VARIATION IN RESPONSES OF BAMBARA GROUNDNUT (*Vigna subterranea* (L) Verdc.) LANDRACES TO SOWING DATE, HEAT, PHOTOPERIOD AND DROUGHT STRESSES.

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DOCTOR OF PHILOSOPHY

IN

CROP PHYSIOLOGY

BY

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DEDICATION

This work is dedicated to the Almighty Father for His abundant grace in seeing me through this programme, my mother Madam Gladys Mensah for all she had to go through to see me educated, my wife Patricia Kyeremateng Berchie and my children Harriet Berchie, Abena Serwaa Berchie, Kwasi Adu Berchie, Emmanuel Sarbeng, Samuel Adu-Luciano, Selina Tweneboah-Koduah, Irene Korangtemaa and my father Nana Agyei-Ababio (II) for their immense support and sacrifices during the course of this study.

DECLARATION

I hereby declare that this thesis is my own original work towards the award of a PhD degree in Crop Physiology. To the best of my knowledge it contains no material previously published by another person nor material which has been accepted for award of any degree of this University or any other University except work which has been duly cited in the text.

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ABSTRACT

Bambara groundnut is an underutilized and until lately, under researched crop. Its ability to produce some yield where other crops such as groundnut fails has been established. Variation in yields of bambara groundnut have been reported by several workers. These differences have been attributed to variations in photoperiod at the different sowing dates within environments and between environments. The balanced nutritional quality of the crop coupled with its resistance to drought makes it a crop of choice to achieve food security, especially, in the dry areas of Africa. A total of 11 experiments were conducted over a period of three years. The objective of the experiments were to determine variation in performance of bambara groundnut landraces to sowing dates, heat, drought and photoperiod stresses. Nine field experiments were conducted in Ghana (Tono near Navrongo, Wenchi and Kumasi). Two controlled environment trials were conducted at the University of Guelph, Guelph-Ontario, Canada. Seven bambara groundnut landraces were studied in Ghana and 13 landraces were studied in Guelph.

Four experiments were conducted in 2007 in three agro-ecological zones of Ghana namely; Wenchi (Transition) Tono (Guinea Savannah), and Fumesua-Kumasi (Forest) to determine the effect of sowing date and heat on the yield of five bambara groundnut landraces namely; Burkina, NAV 4, NAV Red, Black eye and Tom. Thirteen bambara groundnut landraces were evaluated for photoperiod response at 12 h:12 h and 14 h:10 h light:darkness at the Crop Science Department, University of Guelph, Canada. Four hundred grams of Sunshine Mix LA4 was put in 78-4 gallons pot per growth chamber. 4 g of 20:20:20 N:P:K was put into each pot and thoroughly mixed with the soil. One walk-

in growth chamber was used for each treatment. Each landrace was replicated in six pots. Growth chamber temperatures were maintained at 30^{o}C in the day and 25^{o}C in the night at a relative humidity of 60%. Growth chamber PAR ranged between 250-300 umol m^{-2} s^{-1}. A second controlled environment study was conducted in Guelph to evaluate the response of 13 bambara groundnut landrace to drought. 78-4 gallons pots were filled with sandy loam soil per growth chamber. Plants were irrigated till 30 DAS after which irrigation ceased in the drought treatments. Photoperiod was maintained at 12 h:12 h in both the irrigated and drought treatment. The control was irrigated every three days. Pod yields ranged between 600 kg/ ha to 5.5 t/ha and seed yields ranged between 420 kg/ha to 3.8 t/ha respectively for the various sowing dates. Pod yield of over 5 t/ha was produced by Burkina and Black eye. Harvest indices ranged from 0.12-0.53. Burkina landrace proved to be highly drought and heat tolerant. It also proved to be an early maturing landrace. Leaf area index was highest for all the landraces at 105 DAS. Tom obtained a significantly highest leaf area index of 6.5 and Burkina the least of 4.2. Tom was a highly vegetative landrace. Pod yield was highest in the Transition than the Guinea savannah and Forest agroecologies. Where irrigation is available, sowing bambara groundnut just before the rains in February and March in the Transition and Forest agroecologies of Ghana produced high pod yields. Pod yield were low in the late April and June sowings when the heavy rains had established. Though a drought tolerant crop high temperatures beyond 38^{o}C and low relative humidity negatively affected bambara groundnut pod yield apparently through the drying of pollen tube even in the presence of irrigation. Days to seedling emergence was significantly less under 12 h photoperiod than 14 h photoperiod (p=0.02). Days to flowering was significantly higher under 14 h than 12 h photoperiod ($p<0.0001$). Pod numbers and pod dry weights were significantly higher under 12 h than 14 h photoperiod. Five out of the 13 landraces; Burkina, Mottled Cream, Zebra coloured, Tan One and Tan Two (both from Tanzania) podded under 12 and 14 h photoperiod though pod numbers and pod dry weights were higher under 12h than 14 h photoperiod. All but two of the landraces (Tom and Black seed) podded under 12 h photoperiod. Leaf area per plant, shoot dry weight per plant and root dry weight per plant were all higher under 14 h than 12 h photoperiod. Genotypes that produced pods under 14 h photoperiod were observed to be early maturing relative to the others. Morphologically, three plants of Tan One produced three, four and five leaflets on different petioles of the same plant instead of the well known trifoliate character of the crop. Landraces were identified for cultivation in the lower and higher latitudes. Tan One, Tan Two, Burkina and Black eye were identified as relatively highly drought tolerant. Leaflets of these landraces showed spindle shape, erect orientation and reduced canopy size in response to drought.

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List of Abbreviations

DAS	Days after sowing
et al.	And others
MPa	Mega pascals
^oC	Degree Celsius
AM	Available moisture
gm^{-2}	Gram per square metre
h	Hour
hrs	Hours
RLA	Relative leaf area
hd^{-1}	Hours per day
$kgha^{-1}$	Kilogram per hectare
CPMOV	Cowpea mottle virus disease
CABMV	Cowpea ahid-borne virus
Pemov	Peanut mottle virus
PGR	Pod growth rate
LAD	Leaf area duration
LAI	Leaf area index
NAR	Net assimilation rate
VRC	Variety release committee
CSIR-CRI	Council for Scientific and Industrial Research Crops Research Institute
RCBD	Randomised Complete Block Design

ICOUR	Irrigation Company of Upper East Region
t/ha	tonnes per hectare
^{o}Cd	Day degrees
NAV	Navrongo
LSD	Least significance difference
HI	Harvest index
PCR	Polymerase chain reaction
CRD	Complete randomized design
PAR	Photosynthetic active radiation
ANOVA	Analysis of variance
SAS	Statistical Analysis System
NAR	Net assimilation rate
cm	Centimetre
T_b	Base temperature
LER	Land equivalent ratio
DM	Dry matter
Mg	Milligram
Ml	Millilitre
CEC	Cation exchange capacity
%	Percentage
PV	Product value
GR	Glucose requirement

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CHAPTER ONE

INTRODUCTION

Origin and History

Marcgrav De Liebstad (1648) first mentioned Bambara groundnut in the literature. Although he described the crop in Brazil, he named it Madubi d'Angola implying its African Origin (Cited from Begemann, 1988). Du Petit- Thouars (1806) also found it in Madagascar and Mauritius where it was known as "Voandzou" hence giving it the name *Voandzeia subterranea*. Rassel, (1960) reported that the name Voandzeia was carried from the local name "Voanjo": Voa (seed) and "anjo" (that which satisfies well).

Brink and Belay (2006) however, reported that the centre of origin of the crop is probably North-eastern Nigeria and Northern Cameroun. The crop has evolved through different botanical names such as *Glycine subterranea* (L), *Voandzeia subterranea* (L) Thours and *Vigna subterrannea* (L) Verdc. The different vernacular names are bambara groundnut, earth pea and jugo bean, (Brink and Belay, 2006).

Mare'chal *et al.* (1978) found great similarities between bambara groundnut and species of the genus *Vigna*. Verdcourt (1980) confirmed the findings of Mare'chal *et al.* (1978) hence proposing the name *Vigna subterranean* (L.) Verdc.

Several writers have reported that bambara groundnut originated from the African continent. The name bambara appears to be derived from a Malian tribe the Bambara (Dalziel, 1937; Jacques-Felix, 1946; Rassel, 1960; Hepper, 1963 and Begemann, 1988).

West Africa produces between 45-50% of the estimated annual world production which was quoted as 330,000t in the 1980s (Brink and Belay 2006, Coudert, 1984). The major countries producing bambara groundnut are Burkina Faso, Chad, Cote d'ivore, Ghana, Mali, Niger and Nigeria.

Little research efforts have gone into bambara groundnut to develop high yielding varieties because the crop is perceived as having a limited economic potential outside its areas of cultivation.

The crop has been described by Azam-Ali *et al.* (2001) as an underutilised crop. They reported that despite the several years of cultivation of the crop, bambara groundnut is still, cultivated from landraces rather than varieties bred specifically for particular agro-ecological condition or production systems. The crop has until recently not received the support of International Agricultural Scientists and funding agencies. This is because the crop has been described as a 'poor man's' crop which is cultivated mainly for subsistence rather than for cash.

Doku (1997) reported that unlike soybean, which received considerable material and financial support on its introduction, bambara groundnut has not received governmental or international support in Ghana. However, he observed that work done at the University of Ghana in the 1960's and 1970's gained international recognition.

Still considering why the crop is considered as an under-utililised crop, Smartt and Simmonds (1995) observed that groundnut which was introduced into West Africa from Brazil may have replaced bambara groundnut because seeds of groundnut contain significant amount of oil and can be cultivated as an oil seed crop. In this way they reported that a cash crop with export potential for the colonial powers replaced a food crop for the subsistence of the local population

Azam-Ali (2001) reported that Bambara groundnut has not been improved through co-ordination breeding programs, hence the existence of different genotypes as landraces. Zeven (1998) described a landrace as a variety with a high capacity to tolerate biotic and abiotic stress, resulting in high yield stability and intermediate yield level under a low input agricultural system. Landraces can therefore be described as a mixture of genotypes with highly diverse population between and within them (Azam-Ali *et al.*, 2001). Landraces differ from cultivars in the sense that landraces are not uniform and stable in their characteristics from season to season.

Factors limiting increasing utilization of bambara groundnut include lack of awareness, best agronomic practices, lack of recipes, ignorance of its nutritional value, limited potential as a cash crop, unavailability of seeds, access to market and hardness to cook.

Doku and Karikari (1971) observed that the cultivated bambara groundnut originated from *Vigna subterranea var. spontanea* which evolved from a series of gradual changes. Among the changes they noted, was the switch from open to bunched growth habit and outbreeding to inbreeding with a reduction in shell thickness. Smartt (1985) observed that through successive cultivations, farmers have selected genotypes with desirable traits, which include high yields and bunched habits whichs are easier to harvest

1:2. Justification of study

Weather is a major significant variable affecting crop yields. In most developing countries where agricultural productivity depends greatly on the natural environment the importance of weather becomes highly imperative. An effective crop production system should be able to take advantage of climatic opportunities and effectively combat adverse environmental conditions when possible. To be able to achieve this it is important to have a fundamental knowledge of the way in which the plants interact with the environment. This need becomes more imperative considering rapidly changing climatic conditions such as erratic rainfall, global warming and its effect on agriculture and crop production as well as the downward movements of the Sahelian region among others.

Bambara groundut is a crop with a high potential for the attainment of food security and poverty alleviation in Africa, especially in the drier areas of the continent. The crop has been described as drought tolerant and would do well in areas where rainfall would not support other legumes. At a time when consumers are concerned about the intake of more fatty and oily foods, the relatively low oil content of bambara groundnut (5- 6%) high carbohydrate (40-60%) and relatively high amount of protein (16-25%) make the crop a complete food capable of reducing nutritional deficiencies and a probable raw material source for the canning industry. With the demand of bambara groundnut exceeding supply in the sub-region, Ghana stands to benefit in foreign exchange earning with increased hectarage and productivity of the crop. Variable yields in bambara groundnut have been reported resulting from changes in photoperiod, such that photoperiod beyond 12 h reduced pod yield (Harris and Azam-Ali, 1993). Obtaining early maturing and drought tolerant bambara groundnut landraces become imperative considering the erratic rainfall which affect the amount, duration and distribution of rainfall in most of the bambara producing areas in Ghana. On the continental level the identification of landraces which are relatively insensitive to photoperiod will provide materials which can be cultivated in areas where bambara groundnut production is negatively affected by long photoperiod. The findings of this study can also result in the exchange of materials with other research institutes and Universities involved in bambara groundnut research on the continent and beyond.

1.3 Objectives of study

The general objective of the study was to determine the variation in response of selected bambara groundnut landraces to sowing dates and abiotic stresses namely; heat, drought and photoperiod.

The specific objectives were to identify:

- genotypic responses to flowering, pod initiation, pod filling and final grain yield of selected bambara groundnut landraces to different sowing dates.
- the responses of the selected genotypes to heat and drought stress under field conditions and under controlled conditions.
- day-neutral bambara groundnut landraces for wide range cultivation within the sub-region and beyond (photoperiodism of the landraces)

- the effect of seed priming on seedling emergence and establishment of bambara groundnut landraces.

1.4 Experimental hypothesis

The null hypothesis of this study is that different bambara groundnut landraces respond similarly to differences in sowing dates, heat stress, photoperiod and moisture stress, and do not differ in dry matter production and partitioning into leaves, stem and pod yield.

The alternative hypothesis is that different bambara groundnut landraces respond differently to sowing dates, heat, photoperiod and moisture stress, and differ in dry matter production and partitioning into leaves, stem and pod yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Description of plant

Bambara groundnut belongs to the family leguminosae. It is an indeterminate crop and carries a trifoliate leaf on each prominent erect petiole. Pod development in bambara groundnut is geotropic and this makes breeding through artificial hybridization difficult.

Bambara groundnut is grown for seeds. The crop is similar to groundut, an annual with compound leaves of three leaflets. Erect type of bambara groundnut also exist. The plant forms pods and seeds on or just below the ground with flower stalk elongating and penetrating the soil. The peg creates a tunnel through which fertilized flower is drawn into the soil. Bambara groundnut grows best under climates suitable for groundnut. The crop needs bright sunshine, high temperatures, and at least four months free of frost and frequent rains to grow well. Bambara groundnut performs better under conditions too dry for peanut. The crop has many common names such as Congo groundnut, Congo gobber, Madagascar groundnut, earth pea, njugo bean (South Africa), Voandzou, nzama (Malawi) and underground bean". (Docume HS547, 2003; Stephens, 2003).

Smartt (1985) reported one of the attractive features of bambara as its wide genetic variability resulting from its wide geographic dispersion in Africa. This gave scope for selection which is observed most in variation in seed size, colour and pattern of testa.

2.2 Seed germinability in bambara groundnut

Life cycles in the plant kingdom begin and end with seed and seeds are the thread of life connecting successive plant generations (Darold *et. al.*, 1982). Some seed may not grow upon water imbibition and this is described as the failure of viable seeds to initiate growth when placed in conditions favourable for development (Darold *et. al.,* 1982). Germination of bambara groundnut is hypogeal with the cotyledons remaining underground.

Bambara seed germination is slow and sporadic and seedling emergence occurs between 7-15 days after sowing (DAS) although seedling emergence has been found to occur in 21 DAS (Linnemann and Azam-Ali, 1993). For successful crop production, seed germination should be both rapid and uniform through the soil surface. Sesay and Yarmah (1996) reported that this ensures quick canopy closure in the growing season, promoting the suppression of weeds and maximizing light interception.

Sreeramulu (1983) reported that bambara groundnut seed germinability was not adversely affected up to 12 months storage. Germination however declined rapidly after 12 months and after 24 months storage, no germination was observed. Seedling vigour was also affected for seeds stored for 12 months and more. He observed increase in total phenol and inhibitory phenolic acids with decrease in content of synergistic phenolic acids. He also reported of a reduction in auxin content for seeds stored for 18 months and more.

On seed germination, Hadas and Russo (1974) reported that a good stand can be obtained by complete and fast germination and where germinating seeds are slow in taking up water, emergence is impaired and the final plant stand is reduced. Studying the effect of seed size on germination of bambara groundnut, Temu (1994) observed a higher percentage emergence for large seeds of a Botswana cream seeded landrace compared to the small seeds, however, in a Zimbabwean red-seeded landrace, small seeds had a higher percentage emergence than the large seeds.

Zulu (1989) reported that seed germination in bambara groundnut seems to be more sensitive to moisture stress than groundnut. Zulu (1989) attributed this to the restrictive uptake of water by bambara groundnut due to the hard seed coat. Mabika (1991) also reported that scarification by scratching three openings on the seeds did not hasten germination. On the contrary, it delayed germination and also reduced the final germination percentage. Seed priming by pre-soaking the seeds in distilled water at 21^{o}C for 24 h did not significantly affect the germination of the crop (Mabika, 1991).

Desmosthermis and Krisna (2000) observed that *Campsis radicans* seed germination and seedling emergence required fluctuating temperatures and 12 h photoperiod for maximum germination.

2.3 Moisture requirement

Day (1981) reported that crop productivity in the arid and semi arid regions of the tropics is greatly dependent on water since among other things leaf size and longevity depend on the availability of water and, therefore, in these areas water sets the limit to crop growth and productivity.

Moderate water deficiencies can result in stunting, distorted development and much reduced crop yields, and prolonged drought can cause crop failure (Slatyer, 1969).

Squire (1990) reported that severe drought prevents seeds from germinating and developing into strong seedlings. Bambara groundnut has been considered not as a high yielder but a crop well-adapted to the arid and semi arid regions of the tropics.

Ameyaw and Doku (1983) observed significant yield differences in bambara groundnut landraces grown under four moisture-stress treatments ie 30% available moisture (AM), 40% AM, 50% AM and 75% AM. Field capacity was considered as 100% available moisture. Grain yields obtained were 186 gm^{-2} at 30% AM, 892 gm^{-2} at 40% AM, 543 gm^{-2} at 50% AM and 87gm^{-2} at 75% AM. The highest moisture content produced the least grain yield.

Berchie (1996) working on light use and dry matter production of three bambara groundnut landraces in relation to soil moisture observed that DipC and DodR from Botswana and Tanzania respectively were able to maintain some green leaves from 27 DAS to 145 DAS without irrigation under glass house temperature of 27±5°C. LunT from Sierra Leone under stress however, could not maintain any green leaf after 112 DAS. DipC and DodR originated from drier areas whereas LunT originates from Sierra Leone with a relatively higher rainfall. Berchie (1996) further reported that DipC showed vertical leaf orientation under water stress to reduce radiation load and excess transpirational losses under stored conditions that were not observed in LunT. These differences in the landraces in response to water stress have an important implication in selection and breeding for landraces adapted to the semi-arid regions.

Berchie *et al*. (2002) reported that among the drought treatments, dry matter partitioning in three bambara groundnut landraces were more to the leaves, followed by the stem and the pods. Among the irrigated treatments, however, dry matter partitioning occurred more to the pods followed by the leaves and then the stem. Berchie *et al.* (2002) also observed differences in the trend of dry matter partitioning to pods among the landraces with DipC showing a linear trend of dry matter partitioning to the pods between 80-145 DAS. Dry matter partitioning to pods in LunT94 however, tapered between 120-145 DAS.

Nageswara Rao *et al.* (1985) in comparative studies of the effect of drought occurring at different stages of growth in groundnut observed that terminal drought (i.e. during pod filling) had the greatest impact on yield. Sivakumar (1988) observed that the groundnut grown in the Sahel often experiences water deficit during the phase of pod-filling and that this period coincides with the end of the rainy season. The reason for this phenomenon is because of the short growing season in which available moisture supports crop growth. On seedling emergence, Sesay *et al.* (2004) observed that delayed and prolonged seedling emergence was observed at Luve in 2001 and at Malkernes in 2002 due to drought.

Fischer and Maurer (1978) noted that high yield of groundnut under drought stress could be attributed to an escape mechanism rather than stress tolerance. However, Ludlow and Muchow (1988) observed that many morphological, physiological and biochemical traits may contribute to the improved performance of drought affected crops.

Under less favourable conditions for crop growth e.g. limited water supplies and infertile soil, bambara groundnut was found to yield better than other legumes for example groundnut (National Research Council, 1979).

Collinson *et. al.* (1996) observed that bambara groundnut responds to drought by partitioning more assimilates into roots relative to shoots to exploit a greater soil volume for water absorption. The level of soil drought imposed on cowpea genotypes reduced the partitioning of assimilates to leaves and increased the partitioning to roots (Osinobi, 1985)

Collinson *et al.* (1997) reported that bambara groundnut has been able to withstand water stress through a combination of osmotic adjustment, reduction in leaf area index and effective stomatal regulation of water loss. Drought tolerant plants are characterized by low stomatal resistance under irrigated conditions and high stomatal resistance under drought conditions (Golestani and Assad, 1998; Serrano and Penuelas, 2005).

Schafleitner *et al.* (2007) in a field screening for variation of drought tolerance in *Solanum tuberosum* identified that clone Col.155 yielded best under both drought and irrigated conditions even though the highest yielding clone also had the highest drop in percentage of their potential yield.

Reduction in the amount of cytokinins supplied from the root to the leaves as a result of water stress may have a parallel effect on both the intracellular and stomatal resistance (Mansfield and Davies, 1985). Cytokinins promote stomatal opening and may enhance photosynthesis by stimulating chlorophyll and enzyme synthesis (Hay and Walker, 1992). They observed that the development of water stress is more gradual than that imposed in experimentation and the development of water stress on the field allows the plant to time for adaptation to the changing environment. Jordan and Ritchie (1971) also observed that cotton plants grown in a greenhouse had their stomata closed at leaf water potential of -1.6 MPa, whereas those of plants grown in the field were still partially open at -2.7 MPa.

Slatyer (1969) reported that the deleterious effects of water deficits are usually most pronounced in tissues and organs which are in the stages of most rapid growth and development thus there are periods of growth when there is relatively greater or lesser sensitivity to water stress as far as economic crop yield is concerned. The initiation and differentiation of vegetative and reproductive primordial in the apical meristerm and the enlargement of the cells thus differentiated are very sensitive to stress and the effect on primordial initiation appears to be superficially similar to dormancy, such that initiation can be completely suspended without the potential for subsequent development being impaired as long as the stress in not too severe or too protracted (Slatyer, 1969).

Gardiner and Niemann (1964) also observed that cell division may continue during water stress conditions though at a much reduced rate, until quite severe conditions exist. Gardiner and Niemann (1964) reported that this situation provides an enhanced opportunity for a relatively rapid resumption of expansion growth when stress is removed. The renewed development upon rewatering often proceeds at a more rapid rate than in the controls enabling stressed plants to catch up (Slatyer, 1969).

