattern of emergence. Mottled Cream flowered earlier (at 30 days) than the other four landraces. The other four landraces namely; Nav Red, Nav 4, Black eye and Burkina flowered after 40 days (Table 4.1).

Table 4.1: Days to 50% emergence and flowering of the landraces

Landraces	*50% emergence*	*50%flowering*
Nav 4	12	43
Nav Red	14	45
Black Eye	14	46
Mottled Cream	7	30

Burkina	14	47

4.3 Leaf number per plant

Leaf number results as affected by landrace and plant population density are presented in Table 4.2. At 27 DAP; differences among landraces were not significantly different (P > 0.05). At 87 DAP, however, treatment differences for the landraces were

significant

(P < 0.05). The leaf numbers of Burkina was the greatest, but this was significantly higher than that of the Mottled Cream only. All other treatment differences were not significant. Treatment differences at 67 DAP, 87 DAP, 107 DAP and 127 DAP followed a similar pattern. On all these sampling occasions, the treatment effect of the Mottled Cream was significantly lower than all other treatment effects. All other treatment differences were not significant at all these occasions.

Population density did not significantly (P > 0.05) affect leaf production in all the landraces during sampling at 27 DAP, 47 DAP, and 67 DAP. At 87 DAP, the wider spacing (50 x 40) resulted in producing the greatest number of leaves and this was significantly different from the other spacing treatments. At 107 DAP; the medium population density (50 x 30) treatment effect was significantly lower than those of the other treatments all of whose effects were statistically similar. At 27 DAP, the difference between medium and least density treatments was significant but all other treatment differences were not significant at 5 % level of probability.

Table 4.2: Effects of spacing on Leaf Number per plant of five bambara groundnut

Landraces sampled over six occasions

Treatment	Days After Planting					
	27	*47*	*67*	*87*	*107*	*127*
Landraces						
Nav 4	25.4	61.8	191.1	266.6	270.4	245.5
Nav Red	26.0	64.5	208.1	248.8	244.8	225.0
Black Eye	25.8	63.7	206.9	257.3	293.4	272.3
Mottled C	26.5	47.7	106.2	110.9	96.4	57.3
Burkina	22.1	77.5	197.0	234.2	240.3	229.0
LSD (5%)	**NS**	**NS**	**51.6**	**49.6**	**93.2**	**88.7**
Spacing (cm)						
50 x 20	26.0	63.8	177.3	196.8	218.6	198.2
50 x 30	24.7	64.7	178.4	207.7	121.2	186.4
50 x 40	24.8	60.6	189.9	266.2	256.4	232.9
LSD (5 %)	**NS**	**NS**	**NS**	**23.3**	**93.2**	**36.8**
CV (%)	**8.7**	**6.4**	**1.4**	**3.4**	**2.2**	**4.5**

NS- Not Significant

4.4 Petiole length;

The results of petiole length of the landraces are indicated in Table 4.3. At 27 DAP, Nav 4 had the longest petiole and this was significantly higher than the other landraces except that of Nav Red. Nav Red also had significantly longer petiole than that of Burkina. The petiole length of the Nav Red was longest and this was significantly longer than that of Mottled Cream and Burkina only. At 107 DAP and 127 DAP, treatment effect of Nav Red was greatest and was significantly higher than all other treatment effects except that of Nav 4. Population density effect was significant only at

47 DAP

Table 4.3: Effects of spacing on Petiole Length (cm) of bambara groundnut Landrace sampled over six occasions Days After Planting

Treatment	*27*	*47*	*67*	*87*	*107*	*127*
Landraces						
Nav 4	14.26	17.48	20.14	21.36	21.94	21.94
Nav Red	12.97	18.07	20.38	21.90	22.38	22.40
Black Eye	11.08	17.14	18.33	20.18	20.76	20.76
Mottled C	10.82	13.53	15.08	16.68	16.68	16.68
Burkina	10.31	14.88	16.44	18.02	18.53	18.53
LSD (5%)	***2.6***	***2.1***	***2.3***	***1.6***	***1.6***	***1.6***
Spacing (cm)						
50 x 20	12.33	16.77	18.29	19.44	19.89	19.89
50 x 30	1.87	15.81	17.88	19.67	20.09	20.10
50 x 40	11.47	16.11	18.05	19.77	20.20	20.20
LSD (5%)	***NS***	***0.7***	***NS***	***NS***	***NS***	***NS***
CV (%)	***1.1***	***1.3***	***2.2***	***0.3***	***0.4***	***0.4***

4.5 Canopy Spread

Table 4.4 shows the results of the canopy spread as affected by landrace and spacing. At 27 DAP, the greatest effect was measured in the Black Eye landrace and this was significantly higher than the effect of Mottled Cream and Burkina only. At 47 DAP, treatment effects of the Mottled Cream were significantly lower ($P < 0.05$) than all other treatments which recorded statistically similar canopy spread. At 67 DAP and 87 DAP, Nav Red recorded the greatest canopy spread, which was significantly higher than those of Mottled Cream and Burkina only. At 107 DAP and 127 DAP, treatment effect of Nav

4, Black Eye and Nav Red were similar and their effect was generally higher than the effect of the Mottled Cream only. On both occasions, treatment effect of Burkina was significantly higher than that of the Mottled Cream.

Spacing or plant population density effect on canopy spread of the landraces was significant only at 127 DAP. The effect of the 50 x 40 cm spacing was significantly higher than other treatments. All other treatment differences were not significant.

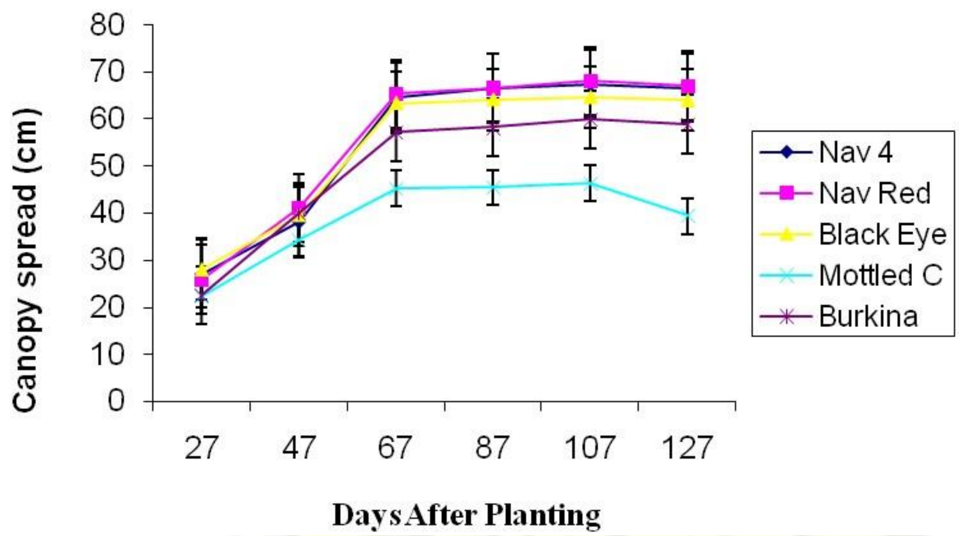

Figure 4.1: Canopy Spread as affected by landrace

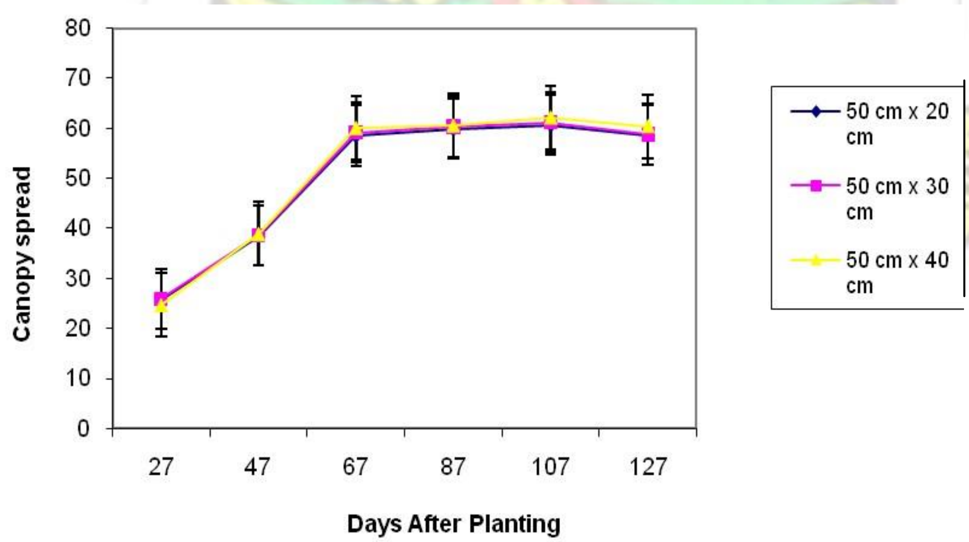

Figure 4.2: Canopy Spread as affected by Population density

4.5 Petiole Internodes Ratio (PIR)

The PIR for the landraces were recorded at 67 days after sowing. Nav4, Nav Red and Black Eye recorded PIR values of 1:3, Burkina 1:5, while Mottled Cream recorded the highest PIR value of 1:7.