Early flowering coupled with the plant's ability to delay senescence which enables the plant to survive during mid and later season drought thus allowing the plant to produce a second flush of pods and thus offers the greatest potential for managing both mid and late season drought conditions (Gwathmey and Hall, 1992). Muchero *et. al.* (2008) observed significant genetic variation in response to drought stress on 14 cowpea genotypes. These variations were manifested in a range of discrete physiological and morphological characteristics which were apparently related to the ability of the cowpea plants to tolerate and recover from seedling and young plant stage drought.

2.4 Radiation use

Hay and Walker (1992) reported that growing a crop is an exercise in energy transformation in which incident solar radiation is converted into more useful forms of chemical potential energy located in the harvestable parts (e.g. starch in cereal grains and potato tubers and lipids in oils seeds). They noted that the crop can achieve this through processes which involve the following:

- Interception of incident solar radiation by the leaf canopy;
- Conversion of the intercepted solar radiation to plant dry matter;
- Partitioning of the plant dry matter produced between the harvestable parts or the economic parts and the rest of the plant.

Radiation and carbon dioxide are two atmospheric inputs that are used directly by a crop and optimum plant population and potential grain yield per hectare are higher in high radiation, cloudless seasons where water is not limiting (Norman *et al.,* 1995). They also reported that fertilization of grain primordial is widely believed to be the developmental event most sensitive to environmental stress and low fertility may result from cloudiness (low radiation).

Collinson *et al.* (1999) working on the effect of soil moisture on light interception and the conversion coefficient for three landraces of bambara groundnut, observed that fractional light interception (f) declined by ca. 14% at 14.00h (compared to the 0.930h) in the droughted treatment of two bambara groundnut landraces DodR and DipC but not in LunT. In the irrigated treatment however, there was a small decline (4%) in (f) at 14.00h for DodR and no decline in DipC or LunT. By implication, under drought conditions DodR and DipC were able to reduce radiation load which is an efficient adaptation to drought stress whereas LunT could not. Under irrigated conditions however, DipC could maximize light interception by retaining leaf angles for maximum light capture. Collinson *et al*. (1999) again observed significant differences between landraces in terms of light reflectivity (expressed as % of incoming radiation) with light reflectivity being higher in the droughted than the irrigated treatments for all three landraces.

On leaf orientation and radiation interception, Duncan (1969) observed that with near vertical leaves, it is possible for a plant to intercept light at low levels of illumination through a more effective light penetration within the canopy since with such plants mutual shading of neighbouring plants is minimised.

2.5 Flowering and pod production

Studying the flowering, pollination and pod formation of bambara groundnut in Ghana, Doku (1968) observed that both self and cross pollination which do occur due to the activities of ants are observed in bambara groundnut. He noted that cross pollination occurs more with landraces having open habit which resemble the wild ancestor while the bunched types may be highly self-pollinated.

Doku and Karikari (1970) working on flowering and pod production of bambara groundnut reported that more flowers and pods are produced during the dry season. They also observed that fertility co-efficient which was calculated as the rate of number of pods divided by number of flowers was higher for the bunch than the spreading landraces. Even though the fertility co-efficient did not differ much with respect to the rainy and dry seasons, it was slightly higher during the dry season. They concluded that where water is available bambara groundnut must be cultivated during the dry season. The authors noted that the flowers of bambara groundnut are positively geotropic.

Development of ovary occurs only if it is on the soil surface or beneath the surface of the soil. Considering that a period of 40 days is required for pod and seed development in most bambara groundnut landraces (Doku and Karikari 1970; Linnemann and Azam-Ali, 1993) indeterminate flowering is likely to result in low fertility coefficient thus all flowers produced 40 days before harvesting would not produce mature seeds (Kumaga *et al*,. 2002).

Pod filling in bambara groundnut is primarily dependent on current assimilation and a reduced green area during the plant's growth and development is likely to have a significant reduction in yield (Collinson *et al.*, 1999; Sesay *et al.*, 2004). The implication is to have a drought tolerant crop that can maintain green leaf area over a longer time of the crop's growth and development (Collinson *et. al.*, 1999).

Lawn (1989) attributed the effect of drought on the harvest index (HI) of bambara groundnut to flower abortion, and poor seed filling. When drought during pod filling is so severe to inhibit transient photosynthesis, pod filling will depend totally on the mobilization of stored reserves into the seed (Lawn, 1989). Collinson *et al.* (1996) observed that bambara groundnut partitions more assimilates into roots relative to the shoots under stress. This response is associated with greater root proliferation relative to leaf development.

2.6 Photoperiodic response

Studying the effect of photoperiod on the development of bambara groundnut, Linnemann (1991) observed marked difference in response of bambara groundnut landraces to photoperiod and that two ways were distinguished. These are (i) day-neutral for flowering with fruit set delayed by long photoperiod and (ii) day-neutral for flowering with fruit set inhibited by long photoperiod (14 hrs). She reported that the delay or absence of fruit set under long photoperiod is caused by the growth of fertilized ovaries being checked. She also observed that long daylength facilitated leaf production with plants grown in a 14 h photoperiod producing leaf much longer than plants grown in 10 h or 12 h photoperiod. This however may be as a result of delay in flowering and pod set under long photoperiod (Brink, 1999).

Responses of genotypes to photoperiod differ with bambara groundnut landraces. In many genotypes, flowering is photoperiod insensitive whilst the onset of podding is retarded by long photoperiod. Linnemann and Craufurd (1994) again reported that a 14 h daylength was short enough to induce flowering, but did not result in pod set for all selections used in her study. However, plant set pod in the short day treatment of 11 h. The plants under the longer daylength probably used their assimilates mainly to produce new leaves. However, under short daylength of 11 h the sink presented by the growing pod prevented further vegetative development after the flower onset.

Harris and Azam-Ali (1993) working on a field study confirmed the evidence from controlled environment experiment that although flowering bahaviour in some landraces of bambara groundnut are unaffected by daylength, the filling of pod is more rapid at day length of less than c.12 h. The authors implied that this characteristic has practical implication in bambara groundnut cultivation. Firstly, this explains the annual variability in bambara groundnut yield throughout Africa, which could be due to the fact that crops are generally sown in response to the onset of rainfall rather than at specific daylength (Harris and Azam-Ali 1993, Azam-Ali *et al*. 2001). Secondly this gave an indication of the potential for selecting bambara groundnut cultivars which are insensitive to daylength during podding for all year round cultivation (Harris and Azam-Ali, 1983).

Assessing the onset of podding on bambara groundnut is more difficult because the pods develop underground and it should be possible to remove the soil regularly to monitor pod development (Linnemann and Crauford, 1994). Linnemann (1993) again mentioned that the onset of flowering, progress of flowering, onset of podding and progress in pod growth were all retarded by long daylength above 14 hrs but the effect on podding was greater than on flowering and that some plants fail to produce pods under photoperiods of 14 and 16 hrs. She observed that in a photoperiod sensitive genotype (Ankpa) from Nigeria, pod development under photoperiod of 14 hrs per day or longer was delayed compared to 13 hrs per day or less.

Squire (1990) reported that the period generally sensitive to photoperiod within the life cycle of most species is between sowing and the start of reproductive development. He noted that most tropical crops require days shorter than a certain daylength if they are to flower in the shortest time i.e., "short day crop". Flohr *et al.* (1990) observed that groundnut cultivar Cv. NC AC 17090 flowered irrespective of photoperiod but daylength greater than 15 h increased the time required for peg and pod initiation and the time for each fruit to mature. Hadley *et al.* (1983) however, reported that in cowpea differential effects of photoperiod on the onset of flowering, pod production and maturity were not found.

Some wild plants of some species have adapted to different photoperiods to suit the environment where they are found and in the Kangaroo grass (*Themedia australia*) northern populations are short or intermediate day plants whereas further south they are long day in the higher rainfall areas with a requirement for vernalization in the coldest areas (Evans, 1993). In the arid interior with sparse and erratic rainfall, the species are indifferent to daylength and flower after rain at any season (Evans, 1993). He reported however, that no domesticated plants display such a wide range of response to photoperiod.

2.7 Temperature and crop development

The relation between crop and environment is a true interaction in that it operates in both directions; the environment affects the crop and the crop modifies the environment (Norman *et al.,* 1995). Low fertilization of grain primordia may result from temperatures greater than about 12^{o}C above or below the optimum for the whole plant and from water deficit (Norman *et al.,* 1995).

Most crops in the tropics display a broad optimum from 25-35^{o}C hence plant population and optimum grain yield per hectare at a given tropical location are not detectably correlated with temperatures except where seasonal differences in temperature are substantial e.g. continental wet and dry tropical climates of North India (Norman *et al.,* 1995). In the tropics the cultivation of any crop is limited by altitude because of specific cardinal temperatures that must be met for crop developmental events to occur (Trewartha, 1968).

The mean temperatures affect the time taken to achieve physiological maturity in a crop during the season. In bambara groundnut, bunch genotypes mature earlier than the spreading type (Goli, 1997). Massawe *et al*. (2003) observed a base temperature of 8.1^{o}C for five landraces of the crop from Malawi to 12 ^{o}C for landraces from Tanzania, Botswana and Sierra Leone for leaf appearance. Base temperatures (T_b) values for germination were observed as 11.5 ^{o}C -12.3^{o}C (Massawe, 2000). The base temperature is the temperature below which development and expansion ceases. Massawe *et al*. (2003) again reported that temperature for rate of leaf appearance (RLA) in bambara is not a species characteristic but rather depends on the landrace.

Sinclair (1994) and Crauford *et al.* (1997) reported a constant phyllochron in cowpea and soybean genotypes even though their base temperatures (T_b) varied among genotypes. Massawe *et al*. (2003) however, observed differences in phyllochron as well as base temperatures (T_b) for different bambara landraces. He noted that the landrace variations in relation to leaf appearances may allow selection of landraces for different environments. The phyllochron is the thermal time between the appearances of successive leaves.

On plant canopy development, Bennet (1998) observed that canopy development is an important development of crop radiation capture. He reported that in the absence of stress, canopy development is mainly driven by temperature. In modeling for crop growth, leaf area is derived from the relationship between temperature and the rate of leaf appearance and the relationship between leaf number and leaf area (Bennet, 1998).

2.8 Photoperiod and temperature interaction

In a study on the interactive effect of temperature and photoperiod on phenological development in three genotypes of bambara groundnut, Linnemann and Crauford (1994) observed that all three genotypes were sensitive to photoperiod with respect to podding. The authors observed that Ankpa 2 the first genotype to start flowering also produced pods earliest. Podding also occurred sooner at 28.1^{o}C than 20.2^{o}C and sooner in short (10 and 11.3h d^{-1}) than long above 12.66 h d^{-1} photoperiod (Linnemann and Crauford, 1994). The onset of podding was therefore hastened by warmer temperatures and delayed by longer photoperiod.

Kurt and Bozkurt (2006) observed an interaction of temperature and photoperiod on maximum seedling emergence of flax seed. Maximum seedling emergence of the two varieties used; Sari 85 and Windemore were obtained at 30^{o}C under 12:12 h light photoperiod though this was not significantly different from 25^{o}C. The lowest seedling emergence was obtained at 10^{o}C under completely dark conditions 24 h dark period (Kurt and Bozkurt, 2006). The combination of high temperatures, drought and long days can slow down or inhibit floral bud development, resulting in few flowers being produced and substantially reduce production (Nielson and Hall, 1985; Patel and Hall, 1990).

2.9 Yield and planting dates

Seed yields of bambara groundnut have been quoted by Stanton *et al.* (1966) to average between 650-850 kg/ha. With good agronomic practices such as sowing good seed, the crop has a potential to produce higher yields. Johnson (1968) quoted grains yields of 3870 Kg/ha in Zimbabwe. He reported that the timing of planting of bambara is critical to the yield of the crop. For Zimbabwe, he recommended mid-November as the optimum sowing date noting that delaying the sowing date by only three weeks from 30th November caused a yield reduction from 2530 kg ha^{-1} to 840 kg ha^{-1} in a clay soil and from 1420 kg ha^{-1} to 200 kg ha^{-1} in a sandy soil. The underlying factors accounting for this yield difference were however, not identified.

Kumaga *et al.* (2002) observed higher leaf and flower numbers in major season planting of bambara groundnut than in the minor season at the study conducted at the University of Ghana farm in Legon, Accra. They attributed this to higher average rainfall and temperature during the major season planting. Pod numbers and pod yield were however, higher in the minor than the major season. Kumaga *et al.* (2002) again attributed the increased in vegetative growth in the major season to physiological processes such as cell growth, wall synthesis, stomata opening, CO_2 assimilation and photochlorophyll formation in the plants. Differences in photoperiod did not influence podding or seed yield because photoperiod does not change much between the two growing seasons ranging between 12 hrs and 12.4 hrs (Kumaga *et al.* 2002). They noted no significant difference in days to flowering between the major season and minor season although flowering occurred a few days earlier in the major than minor season.

Bambara groundnut production by subsistence farmers is characterized by low and unpredictable yields, (Linnemann and Azam-Ali 1993; Sesay *et al*. 1999; Hampson *et al*. 2000). The crop was observed to be grown by farmers over a wide range of sowing dates. For a given farmer, Sessay *et al.* (2004) observed that the time of planting for bambara groundnut in Swaziland varies from October to January. Within this period however, changes in the environmental conditions notably daylength and temperature may limit the time for growth, reproductive development and yield formation. Harris and Azam-Ali (1993) also attributed the low and unpredictable yields obtained by subsistence farmers to the year to year variation to planting dates.

2.10 Hormonal changes associated with seed development.

Sreeramulu (1982) observed that auxins and gibberellins were low in young bambara seeds. The content of the hormones increased up to 30 days after development. There is however, a rapid decline after 40 days till maturity. He worked on changes in auxins, gibberellins and inhibitors in developing bambara seeds at 10, 20, 30, 40, 50 days of seed development. He observed that during the most active period of seed development maximum inhibitor accumulation occurs.

2.11 Uses

Bambara groundnut is essentially grown for human consumption. The seed makes a complete food containing sufficient quantities of protein, carbohydrate and fat (Goli, 1997). Bambara seeds play an important role in traditional festivities or ceremonies e.g. funeral rites. Mature dry seeds are boiled and eaten as pulse. They can also be ground into flour sometimes after roasting to prepare porridge (Brink and Belay, 2006). Immature seeds are boiled and eaten as snack. Seeds are also used as animal feed for the feeding of pigs and poultry and the stover used as fodder. As medicinal treatment, leaf preparations are applied on diseases and infected wounds in Senegal with the leaf sap applied to the eyes to treat epilepsy (Brink and Belay, 2006). The roots are also taken as aphrodisiac (Brink and Belay, 2006). In Nigeria the Igbos use the plant to treat venereal diseases (Brink and Belay, 2006). The seeds can be eaten fresh or grilled when immature.

The mature hard seed is however, boiled before eaten and many preparations can be made from it. Linnemann (1990) reported of bread made from bambara groundnut flour in Zambia. In Nigeria, paste made from dried seeds is used in the preparation of fried or steamed products as ‘akara’ and ‘moin-moin’ (Obizoba, 1983). Coudert (1984) concluded that the demand for bambara groundnut in West Africa exceeds the present supply.

Bambara groundnut could be canned and over 40,000 cans of various sizes were produced annually (Doku and Karikari, 1971). Rassel (1960) also reported that the haulm is palatable and the leaves are rich in nitrogen and phosphorus and therefore suitable for animal grazing. Doku (1997) reported that in Southern Ghana the beans are usually soaked overnight, boiled to produce a kind of porridge to which pepper and salt are added forming “aboboi”. This can be served with “gari” which is roasted cassava gratings.

Nguy-Ntamag (1997) observed that in Cameroon, the crop is mainly consumed fresh. Fresh testa free seeds are also cooked with seasoning and eaten as a complete meal or ground to make a pudding (traditional cake) to which taro leaves may be added. Colour and grain size are major preference by bambara groundnut consumers with white or cream colour and big size being preferred in the Transition and Guinea Savanna agro-ecological zones (Berchie *et al.,* 2010; Adu-Dapaah *et al.,* 2006). Plate 2.1 shows different bambara groundnut seed colours. Amarteifio *et al*. (1998) observed the lowest tannin level in the cream, intermediate in red and highest in black coloured bambara seeds. They mentioned that cream coloured seeds are often preferred to red and black seeds because they are less bitter and take less time to cook.

Plate 2.1 Bambara groundnut seeds

2.12 Nutritional content

The ratio of saturated: unsaturated fatty acid is 1:2. (Brink and Belay, 2006). The oil content of the seed is low to be used as an oil crop. The mature seeds of the crop are rich source of protein (16-25%), carbohydrate (42-60%) and relative to groundnut low in lipids (5-6%) (Poulter and Caygill, 1980; Ankroyed and Doughty, 1982; Deshpande and Demodaran (1990); Brough and Azam-Ali, 1992).

2.13 Pests and Disease

Bambara groundnut has the ability to resist pests and diseases compared to other legumes like groundnut and cowpeas. However, the yield of the crop can be severely reduced by several diseases. Doku (1977) reported that most diseases affecting bambara groundnut affect the crop under high rainfall conditions for which the crop is not adapted. Singh and Rachie (1985) and Singh and Allen (1979) reported that Cercospora leaf spot may be considered as the major disease affecting bambara groundnut. They noted that the species *Cercospora camescen*, *Cercospora cruenta* and *Cercospora voandzeiae* are widely spread in Africa with the first two species also affecting cowpea.

Other diseases that affect the crop are the powdery mildew (*Erisiphe polygoni* and Fusariusm wilt (*Fusarium oxysporum*) (Amstrong *et al*, 1975; Ezedinma and Maneke, 1985; and Ebbels and Billington, 1972.). Bambara groundnut is also affected by viral diseases. These include cowpea mottle virus disease (CPMOV); cowpea aphid-borne mossaic virus (CABMV) and peanut mottle virus (Pemov) (Brink and Belay, 2006).

Yield of bambara can also be affected by root knot nematodes (*Meloidoigyne javanica* and *M eloidoigyne incognita)* and root lesion nematodes *Pratylenchus spp*. (Ezedinma and Maneke, 1985).

2.14 Leaf number and leaf area index

Azam-Ali (2003) in a green house study on bambara groundnut at the University of Nottingham observed a remarkable restriction in canopy size of droughted treatment through reduction of leaf initiation beyond 50 DAS especially for Uniswa Red and DipC while the irrigated treatments actively initiated leaves until close to 80 DAS. The reduction of leaf number in Uniswa Red and DipC were considered by the author as possible mechanisms for reducing total leaf area under limited soil moisture conditions, a drought mechanism considered as water conservation strategy. Osinobi (1985) observed that high leaf water potential maintained by cowpea genotypes under drought are obtained through its sensitive regulation of stomata and leaf area. Measuring the relative vegetative index simultaneously in drought exposed and irrigated plant gives an estimate of drought stress and is also a measure for good cover and canopy size (Mongensen *et. al*., 1996, Ridao *et. al*. 2006)

2.15 Growth Analysis

Clewer and Scarisbrick (1991) described two systems of crop experimentation.

These are:

- Application of husbandry treatment at defined growth stages which is followed by the measurement of total plot yield

- Application of husbandry treatment followed by regular sampling (growth analysis) to measure the agronomic and morphological characters affected by the treatment and final harvest of non-sampled section of the plot used for yield assessment. Yield results are therefore integrated in relation to crop growth rate and yield component analysis. The authors observed that the first approach to crop experimentation is risky because it places "all eggs on the yield basket". With regular crop sampling however, as in the second approach the response to husbandry practices can still be determined even when the yield data are completely lost or have become unreliable.

Duncan *et al*. (1978) observed that crop yield is a product of crop growth rate (C) the partitioning of dry matter to reproductive sinks (p) and the duration of the crop reproductive phase (Dp). The C and p components are normally determined through growth analysis using destructive analysis. The Crop growth rate (C), Pod growth rate (PGR) and partitioning coefficient (p) was given by Williams (1992) after adjusting for high energy of pods (Duncan *et al.* 1978) as follows:

CGR = Haulm yield + (Pod yield x 1.65) / T_T

PGR = (Pod yield x 1.65)/ T_T-T_v-15

p = PGR/CGR.

Where

T_T = Number of days from sowing to harvest

T_v = Duration from sowing to 50% flowering.

The beginning of pod filling period was taken as 15 days after flower opening and pod yield was multiplied by 1.65 to adjust for the high energy of pods (Duncan *et al.*

1978). Leaf area Duration (LAD) is represented by the area under the curve of a graph of leaf area index (LAI) against days after sowing or time. Mathematically, this is expressed as the integral of LAI from crop emergence to harvest. An approach to improve crop yield is therefore to increase LAI at the early growth stage or leaf area duration (Forbes and Watson, 1994). This can be obtained through early sowing, optimum plant density, and use of nitrogen fertilizer, control of pests and diseases and reduction of weed competition.

LAI is a major factor determining the rate of dry matter production per unit ground area in a crop at a time (i.e. crop growth rate (CGR) which is given as the product of LAI and the rate of dry matter production per unit leaf area (i.e. net assimilation rate (NAR). CGR= LAI x NAR: Increasing net assimilation rate also increases crop yield especially at the late growth phase. Enyi (1977) in a growth analysis experiment reported that the higher yield on alternately branching peanut cultivar (Dodoma edible) compared to a sequentially branching type (Natal Common) was as a result of a longer leaf area duration (LAD) and longer leaf area duration between the period of pod initiation and harvest (LADp) of Dodoma Edible. He reported a positive and linear correlation between grain yield and leaf area duration in groundnut (r = 0.853). In a similar study Choudhari *et al.* (1985) reported that the higher pod yield of 29 bunch groundnut genotypes under irrigation in summer was due to higher leaf area duration (LAD) and leaf area duration between pod initiation and harvest (LADp) and biomass compared to treatments under rainfed conditions.

Duncan *et al.* (1978) working on the physiological factors contributing to 100% increase in peanut yields over a period of 40 years in Florida reported that pod yield was greatly affected by partitioning of assimilates to the pods. This resulted in an increase in the harvest index (HI) from 23% to 51% in the Early Bunch variety. Harris *et al.* (1988) in summarizing the components of yield determinants in peanut reported that the number of pods produced and the final pod weight determines peanut yields. The number of pods depended on the number of pegs and the percentage of pegs that develop into pods (Harris *et. al.*, 1988). Sesay *et. al.* (2004) studying on agronomic performance and morphological trait of field grown bambara groundnut landraces in Swaziland reported that the pattern of seasonal accumulation of dry matter in component plant parts confirmed the observation that pod-filling in bambara groundnut is largely dependent on current rather that stored assimilates. The number of pods per plant, total above-ground dry matter at plant maturity and harvest index were important determinants of seed yield and this gives cause to the selection for these parameters in bambara groundnut (Sesay *et. al.*, 2004).

2.16 Place in cropping system

The cultivation of bambara groundnut seems to have preceded the introduction of the common peanut or groundnut (Goli, 1997). The crop is found intercropped in many farming systems. Bambara is found cultivated with cereals and roots and tubers. Karikari *et al*. (1997) reported that one of the crops that feature prominently in Botswana farming systems is bambara groundnut (*Vigna subterranea*) with the crop having the third highest production of the grain legumes after cowpea and groundnut. Chaba (1994) observed that bambara groundnut is grown in Botswana as an intercrop with sorghum, millet and maize and in areas where millet is the main stable, it is usually intercropped with bambara groundnut. Working on bambara groundnut cultivation in Burkina Faso, Drabo *et al*. (1997) observed that bambara groundnut is cultivated in all regions of Burkina Faso. They also reported that the crop comes after peanut and cowpea as a grain legume and is mainly intercropped with cereals (sorghum, millet, maize), however, in poorer soils it is grown as a monoculture.

Doku (1997) reported that in Ghana bambara groundnut is grown in mixed cropping with yam where the crop is planted on the yam mounds. The bambara groundnut protects the mound from erosion, conserves moisture and prevents temperature fluctuations in the mound. With respect to crop rotation Mukurumbira (1985) observed that bambara groundnut has a greater residual nitrogen than groundnut, maize or fallow and in the rainfed agricultural system in Zimbabwe, there was no nitrogen requirement for maize when it succeeded bambara groundnut in rotation.

CHAPTER THREE

3.1 General Materials and Methods

3.1.1 Experimental sites

A total of 11 experiments were conducted from 2007-2009 at four locations namely; Wenchi (2^{o}W, 8^{o}N) in the Transition agroecology of Ghana, Tono near Navrongo (1^o W 11^{o}N) in the Guinea Savanna agroecology of Ghana, Kumasi (1^{o}30'W, 6^{o}45'N) in the Forest agroecology of Ghana and the University of Guelph, Guelph, Ontario-Canada. The experiments were planted on the field in Ghana and under controlled environment in Canada. The experiments examined the effect of drought, heat and sowing dates and photoperiod on the performance of bambara groundnut landraces.

3.1.2 Plant material

Five bambara groundnut landraces were used for the 2007 experiment except in the August, 2007 minor season sowing where six landraces were used. Landraces were used because there were no released improved varieties in Ghana. The names of the landraces were given by the author taking into consideration the colour and the source of the material where local names did not exist. The landraces used and their brief descriptions are as follows;

Navrongo 4 (NAV 4): Cream coloured seed with ash coloured eye. The grain size is big originating from Navrongo in the Upper East Region of Ghana with 100 seed dry weight ranging between 70-80 g

Summoligu (NAV Red): Local name meaning red bambara. Local landrace from the Upper East Region of Ghana with 100 seed dry weight ranging between 70 – 80 g.

Sumpiligu: (Black- eye): Local name meaning white bambara. Cream coloured seed with conspicuous black eye and medium grain size with 100 seed weight ranging between 60 – 70 g

Tom: Brownish cream coloured bambara from Tom, Nkoranza in the Brong-Ahafo (Transition) Region of Ghana with big grain size ranging between 80 – 90 g

Burkina: White coloured bambara from Burkina Faso with medium grain size 50 – 60 g.

3.1.3 Experimental design

At Wenchi, five sowings were done in a Factorial arrangement in a Randomised Complete Block Design (RCBD) with three replications. In Tono near Navrongo, two field experiments (heat and drought) were conducted. The design used was a Randomized Complete Block Design with four replicates for the heat trial and three replicates for the drought trial. One sowing was also done at the CSIR- Crops Research Institute, Kumasi using a RCBD with three replicates.

3.1.4 Cultural practices

3.1.4.1 Land preparation, planting and fertilizer application

The land was ploughed, harrowed and ridged at Navrongo. In Wenchi and Kumasi the land was ploughed and harrowed. Soil samples were taken to determine the NPK levels at the Soil Research Institute of the Council for Scientific and Industrial Research (CSIR-SRI) at Kwadaso-Kumasi. The soil nutrient level was maintained at 50 kg ha^{-1} of N, 25 kg ha^{-1} of P and 25 kg ha^{-1} of K. The fields at both Wenchi and Tono were fallowed fields with elephant grass as the dominant vegetation. In Kumasi, the field was planted to soybean during the previous year.

3.1.4.2 Plot size and plant population

Plot size was 6m x 6m (13 rows and 31 hills). Seeds were sown at two seeds per hill at inter row spacing of 50cm and intra row spacing of 20cm. Plots were thinned at 20 days after sowing (DAS) to one plant/hill giving a plant population of 10 plants/m^2 .

3.1.4.3 Weed control

Weeds were controlled using hand-hoeing. Plots were weeded as and when necessary**.**

3.1.4.4 Pest and disease control

No spraying was done against pests and diseases because the crop was relatively tolerant to pests and diseases. Generally the crop is free from pests and diseases in Ghana. Farmers also do not spray bambara groundnut fields in Ghana.

3.1.5 Growth analysis (For all the trials)

The sampling sequence for growth analysis was pre-determined on the row/plant matrix to avoid bias in selecting plants. Ten plants within the final harvest area were not removed. They were used for the final harvest data. Ten plants were removed at each sampling date at 20 DAS, 45 DAS, 60 DAS, 105 DAS and 120 DAS which represented the vegetative flowering, initiation of podding, physiological maturity of some pods and harvesting stages of pods respectively.

Dry weights were obtained at the different sampling dates by drying samples in ovens maintained at 80^{o}C for 48 hours and weighing with electronic scales. Leaf area for samples at Tono was determined at the Faculty of Agriculture of the University for Development Studies at Tamale using leaf area meter (Model C1-202. Leaf area index (LAI) was calculated as the ratio of total leaf area (cm^2) of the crop to the ground area (cm^2) occupied by the crop.

3.1.6 Crop growth rate (CGR)

Crop growth rate (CGR) at maturity was determined for the five landraces. Thermal time from sowing to flowering, podding and maturity were also determined for the five landraces. Crop growth rate was calculated as:

Crop growth rate (CGR) in t ha^{-1} d^{-1} was calculated as:

CGR=Haulm yield + pod yield/Tt

Where Tt is the number of days from sowing to maturity.

3.1.9 **Thermal time**

Thermal time was obtained as follows:

$$\Theta = \sum_{i=1}^{i=n} (T - Tb)$$

Where

Θ=Thermal time in degree days (°Cd)

n= The number of days taken for the developmental stage

T= Mean daily temperature (°C)

Tb = Base temperature (10°C)

The base temperature for bambara groundnut has been quoted as 10°C (Collinson *et al*. 1996, Harris and Azam-Ali, 1993)

3.1.10 **Data collected**

Data collected included:

Days to 50% emergence: This was recorded as the number of days 50% of seedlings on a plot emerged. Seedlings were considered to have emerged when the first true leaf had broken through the soil and was visible. The day of sowing was considered as Day 0 in all the phenological data taken.

Days to 50% flowering: This was recorded as the number of days 50% of the plants on a plot showed fully opened flower with visible corolla colouration .

Days to podding: This was recorded as the number of days 50% of sampled plants on a plot started to produce pods. Ten days after 50% flowering and at 5-day interval some plants within the border rows of each landrace were dug to determine the onset of podding to complement information from the scheduled growth analysis where 10 plants were harvested.

Days to maturity: This was recorded as the number of days at least 50% of sampled plants on a plot took to reach physiological maturity. Plants were considered mature when the leaves turned yellow and majority of the pods had hard shells and ripe seeds.

Plants harvested for each growth analysis were separated into component parts: leaves, petiole, stem, roots and pods as when they appeared. The plant parts were oven dried at 80^{o}C for 48 hours and weighed with a weighing scale.

Leaf dry weight: the weight of the oven-dried leaves measured in grams.

Stem dry weight: the weight of oven-dried stems measured in grams.

Root dry weight: the weight of oven-dried roots measured in grams.

100 pod dry weight: the weight of 100 randomly selected oven-dried pods weighed in grams.

100 pod seed weight: the weight of seeds extracted from 100 randomly selected oven-dried pods and measured in grams.

100 seed dry weight: the weight of 100 randomly selected oven–dried seeds measured in grams.

Immature pod dry weight: the weight of oven-dried immature pods harvested from sampled plants measured in grams

Mature pod dry weight: the weight of oven-dried mature pods harvested from sampled plants measured in grams

Total pod yield: the total weight of oven-dried pods harvested from sampled plants measured in grams.

Leaf area: the leaf area was measured using a leaf area meter (Model C1-202) for samples from Tono and leaf area meter Li-3100, USA for samples at Guelph, Canada.

3.1.9 Harvest index

Pod and seed harvest indices were calculated as follows

Pod harvest index (PHI) = Total pod yield /Total biomass yield

Seed harvest index (SHI) = Total seed yield/Total biomass yield

3.1.10 Meteorological data

Meteorological data on temperature, rainfall, humidity, evaporation and sunshine hours were obtained from the Ghana Meteorological Services Department at Navrongo and Wenchi. The data was used to calculate sunshine hours and determine the thermal time for the different developmental stages (Appendices I-III).

3.1.11 Data analysis

Data were analysed using the Genstat statistical package. Means separation were done using the Least Significance Different (LSD) method at 95% level of probability

CHAPTER FOUR

YEAR ONE PRELIMINARY STUDIES

The following studies were undertaken in 2007:

4.1 Experiment 1: Effect of sowing date on the performance of five bambara groundnut landraces, at Wenchi (Transition agro-ecology of Ghana).

4.2 Experiment 2: Evaluation of five bambara groundnut landraces to heat and drought stress at Navrongo (Guinea Savannah agro-ecology of Ghana).

4.3 Experiment 3: Evaluation of bambara groundnut genotypes under forest agro-ecology (Fumesua-Kumasi)

4.4. Experiment 4: Effect of August sowing on the performance and yield of six bambara groundnut landraces

4.1 Experiment 1: Effect of Sowing Date on the Performance of Five Bambara Groundnut Landraces at Wenchi (Transition agro-ecology of Ghana)

4.1.1 Introduction

The transition agro-ecology is one of the major bambara groundnut cultivation zones in Ghana. Unfortunately, not much effort has gone into evaluating the performance of the bambara groundnut landraces at different sowing dates in Ghana. Working on the effect of planting time on growth, flowering and seed yield of nine bambara groundnut landraces, Kumaga *et al.* (2002) observed that moderate rainfall, coupled with relatively high temperatures over the entire growing period, may be required for high pod and seed yield. The yield per plant was generally higher in the minor season than the major (Kumaga *et al.* 2002). Sesay *et al*. (2008) observed that the variation in pod yield across sowing dates was closely associated with variation in pod number per plant, seed size, harvest index and dry matter production. This preliminary study was undertaken to determine whether differences in sowing dates could affect the performance of five bambara groundnut landraces in the Transition agro-ecology of Ghana.

4.1.2 Materials and methods

Plants were sown on five different sowing dates at Wenchi in the Transition agro-ecology to simulate changes in duration of day length if any and environmental changes over the growing periods. The five planting dates were; 13th February, 27th February, 12th March, 26th March and 9th April 2007. Experimental design and plant population, weed control and other agronomic practices were the same as described in the general material and methods.

4.1.3 Results

4.1.3.1 Days to 50% emergence

There was a highly significant difference among the landraces ($p<0.001$), planting dates ($p<0.001$) and landrace and planting dates interaction ($p<0.001$) with respect to days to 50% emergence. Black eye used the least mean number of days to 50% emergence over all planting dates (10 days) whilst Burkina used the greatest mean number of days to 50% emergence over all planting dates (11 days) (Table 4.1). Mean days to 50% emergence for all the landraces was significantly lower (p<0.001) for the 26/03/07 and 9/04/07 sowings (9 days) and highest (14 days) for the 13/02/07 sowing (Table 4.1).

4.1.3.2 Days to 50% flowering

There was a highly significant difference among landraces (p<0.001), planting dates (p<0.001) and landrace and planting dates interaction (p<0.001) with respect to days to 50% flowering. Burkina took the least mean number of days to 50% flowering (34 days) and Tom took the greatest mean number of days (39 days) to 50% flowering (Table 4.1). Plants sown on 9/04/07 gave the least number of days to 50% flowering (32 days). Those planted on the 13/02/07 took a longer duration to 50% flowering (38.7days) (Table 4.1).

4.1.3.3 Days to Podding

There was a highly significant difference (P< 0.001) among the landraces, and landrace and planting date interaction (p<0.001) with respect to days to podding. Burkina had the least mean number of days to podding for all the sowing dates (53 days) with Tom having the greatest mean number of days to pod production (74 days) (Table 4.1).

Significant difference in days to podding was also observed for the different sowing dates (P<0.001). The 9/04/07 sowing had the least number of days to podding (54 days) with 13/02/07 sowing resulting in the greatest mean number of days to podding (71 days) (Table 4. 1).

4.1.3.4 Days to Maturity

There were highly significant differences ($p< 0.001$) among landraces, planting dates and landrace by planting dates interaction with respect to days to maturity. Burkina was the earliest maturing landrace (106.4 days) with Tom being a late maturing landrace (117.5 days) (Table 4.1).

Pod maturity was significantly earliest ($p<0.001$) for the 9/04/07 sowing (97.0 days) and latest for the 13/02/07 sowing (118.1 days) (Table 4.1).

Table 4.1: Days to 50% emergence, 50% flowering, podding and maturity as affected by landraces and sowing dates

	Days to 50% emergence	Days to 50% flowering	Days to podding	Days to maturity
Landraces				
Black eye	9.7	36.3	67.6	109.2
Burkina	10.9	33.5	53.2	106.4
NAV4	10.4	35.9	54.7	108.9
NAV Red	10.5	35.4	55.0	108.9
Tom	10.4	38.9	73.6	117.5
Mean	10.4	36.0	60.8	110.1
CV%	7.3	1.7	3.7	0.7
LSD (0.05)	0.5	0.4	0.7	0.5
P value	<0.001	<0.001	<0.001	<0.001
Sowing dates				
13/02/07	14.1	38.7	70.5	118.1
27/02/07	9.2	35.0	57.6	111.9
12/03/07	8.7	35.4	55.9	111.0
26/03/07	8.5	34.8	55.6	111.0
9/04/07	8.5	31.8	53.7	97.0
Mean	9.8	35.1	58.7	109.8
CV (%)	7.3	1.7	3.7	0.7
LSD (0.05)	0.5	0.4	1.6	0.5
P value	<0.001	<0.001	<0.001	<0.001

4.1.3.5 Immature/mature pod dry weight

The immature pod weight was taken to determine which of the landraces produced the greatest number of immature pods at maturity. There was a highly significant difference ($p<0.001$) among the landraces and planting dates. There was however, no significant landraces and planting dates interaction. Among the landraces, Black eye produced the highest number of immature pods (57.9) and Tom the least (30.2) (Table 4.2).

With planting dates, the 13/02/07 sowing produced the highest mean number of immature pods (50.8) while the 27/02/09 sowing produced the least mean number of immature pods (34.7) (Table 4.2). Mature pod yield was significantly greatest in NAV Red (351.1 g) and least in Tom (56.8 g) ($p<0.001$). The 26/03/07 sowing produced the greatest mature pod yield (331.3 g) with the 9/04/07 sowing producing the least mature pod yield (183.3 g) (Table 4.2).

4.1.3.6 Total pod dry weight

There was a highly significant difference ($p < 0.001$) for landrace and planting date with respect to total pod weight. Landrace by planting date interaction was also significant. Tom produced the lowest mean total pod yield 87.0 g m^{-2} among the landraces whilst NAV Red gave the greatest total pod yield of 416.0 g m^{-2} (Table 4.2). The 13/02/ 2007 sowing gave the highest pod yield (421.6 g m^{-2}) followed by the 26/03/07 sowing (378.0 g m^{-2}) (Table 4.2).

Table 4.2 Immature, mature and total pod dry weight (g/ha) as affected by landraces and sowing dates, grown at Wenchi in 2007.

	Immature pod dry weight (g m^{-2})	Mature pod dry weight (g m^{-2})	Total pod dry weight (g m^{-2})
Landrace			
Black eye	57.9	333.9	386.3
Burkina	42.1	325.5	365.6
NAV 4	53.9	327.8	380.6
NAV Red	59.3	351.1	416.0
Tom	30.2	56.8	87.0
Mean	48.7	279.0	327.0
CV (%)	31.1	21.7	19.0
LSD (0.05)	10.1	40.3	41.4
P value	<0.001	<0.001	<0.05
Sowing dates			
13/02/07	50.8	374.1	421.6
27/02/07	34.7	220.0	248.0
121/03/07	46.0	256.7	308.0
26/03/07	46.7	331.3	378.0
9/04/07	45.3	183.3	228.7
Mean	44.7	273.1	316.9
CV (%)	31.1	21.7	19.0
LSD (0.05)	10.1	44.2	45.3
P value	<0.001	<0.001	<0.05

4.1.3.7 Harvest Indices

Table 4.3 shows the pod yield and harvest indices for the various landraces at the different sowing dates. Pod harvest index was significantly greatest for NAV 4 (0.45) and the 13/02/07 sowing (0.45), ($p<0.05$).

Table 4.3: Total dry matter, pod yield and harvest indices as affected by landraces and sowing dates, grown at Wenchi in 2007.

	Total dry matter ($g\ m^{-2}$)	Total Pod yield ($g\ m^{-2}$)	Pod Harvest Index
Landrace			
Black- eye	901.1	386.4	0.43
Burkina	869.7	365.0	0.42
NAV 4	846.9	380.6	0.45
NAV Red	935.4	416.0	0.44
Tom	734.3	87.0	0.12
Mean	857.5	327.5	0.37
CV (%)	9.0	19.0	5.0
LSD (0.05)	112.6	41.4	0.18
P value	<0.001	0.005	<0.05
Sowing date			
13/02/07	942.8	421.6	0.45
27/02/07	794.5	248.0	0.31
12/03/07	882.4	308.0	0.35
26/03/07	915.1	378.0	0.41
9/04/07	752.6	228.7	0.30
Mean	857.5	317.0	0.37
CV (%)	9.0	21.7	17.7
LSD (0.05)	118.3	44.2	0.09
P value	<0.001	<0.001	<0.05

4.1.3.8 Crop growth rate and thermal time

Table 4.4 shows the crop growth rate at maturity and thermal time for different stages of the crops growth for the 13/02/07 sowing. Crop growth rate was significantly different ($p<0.05$) and ranged between 0.056 to 0.089 t ha^{-1} d^{-1} with a mean of 0.080 t ha^{-1} d^{-1}. Crop growth rate was highest for NAV Red (0.089 t/ha/d) even though this was not significantly different from Burkina and Black eye. Tom had the lowest crop growth rate (0.059 t/ha/d).

Thermal time to maturity was significantly different ($P<0.05$) among the landraces with Tom having the highest thermal time of 2109.0 ^{o}Cd.

4.1.3.9 Dry matter partitioning

The trend of dry matter partitioning was similar for all the landraces at the 13/02/07 sowings except Tom. The trend of dry matter partitioning was shown for the various landraces to indicate how the various landraces partitioned assimilates to their different plant parts during the growth and development phases. Dry matter partitioning to the leaves was greater during the initial stages of plant growth. However, with the commencement of podding, there was a decrease in leaf dry matter with increase in pod dry matter for all the landraces except Tom where leaf dry matter was highest till harvest (Figures 4: 1a-e).

Table 4.4. Crop growth rate (sowing to harvest) and thermal time for bambara groundnut landraces for 13/02/07 sowing at Wenchi.