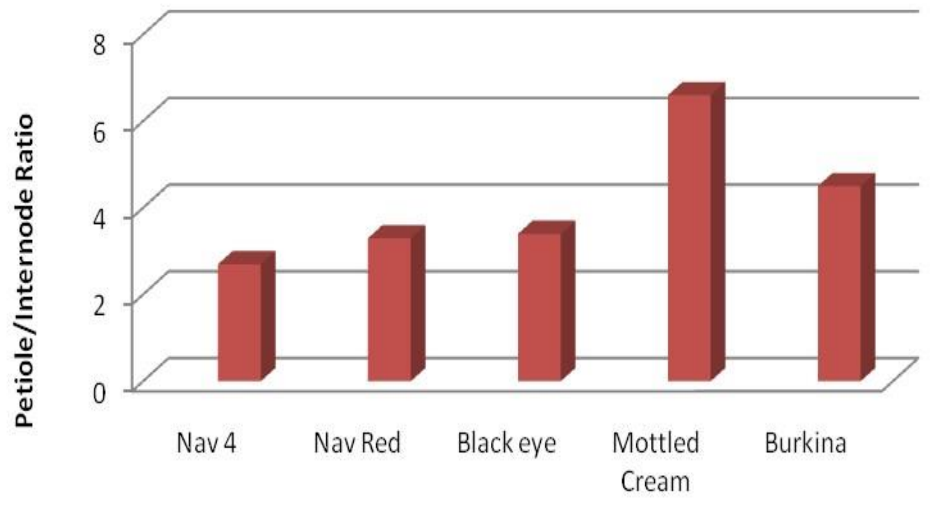

Figure 4.3: Petiole internode ratio as affected by landrace

4.6 Leaf Area Index

At 27 DAP and 47 DAP, no significant landrace effect was observed. At 67 DAP, treatment effect of Burkina was the greatest and this was significantly higher than the effect of Mottled Cream and Black Eye only. All other treatment effects were similar. At 87 ADP, 107 DAP and DAP, leaf area index of Burkina was still the greatest, but this effect was significantly higher ($P < 0.05$) than that of the Mottled Cream only. All other treatment effects were similar (Fig 4.4).

Spacing effect on leaf area index showed a consistence pattern of the greatest effect in the 50 x 20 cm spacing on all sampling dates. The difference between the 50 x 30 cm and 50 x 40 cm spacing were not significant in all sampling dates (Fig 4.5).

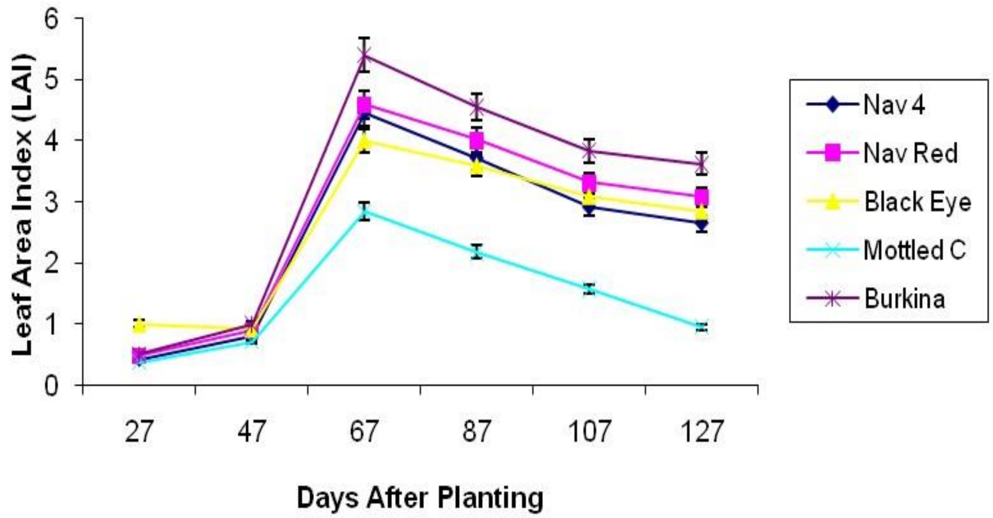

Figure 4.4: Leaf Area Index as affected by landrace

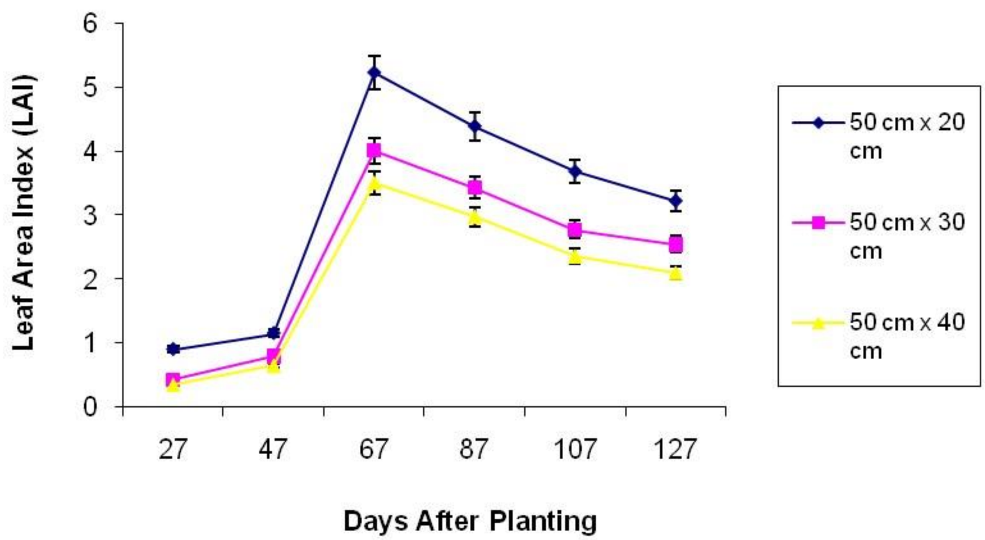

Figure 4.5: Leaf Area Index as affected by population density

4.7 Total Dry Weight per plant

Results for total dry matter over the sampling periods are presented in Fig 4.6. At 27

DAP there was no significant treatment difference among the landraces. At 47 DAP and 67 DAP, the greatest effect was measured in the Burkina and this was significantly greater than the effects of Nav Red and Mottled Cream. At 107 DAP and 127 DAP sampling occasions, treatment effect of the Mottled Cream was significantly lower than that of the Burkina, Nav Red and Black Eye.

Population density effects on total plant dry matter was significant at 107 DAP for 50 x 40 cm spacing. The other treatments were not significant (Fig 4.7).