Landrace	Crop growth rate tons/ ha/day	Thermal time (°Cd) to 50% flowering	Thermal time (°Cd) to podding	Thermal time (°Cd) to maturity
Burkina	0.088	620.0	986.5	1817.5
Black eye	0.086	686.0	1224.7	1863.7
NAV 4	0.076	680.0	1012.5	1857.2
NAV Red	0.089	680.0	1021.4	1857.2
Tom	0.059	707.0	1338.7	2109.0
Mean	0.080	674.4	1116.8	1901.0
LSD (0.05)	0.003	14.5	210.0	158.1

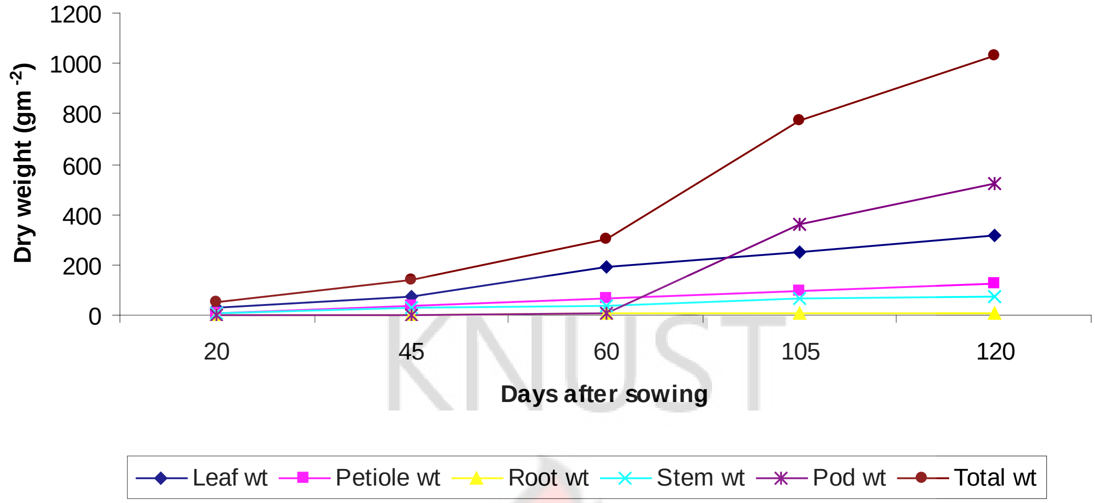

Figure 4: 1a **Dry matter partitioning 13/02/07 sowing (Black eye)**

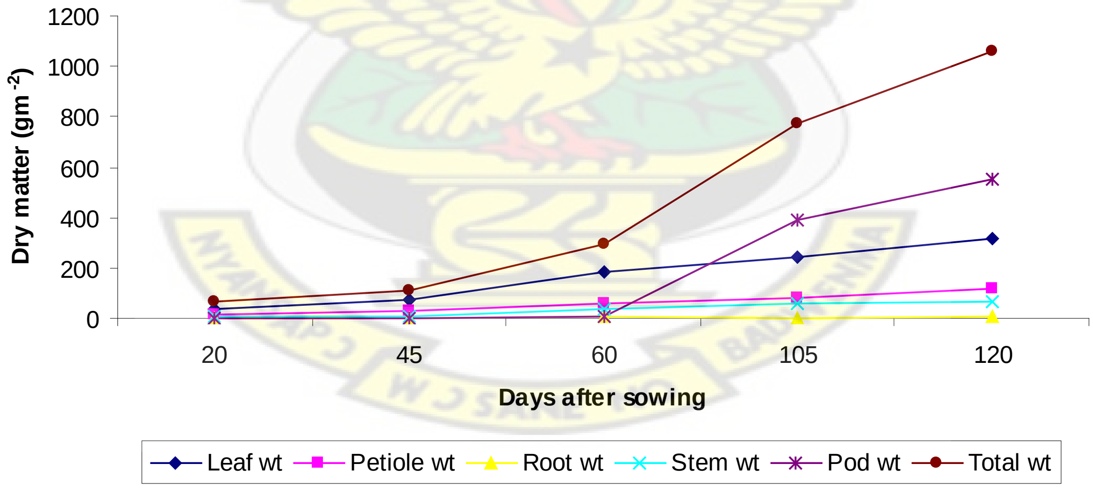

Figure 4:1b **Dry matter partitioning 13/02/07 sowing (Burkina)**

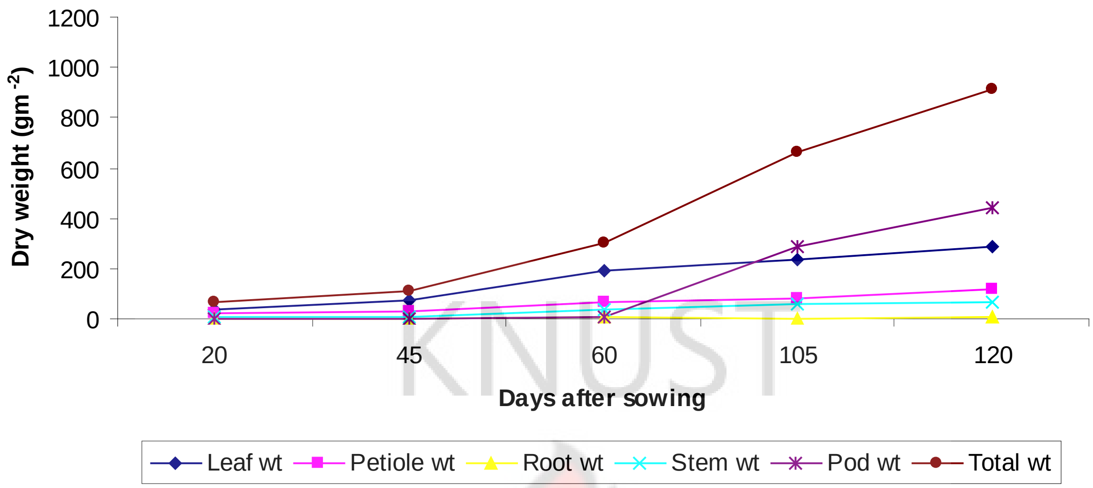

Figure 4:1c **Dry matter partitioning 13/02/07 sowing (NAV 4)**

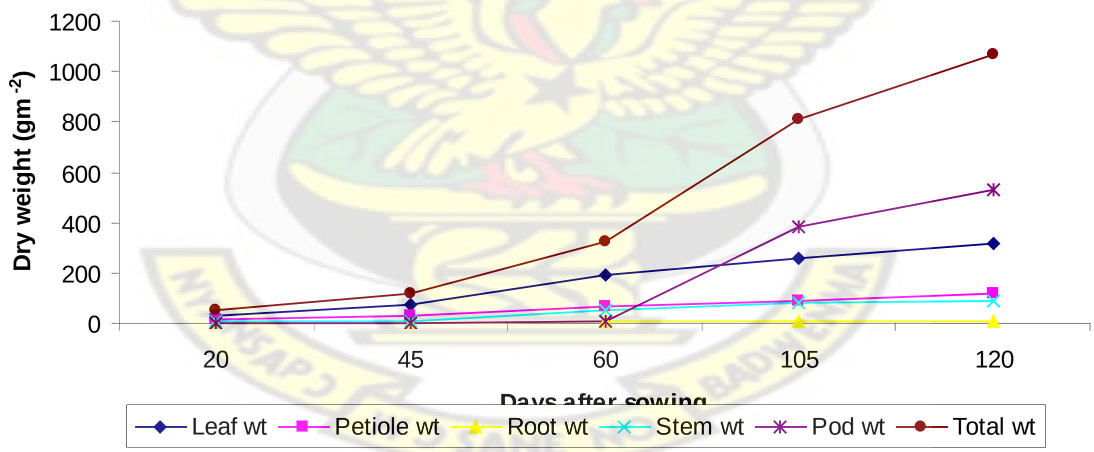

Figure 4:1d **Dry matter partitioning 13/02/07 sowing (NAV Red)**

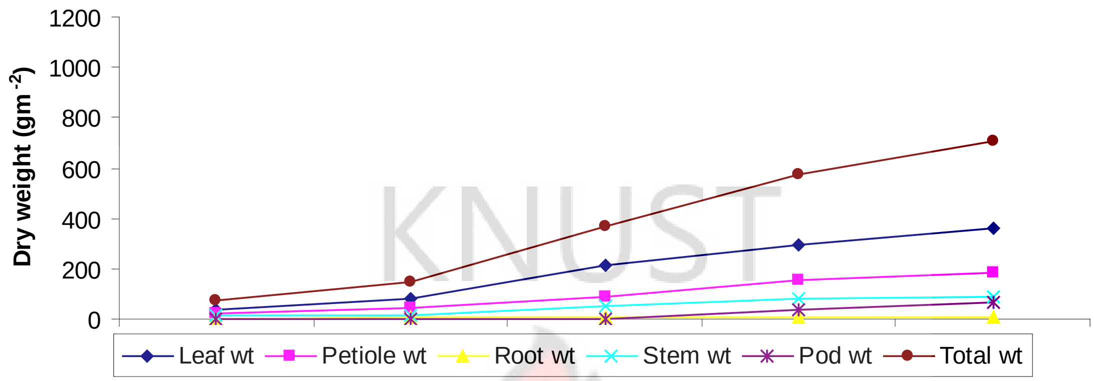

Figure 4:1e **Dry matter partitioning 13/02/07 sowing (Tom)**

Plate 4.1: Tom showing very few pods and more vegetative characteristics at harvest

Plate 4.2: Black eye with more pods and less vegetative characteristics.

4.1.4 Discussion

4.1.4.1 Interaction effect

Even though sowing date by landrace interaction effects were observed in some results of this study, Clewer and Scarisbrick (2001; 1991) reported that it is debatable whether different sowing dates can be regarded as factor levels. Little and Hills (1977) also observed that several years' results involving several harvests each year may be combined as a split plot analysis with varieties as the main plots, years as split plots and harvest as split-split plots, however, the interaction of varieties x years x harvests usually is not of primary importance. In soybean nitrogen fixation trials at various locations, although there were significant inoculant by variety and inoculant by location interactions only main effects were reported because F values for main effects were much larger than the interaction effects (Sarkodie-Addo, 1991). Similar paths were followed in the present study since the main effect F values were much higher. Where the interaction effects were significant, they were just mentioned in the test.

4.1.4.2 Days to 50% emergence and 50% flowering

Sesay (2005) working on time of sowing in Swaziland reported that the longer period from sowing to flowering for the October 13 sowing was due to the delay in seedling emergence caused by the late rains. A similar observation was made in the days to 50% emergence and eventually days to 50% flowering in this study. February falls within the dry season at Wenchi. Problems with water supply by the irrigation system at the experimental site affected the days to emergence for the plants sown in February. It is possible the dry nature of the soil affected the imbibition of moisture needed for rapid seedling emergence. The practical significance of this result is for growers to have an efficient irrigation system so as to crop bambara groundnut during the dry season or to take advantage of weather forecast from the Meteorological Services Department before sowing their seeds. This is because seedling emergence and establishment can greatly be affected by soil moisture availability. This will also save farmers from the loss of seeds. Sowing at the appropriate period or time in the absence of irrigation can enhance establishment which will enable the crop to maximize the capture and use of resources like irradiance through early canopy development and reduce weed competition by etiolating weed competitors.

Squire (1990) reported that severe drought can prevent seeds from germinating. The fact however, that the bambara groundnut seeds could remain dormant in the dry soil under the high temperature and eventually emerge with improved irrigation in this study shows the resilience of the crop as a drought resistant crop even at the seed stage. Improvement in the irrigation system and the onset of rains in March and April hastened the germination of plants sowed in March and April.

4.1.4.3 Days to maturity

Knowing the maturity date is important in avoiding pods from getting rotten in the soil. April sowing resulted in the least number of days to maturity (97 days) and the 13th February the longest number of days (118) (Table 4.1). Moisture availability in the April sowing which led to early seedling emergence could have facilitated the early maturity of the crops. Achtrich (1980) reported that the length of vegetative cycle was an important factor in adaptation of plants to dry conditions.

The landrace Burkina is from Burkina-Faso a Sahelian country with low rainfall and might have adapted to drought stress by maturing early to escape drought. Photoperiod in this study ranged between 12.3 h and 12.7 h with a mean of 12.5 h within the growing period (Appendix III). Linnemann (1994) reported that photoperiod apparently affects the number of developing sinks, and as a consequence, the total sink strength of the plant irrespective of the numerous ovaries present on plants. The difference in photoperiod in this study was however, not significant to affect days to flowering and days to maturity over the various planting dates. This result is in agreement with Kumaga *et. al.* (2002) who reported that differences in light hours between the minor and major season in Ghana were too small to significantly influence flowering dates. The April planting was done when the major season rainfall had began and it is possible available moisture might have influenced the development of reproductive structures as well as increase a source capacity. It is also possible the strong source and sinks created could have accounted for the early partitioning of dry matter to pods in the April sown plants.

Delayed emergence for the February planting might have resulted in late maturity of plants. Begeman (1988) reported that it is impossible to refer to a particular landrace as a 90 day variety, because of the significant variation in maturity of the same landrace under different environmental conditions. Photoperiod, temperature, drought or moisture availability, pest and diseases can affect the duration of plant maturity. Days to maturity could therefore be stated with respect to a particular landrace and for certain location and planting time.

4.1.4.4 Immature and total pod dry weight

For any plant improvement on bambara groundnut towards determinacy it is anticipated that a high ratio of mature to immature pods at maturity is favourable. The 13/02/07 treatment produced the highest number of immature pods. This was in the dry season where soil moisture level was low. Practically this has an implication in water management if more mature pods are to be obtained. Low sink strength and source capacity could have resulted in more pods not being filled under moisture stress conditions.

Tom produced the least number of immature pods (Table 4.2). However, when the immature pods were expressed as a percentage of mature pods at maturity, the following values were obtained; Black eye, 17.3%; Burkina, 13.0%; NAV 4, 16.4%; NAV Red, 16.9% and Tom 53.2% an indication that Burkina has a potential for improvement if obtaining a determinate crop is to be considered.

Monthly mean sunshine hours between February and June for the 13/02/07 sowing (866.2 hrs) from emergence to harvesting was higher compared to the subsequent sowings. This period was within the dry season and the mid-part of the rainy season when cloud cover was minimal and sunshine hours were greater (Appendix 1). This study showed that where water was not limiting (where irrigation facilities are available) and soil conditions are favourable for bambara groundnut production, dry season cultivation of bambara groundnut can result in high pod yield. Total pod yield for 13/02/07 planting under irrigation was

421 g m^{-2} (Table 4.2). The April planting gave the least total pod yield of 228.7 g m^{-2} (Table 4.2). Total sunshine hours from emergence to harvest for the April sowing was 576.5 hrs and this was as a result of cloud cover during the major rainfall season and the relatively shorter days to maturity (97 days) relative to a mean of 112 days for the 13th February sowing. It should also be noted that pods had to be harvested earlier in the April sowing since the mature pods were showing signs of rot because of the rains. Despite the shorter days to podding (54 days) for the 09/04/07 sowing compared to 70 days for the 13/02/07 sowing, the longer duration of pod filling (50 days) for the 13th February sowing relative to 43 days for the 09th April sowing could have also accounted for the higher pod yield of the 13/02/07 sowing relative to the 09/04/07 sowing. Witzenberger *et. al.* (1988) attributed pod yield in groundnut to shoot growth rate, partitioning factor and effective pod filling period. Differences in effective pod filling period in this study could have accounted for the mean differences in pod yield for all the landraces at the different sowing dates.

4.1.4.5 Pod harvest indices

Pod yield and harvest index (HI) were highest with the 13/02/07 planting (Table 4.3). NAV 4 and NAV Red had the highest mean harvest indices of 0.45 and 0.44 respectively. Even though Burkina did not have the highest mean harvest index, its shorter maturity period and performance across the various sowing dates makes it a candidate to consider especially for the drier areas. Pod yields of over 5 t ha^{-1} in some of the 13/02/2007 sowing seemed high but with a mean shelling percentage of 70%, the kernel yield was 3.87 t ha^{-1}. Johnson (1968) reported kernel yield of 3.87 t ha^{-1} in Zimbabwe which is similar to the highest kernel yield obtained in this study.

Mkandawire and Sibuga (2002) reported harvest indices of 0.57 (flat seedbed) and 0.58. (ridge seedbed) in a study conducted at Morogoro in Tanzania. Pod harvest indices for Black eye, NAV Red and Burkina for the 13/02/07 sowing were 0.50, 0.53 and 0.51, respectively which are in agreement with values obtained by Mkandawire and Sibuga (2002). Squire (1990) reported HI values of 0.3 to 0.6 for indeterminate crops under wet conditions. The results observed among all the landraces agreed with values obtained by other workers except Tom which obtained a very low harvest index of 0.12 (Table 4. 3).

4.1.4.6 Crop growth rate and thermal time

Crop growth rate was highest in NAV Red (0.089 t ha^{-1} d^{-1}) but this was not significantly different from that of Burkina and Black eye. Tom showed significantly low ($p=0.05$) crop growth rate (0.059 t ha^{-1} d^{-1}). The low crop growth rate in Tom reflected in the low pod and seed yields of the landraces. Sesay *et al.* (2006) obtained a mean crop growth rate of 0.081 t ha^{-1} d^{-1} with a range of 0.062 - 0.099 t ha^{-1} d^{-1} for groundnut cultivars grown under irrigated conditions. Mean crop growth rate for this study was 0.080 t ha^{-1} d^{-1} with a range of 0.059 - 0.089 t ha^{-1} d^{-1}. It should be noted that water was not limiting in this study.

Thermal time to crop maturity in this study ranged between 1817 ^{o}Cd to 2109 ^{o}Cd with a mean of 1901^{o}Cd. Collinson *et al*. (1996) obtained mean thermal time of 2163 ^{o}Cd to 2773 ^{o}Cd in Sierra Leone. Sesay *et al.* (2008) also observed mean thermal times of 1428 ^{o}Cd in a study on bambara groundnut in Swaziland. Differences in thermal time could be due to the days to maturity of the various landraces and the environmental conditions under which they were cultivated.

4.1.4.7 Dry matter partitioning

Tom partitioned more dry matter to the leaves, petiole and stem at the instead of pods. However, in the case of the other landraces, podding resulted in more assimilates being directed into the developing pods. That is for seed production, Tom is not a good candidate (Figures 4.1a-e). Wright (1989) observed that earlier in the reproductive phase when flower initials are not strong sinks, vegetative development seems dominant and where assimilate supply is limited under low light intensity and drought the apex is a stronger sink. The current study showed clear evidence of genotypic differences among the landraces.

4.2 Experiment 2: Evaluation of Five Bambara Groundnut landraces to Heat and Drought Stress at Navrongo (Guinea Savannah Agroecology of Ghana)

4.2.1 Introduction

The Upper East Region of Ghana is one of the hottest regions recording the highest temperatures in the country according to (Ghana Meteorological Services Report, 2007). Mean maximum monthly temperatures for the growing period; February to May were 38.7, 40.2, 37.6 and 34.7 degrees Celsius, respectively (Appendix II). The region also experiences a unimodal rainfall (May-September). The high temperature and the long spell of drought during the experimental duration presented the site an ideal place to conduct a heat and drought trial. Heat tolerant peanut genotypes have been identified in Niger on the basis of partitioning of dry matter to pods at high (32 to 34^{o}C) temperatures (Greenberg *et al*., 1992, ICRISAT, 1994).

The objective of this study was to determine differences in response of five bambara groundnut genotypes to heat and drought stress and to identify genotypes which could be sown in areas of high temperatures where irrigation is available and also those which will produce some yields where rainfall is low.

4.2.2 Materials and methods

This trial was conducted at Tono on the field of the Irrigation Company of the Upper East Region (ICOUR). Seeds were sown on ridges and irrigated to field capacity once weekly using furrow irrigation. The heat trial was sown on the 10th of February 2007 and irrigated once weekly till maturity. Seeds for the drought trial was sown on the 11th of

February 2007. For the drought treatment, plants were irrigated until 30 days after sowing (DAS) after which no irrigation was done. Seedling emergence was recorded from the 5th day to the 18th day after sowing. Two seeds were sown per hill at a spacing of 50 cm by 20 cm and thinned to one seedling per hill (10 plants/m^2) 20 DAS. Weeds were controlled using hand hoeing as and when fields were weedy. Plant dry weights were obtained by drying samples in an oven maintained at 80^{o}C for 48 hours. Plant height and width were measured using a ruler at 90 DAS when the crops on the irrigated plots had almost attained full canopy cover. Root dry weights were taken for the drought plot at 105 and 120 DAS.

4.2.3 Growth analysis and leaf area measurements

Ten plants were removed for each growth analysis at 20, 45, 60, 105 and 120 DAS. Ten plants within the central harvest area were not removed. They were used for the final harvest data. Leaf area was determined at the Faculty of Agriculture, University for Development Studies, Nyankpala Campus, Tamale using a leaf area meter C1-202.

4.3.4 Results (Tono Heat Trial)

4.2.4.1 Leaf dry weight, plant height and plant width

Leaf dry weight was significantly different at 45 DAS ($p<0.05$) with Tom having the highest leaf dry weight of 19.7 g/m^2. No significant difference was subsequently observed in leaf dry weight among the landraces for the various sampled dates (Table 4.5). Plant height was significantly different among the landraces ($p<0.05$). Significant difference was also observed among landraces with respect to plant width ($p<0.05$) (Table 4.5). Tom had the highest plant height and width of 25.30cm and 40.15cm respectively. Burkina however, had the least height and spread of 20.45 and 30.90 centimetres respectively.

4.2.4.2 Pod dry weight

Pod dry weight was significantly different at maturity ($p<0.001$). Burkina produced the highest pod dry weight of 118.50 g/m^2 while Tom produced no pods (Table 4.5).

4.2.4.3 Leaf area and leaf area index

Leaf area was significantly different at 45 DAS ($p<0.05$) and 60 DAS ($p<0.05$). Leaf area was however, not significantly different at 105 and 120 DAS. The highest leaf area per plant was attained by Tom at 105 DAS (6540 cm^2) though there was no significant difference among the landraces. Leaf area index followed a similar trend as the leaf area with the highest leaf area index being by Tom at 105 DAS (6.5) even though it was not significantly different (Figures 4.2a and 4.2b) from that of the other landraces.

Table 4.5 Leaf dry weight (g/m^2), plant height, canopy spread (cm) and pod dry weight (g/m^2) for five bambara groundnut landraces at Tono (Heat trial)

Landrace	Leaf Dry wt. (g/m^2) 45 DAS	Leaf Dry wt. (g/m^2) 60 DAS	Leaf Dry wt. (g/m^2) 105 DAS	Leaf Dry wt. (g/m^2) 120 DAS	Plant height (cm) (90DAS)	Canopy spread (cm) (90DAS)	Pod dry Weight (g/m^2) (120DAS)
Black eye	11.36	62.00	206.00	123.00	20.45	38.15	48.70
Burkina	13.18	62.80	205.00	110.00	20.45	30.90	118.50
NAV 4	17.16	63.70	159.00	138.00	21.32	39.95	54.00
NAV Red	12.54	49.90	103.00	104.00	22.52	36.55	52.50
Tom	19.71	69.00	247.00	90.00	25.30	40.15	0.00
Mean	14.79	61.40	196.00	113.00	22.01	37.14	54.70
CV %	26.1	17.40	28.10	41.50	7.2	10.7	20.50
LSD (0.05)	5.92	NS	NS	NS	2.45	6.13	17.30
P value	0.048				0.005	0.037	<0.001

NS = Not significant.

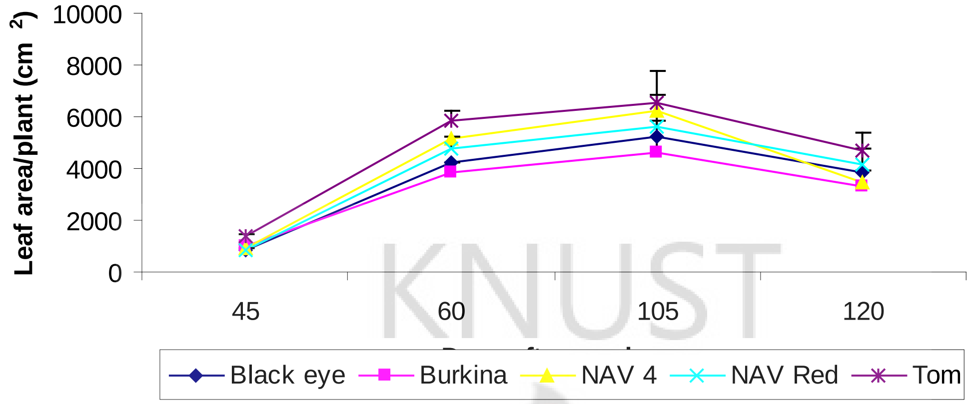

Figure 4.2a Leaf area per plant cm^2 against DAS (Tono heat trial). Bars indicate standard error of the mean.