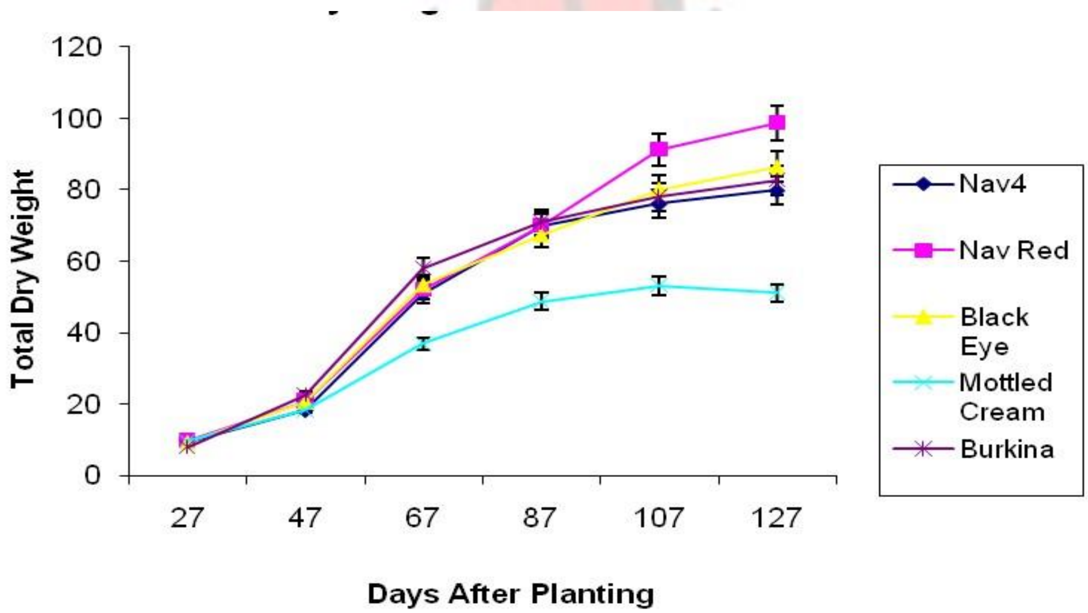

Figure 4.6: Total Dry Weight as affected by population density

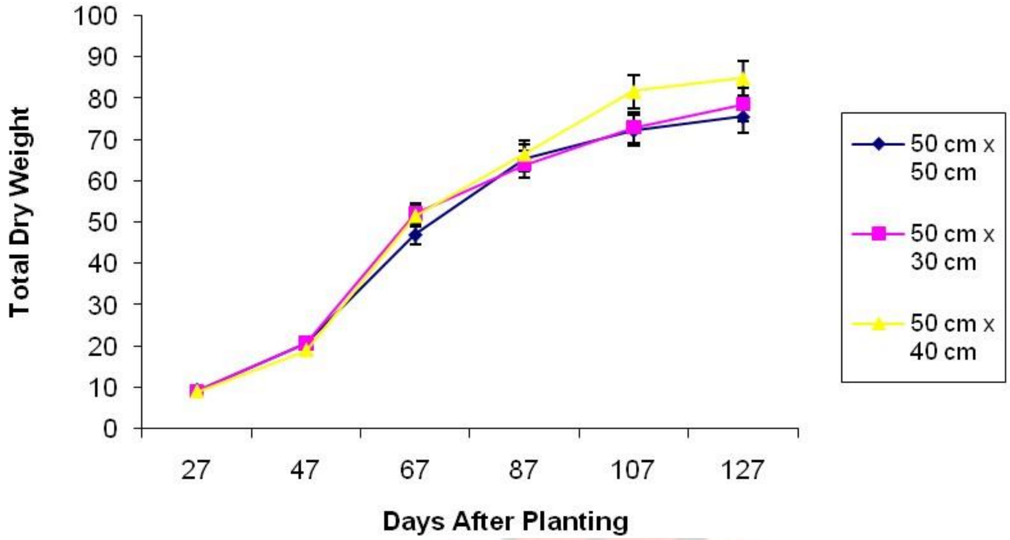

Figure 4.7: Total Dry Weight as affected by population density

4.8 Crop growth rate (C)

Results are presented in Table 4.7. At both harvest intervals 2-3 and 3-4, the greatest effect was measured in the Nav Red and this was significantly higher than effects of the Mottled Cream. Also the effect of Burkina was significantly lower than that of the Nav Red. Results at harvest interval of 4-5 show that C measured in Mottled Cream was significantly lower than all other landraces. The effect of population density was significant at harvest intervals of 1-2, 2-3 and 3-4. On all these sampling occasions, C of 50 x 20 cm spacing was significantly higher than that of 50 x 30 cm, whose effect was also significantly higher than that of 50 x 40 cm spacing. However, at 2-3, the effect of the 50 x 30 cm and 50 x 40 cm spacing was statistically similar. No significant treatment differences were observed at 3-4 and 4-5 harvest intervals.

Table 4.[1]: Effect of spacing on Crop Growth Rate (g/m^2/day) of bambara Groundnut landraces

	Harvest Intervals				
Treatment	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**
Landraces					
Nav 4	4.16	11.17	6.16	4.27	1.84
Nav Red	3.96	11.65	7.68	7.02	3.81
Black eye	4.31	11.71	6.04	4.23	1.41
Mottled cream	3.05	7.17	4.03	1.14	-0.84
Burkina	5.11	12.70	5.29	2.98	1.12
LSD (5%)	***NS***	***NS***	***NS***	***3.57***	***1.89***
Spacing (cm)					
50 x 20	5.66	13.50	7.82	4.34	1.34
50 x 30	3.96	10.98	5.04	3.07	1.74
50 x 40	2.72	8.16	4.66	4.36	1.32
LSD (5%)	***0.54***	***1.97***	***1.68***	***NS***	***NS***
CV (%)	***4.6***	***13.7***	***15.6***	***13.7***	***15.6***

[1] .9 Net Assimilation Rate (NAR)

The results for the net assimilation rate are presented in Table 4.5. Treatment differences of the landraces were not significant (P > 0.05) at 1- 2, 2-3 and 3-4 harvest intervals. At 4-5 harvest interval, Nav Red recorded the greatest effect and this was significantly higher than those of the Mottled Cream and Burkina only. At 4-5 harvest interval, the treatment effect of the Mottled Cream was significantly lower than all other treatment effects.

Results showed that apart from sampling at 1-2 harvest interval, where the 50 x 20 cm spacing effect was significantly higher than that of 50 x 40 cm spacing only, all other treatment differences were not significant on all sampling occasions.

Table 4.5: Effect of spacing on Net Assimilation Rate (g/m^2/day) of bambara groundnut landraces sampled over five times

Harvest Intervals	1-2	2-3	3-[1]	[2]-5	5-6
Landraces					
Nav 4	7.04	5.25	1.51	1.35	0.73
Nav Red	5.99	5.25	1.72	1.92	1.22
Black eye	6.73	5.73	1.58	1.37	0.61
Mottled cream	5.88	4.68	1.66	0.69	-0.69
Burkina	7.87	4.94	1.18	0.68	0.34
LSD (5%)	***2.32***	***3.09***	***0.55***	***1.17***	***0.85***
Spacing (cm)					
50 x 20	7.10	5.00	1.74	0.98	0.25
50 x 30	6.85	5.57	1.37	1.05	0.54
50 x 40	5.87	4.90	1.47	1.57	0.53
LSD (5%)	***0.96***	***0.93***	***0.60***	***0.87***	***0.47***

[1] .10 Yield data

[2] .10.1 Pod number per plant:

Mottled Cream started podding earlier than the other four landraces but produced only a few pods initially. However, podding increased in all the landraces after 87 DAP to 127 DAP (Table 4.9). At 87 DAP Mottled Cream produced significantly ($P < 0.05$) greater

CV (%)	***4.3***	***14.7***	***17.7***	***32.7***	***16.6***

pod number/ plant than the other landraces. The difference between those of Nav 4 and Nav Red were not significant but either effect was significantly higher than both the Black Eye and Burkina. At 107 DAP, no significant difference was observed among the landraces. At 127 DAP, Mottled Cream produced the least number of pods, and this was significantly lower than all treatment effects, except that of Nav 4 (Fig 4.8).

Population density did not significantly affect number of pods per plant at 87 DAP, 107 DAP and 127 DAP sampling occasions. However, at 67 DAP; pod production from the 50 x 20 cm spacing was significantly higher than other treatment effects (Fig 4.9).

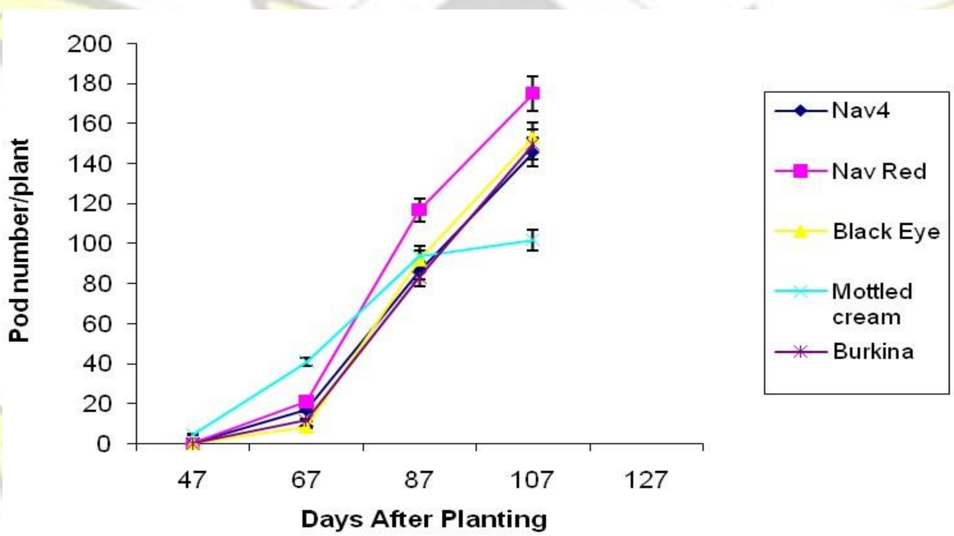

Figure 4.8: Podding as affected by landrace

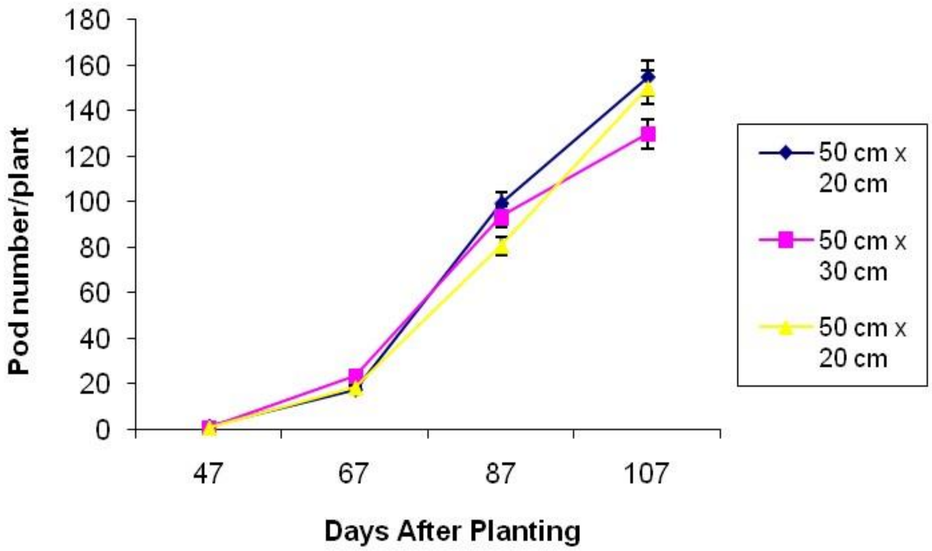

Figure 4.9: Podding as affected by population density

4.10.2 Husk Dry Weight

Results of husk dry weight are presented in Table 4.10. Mottled Cream produced significantly lower husk dry weight than those of Nav Red, Black Eye and Burkina. Husk yield of 50 x 20 cm spacing was significantly higher than the medium and the lowest density treatment.

4.10.3 Pod Yield (kg/ha)

Pod yield results are presented in Table 4.10. No significant difference was measured among the various landraces ($P > 0.05$). Population density, however, had significant effect ($P < 0.05$) on pod yield. Pod yield from the highest density represented by the 50 x 20 cm spacing was significantly higher than other treatment effects. The difference between the medium and the lowest density was not however, significant.

Table 4.6: Effect of spacing on Husk and Pod Yield of Five bambara groundnut landraces

Treatment (kg/ha)	Husk dry wt	Pod Yield	(kg/ha)
Landraces			
Nav 4	1229.0	2517.4	
Nav Red	1472.4	3281.5	
Black Eye	1538.3	2531.1	
Mottled Cream	759.3	2379.8	
Burkina	1664.1	3219.0	
LSD (5%)	***597.2***	***NS***	
Spacing (cm)			
50 x 20	1548.1	3399.0	
50 x 30	1262.8	2733.4	
50 x 40	1187.2	2224.3	
LSD (5%)	***275.4***	***610.2***	**CV**
(%)	**13.4**	**14.6**	

4.10.4 Final Seed Yield and Components

Seed Yield

Final seed yield results are presented in Table 4.7. There was no significant (P > 0.05) difference among the landraces. However, spacing (plant density) showed a significant effect on seed yield. The greatest yield was produced by the closest spacing, (which has the largest plant population), and this effect was significantly higher than other treatments. Seed yield results of the medium population density, (50 x 30 cm spacing) was also significantly higher than that of the lower population density (50 x 40cm) spacing.

Seed number per pod

Results in Table 4.7 showed that both landrace and population density did not significantly (P > 0.05) affect seed number per pod. Number of seeds per pod averaged 1-2.

100 Seed Weight

Results indicated that Mottled Cream recorded the greatest mean seed weight (Table 4.7) which was significantly higher than other treatments. Seed weight of Burkina was significantly lower than that of the Black Eye only. All other treatment means were similar. Population density did not significantly (P > 0.05) affect seed weight.

Table 4.7: Effect of spacing on final seed yield and components of bambara groundnut landraces:

Treatments (Kg/ha)	**Seed Yield**	**Seed No./Pod**	**100 Seed wt (g)**
Landraces			
Nav 4	1254.5	1.0	41.1
Nav Red	1519.7	1.0	44.3
Black Eye	1235.8	1.0	45.5
Mottled Cream	1656.4	2.0	68.0
Burkina	1322.6	1.0	37.0
LSD (5%)	**NS**	**NS**	**7.4**
Spacing (cm)			
50 x 20	1684.7	1.2	47.5
50 x 30	1422.3	1.2	47.3
50 x 40	1084.4	1.2	46.7
LSD (5%)	**214.2**	**NS**	**NS CV (5%)**
9.7	**0.0**	**4.2**	

Shelling % and Harvest Indices

Results are presented in Table 4.8**.** Shelling % of Mottled Cream was the highest, and this was significantly higher than all other treatment means, which produced similar effects. Plant population density did not significantly affect Shelling percentage.

Pod harvest index was significantly higher for Mottled Cream than the other landraces (Table 4.8) except Burkina. All other treatment differences were not significant. Population density did not significantly ($P > 0.05$) affect pod harvest index.

Seed harvest index was again greatest in the Mottled Cream and this was significantly higher than all other treatment effects. The other treatment differences were not significant.

Medium population density resulted in the greatest seed harvest index, but this was significantly larger than the largest population density (50 x 20 cm) spacing only.

Table 4.8: Effect of Spacing on Shelling % and harvest indices of five Bambara groundnut landraces

Treatment	Shelling %	Pod HI	Seed HI
Landraces			
Nav 4	50.3	45.0	22.5
Nav Red	47.4	43.9	20.9
Black Eye	50.4	40.9	20.4
Mottled Cream	70.6	64.9	44.7
Burkina	41.7	54.0	22.4

LSD (5%)	**11.8**	**15.0**	**9.5**
<u>Spacing (cm)</u>			
50 x 20	50.5	48.0	23.9
50 x 30	53.8	49.2	27.8
50 x 40	51.9	52.4	26.8
LSD (5%)	**NS**	**NS**	**3.7**
CV (%)	**6.2**	**3.4**	**2.3**

4.11 Nutritional and mineral composition of five bambara groundnut landraces

Results for the proximate analysis and mineral content are given in Table 4.9. The protein content of Nav Red, Black Eye and Burkina was above 30 g/100 g while Nav 4 and Mottled Cream were lower. Nav 4 recorded the highest carbohydrate content of 63.67 g/100g followed by Mottled Cream (57g), Nav Red, Black Eye (56g) and Burkina recording the least. With the fat content, Mottled Cream and Burkina recorded the highest of 8.50g followed by Nav Red with Nav 4 and Black Eye recording the least. Burkina, Nav Red and Black Eye produced more fibre than Nav 4 with Mottled Cream producing the least fibre. Black Eye contained more calcium followed by Burkina and Nav Red which had the same amount. Nav Red and Mottled Cream contained the lowest amount of calcium. But in terms of iron content, Nav Red and Mottled Cream contained more iron followed by Burkina with Nav 4 and Black Eye containing the least iron.