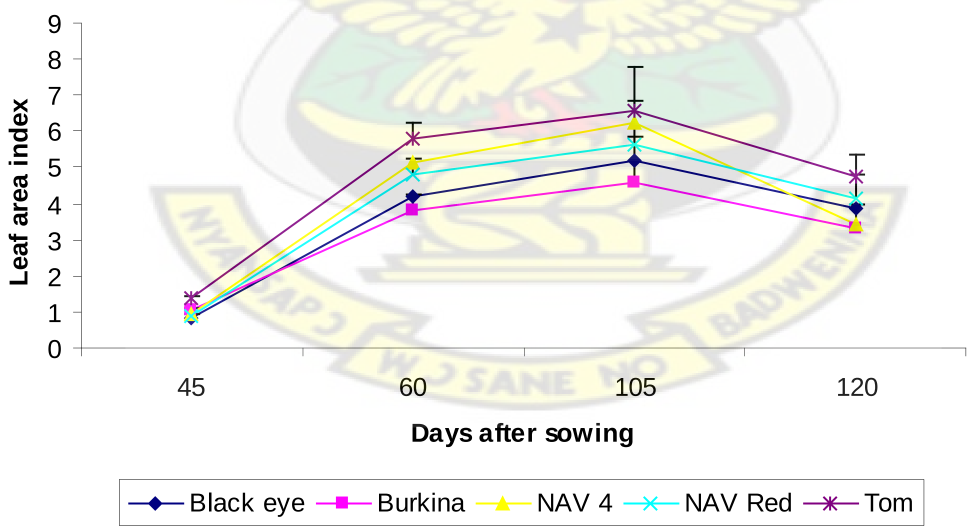

Figure 4.2b Leaf area index against DAS (Tono heat trial). Bars indicate standard error of the mean.

4.2.5. Results (Tono Drought Trial)

4.2.5.1 Leaf and root dry weights and leaf numbers.

There was no significant difference in leaf weight for the various landraces between 20 to 105 DAS. However, significant difference was observed at 120 DAS ($p=<0.05$) with Burkina having the highest leaf dry weight of 196.3 g m^{-2} and Tom the least 93.9g/m^2 (Table 4.6). Root dry weight was significantly different at 120 days with Burkina having the highest of 3.66 g m^{-2} ($p=0.017$) (Table 4.6).

4.2.5.2 Pod production

Some plants of Burkina produced some few pods even under the drought and high temperature conditions. This result is not presented since none of the other landraces produced any pod under these conditions.

4.2.5.3 Leaf area and leaf area index

Significant difference was observed with respect to leaf area between 60 to 120 DAS. Tom maintained a significantly high leaf area between 60 and 105 DAS even though this was not significantly different from that of Burkina at 105 DAS. Burkina however, had a significantly highest mean leaf area per plant (3692 cm^2) at 120 DAS. A similar trend was observed in the leaf area index (Figures 4.3a and 3b).

Table 4.6 The effect of drought on canopy spread, plant height (cm) root, stem and leaf dry weights (g/m^2). Tono.

Landrace	Canopy spread (cm) 90 DAS	Plant height (cm) 90 DAS	Root dry Weight (g m^{-2}) 105DAS	Root dry Weight (g m^{-2}) 120DAS	Stem dry Weight (g m^{-2}) 105DAS	Stem dry Weight (g m^{-2}) 120DAS	Leaf dry Weight (g m^{-2}) 105DAS	Leaf dry Weight (g m^{-2}) 120DAS
B. eye	35.73	18.93	2.01	2.10	63.30	106.80	142.00	103.80
Burkina	31.33	17.00	3.78	3.66	84.00	150.30	159.30	196.30
NAV 4	32.84	19.40	2.19	2.30	65.30	107.80	146.70	106.40
NAV	36.53	19.80	2.31	1.84	72.00	123.20	154.70	132.70
Red Tom	37.67	21.20	2.06	2.17	61.30	96.70	162.00	93.90
Mean	34.83	19.23	2.47	2.41	69.20	117.00	152.90	126.60
CV%	10.9	9.4	27.50	21.3	16.7	21.90	22.1	22.40
LSD, 0.05	NS	NS	NS	0.96	NS	NS	NS	53.46
P value				0.017				0.013

NS= Not significant

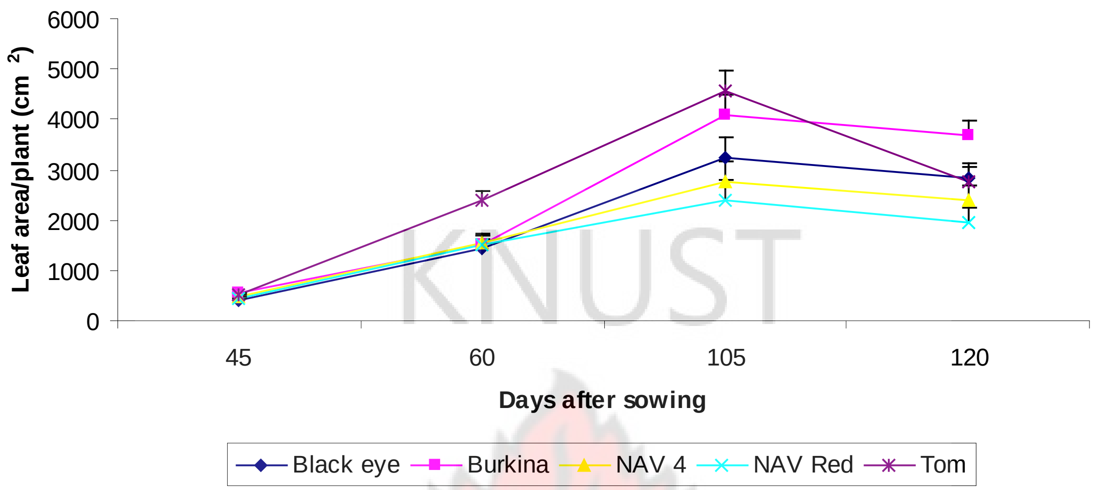

Figure 4.3a Leaf area per plant (cm^2) against DAS (Tono drought trial). Bars indicate standard error of the mean.

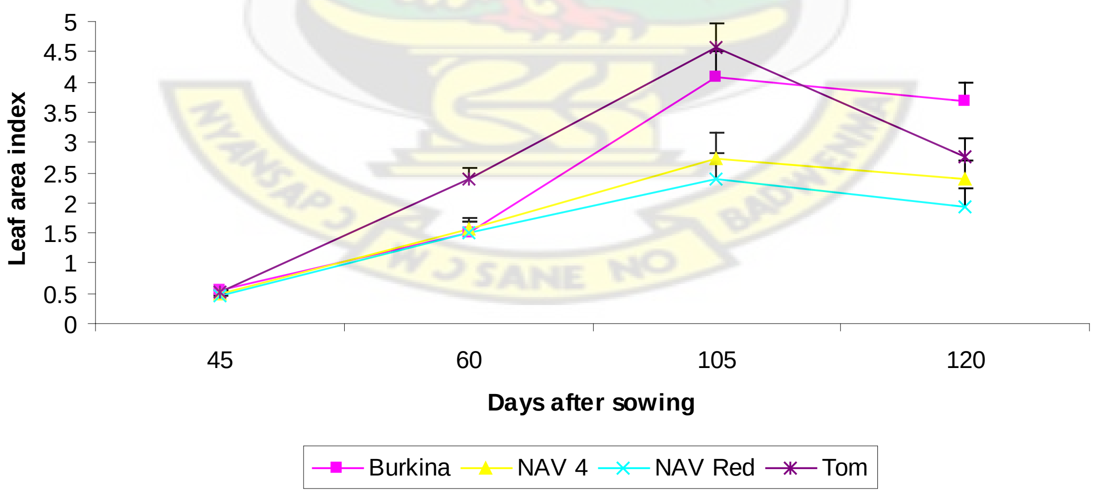

Figure 4.3b Leaf area index against DAS (Tono drought trial). Bars indicate standard error of the mean.

4.2.6 Discussions

4.2.6.1 Plant height, width and leaf dry weights (Tono heat trial)

Tom appeared to have a more canopy spread than the other landraces. It possessed the highest plant height and canopy spread. Tom is a more spreading landrace while the other landraces are more bunched. Even though leaf dry weight was not significantly different after 45 DAS, Tom appeared to be the most vegetative landrace among all the landraces. Burkina expressed more erect plant morphology. Under the high temperature, provision of irrigation enabled the landraces to express their vegetative potential.

4.2.6.2 Pod yield

Pod yields were generally low among all the landraces with Tom producing no pods at all. Burkina produced significantly higher pod yield of 118.50 g/m^2 ($p<0.001$). Plants were sown on February 2007 when temperature mean maximum temperature was high (38.7 ^oC) and mean relative humidity low (20.7 %). Further more, the monthly maximum mean temperature for March 2007 was 40.2^oC and a minimum of 25.4^oC . The monthly mean relative humidity for March was 28.3%. This period was the commencement of flowering and it is possible that despite the irrigation provided, the high temperature during this period (February–May) and the low relative humidity might have created dry conditions which could have resulted in the drying up of flowers affecting pollen germination and tube growth and hence poor pod yield. It is also possible that pegs got dried before penetrating into the soil to develop into pods. The combination of high temperatures, drought and long days can slow down or inhibit floral bud development, resulting in few flowers being produced and substantially reduce cowpea production (Nielson and Hall, 1985; Patel and Hall, 1990).

Farmers will normally not plant bambara at this period. Sowing normally occurs between June to August in the Guinea Savannah agro-ecology when the rains set in and temperature and relative humidity are conducive for the plant growth and development.

Burkina is a landrace from Burkina Faso, a Sahelian country, with very harsh environment. It is therefore possible the landrace might have been adapted to more dry conditions relative to the other landraces. This attribute could have enabled Burkina to produce some pods under those harsh environmental conditions. Malhotra and Saxena (2002) observed that damage caused by heat and drought can be reduced by sowing a variety that can withstand heat and drought or by adjusting planting dates to avoid heat and drought damage. Falconer (1990) supported the idea of breeding for specific adaptation rather than wide adaptation. Patterson *et al.* (1983) also reported that crop adaptation is an important factor that may increase productivity. Craufurd *et al.* (2002) identified that on the basis of partitioning to pods and seeds, peanut genotype 796 and 47-16 could be classified as moderately heat tolerant and genotype ICGV 87282 as heat susceptible. The identification of Burkina as a relatively heat tolerant landrace is very important for bambara groundnut cultivation under high temperature conditions.

4.2.6.3 Leaf area and leaf area index (Tono heat trial)

Tom maintained the highest leaf area and leaf area index between 45 DAS and 120 DAS. The highest leaf area was attained for all the landraces at 105 DAS, thereafter declined due to leaf senescence. Burkina maintained the least leaf area and this could be due to the fact that Burkina partitioned more dry matter into pods than the other landraces. Squire (1990) writing on leaf area index and fractional interception of total solar radiation observed that at LAI of 6.0, groundnut was able to intercept over 90% of total solar radiation. The maximum leaf area index measured in this study was 6.5 for Tom at 105 DAS.

4.2.6.4 Leaf area duration and vegetative dry weights (Tono drought trial)

Even though Tom maintained a higher leaf area under irrigation in the heat experiment, Burkina under drought was able to maintain a significantly higher leaf area and leaf area index at 120 DAS. Burkina exhibited a higher tolerance to drought among the five landraces and maintained longer leaf area duration (LAD) under drought. This again proves the adaptability of Burkina to drier conditions relative to the other landraces. Craufurd *et al.* (2002) reported that peanut genotypes clearly differed in their responses to high temperature and hence in heat tolerance and susceptibility. Leaf area in the drought experiment was lower than in the heat experiment which was irrigated and could be due to reduced biomass production under drought.

4.2.6.5 Root dry weight

Burkina maintained a significantly higher root dry weight under drought after 105 DAS. This attribute could have accounted for the ability of the landrace to absorb relatively much of moisture than the other landraces through the exploration of a greater soil volume or depth for moisture. This ability of Burkina could also have accounted for the landrace's ability to maintain longer leaf area duration under drought. Burkina could also have taken advantage of a few traces of rainfall in April and May to maintain longer leaf area duration. Begemann (1988) reported that earliness of maturity and length of the root system evidently has important relevance to the drought tolerance of bambara groundnut. On the contrary, Tom is a landrace from Nkoranza in the Transition part of Ghana with a bimodal rainfall which relatively may not be as tolerant to drought as Burkina.

Even though data was not analysed, some few Burkina plants were able to produce some pods under the drought condition. This confirms the crops' resilience as a drought tolerant crop and justifies every research effort to improve and promote it as a food security crop especially for the dry areas. Vorasoot *et al*. (2003) observed that seed size of all peanut cultivars used in their study reduced with decrease in available water. Dry matter production, pod yield, seed yield and number of seeds per plant of all the cultivars reduced significantly and Khan 60.3 which was among the highest yielding cultivars produced negligible seed and pod yield with all seeds getting aborted under severe water stress (Vorasoot *et al.,* 2003). Babiker (1989) observed that even though bambara groundnut is a drought tolerant crop, its productivity is substantially reduced by soil moisture stress.

The practical implication of these findings is that even where irrigation is available it is important to test the ability of a crop one intends to cultivate in the Upper East Region of Ghana especially the annuals as to whether they are tolerant or susceptible to heat. This should be done when the crop is cultivated during the dry season under irrigation. Land preparation, seed, irrigation, labour and other agronomic interventions come at a cost and a farmer must be guaranteed of better returns for his/her investment in crop production.

4.3 Experiment 3: Evaluation of bambara groundnut genotypes under forest agro-ecology (Fumesua-Kumasi)

4.3.1 Introduction

Bambara groundnut has been mainly cultivated in the Transition, Coastal Savannah and Guinea Savannah agro-ecologies in Ghana. In most countries within the sub-region bambara groundnut is cultivated in the drier parts where it is intercropped with crops like millet and sorghum which are also adapted to dry areas.

The objective of this study was to determine the performance of bambara groundnut under the forest agro-ecology. This is to promote the crop not only in the dry areas but also in the forest agro-ecologies. Fried plantain and boiled bambara seeds have been a delicacy sometime ago in most parts of Ghana. Plantain is more abundant in the forest region. If bambara can be promoted in the forest agro-ecology, it will not only facilitate the availability of this delicacy but also improve the nutritional complement of taking fried plantain alone, which can also be served in boarding schools and in the school feeding programme of these areas.

4.3.2 Materials and methods

The experimental protocol was as described in the earlier studies. Seeds were sown on the 15th of April, 2007. Five bambara groundnut landraces used were Black eye, Burkina, NAV 4, NAV Red and Tom. Experimental design and cultural practices were as described in the general material and methods.

4.3.3 Results

4.3.3.1 Days to flowering and podding

Number of days to flowering was significantly different ($p<0.05$). Tom used the least number of days to flower (40 days) whilst NAV Red and Black eye took 42 days to 50% flowering. There was a significant difference among the landraces with respect to the number of days to podding ($p<0.05$). Burkina used the least number of days to podding (83 days) (Table 4.7).

4.3.3.2 Days to pod maturity and pod dry weight

Significant differences were observed among the five landraces with respect to days to pod maturity ($p=0.05$) and pod yield ($p<0.05$). Tom produced the greatest pod yield (296 g/m^2) at Kumasi with Burkina producing 133 g/m^2 and Black eye 113 g/m^2 (Table 4.7)

Table 4.7 Performance of bambara groundnut landraces under forest agro-ecology (Fumesua-Kumasi,)

Landrace	Days to 50% flowering	Days to podding	Days to mat.	Pod yield (g/m^2)
Black eye	42.0	86.0	110.0	113.00
Burkina	41.3	83.3	115.0	133.00
NAV 4	42.0	88.0	110.0	180.00
NAV Red	40.3	86.3	110.0	224.00
Tom	400	88.6	120.0	296.00
Mean	41.1	86.5	113.0	189
CV%	1.5	1.7	4.0	34.2
LSD (0.05)	1.2	2.8	5.6	117
P value	0.012	0.015	0.05	0.037

4.3.4 Discussion

Unlike in previous experiments, Tom produced the greatest pod yield under the forest agroecology. Tom is from a relatively high rainfall area with a bimodal rainfall pattern compared to Burkina. NAV Red, Black eye and NAV 4 are all from the Guinea Savannah agro-ecology of Ghana. Rainfall pattern in the transition zone may be closer to that of Kumasi (bimodal) than the Guinea Savannah. It is possible the environment in Fumesua- Kumasi at the time this trial was conducted was more favourable for Tom to express its yield potential. It is however, worthy to note that Wenchi is in the same agro-ecology as the town Tom, near Nkoransa, which is the source of this experimental material. Unfortunately however, Tom did not perform well in the series of experiments conducted at Wenchi relative to the other landraces. It is also worthy to note that only one sowing was done at Fumesua. A series of sowings could confirm the performance of the landrace under the forest agro-ecology. Results of this study however, showed that Tom may have a potential as a good yielder. Since growth analyses were conducted on some specific days it is possible podding could have occurred earlier than 83 days when the growth analysis was conducted. It is also possible the temperature in the forest agro-ecology at the time of sowing could have been lower than in the transition zone thus prolonging the days to podding in terms of the accumulation of thermal time to podding.

4.4 Experiment 4: Effect of August Sowing on the Performance and Yield of Six Bambara Groundnut Landraces

4.4.6 Introduction

In the sowing date evaluation of bambara groundnut landraces, the crop was sown between February and June 2007. Farmers in the Transition zone however, sow bambara groundnut between July and August and harvest them around October and November. This period falls within the minor rainy season. Kumaga *et al.* (2002) observed that moderate rainfall coupled with relatively high temperatures over the entire growing period may be required for high pod and seed yield. Radiation and carbon dioxide are two atmospheric inputs which are used directly by a crop and optimum plant population and potential grain yield per hectare are higher in high radiation, cloudless seasons than in wet or monsoon seasons (Norman *et al.*, 1995). This experiment was conducted to determine the effect of minor season sowing on the performance of six bambara groundnut landraces.

4.4.7 Materials and methods

The experiment was established in the minor season of 2007 and located at Wenchi in the Transition agro-ecology. Planting materials used in this study were Black eye, Burkina, NAV 4, NAV Red, Tom and Ada. All the landraces except Ada were used in the earlier studies. Land preparation was undertaken as described in the earlier studies. Seeds were sown on the 22nd of August, 2007 at a spacing of 50cm x 20cm at two seeds per hill and thinned to one seedling per hill 20 DAS (10 plants/m^2). The plots were weeded manually with hoe as and when weeds appeared competitive. No irrigation was undertaken in this study. Data was analysed using the Genstat statistical package and mean separation was done using the Duncan's Multiple Range Test (DMRT).

4.4.8 Data taken

Data taken were:

Days to flowering

Days to podding

Days to maturity

100 pod dry weight

100 pod seed weight

100 seed weight

Total pod yield

The methodologies for taking the above data have been earlier described.

4.4.4 Results

4.4.4.1 Days to 50 percent flowering

Days to 50% flowering was significantly different ($p<0.001$). Tom flowered late among all the landraces (47 days) (Table 4.8). Treatment effect among Ada, Burkina, NAV 4 and NAV Red was not significantly different even though there were significant differences among Black eye, Ada and Burkina (Table 4.8).

4.4.4.2 Days to podding

Days to podding was significantly different among the various landraces (p<0.001). Days to podding was highest for Tom (73. days) and least with Burkina (63 days) (Table 4.8).

4.4.4.3 Days to maturity

Significant difference was observed on the days to maturity (p<0.001). Tom took the longest number of days to mature (118 days). Ada and Burkina were the earliest maturing landraces (96.7 days) (Table 4.8).

Table 4.8 Effect of landraces on Days to 50% flowering, Days to podding and Days to maturity of bambara groundnut (August sowing)

Landraces	Days to 50% flowering	Days to podding	Days to maturity
Ada	34.0c	64.7cd	96.7d
Black eye	38.0b	67.3b	102.7b
Burkina	34.7c	63.3d	96.7d
NAV 4	36.6bc	66.7bc	100.3bc
NAV Red	36.0bc	66.0bc	98.0cd
Tom	46.8a	72.7a	118.3a

Figures in a column bearing the same letters are not significantly different (p=0.05) by Duncan's Multiple Range Test (DMRT).

4.4.4.4 100 pod dry weight (g)

Significant difference was observed on the 100 pod dry weight ($p<0.001$). Tom attained the highest 100 pod dry weight (116.7g). No significant difference was however, observed among the other landraces on the 100 pod dry weight (Table 4.9).

4.4.4.5 Seed dry weight of 100 pods (g)

The hundred pod seed weight represents the weight of seeds contained in 100 pods. Since some pods may contain about two seeds, the 100 pod seed weight may not necessarily be equivalent to the weight of 100 seeds. Significant difference was observed in the 100 pod seed weight ($p<0.001$). Tom obtained a significantly high 100 pod seed weight (98.7g) ($p<0.001$). No significant difference was however, observed among the other landraces on the 100 pod seed weight (Table 4.9).

4.4.4.6 100 seed dry weight (g)

Significant difference was observed in the 100 seed dry weight ($p<0.001$). Tom attained a significantly high 100 seed dry weight (94.7g) ($p<0.001$). No significant difference was however, observed among the remaining landraces in 100 seed dry weight (Table 4.9)

4.4.4.7 Total pod yield (kg ha^{-1})

Total pod dry weight (kg ha^{-1}) was significantly different among the landraces ($p<0.001$). Total pod yield was highest for Black eye (4575.0 kg ha^{-1}). This however, was not significantly different from NAV Red (4537.0 kg ha^{-1}) (Table 4.9).

Table 4.9 Effect of landraces on pod and seed dry weights of bambara groundnuts (August sowings).

Landraces	100 pod dry weight (g)	100 pod seed weight (g)	100 seed dry weight (g)	Total pod yield (kg ha^{-1})
Ada	82.7b	62.7b	56.0b	4000.0b
Black eye	82.7b	62.7b	56.3b	4570.0a
Burkina	83.3b	63.3b	56.3b	4100.0b
NAV 4	82.7b	65.0b	58.0b	3897.0b
NAV Red	86.3b	65.3b	58.0b	4537.0a
Tom	116.7a	98.7a	94.7a	2260.0c

Figures in a column bearing the same letters are not significantly different (p=0.05) by Duncan's Multiple Range Test.

4.4.5 Discussions

Pod yield for the various landraces were relatively high in the August sowing. Tom which had performed poorly in the same agro-ecology in earlier studies in terms of pod yield, yielded over 2 t ha^{-1} in the August sowing (Table 4.9). Black eye produced the highest pod yield of 4.6 t ha^{-1}. 100 pod dry weight, 100 pod seed weight and 100 seed dry weight were all significantly higher in Tom ($p=0.05$) than the other landraces. This confirms the fact that Tom is a big-seeded landrace and this could attest to farmers' preference for the landrace. Begemann (1988) observed that pod length, number of pods per plant and one hundred seed weight were significantly positively correlated to the yield per plant of the crop.

Even though Tom has a significantly higher 100 seed weight, the poor yields of Tom could be more attributed to the low number of pods produced by the landrace. Even though, Tom could not yield as high as the other landraces for the August sowing, its yield of over 2 t ha^{-1} was relatively high compared to the sowings between February and April in Wenchi. Kumaga *et al.* (2002) reported that fertility coefficient in bambara groundnut which was calculated as the ratio of the number of pods per the number of flowers was higher in the minor season than in the major season.