Table 4.9: Proximate composition and mineral content of the five landraces

Nutrient(g/100g)	Nav 4	Nav red	B/eye	Mottled Cream	Burkina
Protein	26.88	32.50	33.75	29.38	33.75
Carbohydrate	63.67	56.02	56.25	57.83	54.84

Fat	7.00	8.00	7.00	8.50	8.50
Fibre	2.51	3.06	3.09	1.59	3.13
Ash	2.45	3.48	3.00	4.29	2.86
Mineral Composition (mg/100 g)					
Ca	120	88	144	88	120
Fe	1.81	4.31	1.71	4.56	2.11
K	2000	2200	1700	1700	1700
Na	4.80	5.00	4.40	4.20	4.40
Mg	0.62	0.72	0.96	0.58	0.48

CHAPTER FIVE

5.0 GENERAL DISCUSSION

5.1 Effect of plant density on growth and development of bambara groundnut landraces

5.2 Emergence and Flowering

The number of days from sowing to seedling emergence varied from 7 to 14 days. Four landraces (Nav 4, Nav Red, Black Eye and Burkina) took longer time, between 12 to 14 days to emerge. This may be attributed to the thickness of the seed coats but Mottled Cream with thinner seed coat emerged faster, within 7 days (Table 4.1). Under conditions of low rainfall, early emergence would be advantageous. Rapid emergence reduces the period over which seedlings are susceptible to stress and the quicker the roots develop, the more likely the Bambara groundnut seedling is able to withstand drought.

Days to 50% flowering was related to emergence pattern. It was found out that generally, within 24 to 30 days after sowing, flowering would occur among the early maturing landraces like the Mottled Cream. The other four landraces flowered 40 days after sowing (Table 4.1). This may be a varietal characteristic, since these ones are late maturing they flowered late than the early maturing type. Photoperiod is said to influence flowering date in bambara groundnut, during the time of the experiment photoperiod did not change but there was reduction in temperature and sunshine hours

(Appendix 1). This might have influenced the flowering date. Most of these landraces are adapted to the drier regions of Ghana hence the high rainfall and reduced temperature in the experimental area might have also influenced the flowering date. Kumaga *et al*. (2002) had stated that rainfall and temperature appeared to be the two most important climatic factors that influence vegetative growth, flowering and yield of bambara groundnut in Ghana.

5.3 Leaf development

Leaf development in the four landraces showed considerable indeterminacy. There was leaf development during the pod filling period; this can also result in low yield since the dry matter that would have been partitioned into pods filling was used in leaf production. The Mottled Cream produced fewer leaves and leaf production did not occur during pod filling, thus though this landrace produced fewer number of pods, it produced the same seed yield with the other four landraces.

The higher leaf numbers produced per plant by the lower population density could be attributed to reduced interplant competition. Such plants had more growth resources, nutrient, water and abundant sunlight, leading to much branching and production of more leaves. Elia and Mwandemele (1986) has stated that, in higher rainfall, bambara groundnut develops branches more profusely and produces more leaves than in low rainfall.

The fewer leaves produced by the other two higher population densities may be attributed to competition for resources. Climatic factors also influence leaf and shoot development in bambara groundnut, especially rainfall and temperature. The experiment was carried out during the major planting season where the rainfall was higher with reduced temperature; this might have led to production of more leaves. This is in line with Kumaga *et al* (2002) who found that bambara groundnut produced greater number of leaves in the major season than in the minor season and they attributed it to increased physiological activity.

5.4 Effects of plant density and landrace on growth habits

With respect to growth habit, Nav 4, and Nav Red had wider canopies whose spread were about 68 cm and rapid (Fig 4.1). The wider and more rapid spread was due to the low petiole/internode ratio (Fig 4.3). These had long petioles and long internodes in the ratio of 1:3 while the ratio in the Mottled Cream landrace is 1:7 (Fig 4.3) and a canopy spread of 45 cm. Burkina with a canopy spread of about 57 cm and PIR of 1:5 might have taken a semi- spreading habit and Mottled Cream bunched. The growth forms exhibited by the landraces fit well into the classification by Doku and Karikari (1971) spreading, semi-spreading and bunched bambara groundnut varieties.

Mottled Cream with the bunched growth habit was early maturing and higher yielding. This result agrees with Karikari (2000), who studied the variability between local and exotic bambara groundnut landraces in Botswana and observed that three of the local landraces had characteristic bunch growth habit and were early maturing and high yielding, while two of the exotic landraces and one of the local landraces were late maturing with spreading growth habit.

The classification based on the growth habit is very useful; in Northern and Upper East regions of Ghana farmers usually intercrop bambara groundnut with millet, sorghum, maize etc. the spreading ones could be used in intercropping situations where they could form a more rapid ground cover and suppress weed growth. If large scaled mechanized farming of bambara groundnut is considered in Ghana where maximum yield will be aimed at, then the bunched type could be used and planted at very high population densities and the semi-spreading types grown exclusively as subsistence crop by small holders.

5.5 Effect of plant density and landrace on dry matter production

Density Effect

The results showed that leaf area index increased with population density. The highest leaf area value was recorded at a population density of 10 plants /m^2 and thus was observed for all the landraces. This might have intercepted more light than the plants at other densities to cause greater growth and leaf expansion. The increase in LAI also resulted in high yield. It therefore appears that the closest-spaced plants were the most effective in the interception of light and absorption of nutrients and water available to the individual plants. Once this advantage has been gained, the density treatment maintained its superiority in dry matter production.

At the initial stages, there was some wastage of incident solar radiation on bare soil at the lower plant densities thus affecting dry matter accumulation. This result agrees with findings of Egli (1988), Funnah and Matsebella (1985) and Nakagawa *et. al*. (1988) who observed soybean yield to increase with density up 20 plants/m^2, beyond which the reduction in individual plant yield could not be adequately compensated for by increase in number of plants per unit area.

Varietal Effect

Nav Red and Burkina produced the highest leaf area indices than the three landraces (Figure 4.4). This suggests that, Nav Red and Burkina developed a larger photosynthetic surface leading to interception of more solar radiation and hence production of more photosynthate for storage in various organs. There is evidence that dry matter accumulation is directly related to the amount of solar radiation intercepted (Chevula 1991). The high LAI resulted in greater pod yields and this may be due to partitioning of more assimilates into the sink (pod). If more of the photosynthate produced is partitioned into the sink (pod), then the plant is likely to produce higher yields. Even though Mottled Cream produced the lowest LAI and therefore produced the lowest dry matter. However, it produced numerically greater seed yield than the other four landraces though the difference was not significant. This landrace might have partitioned more of it's assimilate into the economic sink. It was observed at the field that, this landrace has a different leaf orientation, leaf shape, dark green and thick leaves (Plate 6); this might have placed it at the advantage of intercepting more solar radiation and efficiently utilising it to produce more photosynthate and partitioning more to the economic sink.

5.6 Effect of plant density and landrace on pod yield

Density effect

Increasing plant population reflected positively on pod number produced per unit area. The 10 plants/m^2 treatment produced the greatest number of pods per hectare (5503 pods/ha), followed by the density two, while the 5 plants/m^2 produced the lowest. Again the 10 plants/m^2 stand produced significantly the highest pod yield. This indicates a linear relationship between plant density and yields. Cumberland (1978) reported higher pod yield of bambara groundnut at 14 than at 7 plants/m^2. Similarly, Mkadawire and Sibuga (2002) reported high pod yields at population densities of 22 than at 9 plants/m^2. On the other hand, they again reported lower pod yield with increase in plant density up to 66 plants/m^2. The results showed that the densities tested did not lead to any severe interplant competition, thus suggesting a linear relationship between density and yield

Varietal Effect

The landraces Nav Red and Burkina produced significantly the greater number of pods per unit area and higher pod dry weight of about 3.3 t/ha and 3.2 t/ha. This shows that these two landraces partitioned more of the dry matter into production of more pods per plant. The two landraces appeared to have had an advantage over the other landraces in area of leaf surface developed resulting in their higher pod yield.

5.7 Effect of plant density and landrace on seed yield and components

Density Effect

The components that determine seed yield are influenced by the amount of solar radiation intercepted by the green crop canopy and the amount of photosynthate produced during the grain filling period, provided that nutrient and soil moisture levels are adequate. Thus the higher LAI produced at the higher densities might have led to the production of the higher seed yields.

The higher seed yield is again attributed to the higher number of pod produced at the closest density, since other components such as seed number per pod and mean seed weight were not significantly affected by the plant density treatment. This result has demonstrated, once again, the importance of seed number per unit area as the major determinants of seed yield as found by Yunusa and Ikwele (1990) in soybean. It could be deduced from the results that the 10 plants/m^2 stand is the optimum population density for high pod and grain yield of bambara groundnut, under the conditions of this study.

Varietal Effect

The number of pods produced per unit area and the pod filling period constitute two important factors that determine the seed yield of leguminous crops. However, with Mottled Cream, the number of pods produced was lowest than the other landraces, yet it produced numerically higher seed yield than the other landraces. This may be attributed to the early maturing nature of this landrace. Karikari (2000) had observed that early maturing landraces were high yielding because they emerged rapidly, flowered earlier and had probably enough time to fill the pods.

Mottled Cream exhibited determinate growth habit while the other four landraces exhibited typical indeterminate growth habit from flowering throughout the growing season until the final harvest. Linnerman (1991) showed that fruit development may be influenced by length of photoperiod. However, photoperiod did not change during the growing season. Therefore, in this study photoperiod did not influence podding or seed yield. Doku and Karikari (1970); Linneman and Azam-Ali (1993), indicated that most cultivars of bambara groundnut require 40 days period for pod and seed development. Hence indeterminate flowering is likely to result in low yield since all flowers produced 40 days before harvesting will not produce mature seeds.

Differences among genotypes have also been attributed to growing season. Ofori (1996) reported that under adequate moisture conditions, the plant produces flowers over a long period and the spreading types produce flowers throughout the growing season.

The greater seed yield produced by Mottled Cream could also be attributed to its 2 seeds/pod, large pod (sink) size and heavier seed weight. This was shown in the high shelling percentage of Mottled Cream.

Again, Mottled Cream produced significantly the lowest husk dry weight indicating that most of its photosynthate produced is converted in to seed production than the husk.

5.8 Effect of plant density and landrace on shelling % and harvest index

Shelling percentage is a reflection of pod filling efficiency and high shelling percentage values indicate effective pod filling. The density treatment did not have any significant effect on the shelling percentage. However, among the landraces Mottled Cream recorded significantly the highest shelling percentage of 70.6%. This may be due to efficient partitioning of assimilates into the seed rather than the husk.

The density treatment did not have any significant effect on pod HI (PHI). However, among the landraces Mottled Cream (PHI = 64.9) and Burkina (PHI = 54.6) were most productive and this may be due to production of lower above ground dry matter by these landraces. With respect to seed HI, the intermediate density of 6.7 plants/m^2 was significantly more productive. It has been postulated (Deloughery and Crookston, 1978) that a sparse stand will use water in the soil more rapidly than a dense stand and will therefore have a greater partitioning factor for grain. With the landraces, the Mottled Cream (SHI = 44.74) again was highly and significantly more productive than the other four landraces and thus again showing the inherent ability of Mottled Cream to partition most of the dry matter produced into the grain. High economic yields are predetermined by dry matter production and partitioning into various sinks of which the grain is the most important. Therefore, any attempt to manipulate plant spacing to maximize yield and cultivar assessment for higher yield are considered successful if subsequent growth characteristics support dry matter partitioning into the grain.

5.9 Nutrient and mineral content of the five landraces

The protein content of 26.88-33.75% was higher than the 20.45% reported by Ijarotumi and Esho (2009) and that of 25.2% and 18. 2% respectively reported by Brough and Azam-Ali (1992) and Brink and Belay (2006) respectively. The fat content of 2.454.29% obtained in this study was also lower than the 5.5-6.8% reported by Enwere and Hung (1996) but higher than that of 3.1% reported by Brink and Belay (2006). The carbohydrate content ranged between 54.89-63.67% and this compares well with 57%, 61.34%, and 65-68% reported by Amarteifio and Karikari (2002), Brink and Belay (2006), and Ijarotumi and Esho (2009) respectively. The ash content estimated at 2.454.28% fell within the range reported by Doku and Opoku-Asiamah (1978). However it was lower than 5.1% reported by Nwokolo (1996). The crude fibre content ranged from 1.59-3.13%. This was similar to 3.0% reported by Brink and Belay (2006) but lower than the 6.2% reported by Nwokolo (1996).

Variations were observed in the nutritional composition of the landraces. This variations may be due to genetic and the interaction of the genotypes with the environment. Application of fertilizer, inoculation with rhizobium can increase protein yields (Linnemann and Azam-Ali, 1993).

In this study however, the soil analysis of the experimental area showed that the phosphorus content is high (Appendix 2). This might have resulted in the high protein content observed in these landraces than those reported in literature. For instant, Deshpande and Domodaran (1990) found that application of phosphorus fertilizer increased protein and free amino acid content in bambara groundnut.

The minerals values for calcium 88-144 (mg/ 100 g) the Navrongo 4 and the Red seeded landraces fell within 95.8 – 99.9, but the values of 120 and 144 were higher for the other three landraces reported by Amarteifio and Karikari (2002). The 1700 – 2200 obtained for potassium is comparable to the values of 1935 reported by Oliveira (1976) but far higher than the 1144 – 1435 reported in most literature. The iron content ranged between 1.71 – 4.56 and fell within most of the values reported in literature except that of Ndiokwere (1982), which was very high (48 mg/ 100g). The 4.20 – 5.00 obtained for sodium falls within those reported by Amarteifio and Karikari (2002) but lower than the 12 reported by Oliveira (1976).

The landraces Burkina, Black Eye and Nav Red contained more protein than Mottled Cream and Nav 4, but the latter contained more carbohydrate. The Nav 4 is the most popular landrace cultivated by the farmers probably because of the colour and taste but it is also low in iron. And again in terms of time of maturity and yield, it is late maturing and low yielding as compared to the Mottled Cream which contained slightly more protein and high iron. The Mottled Cream also matured earlier and proves to yield higher if planted at higher population densities. The Red seeded and the Black Eyed landraces contains more protein and iron, but the Nav Red contains more iron than the Black Eye. The Burkina as the name implies is an exotic one from Burkina Faso but adapted in Ghana. It also contains more protein but low iron.

Generally, there was considerable variation in proximate composition and mineral content of the five landraces studied but there was also similarity in any two of the landraces for a particular nutrient. The Mottled Cream and the Nav Red can be used in areas where there is iron deficiency.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

The five bambara groundnut landraces planted were found to be different in their growth characteristics but there was no significant difference in their seed yield. These landrace differences have important implications in selection and breeding of genotypes. Mottled Cream was found to be the bunched type, while Nav 4, Nav Red and Black Eye had spreading growth habit and Burkina semi-bunched. Mottled Cream flowered earlier, formed pods earlier, reached maturity earlier. Four landraces, Nav 4, Nav Red, Black Eye and Burkina on other hand produced greater dry matter, recorded higher growth rates because they produced higher leaf area indices and finally produced more pods than the Mottled Cream. But their seed yields were lower than the Mottled Cream because they produced more husk dry weight. The landraces also showed considerable variation in nutritional composition, with Nav 4 having more carbohydrate. Nav Red, Black Eye and Burkina contained more protein and fibre.

The study showed that the highest plant density of 10 plants/m^2 produced more dry matter, recorded higher leaf area index and produced greater seed yield than the two lower densities. Therefore, 50 x 20 cm could be described as the optimum population density for cultivating bambara ground nut.

It is recommended that bambara groundnut should be planted at a spacing of 50 cm x 20 cm. But where maximum yield is aimed at, then the bunched type could be used and planted at very high population densities and the semi-spreading types grown exclusively as subsistence crop by small holders and the spreading ones used in intercropping situations where they could form a more rapid ground cover and suppressed weed growth.

It was observed that the Nav 4 is the commonest landrace found in most market but the other landraces are equally good and even better in terms of nutrition. It is therefore recommended that extension officers should educate and encourage farmers to cultivate the other landraces because the legume has great potential to contribute to food security in Ghana. The nutritionist and other allied workers should educate consumers to include bambara ground nut in their meals. The Mottled Cream and the Nav Red should be used in areas where there is iron deficiency.