Generally, the pod yield for all the landraces were higher for the August sowing and this result is in agreement with the findings of Kumaga *et al.* (2002) who reported that minor season planting of bambara groundnut yields better than the major season. This also justifies farmers' decision to sow the crop at this time than in the major season even though the fact that bambara groundnut is regarded as a minor crop compared to maize in the Transition zone may be a factor. Even though the minor season yield in this study was high, the extent of yield can also be affected by the distribution of the rains during the growing period. Bambara groundnut is a drought tolerant crop, however, very low rainfall with poor distribution in the minor season can negatively affect the yields of the crop.

Begeman (1988) observed that the one hundred seed weight as an indicator of the plant yield showed significant difference between the rainy season and the dry season. The minor season as described in this study is not a dry season in this part of Ghana. The Transition agro-ecology in Ghana experiences a bimodal rainfall with the minor season rains not as heavy as the major season rains though adequate to support a good yield of the crop.

Farmers in the village Tom who cultivate bambara groundnut have not had access to other high yielding landraces and they mostly cultivate the landrace Tom which originates from that community. The practical implication of this study is to introduce the other landraces to the community through participatory plant breeding, to enable them take a decision as to whether they would grow these landraces alongside Tom. This however, will depend on the acceptability of the seed by the farmers and consumers.

CHAPTER FIVE

YEAR TWO EXPERIMENTS

The following experiments were undertaken during the year 2008:

5.1 Experiment 5: Evaluation of Performance of Seven Bambara Groundnut Landraces over Six Sowing Dates at Wenchi (Transition agroecology)

5.2 Experiment 6: Evaluation of Performance of six Bambara Groundnut Landraces over six Sowing Dates at the CSIR-Crops Research Institute, Kumasi (Forest agroecology).

5.3 Experiment 7: Controlled Environment Photoperiod Study at the University of Guelph, Guelph, Ontario, Canada.

5.4 Experiment 8: Controlled Environment Drought Trial at the University of Guelph, Guelph, Ontario, Canada.

5.1 Experiment 5: Evaluation of Performance Seven Bambara Groundnut Landraces over Six Sowing Dates at Wenchi (Transition agro-ecology)

5.1.1 Introduction

The present study was undertaken to confirm the performance of the five landraces used in the first year preliminary studies. Two more landraces were added to the earlier five materials to determine the performance of these landraces. Six sowings were done in Wenchi for 2008 instead of the five in the 2007 studies. This was to guarantee the performance of any materials that could be purified and distributed to farmers in the agro-ecology for sowing.

5.1.2 Materials and methods

Two more landraces (Mottled Red and Ada) were added to the five that were used for a similar study in 2007. Mottled Red has a reddish brown mottled colour. The material was purchased from Techiman market in the Brong Ahafo Region of Ghana. “Ada” is a landrace grown in Ada which is found at the Coastal Savannah area of the Greater Accra Region of Ghana. The landrace has similar characteristics to Burkina with respect to seed colour and seed size. The seeds of Ada were purchased from Ada in the Coastal Savannah agroecology. The objectives of this study were;

- To determine differences in pod yield of the seven bambara groundnut landraces over the six sowing dates.
- To determine whether Ada is the same as Burkina with its origin from.

Plate 5.1 Seeds of Ada and Burkina landraces

5.1.2.1 Land preparation, sowing and weed control

Land preparation was similar to that of year 2007. Different sowings were done on 28/02, 13/03, 20/03, 3/04, 17/06, and 23/06/2008. Sowing dates were chosen taking into consideration the dry season, the period just before the rains and the major rainy season. Sowing dates were also chosen to determine whether the minor difference in daylength could affect pod yields of bambara groundnut sown at the different sowing dates. A factorial arrangement in RCBD with three replications was used. Spacing was 50cm x 20 cm. Seeds were sown at two seeds per hill and thinned to one seedling per hill (10 plants/m^2) 20 DAS. Developmental and destructive analyses were done as in the Year 2007 experiment. Weed control was done by hand hoeing. Weeding was done as and when necessary.

5.1.3 Results

5.1.3.1 Days to 50% emergence

Significant differences were observed in days to 50% emergence for the various planting dates and landraces ($p<0.001$) and the interaction ($p<0.005$). Ada and Burkina had the earliest number of days to 50% emergence (10.8 and 10.9 days) respectively with Black eye, Tom and NAV Red a little over 12 days (Table 5.1)

The 13/03/08 sowing emerged earliest among the various dates (10.8 days) with the 23/06/08 sowing registering the longest number of days to 50% emergence (12.8 days) (Table 5.1).

5.1.3.2 Days to 50% flowering

Significant differences were observed with respect to the planting dates and landraces ($p<0.001$) and planting dates by landrace interaction ($p=0.05$) on days to 50% flowering. Ada and Burkina had the least number of days to flowering (37.4 and 37.3 days) respectively and Tom registered the highest number of days to flowering (47.9 days) (Table 5.1).

The 13/03/08 sowing flowered earlier (38.9 days) whereas the 23/06/08 sowings took 42 days to produce 50% flowering (Table 5.1).

5.1.3.3 Days to podding

Significant differences were observed in days to podding for the various landraces ($p<0.001$) and planting dates ($p<0.001$). There was however, no significant difference with respect to the interaction. Ada and Burkina had the least number of days to podding 66.1 days and Tom the longest number of days to podding 77.2 days (Table 5.1).

The 28/02/08 registered the earliest number of days to podding (67.1) whereas the June (17/06/08 and 23/06/08) sowings gave the longest number of days to podding (69 and 70 days, respectively) (Table 5.1).

5.1.3.4 Days to maturity

Significant differences were observed with respect to days to maturity for the planting dates and landraces and the interaction ($p<0.001$). Ada and Burkina recorded the least number of days to maturity 97 and 96 days respectively. Tom had the longest number of days to maturity (120 days) (Table 5.1).

The 13/03/08 sowing significantly registered the least mean number of days to maturity for all the landraces (97.14) ($p<0.001$) with the 23/06/08 sowing registering the longest mean number of days to maturity for all the landraces (105 days) (Table 5.1).

Table 5.1 Days to 50% emergence, 50% flowering, podding and maturity affected by bambara groundnut landraces and sowing dates

	Days to 50% emergence	Days to 50% Flowering	Days to podding	Days to Maturity
Landrace				
Ada	10.8	37.4	66.1	96.5
Black eye	12.7	37.8	67.6	100.9
Burkina	10.9	37.3	66.1	96.4
Mottled Red	11.7	38.5	67.5	101.9
NAV 4	11.2	37.4	67.9	96.9
NAV Red	12.4	38.1	67.1	102.1
Tom	12.1	47.9	77.2	120.0
Mean	11.7	39.2	68.5	102.1
CV%	6.4	3.8	2.6	1.6
LSD (0.05)	0.49	0.98	1.16	1.08
P Value	<0.001	<0.001	<0.001	<0.001
Sowing date				
28/02/08	12.1	40.4	67.1	102.0
13/03/08	10.8	38.9	68.3	97.1
20/03/08	11.4	38.1	68.5	100.1
13/04/08	11.5	36.8	68.1	103.1
17/06/08	11.3	39.0	69.0	104.9
23/06/08	12.8	42.0	69.9	105.4
Mean	11.6	39.2	68.5	102.1
CV%	6.4	2.6	2.6	1.6
LSD	0.4	1.07	1.07	1.00
P value	<0.001	<0.001	<0.001	<0.001

5.1.3.6 Vegetative dry weight

5.1.3.6.1 Leaf dry weight

Tom maintained a significantly highest dry weight at harvest (32.8 g/plant) ($p<0.001$), with Black eye producing 27.7 g/plant at harvest. Ada and Burkina had 26.8 g/plant and 25.7 g/plant respectively at harvest (Table 5.2)

5.1.3.6.2 Petiole dry weight

No significant difference was observed in petiole dry weight at 20 DAS. Significant differences were however, observed in petiole dry weight at 45 DAS ($p<0.001$). Tom had the highest petiole dry weight at harvest ($p<0.001$) of 16.9 g/plant. Ada and Burkina had petiole dry weights of 7.0 and 7.2 g/plant respectively at harvest (Table 5.2)

5.1.3.6.3 Stem dry weight (g/plant)

. Stem dry weight at harvest was significantly different ($p<0.001$) with Tom having the highest of 10.4 g/plant. Sowing date significantly affected stem dry weight ($p<0.05$) with the 13/03/2008 sowing producing the highest mean stem dry weight of 6.9 g/plant and the 23/ 03/08 sowing producing the lowest stem dry weight 6.3 g/plant at harvest (Table 5.2)

Table 5.2 Leaf dry weight, petiole dry weight and stem dry weight (g/plant) as affected by bambara groundnut landraces and sowing dates.

	Leaf Dry weight (g/plant) 120 DAS	**Petiole dry weight (g/plant) 120 DAS**	**Stem dry weight (g/plant) 120 DAS**
Landrace			
Ada	26.8	7.0	5.9
Black eye	27.7	8.1	6.1
Burkina	25.7	7.2	5.9
Mottled Red	26.5	7.8	5.9
NAV 4	26.4	7.7	6.0
NAV Red	26.8	7.7	5.9
Tom	32.8	16.9	10.4
Mean	27.3	8.8	6.6
CV (%)	5.1	5.6	10.7
LSD	0.9	0.3	0.5
P value	<0.001	<0.001	<0.001
Sowing date			
28/02/08	26.8	8.9	6.5
13/0308	27.1	8.6	6.9
20/03/08	27.5	8.7	6.8
13/04/08	29.1	9.3	6.5
17/06/08	28.4	9.1	6.6
23/06/08	24.6	8.7	6.3
Mean	27.2	8.9	6.6
CV (%)	5.1	5.6	10.7
LSD	0.9	0.3	0.4
P value	<0.001	<0.001	0.038

5.1.3.7 Reproductive dry weight

5.1.3.7.1 100 pod dry weight

Significant differences were observed on landraces with respect to 100 pod dry weight ($p<0.001$). No significant difference was observed with respect to planting dates and the interaction with respect to 100 pod dry weight. Tom had the highest 100 pod dry weight (113.9 g) and Ada and Burkina the least 80.0 g and 79.4 g respectively (Table 5.3).

5.1.3.7.2 Seed dry weight of 100 pods (g)

Significant differences were observed for the planting dates and landrace ($p<0.001$) and planting dates and landrace interaction ($p=0.001$) for 100 pod seed dry weight. Tom obtained the highest 100 pod seed dry weight (82.8 g) and Ada and Burkina had 53.3 g and 52.2 g respectively (Table 5.3). Hundred pod seed weight was significantly highest for the 28/02/08 sowing (70.4 g) and least for the 20/03/08 sowing (61.4 g).

5.1.3.7.3 Shelling percentage.

Table 5.3 shows the shelling percentage based on the 100 pod seed dry weights. The 100 pod seed dry weight is not equivalent to the 100 seed dry weight since some pods contained more than one seed. Shelling percentage was greatest with Mottled Red and NAV 4 (74.1 % and 74.2 %), respectively. Shelling percentage was greatest for the 13/03/08 sowing (79.5 %) (Table 5.3).

Table 5.3 100 pod dry weight, seed dry weight of 100 pods and shelling percentage as affected by bambara groundnut landraces and sowing dates.

	100 pod dry weight (g)	Seed dry weight of 100 pods (g)	Shelling percentage (%)
Landrace			
Ada	**80.0**	**53.3**	**66.6**
Black eye	93.3	68.5	73.4
Burkina	**79.4**	**52.2**	**65.7**
Mottled Red	90.0	66.7	74.1
NAV 4	92.8	68.9	74.2
NAV Red	96.1	67.2	70.0
Tom	113.9	82.8	72.6
Mean	92.2	65.7	71.0
CV%	15.0	7.9	5.0
LSD (0.05)	9.2	3.4	3.8
P value	<0.001	<0.001	<0.001
Sowing date			
28/02/08	94.8	70.4	74.2
13/03/08	85.7	68.1	79.5
20/03/08	91.4	61.4	67.2
13/04/08	93.3	64.3	68.9
19/06/08	94.8	63.5	67.2
23/06/08	93.3	66.2	71.2
Mean	92.2	65.7	71.0
CV (%)	15.0	7.9	5.0
LSD (0.05)	NS	3.2	2.6
P value		<0.001	<0.001

5.1.3.7.4 Total pod and seed yields (kg/ha)

Significant differences were observed for planting dates, landraces and the interaction with respect to total pod yield ($p<0.001$). Black eye registered the greatest total pod yield (4631 kg ha^{-1}) with Ada and Burkina registering 4436 kg ha^{-1} and 4511 kg ha^{-1} respectively. Tom registered the least pod yield of 378 kg ha^{-1}. Table 5.4 gives the total seed yield based on total pod yield and the shelling percentage.

5.1.3.8 Harvest indices

Pod harvest index was significantly greatest in Ada and Burkina (0.56) and least in Tom ($P<0.05$). Seed harvest index however, was significantly highest in Mottled Red and NAV 4 (0.41) and least in Tom (0.05) (Table 5.5).

Pod harvest index was significantly highest for the March sowings (0.50) and least for the June sowing (0.41) ($P<0.05$). Seed harvest index was greatest for the 13/03/08 sowings (0.39) and least for the 23/06/08 sowing (0.29) Table 5.5).

Table 5. 4 Total pod, shelling percentage and seed yield as affected by bambara groundnut landraces and sowing dates.

Landrace	Total pod yield (kg/ha)	Shelling percentage (%)	Total seed yield kg/ha
Ada	**4436**	**67**	**2972**
Black eye	4631	73	3381
Burkina	**4511**	**66**	**2977**
Mottled Red	4537	74	3357
NAV 4	4508	74	3336
NAV Red	4381	70	3066
Tom	378	73	276
Mean	3914.0	71.0	2779
CV%	39.9	5.0	39.5
LSD	1775	3.82	1260
P value	<0.001	<0.001	<0.05
Sowing date			
28/02/08	3900	74.0	2886.0
13/03/08	4230	79.0	3341.7
20/03/08	4373	67.0	2930.0
13/04/08	4017	69.0	2771.7
17/06/08	3937	67.0	2637.7
23/06/08	3013	71.0	2139.2
Mean	3911.7	71.2	2734.3
CV (%)	12.1	5.0	14.1
LSD (0.05)	540.0	2.7	483.3
P value	<0.001	<0.001	<0.05

Table 5.5 Total dry weight, pod dry weight, pod harvest index and seed harvest index for bambara groundnut landraces.

	Total dry weight (kg/ha)	Pod dry Weight (kg/ha)	Pod harvest Index	Seed harvest index
Landrace				
Ada	7925.0	4436.0	0.56	0.38
Black eye	8505.0	4631	0.54	0.40
Burkina	8095.3	4511	0.56	0.37
Mottled Red	8265.1	4537	0.54	0.41
NAV 4	8219.4	4508	0.55	0.41
NAV Red	8316.2	4381	0.54	0.37
Tom	5861.2	378	0.06	0.05
LSD (0.05)	1032.6	1775.7	0.18	0.06
CV (%)	11.6	39.9	38.4	38.1
Sowing date				
28/02/08	8120.0	3900.0	0.48	0.36
13/03/08	8530.3	4230.4	0.50	0.39
20/03/08	8833.1	4373.1	0.50	0.33
13/04/08	8437.2	4017.2	0.46	0.33
17/06/08	7967.4	3937.0	0.49	0.33
23/06/08	7283.0	3013.3	0.41	0.29
LSD	615.6	540.0	0.04	0.04
CV (%)	6.6	12.1	7.2	10.0

5.1.4 Discussion

5.1.4.1 Days to 50% emergence, and 50% flowering

As observed in the first year preliminary study, Burkina maintained its earliness in mean number of days to 50 % emergence. No significant difference was however, observed between Ada and Burkina in all these parameters. Again Ada and Burkina were the earliest landraces to flower with the two landraces flowering at 37.4 and 37.3 days after sowing, respectively. Tom however, registered the longest number of days to 50% flowering as in the first year preliminary studies (47.9 days). The results of the two-year studies show that differences exist among bambara groundnut landraces with respect to earliness.

Differences were also observed with respect to sowing dates in days to 50% emergence and 50% flowering. The 13/03/08 sowings emerged earlier than the 26/06/08 sowings. Where water is not limiting, temperature may account for differences in seedling emergence and days to flowering. The 23/06/08 sowings were done in the rainy season. Mean temperature from 13/03/08 to 25/03/08 a period of 12 days with the sowing day as Day 0 was 33.5^{o}C. The mean temperature from the 26/06/08 to 6/07/08 a period of 12 days when seedling emergence was expected to occur with the sowing day considered as Day 0 was 29.1^{o}C. It is also interesting to note that Wenchi registered a total rainfall of 30.1mm on the 12/03/08 a day before the 13/03/08 sowing. It is possible that the relatively higher temperature for the March sowing might have resulted in increased imbibition and uptake of water by the seeds and seedlings respectively, which could have hastened germination and emergence. The earlier emergence for the 13/03/08 sowing resulted in the earliest number of days to 50% flowering. This result is in agreement with observations by Sesay (2005) who reported that the longer period from sowing to flowering for the October 13 sowing in a study conducted on bambara groundnut in Swaziland was due to delay in seedling emergence caused by the late arrival of the rains.

Kurt and Bozkurt (2006) working on the effect of temperature and photoperiod on seedling emergence of two varieties of flax reported that maximum seedling emergence was obtained at 30^{o}C under 12 h dark and 12 h light photoperiod and the best seedling emergence under different photoperiod occurred at 30^{o}C for both varieties even though this was not significantly different at 25^{o}C. Brink (1997) also observed that flowering in three bambara groundnut landraces were influenced by temperature.

5.1.4.2 Days to podding and maturity

Ada and Burkina took the same number of days to podding (66.1) with Tom taking 77 days to podding. Ada and Burkina were also the earliest maturing landraces taking 96.4 and 96.5 days to mature respectively whereas Tom took 120 days to mature. The same result was observed in the first year preliminary study with Burkina exhibiting an early maturing landrace and Tom a late maturing landrace. In bambara groundnut, bunch types mature earlier than the spreading type (Goli, 1997). Ada and Burkina both exhibit bunch characteristics.

The early seedling emergence for the 13/03/08 sowing and a relatively higher temperature over the growing period could have resulted in the earlier maturation of the crops grown on that date relative to the 26/06/08 sowings. Changes in environmental conditions at the time of sowing can therefore affect phenological development of bambara groundnut. It is impossible to call a particular landrace e.g. a 90 day variety because of the significant variation of the same landrace under different environmental condition (Begeman, 1988).

5.1.4.3 Vegetative and reproductive dry weights

Tom produced the highest mean leaf dry weight (32.8 g/plant) with Ada and Burkina producing the least leaf dry weights (24.8 and 25.7 g/plant) respectively at harvest. Petiole and stem dry weights followed a similar trend. Tom again showed the highest vegetative dry weight. Ada and Burkina produced the least vegetative dry weight.

Contrary to the vegetative dry weight, Tom produced the least pod and seed yield; 378 and 276 kg ha^{-1}, respectively. Ada and Burkina produced pod yields of 4.4 and 4.5 t ha^{-1} which were not significantly different from each other. Black eye however, produced the highest pod yield of 4.6 t ha^{-1} which was significantly higher than Ada but not significantly different from Burkina. Black eye produced a mean seed yield of 3.4 t ha^{-1}.

Decreased partitioning to grain competitively favours partitioning towards organs that continue vegetative growth, hence increasing dry matter production and leaf area (Wallace and Yan, 1998). Wright (1989) observed that plant sinks play a role in assimilate distribution and the eventual pattern of carbohydrate distribution is relative to the competitive ability of the various sinks. It is possible the reproductive sinks of Tom were not strong enough to influence the distribution of assimilates towards pod formation.

Even though pod yield of Tom was poor, the 100 seed weight was the highest. The poor yield of Tom was therefore manifest in the few number of pods it produced and not the 100 seed weight and hence the shelling percentage. Tom is a big-seeded landrace by visual observation and this attribute could have endeared it to farmers and accounted for their continuous cultivation. Adu-Dapaah *et al*. (2006) in a survey in three regions of Ghana observed that consumers have a preference for big-seeded bambara groundnut. It is also interesting to note that Tom has a creamish brown colour which is also acceptable to consumers. The big pods and seeds of Tom could be due to the fact that since the landrace produces fewer pods, competition for assimilates by the few pods may be low.

5.1.4.4 Shelling percentage

Shelling percentage gives the proportion of the pod which forms the seed. A range of 66 to 74% was obtained as the shelling percentage for the seven landraces with a mean of 71.0%. Massawe *et al.* (2005) obtained shelling percentage of 74.5 for Dod R 1995 and 70.6 for LunT 1995, two bambara groundnut landraces, in a study conducted at the University of Nottingham, in the United Kingdom. These values agree with the shelling percentages obtained in the present studies.

5.1.4.5 Pod harvest index

Apart from Tom which had a low pod harvest index of 0.06, pod harvest indices ranged from 0.54-0.56 for the landraces. These values agree with pod harvest indices of 0.57 – 0.58 quoted by Mkandawire and Sibuga (2002) flat seed bed and ridge seedbed, respectively in a bambara groundnut study in Morogoro, Tanzania.

5.1.4.6 Seed harvest index

Seed harvest index did not necessarily follow the same trend as pod harvest index. The seed harvest index is affected by both pod yield and shelling percentage which also affect the total seed yield. Even though Ada and Burkina obtained the highest pod harvest index of 0.56 their seed harvest indices of 0.38 and 0.37 respectively were not the highest. This was due to their low shelling percentage of 67 and 66 percent, respectively. Mottled Red and NAV 4 with shelling percentage of 74 percent obtained the highest seed harvest index of 0.41. The practical implication of this result is that in any crop improvement programme for high seed yield in bambara groundnut, emphasis should not only be laid on pod yield but also the shelling percentage which measures the percentage of the pod which forms seeds.

5.1.4.7 Is Ada the same as Burkina**?**

Ada is in the Coastal Savanna agro-ecology of Ghana. It is one of the major bambara groundnut growing areas in Southern Ghana. Bambara groundnut landrace Ada originates from this part of Ghana. Seed size, and colour of this landrace are similar to that of Burkina. The idea of including the two landraces was to determine whether the two landraces are the same. Morphological and yield data from the study showed that Ada and Burkina are very similar landraces and a molecular study to confirm this result will be very relevant. Trade in bambara groundnut cuts across international boundaries. It is possible traders might have sent Burkina to Ada or vice-versa from where farmers might have cultivated and given them local names. It is important that a polymerase chain reaction (PCR) technique is used to determine whether Ada is the same genotype as Burkina. The interest in this is at least to help scientists document genetic materials and also to appreciate the movement of bambara groundnut genotypes across international boundaries.