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APPENDICES

Appendix 1 Climatic data for KNUST during the period of study (2008)

Month	*Average*	*Temp(^{0}C)*	*Total rainfall*	*Sunshine hours*	*Relative H*
	Max	*Min*	*(mm)*		*(%)*

January	33.3	19.2	0.0	7.1	48
February	34.6	21.7	61.7	5.7	79
March	34.2	22.6	134.1	6.1	81
April	33.3	22.9	117.1	5.5	83
May	33.0	22.8	185.8	5.3	82
June	31.4	22.5	279.8	4.6	85
July	29.8	22.3	145.0	3.3	88
August	29.5	20.8	164.5	3.4	88
September	30.0	21.3	164.5	3.3	87
October	31.3	21.6	95.8	5.7	85
November	32.7	22.2	30.7	4.8	84
December	32.6	21.1	47.5	5.6	84

Source: KNUST Meteorological Station

Appendix II

Chemical properties of Soil at the experimental site

Chemical Composition	(0-15cm) depth	(0-30cm) depth
pH	6.24	6.16
Organic carbon(%)	0.619	1.80
Organic Matter (%)	1.067	0.168
Available P(mg/kg)	29.74	25.22
Total N (%)	0.182	0.168
Exchangeable Bases(Cmol/kg/Me/100g)		
Ca	5.00	4.20
Mg	1.60	1.80
K	0.146	0.103
Na	0.248	0.232

Available P (mg/kg), from 20.0mg/kg and above = Adequate to high

Total N (%), From 0.2 % - 0.5 = Medium

Exchangeable K, From 0.05 – 0.2 = Medium

Appendix
III

PLATE 3 **PLATE 4**

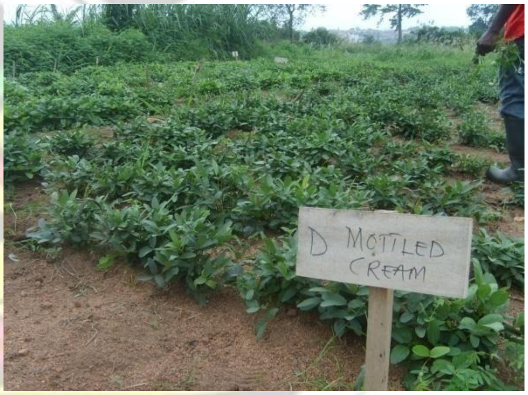

PLATE 5 **PLATE 6**

Appendix

IV

Number of leaves per plant 27 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	144.866	72.433	0.67	
Variety	4	107.859	26.965	0.25	0.901
Error	8	860.688	107.586	22.29	
Spacing	2	14.600	7.300	1.51	0.245
Variety X Spacing	8	112.553	14.069	2.91	0.025
Residual/Error	20	96.547	4.827		
Total	44	1337.112			

Number of leaves per plants 47DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	484.71	242.35	0.90	
Variety	4	4048.41	1012.10	3.77	0.052
Error	8	2147.83	268.48	4.74	
Spacing	2	141.59	70.79	1.25	0.308
Variety X Spacing	8	978.12	122.26	2.16	0.078
Residual/Error	20	1131.98	56.60		
Total	44	8932.63			

Number of leaves per plants 67DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	201.5	100.8	0.04	
Variety	4	66196.6	16549.2	7.34	0.009
Error	8	18041.1	2255.1	2.65	
Spacing	2	1460.2	730.1	0.86	0.439
Variety X Spacing	8	3793.1	474.1	0.56	0.799
Residual/Error	20	16999.3	850.0		
Total	44	106691.9			

Number of leaves per plants 87DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1775.6	887.8	0.43	
Variety	4	147928.1	36982.0	17.75	<.001
Error	8	16663.9	2083.0	2.23	
Spacing	2	41776.2	20888.1	22.38	<.001
Variety X Spacing	8	14185.9	1773.2	1.90	0.117
Residual/Error	20	18667.0	933.4		
Total	44	240996.8			

Number of leaves per plants 107 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	734	367	0.05	
Variety	4	214455	53614	7.30	0.009
Error	8	58775	7347	2.88	
Spacing	2	17063	8531	3.35	0.056
Variety X Spacing	8	33742.	4218.	1.66	0.171
Residual/Error	20	50938.	2547.		
Total	44	375707			

Appendix

Number of leaves per plants 127 DAS

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	2601	1301	0.20	
Variety	4	260600	65150	9.78	0.004
Error	8	53291	6661	2.85	
Spacing	2	17545	8772	3.75	0.041
Variety X Spacing	8	16540	2067	0.88	0.547
Residual/Error	20	46785	2339		
Total	44	397361			

V

Plant Height 27 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.485	0.243	0.04	
Variety	4	99.430	24.857	4.52	0.033
Error	8	44.004	5.500	1.62	
Spacing	2	5.556	2.778	0.82	0.456
Variety X Spacing	8	21.926	2.741	0.81	0.606
Residual/Error	20	68.071	3.404		
Total	44	239.472			

Plant Height 47 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.2853	0.6427	0.17	
Variety	4	132.1947	33.0487	8.55	0.005
Error	8	30.9347	3.8668	3.93	
Spacing	2	7.2360	3.6180	3.67	0.044
Variety X Spacing	8	6.8240	0.8530	0.87	0.560
Residual/Error	20	19.6933	0.9847		
Total	44	198.1680			

Plant Height 67 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	4.715	2.358	0.53	
Variety	4	191.648	47.912	10.67	0.003
Error	8	35.920	4.490	2.62	
Spacing	2	1.292	0.646	0.38	0.691
Variety X Spacing	8	5.550	0.694	0.40	0.905
Residual/Error	20	34.278	1.714		

Appendix

Total	44	273.403

Plant Height 87 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.124	0.062	0.03	
Variety	4	177.579	44.395	19.96	<.001
Error	8	17.792	2.224	1.02	
Spacing	2	0.849	0.425	0.20	0.824
Variety X Spacing	8	19.633	2.454	1.13	0.387
Residual/Error	20	43.531	2.177		
Total	44	259.508			

Plant Height 107 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.227	0.114	0.05	
Variety	4	208.594	52.149	24.56	<.001
Error	8	16.988	2.124	1.06	
Spacing	2	0.755	0.378	0.19	0.829
Variety X Spacing	8	17.207	2.151	1.08	0.417
Residual/Error	20	39.938	1.997		
Total	44	283.710			

Plant Height 127 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.232	0.116	0.05	
Variety	4	209.526	52.381	24.23	<.001
Error	8	17.294	2.162	1.09	
Spacing	2	0.768	0.384	0.19	0.825
Variety X Spacing	8	17.332	2.166	1.10	0.405
Residual/Error	20	39.493	1.975		

Total	44	284.646

VI

Canopy Spread 27 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	2.403	1.202	0.12	
Variety	4	248.661	62.165	6.13	0.015
Error	8	81.186	10.148	1.97	
Spacing	2	8.483	4.242	0.83	0.452
Variety X Spacing	8	20.439	2.555	0.50	0.844
Residual/Error	20	102.771	5.139		
Total	44	463.943			

Canopy Spread 47 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	41.66	20.83	0.85	
Variety	4	257.71	64.43	2.63	0.114
Error	8	195.78	24.47	1.09	
Spacing	2	0.73	0.36	0.02	0.984
Variety X Spacing	8	112.48	14.06	0.63	0.747
Residual/Error	20	449.38	22.47		
Total	44	1057.73			

Canopy Spread 67 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	91.74	45.87	1.27	
Variety	4	2576.61	644.15	17.88	<.001
Error	8	288.29	36.04	2.95	
Spacing	2	16 .05	8.02	0.66	0.529

Appendix

Variety X Spacing	8	85.80	10.73	0.88	0.551
Residual/Error	20	244.35	12.22		
Total	44	3302.83			

Canopy Spread 87 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	63.11	31.56	1.29	
Variety	4	2886.58	721.64	29.40	<.001
Error	8	196.35	24.54	2.27	
Spacing	2	3.40	1.70	0.16	0.856
Variety X Spacing	8	96.90	12.11	1.12	0.392
Residual/Error	20	216.33	10.82		
Total	44	3462.67			

Canopy Spread 107 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	22.062	11.031	0.41	
Variety	4	2904.389	726.097	27.30	<.001
Error	8	212.740	26.593	3.53	
Spacing	2	14.974	7.487	0.99	0.387
Variety X Spacing	8	73.182	9.148	1.22	0.340
Residual/Error	20	150.511	7.526		
Total	44	3377.858			

Canopy Spread 127 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	18.723	9.362	0.42	
Variety	4	4790.372	1197.593	53.22	<.001
Error	8	180.028	22.504	3.30	
Spacing	2	28.656	14.328	2.10	0.149

Variety X Spacing	8	61.615	7.702	1.13	0.386
Residual/Error	20	136.396	6.820		
Total	44	5215.790			