5.2 Experiment 6: Evaluation of Performance of six Bambara Groundnut Landraces over six Sowing Dates at the CSIR-Crops Research Institute, Kumasi (Forest agroecology)

5.2.4 Introduction

This trial was conducted to confirm the performance of the five bambara groundnut landraces in the Year One preliminary study. One more landrace (Mottled Red) was added to the five used in the study in 2007.

5.2.2 Materials and methods

Six sowings were undertaken at the Crops Research Institute, Fumesua in Kumasi on the following dates; 12/03/08, 19/03/08, 14/04/08, 28/04/08, 01/06/08, 18/06/08. Experimental design, cultural practices and data taken were the same under the general materials and methods. Plate 5.2 shows the experimental bambara groundnut field at the CSIR-Crops Research Institute, Kumasi.

Plate 5.2 Author (middle) explaining a point to an MSc student and a technician at the CSIR-Crops Research Institute, Fumesua, Kumasi on a bambara groundnut field

5.2.3 Results

5.2.3.1 Days to 50% emergence

There was no significant difference with respect to landraces and interaction in days of emergence. Significant differences were however, observed with respect to planting dates ($p<0.001$). The 19/03/08, 28/04/08 and 01/06/08 sowings emerged earliest (8.2 days) relative to the 13/03/08 (9.4 days) (Table 5.6)

5.2.3.2 Days to 50% flowering

Significant differences were observed for planting dates ($p<0.001$) and landraces ($p<0.001$) with respect to days to 50% flowering (DFF). NAV Red recorded the least number of days to 50% flowering (42.8 days) and Tom the longest number of days (48.7 days) (Table 5.6). The 19/03/08 and 14 /04/08 sowings resulted in the least number of days to 50% flowering (Table 5.6)

5.2.3.3 Days to maturity

There was a significant difference in the number of days to pod maturity for the landraces ($p<0.001$), sowing dates ($p<0.001$) and the interaction ($p<0.001$). Tom recorded the highest mean of 114 days to maturity over the six planting dates.

Days to maturity was least for the 18 /06/08 sowing (98.2days) and greatest for the 01/06/08 sowing (111.3 days) (Table 5.6)

5.2.3.4 Total pod yield (kg/ha)

There was a significant difference in sowing dates ($p<0.001$) and landrace ($P=0.003$) with respect to total pod dry weight. Mottled red produced the highest pod yield of 149.3 g m^{-2} (1.5 t ha^{-1}) (Table 5.6). There was no significant difference with respect to the interaction.

The 19/03/08 sowing date produced the highest total pod dry weight of 233.3 gm^{-2} (2.3 t ha^{-1}) relative to the 18/06/08 sowing which gave the least mean pod yield of 27.8 g m^{-2} (278 kg ha^{-1}) for all the landraces (Table 5.6)

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Table 5.6 Days to 50% emergence, 50% flowering, maturity and pod yield as affected by bambara groundnut landrace and sowing date.

	Days to 50% emergence	Days to 50% flowering	Days to maturity	Pod yield (g m^{-2})
Landrace				
Black eye	8.6	44.2	105.2	110.6
Burkina	8.9	44.0	105.8	116.7
Mottled red	8.3	44.4	105.7	149.3
NAV 4	8.7	43.6	106.2	117.2
NAV Red	8.4	42.8	102.2	177.2
Tom	8.6	48.7	114.5	91.7
Mean	8.6	44.4	107.3	127.2
CV (%)	6.6	2.3	3.3	14.2
LSD (0.05)	NS	0.67	2.36	18.0
P value		<0.001	<0.001	0.003
Sowing date				
12/03/08	9.4	44.8	105.7	208.1
19/03/08	8.2	41.5	110.8	233.2
14/04/08	8.3	45.7	111.1	141.6
28/04/08	8.2	41.6	106.6	119.0
01/06/08	8.2	46.1	111.3	33.5
18/06/08	9.2	42.9	98.2	27.9
Mean	8.6	43.8	107.3	127.2
CV (%)	6.6	2.3	3.3	14.2
LSD (0.05)	0.4	0.7	2.4	43.2
P value	<0.001	<0.001	<0.001	0.003

5.2.4 Discussion

No significant difference was observed among the landraces with respect to days to seedling emergence. The April sowing however, emerged earliest among the sowing dates. It is possible the April sowing emerged earlier because there was adequate moisture in the soil for seed imbibition and temperature was adequate for germination. Delayed seedling emergence for the 12/03/08 sowing could be due to the fact that despite the favourable temperature for seedling emergence, there was not adequate moisture in the soil since the rains have not began and the field could also not be irrigated because the irrigation system was faulty.

A combination of high rainfall, low irradiance due to cloud cover and symptoms of fungal diseases might have resulted in the low yield in the June planting. This period fell within the peak of the major rainfall season in Ghana. It is interesting however, to note that at the various sowing dates, yields of 3 t/ha and 2.4 t/ha were recorded for Mottled Red and Burkina, respectively for the 12/03/08 sowing. It therefore suggests that when bambara groundnut is cultivated at the appropriate time in the forest agro-ecology of Ghana, relatively high yields could be attained. Results from this study also showed that excessive rainfall affects bambara yields in Ghana. Photoperiod however is not a major factor in variation of bambara yields in Ghana since photoperiod does not vary much throughout the year in Ghana.

Very low pod yields were obtained in the 5th and 6th sowings (Table 5.6). The practical implications of this result are that in the forest belt it is important to consider the date to plant bambara groundnut. Sowing bambara during the major rainy season does not produce a good crop yield.

5.3 Experiment 7: Photoperiod Study under Controlled Environment at the University of Guelph, Guelph, Ontario, Canada

5.3.1 Introduction

Evidence to suggest that bambara groundnut grown under long photoperiod produced more leaves than those grown under short photoperiod has been established (Brink, 1999). Azam-Ali (1998) observed that the continued leaf production under longer daylengths is associated with a corresponding decline in the fraction of dry matter allocated to pod structures. Very little information however, exists on bambara groundnut landraces that are insensitive to photoperiod. This study was conducted to determine the performance of 13 bambara groundnut landraces to two photoperiod regimes; 12h:12h, light:dark and 14h:10h, light:dark. Six of the bambara groundnut landraces used for the study were used in earlier field studies in Ghana. These were; Tom, Burkina, NAV 4, NAV Red, Mottled Red and Black eye.

5.3.2 Material and methods

The other seven landraces used in the study were;

Zebra coloured: Small cream seed size with a zebra coloured pattern purchased from Techiman market in Ghana. 100 seed weight ranges between 40 -50 g.

Black seed:	Big seeded bambara with black seed colour purchased from Techiman market. 100 seed weight ranges between 70 – 80 g
Mottled cream:	Small seed size with cream and red mottling colour purchased from the Navrongo market. 100 seed weight ranges between 40 -50 g.
Brown with white eye:	Big seeded size with brown colour and white eye. Purchased from Techiman market in Ghana. 100 seed weight ranges between 70 – 80 g
Tan 1	A landrace from Tanzania. Small seeded size with light brown seed colour and black spots. 100 seed weight ranges between 30 – 50 g
Tan 2	A landrace from Tanzania. Small seeded size with dark brown seed colour and black spots 100 seed weight ranges between 30 – 50 g
Red eye	Cream coloured seed with conspicuous red eye from Techiman, Ghana. 100 seed weight ranges between 70 – 80 g

Plate 5.3 shows seeds of some of the landraces used in the study at the University of Guelph, Ontario-Canada.

Plate 5.3. Some of the planting materials used for the Guelph study

One hundred and fifty six 4-litre pots were filled with Sunshine Mix LA4 (55-65% Canadian Sphagnum peat moss, 35-45%, perlite, dolomitic limestone for pH adjustment and wetting agent). 20:20:20 N:P:K was applied at 4 g/pot at sowing. The fertilizer was mixed thoroughly with the soil, watered and left to settle till the next day.

Two walk–in growth chambers (6&7) at the Crops Science Department of the University of Guelph were used for the study. Each growth chamber contained 78 pots. Seeds were sown on the 11th of October, 2008 (Day 0) at two seeds per pot and thinned to one seedling per pot on emergence. Plants were arranged in a Completely Randomised Design (CRD) with each landrace represented by six pots per growth chamber. Growth chamber temperatures were kept at 30^{o}C (day) and 25^{o}C (night) and a relative humidity (RH) of 60%.

The growth chamber Photosynthetic Active Radiation (PAR) was measured with an Apogee, Model Basic Quantum Meter Electric Calibration (BQM-E) and ranged between 230-300 umol m^{-2} s^{-1}. Light was supplied by incandescent 40 Watt bulbs, FO6T12 Sylvania cool white fluorescent VHO 8 long and 2 small bulbs. Pots were watered every three days for both photoperiod treatments. The positions of the pots were randomly shifted every three days to prevent any possible effect of the positions of the pots in the growth chamber and differences in light intensity within the chamber on plant growth. Biological pest control was undertaken after crop establishment using *Amblyseius cucumeris* and *Phytoseiulus persimillis* to control Western flower thrips and red spider mites respectively.

Leaf area was measured using a leaf area meter (Licor-3100, USA). Plant dry weight was obtained by placing samples in an oven maintained at 80^{o}C for 48 hrs after which the samples were weighed.

5.3.3 Data taken

The following data were taken in the photoperiod study using the methodologies previously described;

Days to emergence

Days to flowering

Pod number

Pod dry weight

Root dry weight

Shoot dry weight

Leaf area

Morphological changes with respect to the two photoperiod treatments were also observed during the period of plant growth and development. No destructive analysis was done until the final plant harvest due to the few number of plants per landrace per growth chamber for this study.

5.3.4 Statistical analysis

Both the photoperiod studies and the drought studies conducted at the University of Guelph were analysed for Variance (ANOVA) using the Statistical Analysis System (SAS). Days to flowering, days to emergence, pod dry weight and root dry weight in the photoperiod trial were log transformed before analysis.

5.3.5 Results

5.3.5.1 Days to emergence

There was significant difference with respect to landrace ($p<0.0001$) and photoperiod ($p=0.02$) in days to seedling emergence. No significant difference was observed with respect to photoperiod by landrace interaction (Figure 5.1). Emergence occurred earlier under 12 h photoperiod in most of the landraces than under 14 h photoperiod. Burkina, Zebra coloured, Tan Two and Mottled Cream emerged relatively earlier than the other landraces in both photoperiod regimes.

5.3.5.2 Days to flowering

Significant differences were observed with respect to landraces ($p<0.0001$) and photoperiod ($p=0.0002$) in days to flowering. No significant difference was however, observed in the landrace by photoperiod interaction. Plants sown under 12 h photoperiod flowered earlier than those sown under 14 h photoperiod for all the landraces. Burkina, Mottled Cream and Zebra coloured flowered earlier under both 12 h and 14 h photoperiod. They all flowered before 40 DAS under the two photoperiod regimes.

Black Seed, Brown with white eye and Tom flowered late under both 12 and 14 h photoperiod (Figure 5.2). They all flowered after 47 DAS under the two photoperiod regimes.

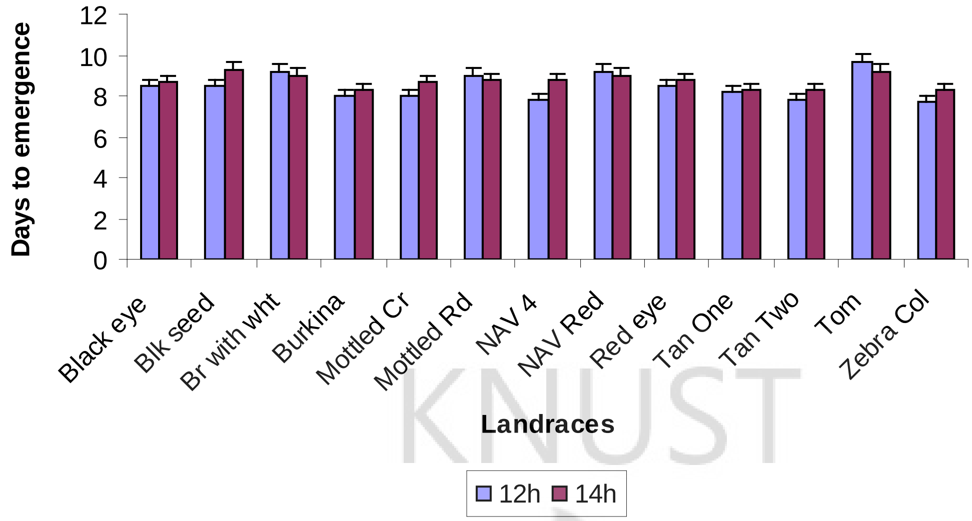

Figure 5.1 **Days to seedling emergence as affected by landraces and 12 and 14 h photoperiod. Bars indicate standard error of the mean.**

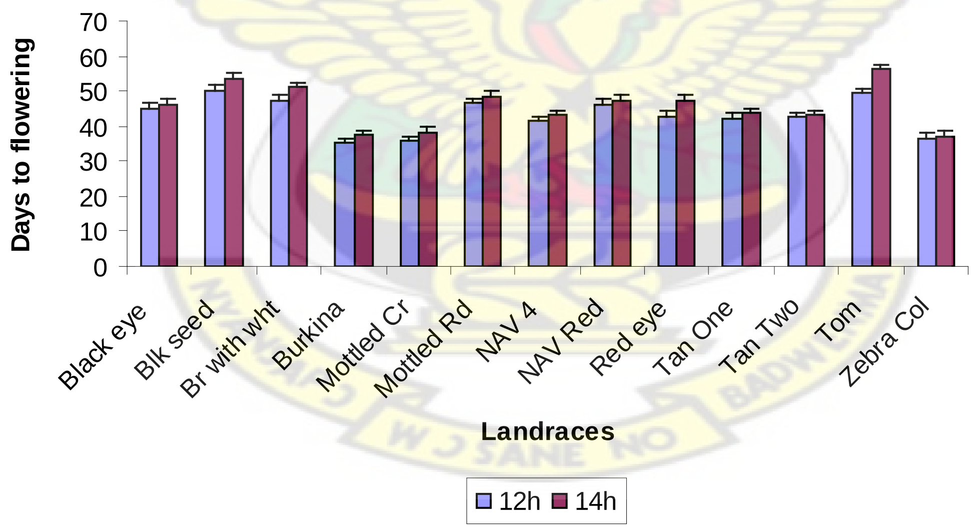

Figure 5.2 **Days to flowering as affected by landrace and 12 h and 14 h photoperiod. Bars indicate standard error of the mean.**

5.3.5.3 Number of pods

Significant differences were observed in pod numbers with respect to landraces ($p= 0.003$) and photoperiod ($p<0.0001$) and photoperiod and landrace interaction ($p=0.003$). More pods were produced by the landraces under 12 h than under 14 h. All the landraces except Tom and Black Seed produced pods under 12 h photoperiod. Under 12 h, Tan One, one of the landraces from Tanzania produced the highest number of pods per plant (27 pods) followed by Burkina (13.75 pods) and Tan Two another landrace from Tanzania (10.67 pods). Under 14 h photoperiod, only five out of the 13 landraces produced some pods. Mean pods per plant produced by these landraces were; Burkina (2.25 pods), Mottled cream (1.00 pod), Tan One (1.75 pods), Tan Two (0.25 pod) and Zebra coloured (1.67 pods) (Fig. 5.3).

5.3.5.4 Pod dry weight

Pod dry weight was significantly different with respect to landrace ($p=0.006$) and photoperiod ($p<0.001$). There was however, no significant difference with respect to interaction. Tan One produced the highest pod dry weight per plant (3.99 g) followed by Burkina (3.41 g) and Tan Two (2.18 g) all under 12 h photoperiod.

Under 14 h photoperiod, Zebra coloured and Burkina produced mean pod dry weight of 0.38 g per plant followed by Tan One, Mottled Cream and Tan Two with 0.36 g, 0.23 and 0.05 g/plant, respectively (Fig 5.4).

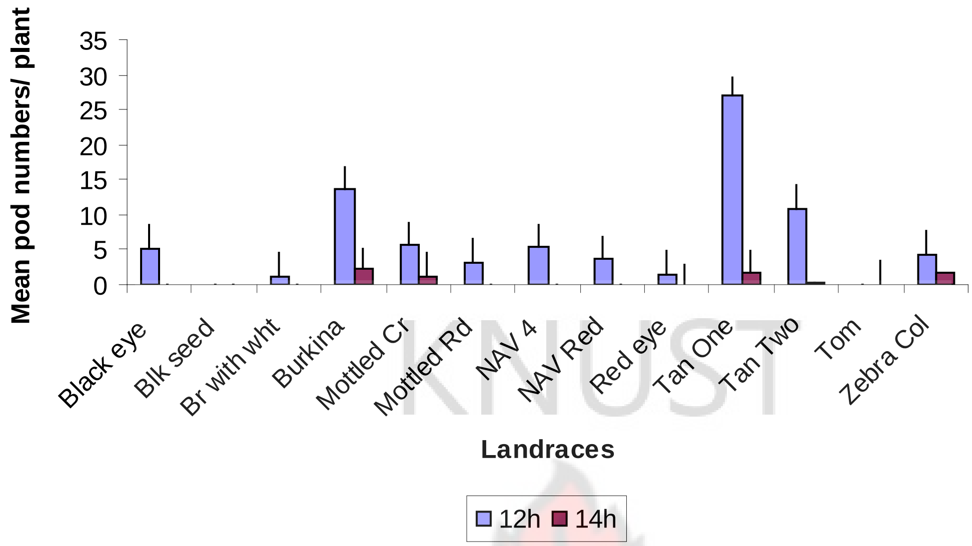

Figure 5.3 Mean pods /plant as affected by landraces and 12 and 14 h photoperiod. Bars indicate standard error of the mean.

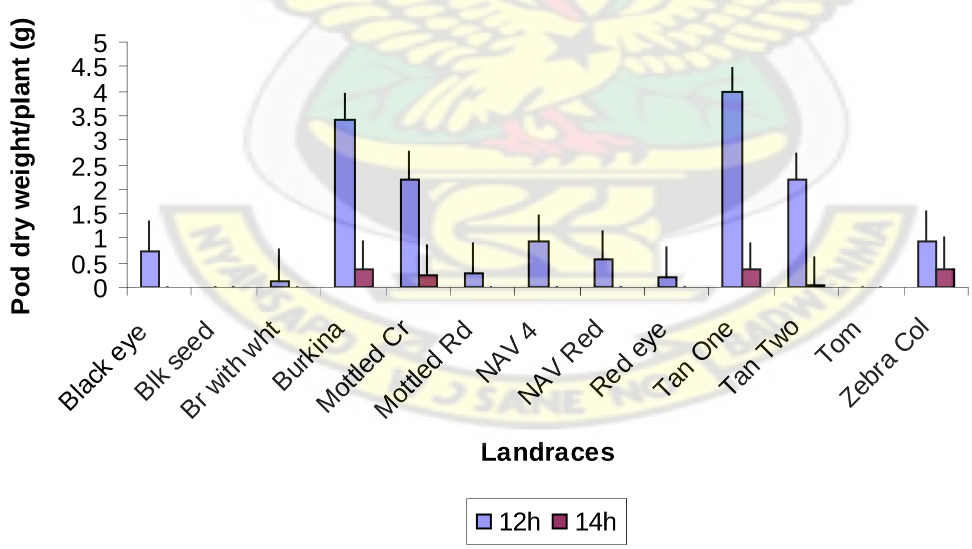

Figure 5.4 Mean pod dry weight/plant as affected by landraces and 12 and 14 h photoperiod. Bars indicate standard error of the mean.

5.3.5.5 Shoot dry weight

Significant differences were observed in shoot dry weight with respect to landrace ($p<0.0001$) and photoperiod ($p<0.0001$). No significant difference was observed with respect to landrace and photoperiod interaction. Shoot dry weight was higher under 14 h photoperiod than under 12 h photoperiod. Tan Two under 14h photoperiod produced the highest mean shoot dry weight per plant (27.59 g) followed by Brown with white eye (26.85 g). Mottled Cream produced the least shoot dry weight under 14 h (11.71 g). Under 12 h photoperiod, Tan Two produced the highest shoot dry weight (22.23 g), followed by Black Seed (20.03 g) with Zebra coloured producing the least mean shoot dry weight per plant (4.86 g) (Figure 5.5).

5.3.5.6. Leaf area per plant

Significant differences were observed in leaf area with respect to landrace ($p<0.0001$) photoperiod ($p<0.0001$). No significant interaction effect was observed. Leaf area was higher under 14 h than under 12 h. Tan One produced the highest mean leaf area per plant (2411.91cm^2) under 14 h. Mottled Cream produced the least leaf area under 14 h (1113.00 cm^2). Under 12 hours, Tan One produced the highest leaf area (2266.13 cm^2) with Zebra coloured producing the least leaf area (340.32 cm^2) (Figure 5.6).

5.3.5.7 Root dry weight (g)

Significant differences were observed in root dry weight with respect to landrace (p=0.004) and photoperiod (p=0.02). There was no interaction effect. Mean root dry weight was greater under 14 h photoperiod than under 12 h photoperiod.

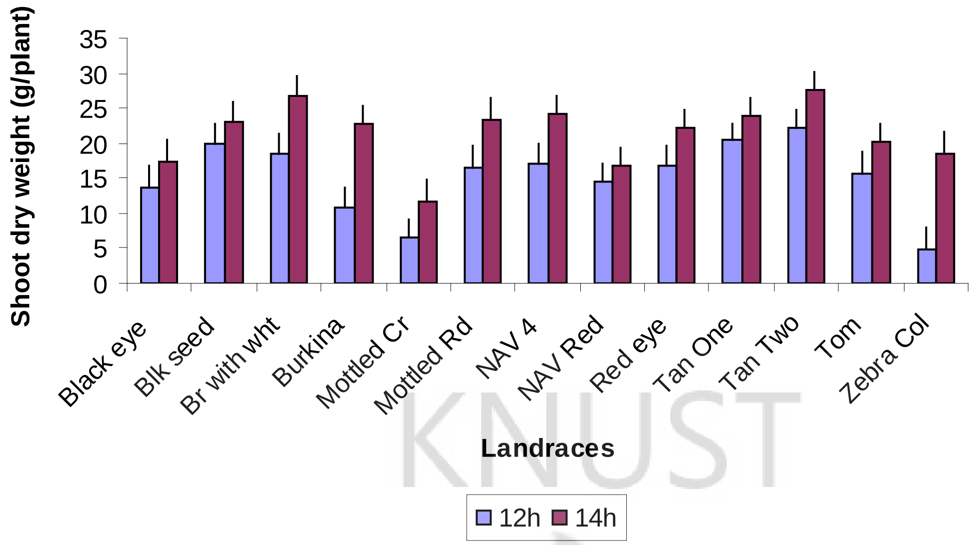

Figure 5.5 Shoot dry weight/plant as affected by landraces and 12 and 14 h photoperiod. Bars indicate standard error of the mean.