VII

Leaf Area Index 27 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.9541	0.4770	1.05	
Variety	4	2.3496	0.5874	1.29	0.350
Error	8	3.6402	0.4550	0.95	
Spacing	2	2.6881	1.3441	2.81	0.084
Variety X Spacing	8	4.6223	0.5778	1.21	0.345
Residual/Error	20	9.5827	0.4791		
Total	44	23.8370			

Leaf Area Index 47 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.00609	0.00305	0.04	
Variety	4	0.44247	0.11062	1.42	0.312
Error	8	0.62451	0.07806	3.80	
Spacing	2	1.99033	0.99517	48.51	<.001
Variety X Spacing	8	0.33767	0.04221	2.06	0.091
Residual/Error	20	0.41033	0.02052		
Total	44	3.81140			

Leaf Area Index 67 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.9541	0.4770	1.05	
Variety	4	2.3496	0.5874	1.29	0.350
Error	8	3.6402	0.4550	0.95	

Appendix

Spacing	2	2.6881	1.3441	2.81	0.084
Variety X Spacing	8	4.6223	0.5778	1.21	0.345
Residual/Error	20	9.5827	0.4791		
Total	44	23.8370			

Leaf Area Index 87 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.7274	0.3637	0.34	
Variety	4	28.0098	7.0024	6.49	0.012
Error	8	8.6255	1.0782	4.12	
Spacing	2	15.8308	7.9154	30.21	<.001
Variety X Spacing	8	3.5070	0.4384	1.67	0.167
Residual/Error	20	5.2394	0.2620		
Total	44	61.9399			

Leaf Area Index 107 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.0122	0.0061	0.01	
Variety	4	25.5993	6.3998	5.95	0.016
Error	8	8.5989	1.0749	4.35	
Spacing	2	14.0318	7.0159	28.37	<.001
Variety X Spacing	8	2.7277	0.3410	1.38	0.265
Residual/Error	2	4.9454	0.2473		
Total	44	55.9153			

Leaf Area Index 127 days

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	0.0002	0.0001	0.00	
Variety	4	36.5705	9.1426	8.27	0.006
Error	8	8.8407	1.1051	4.18	

Spacing	2	9.7402	4.8701	18.42	<.001
Variety X Spacing	8	3.8965	0.4871	1.84	0.128
Residual/Error	20	5.2881	0.2644		
Total	44	64.3362			

VIII

Crop Growth Rate (C) 1 – 2 Harvest Interval

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.0546	0.5273	0.85	
Variety	4	19.7223	4.9306	7.95	0.007
Error	8	4.9622	0.6203	1.22	
Spacing	2	65.0932	32.5466	63.91	<.001
Variety X Spacing	8	8.0873	1.0109	1.99	0.102
Residual/Error	20	10.1849	0.5092		
Total	44	109.1045			

Crop Growth Rate (C) 2 – 3 Harvest Interval

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	66.924	33.462	0.91	
Variety	4	166.056	41.514	1.13	0.406
Error	8	293.032	36.629	5.50	
Spacing	2	213.673	106.837	16.05	<.001
Variety X Spacing	8	45.449	5.681	0.85	0.569
Residual/Error	20	133.116	6.656		
Total	44	918.249			

Crop Growth Rate (C) 3 - 4 Harvest Interval

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	24.919	12.460	2.05	
Variety	4	63.755	15.939	2.62	0.115

Appendix

Error	8	48.734	6.092	1.25	
Spacing	2	89.672	44.836	9.17	0.001
Variety X Spacing	8	67.250	8.406	1.72	0.155
Residual/Error	20	97.776	4.889		
Total	44	392.107			

Crop Growth Rate (C) 4 - 5 Harvest Interval

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	48.42	24.21	2.24	
Variety	4	166.11	41.53	3.85	0.050
Error	8	86.33	10.79	0.92	
Spacing	2	16.49	8.24	0.70	0.507
Variety X Spacing	8	117.91	14.74	1.26	0.320
Residual/Error	20	234.82	11.74		
Total	44	670.08			

Crop Growth Rate (C) 5 – 6 Harvest Interval

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	1.441	0.720	0.24	
Variety	4	99.903	24.976	8.26	0.006
Error	8	24.201	3.025	1.63	
Spacing	2	1.713	0.857	0.46	0.637
Variety X Spacing	8	52.912	6.614	3.57	0.010
Residual/Error	20	37.086	1.854		
Total	44	217.256			

Net Assimilation Rate 1 - 2

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Replication	2	2.406	1.203	0.26	

Variety	4	15.406	3.852	0.85	0.534
Error	8	36.445	4.556	2.87	
Spacing	2	12.669	6.335	4.00	0.035
Variety X Spacing	8	10.556	1.319	0.83	0.585
Residual/Error	20	31.698	1.585		
Total	44	109.181			

IX

Net Assimilation Rate 2 - 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	17.190	8.595	1.06	
Variety	4	6.111	1.528	0.19	0.938
Error	8	64.756	8.095	5.41	
Spacing	2	3.913	1.956	1.31	0.293
Variety X Spacing	8	11.725	1.466	0.98	0.480
Residual/Error	20	29.928	1.496		
Total	44	133.624			

Net Assimilation Rate 3 - 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	2.2004	1.1002	4.27	
Variety	4	1.6126	0.4032	1.56	0.273
Error	8	2.0619	0.2577	0.42	
Spacing	2	1.1170	0.5585	0.91	0.418
Variety X Spacing	8	3.1461	0.3933	0.64	0.734
Residual/Error	20	12.2634	0.6132		
Total	44	22.4013			

Net Assimilation Rate 4 - 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Appendix

Replication	2	4.633	2.316	2.01	
Variety	4	9.936	2.484	2.16	0.164
Error	8	9.202	1.150	0.89	
Spacing	2	3.120	1.560	1.21	0.320
Variety X Spacing	8	11.132	1.391	1.08	0.418
Residual/Error	20	25.860	1.293		
Total	44	63.882			

Net Assimilation Rate 5 - 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.1630	0.0815	0.13	
Variety	4	18.0941	4.5235	7.46	0.008
Error	8	4.8483	0.6060	1.57	
Spacing	2	0.8036	0.4018	1.04	0.372
Variety X Spacing	8	7.1594	0.8949	2.32	0.061
Residual/Error	20	7.7229	0.3861		
Total	44	38.7914			

X

HUSK DRY WEIGHT (Kg/ha)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	959184	479592	1.59	
Variety	4	4605597	1151399	3.82	0.051
Residual	8	2410439	301305	2.31	
Spacing	2	1087813	543907	4.17	0.031
Variety X Spacing	8	918880	114860	0.88	0.549
Residual/Error	20	2606459	130323		
Total	44	12588371			

POD DRY WEIGHT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	4986123.	2493061.	1.13	
Variety	4	6620700.	1655175.	0.75	0.585
Residual	8	17661084.	2207635.	3.44	
Spacing	2	10403253.	5201627.	8.11	0.003
Variety X Spacing	8	3793293.	474162.	0.74	0.657
Residual/Error	20	12830578.	641529.		
Total	44	56295031.			

Appendix

Appendix XI Seed Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	542825	271413	0.58	
Variety	4	1177358	294339	0.63	0.657
Residual	8	3753679	469210	5.86	
Spacing	2	2723540	1361770	17.01	<.001
Variety X Spacing	8	1042421	130303	1.63	0.179
Residual/Error	20	1600928	80046		
Total	44	10840752			

Pod Harvest Index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	86.57	43.28	0.23	
Variety	4	3500.25	875.06	4.61	0.032
Residual	8	1520.10	190.01	2.43	
Spacing	2	158.67	79.33	1.02	0.380
Variety x Spacing	8	464.11	58.01	0.74	0.654
Residual/Error	20	1561.29	78.06		
Total	44	7290.99			

Appendix XII Seed Harvest Index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	10.62	5.31	0.07	
Variety	4	3907.98	976.99	12.77	0.002
Residual	8	612.29	76.54	3.17	
Spacing	2	120.65	60.32	2.50	0.108
Variety X Spacing	8	134.28	16.78	0.69	0.69
Residual/Error	20	483.15	24.16		
Total	44	5268.96			

Shelling Percentage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	312.84	156.42	1.32	
Variety	4	4292.98	1073.24	9.05	0.005
Residual	8	948.49	118.56	1.84	
Spacing	2	80.58	40.29	0.62	0.546
Variety X Spacing	8	356.09	44.51	0.69	0.696
Residual/Error	20	1290.67	64.53		
Total	44	7281.64			