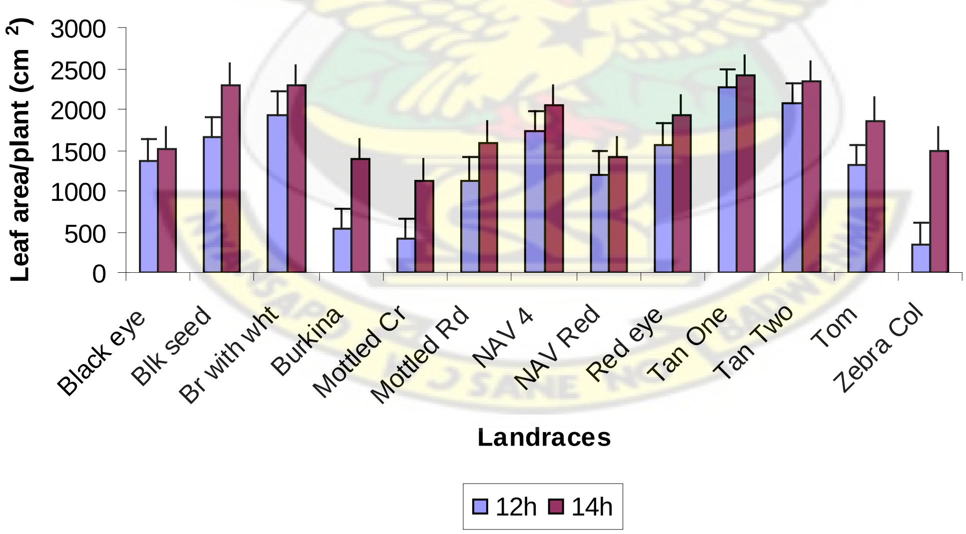

Figure 5.6 Leaf area/plant as affected by landraces and 12 and 14 h photoperiod Bars indicate standard error of the mean.

5.3.5.8 Plant morphology

Bambara groundnut has been described as a trifoliate plant with three leaflets being borne on a petiole. It was interesting to note however, that Tan One from Tanzania had some of the plants producing three, four and five leaflets on the same plant (Plate 5.4). The crop has until recently been considered as an underutilized crop with little research work done on it. It has not been bred for uniformity even though farmers have selected for characteristics which meet their needs like yield, taste, seed colour and seed size among others. Some of the landraces still maintained their primitive characteristics and it is possible this could have accounted for the Tanzanian landraces having the same plant with different leaflet numbers.

Canopy size within landraces was greater under 14 h photoperiod than under 12 h photoperiod for the same days after sowing. This was reflected in the higher leaf area within landraces under 14 h than under 12 h photoperiod (Plate 5.5).

It was also interesting to observe pods formed on stems which have extended out of the pots instead of on the soil and beneath the surface of the soil (Plate 5.6).

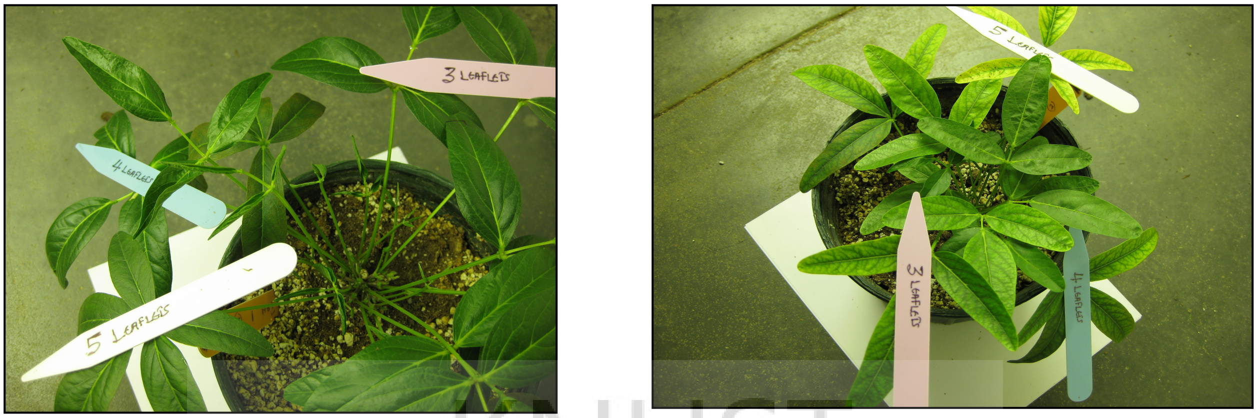

Plate 5.4. Multiple (3, 4 and 5) leaflets on the same plant (Tan One from Tanzania)

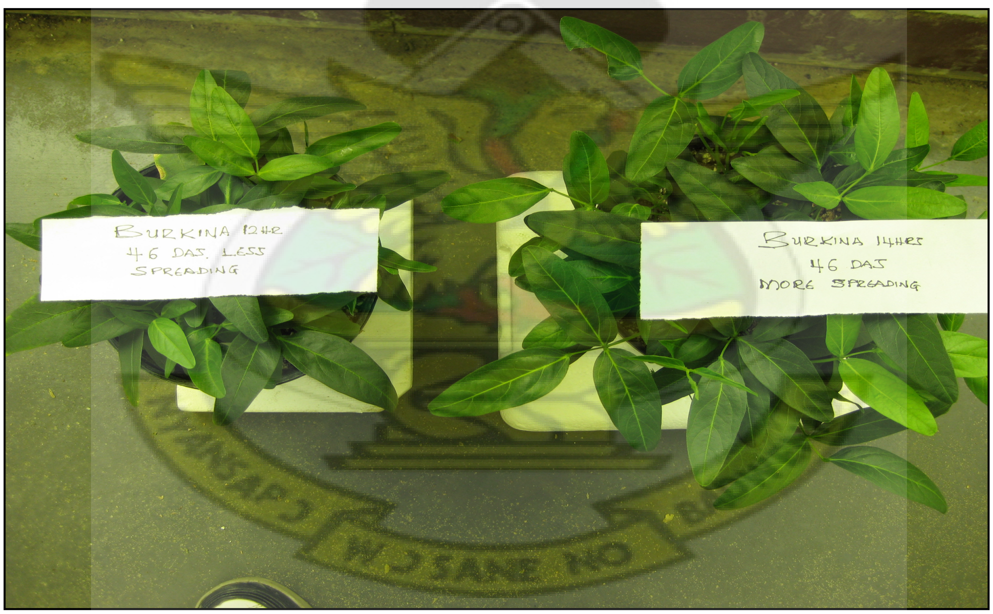

Plate 5.5. Canopy size under 12 h (L) and 14 h (R) photoperiod (Burkina 46 DAS)

Plate 5.6 Pod development in Tan One under 12 h (Left) and 14 h (Right) 108DAS

Plate 5.7 Pod development in Burkina and Mottled cream under 12 h (Left) and 14 h (Right) 130 DAS

5.3.6 Discussion

5.3.6.1 Days to emergence

Emergence occurred earlier in most of the landraces under 12 h than under 14 h. This result is in agreement with findings from Desmosthermis and Krisna (2000) who reported that under fluctuating temperatures, 12 h photoperiod are required for maximum germination of *Campsis radicans.* This result shows the importance of date of planting on emergence and establishment of bambara groundnut especially in countries in the lower and higher latitudes where photoperiod effect has a practical implication in bambara groundnut cultivation. For early seedling emergence for quick and maximum canopy development to enhance optimum radiation capture and weed control, the role of agro-meteorologist in advising farmers on time of planting is crucial.

5.3.6.2 Days to flowering

Plants sown under 12 h photoperiod flowered earlier than those sown under 14 h photoperiod for all the landraces. This result is in agreement with observations by Linnemann (1993) who reported that the onset of flowering, progress of flowering, the onset of podding and pod development are all retarded by long photoperiod. Linnemann (1993) observed that long photoperiod did not only delay the appearance of first flower but also continued to influence the production of subsequent flowers. Florh *et al.* (1990) reported that flower, peg and pod production in groundnut are also affected by photoperiod, however, Hadley *et al*. (1983) observed that in cowpea differential effects of photoperiod on the onset of flowering, pod production and maturity were not found.

5.3.6.3 Number of pods and pod dry weight

Under 14 h photoperiod, only five out of the 13 landraces studied produced some pods. Pod development in bambara groundnut is fastest at day length shorter than 12 hours and slows down as daylength increases (Harris and Azam-Ali, 1993). Working on common bean *(Phaseolus vulgaris (L)*, Wallace *et al*. (1993) and Wallace and Yan (1998) reported that long photoperiods inhibited the partitioning of dry matter to seeds and increased assimilate partitioning to vegetative organs. Harris *et al*, (1988) also observed that under short daylength, more assimilates were partitioned to pods in peanut. Even though Burkina produced more pods (2.25 pods) under 14 h than Zebra (1.67 pods) they both registered the same pod dry weight. This was because Zebra produced more mature pods even though fewer under 14 h which could be due to the fact that Zebra may be an earlier maturing landrace than Burkina. Similarly, Tan One produced more pods under 12 h (27 pods) relative to Burkina (13 pods), mean pod dry weight for the two landraces were not significantly different and could be due to Burkina having a higher shelling percentage than Tan One which has smaller seed size. It is also possible that being an earlier maturing landrace Burkina might have produced more mature pods with higher dry matter content than Tan One at the time of harvest.

It is interesting to note that landraces that emerged earliest and flowered earliest were those that produced pods under 14 h. These landraces may possibly be the early maturing genotypes. Edamame (pronounced “eh-dah-MAH-may”) is a traditional Japanese vegetable also called “vegetable soybean” and “sweet bean” a nutritious and tasty vegetable or snack food with a sweet nutty flavour (Miles *et al*., 2000). Miles *et al*.

(2000) reported that all edamane except the earliest maturing varieties are photoperiod sensitive and for cultivation in the high latitudes under long summer days, early maturing varieties which are less sensitive to photoperiod must be cultivated. Traditional pigeon pea cultivars are highly sensitive to photoperiod and take from 175-280 days to mature (Mcpherson *et al.*, 1985). However, Singh *et al,* (1990) reported that early maturing pigeon pea varieties developed by the International Crop Research Institute for the Semi Arid Tropics (ICRISAT) are relatively photoperiod insensitive and mature in 125 to 140 days.

Not much work has been done to identify early maturing bambara groundnut landraces. The present studies have identified three landraces (Burkina, Zebra coloured and Mottled cream) that are potentially early maturing and which are also less sensitive to photoperiod. Practically this result enables bambara groundnut farmers to obtain materials which can enable them to harvest some pods even when sowing is delayed due to the onset of rains in photosensitive agro-ecological zones.

5.3.6.4 Shoot dry weight

Azam-Ali (1998) reported that the continuous leaf production of bambara groundnut landraces under longer daylength is associated with a corresponding decline in the fraction of dry matter allocated to pod structures. The same observation was made in the present study where under 14 h photoperiod plants produced more vegetative materials hence more shoot dry weight than under 12 h where plants relatively produced more pods and less shoot dry weight.

5.3.6.5 Leaf area

Working on photoperiod responses of extra early short duration pigeon pea lines developed at different latitudes, Chauhan *et al.* (2002) observed an increase in total dry matter in all lines which was attributed to increase in both number of leaves, individual leaf area and consequently increased leaf area duration. In the present studies, leaf area significantly increased under 14 h photoperiod relative to the 12 h photoperiod. Increased leaf area duration under 14 h photoperiod was observed. It is possible that with the relatively more assimilate partitioned to pods under 12 h photoperiod, leaf senescence was higher under 12 h photoperiod with the formation of fewer new leaves even though the crop is indeterminate. This however, was not the case of the 14 h photoperiod where assimilates were directed into leaf growth and development with increased leaf area. At harvest, leaf senescence by visual observation was much more prominent under 12 h than under 14 h photoperiod.

5.4. Experiment 8: Drought Trial Under Controlled Environment at the University of Guelph, Ontario, Canada

5.4.3 Introduction

A major positive attribute of bambara groundnut is its tolerance to drought. This makes it a crop of choice in the attainment of food security if this is combined with its excellent nutritional values. Differences however, exist in bambara groundnut landraces in their responses to drought. Berchie *et al*. (2002) reported differences in response to drought of three bambara groundnut landraces. This experiment was conducted to determine differences in responses of 13 bambara groundnut landraces to drought.

5.4.2 Materials and methods

Plant materials used were similar to that used in the photoperiod study. 156 4-litre pots were filled with sandy loam top soil with pH of 7.3. The organic matter content of the soil was 8.4% dry weight and Cation Exchange Capacity (CEC) of 27 Cmol+/Kg. Total nitrate content of the soil was 14.4 mg/Kg with total nitrogen content of 0.46% dry weight. 20:20:20 N:P:K (Nitrogen:Phosphorus:Potassium) was applied at 4 g/pot and watered. The pots were left to settle overnight. Seeds were surface sterilised and treated with Apron Combi applied at 0.03 ml in 100 seeds using a micropipette to dispense the chemical before sowing against soil and seed-born fungus. Seeds were sown on the 30th of October, 2008.

Plants were irrigated till 30 DAS. Irrigation ceased at 30 DAS and resumed at 60 DAS. The control was irrigated every three days. Two growth chambers (1&2) of the

Department of Crop Science of the University of Guelph were used for the drought study. Growth chamber temperatures were maintained at 30^oC in the day and 25^oC in the night for both growth chambers. Light was maintained at PAR of 200-250 umol m^{-2} s^{-1} and photoperiod of 12 h:12 h, light:dark for both growth chambers.

Soil moisture content was determined by taking random samples of the soil. The volume of the soil was measured in a graduated cylinder. Six samples of the soil irrigated to field capacity were weighed and placed in weighed labeled envelopes. They were placed in an oven maintained at 80^oC for 48 hours. The bulk density of the soil was determined as the dry weight of soil sample divided by the volume of soil sample. The weight of soil water was obtained by subtracting the weight of the oven dry soil from the weight of irrigated soil. The percentage moisture content of the soil was calculated as the weight of soil water divided by the weight of oven dry soil times 100. The soil moisture content at the termination of the experiment 30 days after exposure to drought was also determined in a similar way. Pot positions were randomised every 3 days to prevent possible bias due to light and growth chamber effect

5.4.3 Data collected and statistical analysis

Phenological data were collected on the drought and irrigated trials. Yield data was not obtained in this experiment since the landraces had not podded at the termination of this experiment. The trial was sown on the 30th of October, 2008 about three weeks after sowing the photoperiod trial due to unavailability of growth chambers. Chlorophyll content was determined using a Minolta SPAD 502 Chlorophyll Meter. Stomatal conductance was measured using a LI-6400 Chlorophyll Fluorometer. Days to flowering and stomatal conductance in the drought study were square root transformed before analysis.

5.4.4 Results

5.4.4.1 Days to emergence

There was significant difference on days to emergence with respect to landrace ($p=0.0003$). No significant difference was observed on days to emergence with respect to irrigation treatment. Both the drought and irrigated treatments were irrigated from sowing to 30 DAS. Irrigation was stopped for the drought treatment after 30 DAS. This could have accounted for the lack of significance difference between the irrigated and drought treatment in the days to emergence. Burkina, Mottled cream and Zebra coloured were the earliest landraces to emerge after sowing. These landraces emerged as early flowering types in the photoperiod study.

5.4.4.2 Days to flowering

Significant difference was observed in days to flowering with respect to landrace ($p<0.0001$), irrigation treatment ($p<0.0001$) and landrace and irrigation treatment interaction ($p<0.0001$) (Figure 5.7). Only Black Eye, Burkina, Tan One, Tan Two, Mottled Cream and Zebra coloured produced flowers under both the irrigated and drought treatment. There was no common trend in the days to flowering between the drought and irrigated treatment. Whereas Burkina, Mottled Cream, Tan One and Tan Two flowered earlier under drought than under irrigated, Black eye flowered earlier under irrigated than under drought condition. No significant difference was observed between Zebra coloured under drought and irrigated treatments with respect to days to flowering even though days to flowering was earlier under irrigated than drought conditions.

5.4.4.3 Stomatal conductance

There was significant difference in stomatal conductance with respect to landrace (p=0.02) and irrigation treatment (p=0.0001). There was also an interaction effect (p=0.01) (Figure 5.8). Stomatal conductance was higher under irrigated treatment than under drought treatment. Among the drought treatments, no significant difference was observed for the various landraces with respect to stomatal conductance.

5.4.4.4 Percentage soil moisture content

Mean percentage soil moisture content at the start of the experiment was determined to be 21.6%. After the termination of the experiment, mean percentage soil moisture content of the drought treatment was determined as 5.8%.

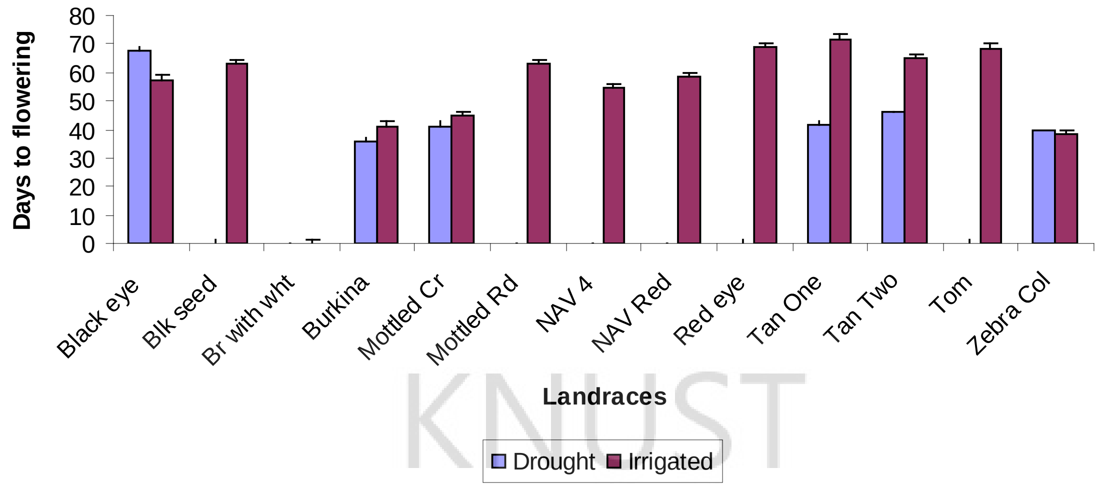

Figure 5.7 Days to flowering as affected by landraces and irrigation treatment. Bars indicate standard error of the mean.

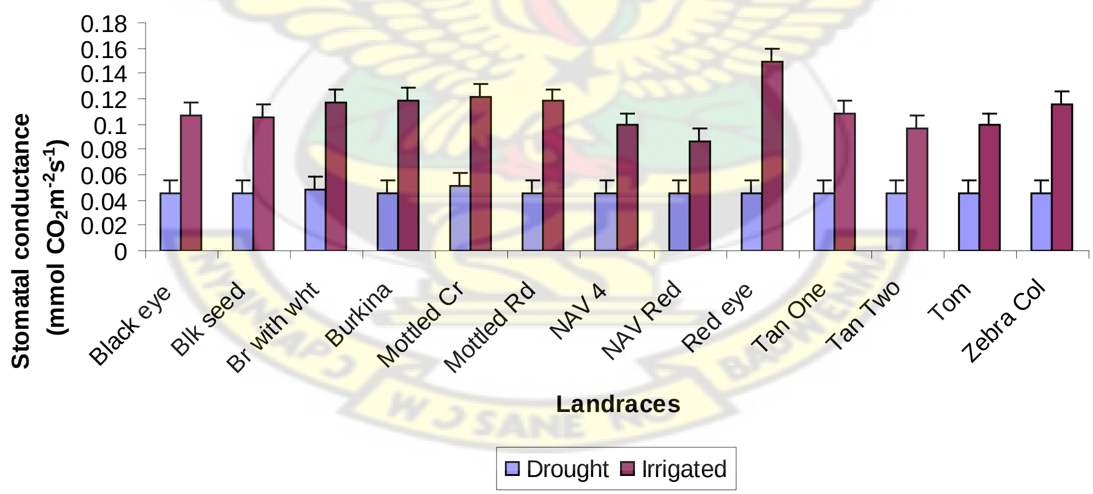

Figure 5.8 Stomatal conductance as affected by landraces and irrigation treatment (52DAS). Bars indicate standard error of the mean.

5.4.4.5 Leaf chlorophyll content

Leaf chlorophyll content was significantly different with respect to landrace ($p=0.0002$), irrigation treatment ($p=0.0001$) and irrigation by landrace interaction ($p=0.01$). Leaf chlorophyll content was higher under irrigated than under drought treatment for all the landraces (Figure 5.9).

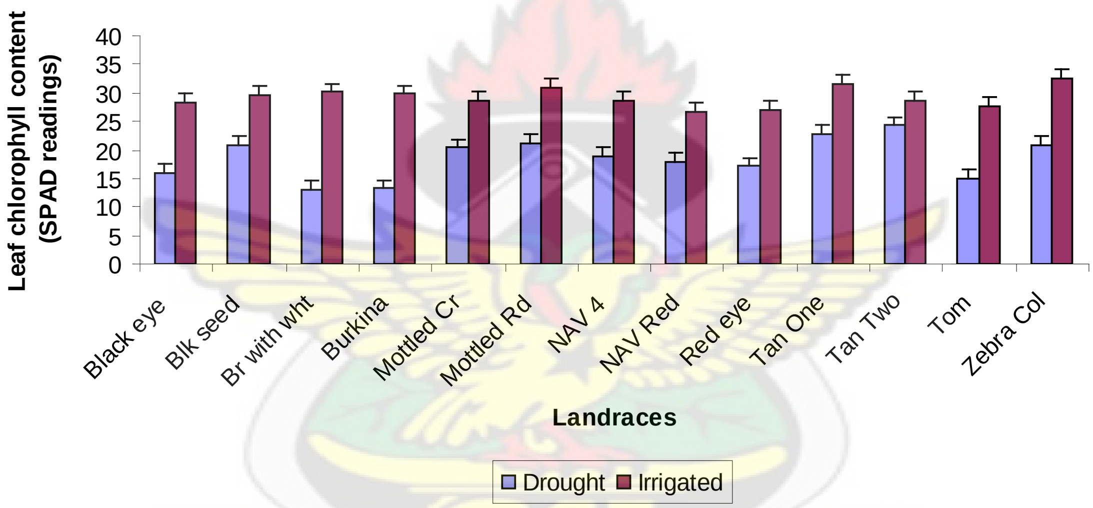

Figure 5.9 Leaf chlorophyll content as affected by landraces and irrigation treatment (52DAS). Bars indicate standard error of the mean.

5.4.4.6 Leaf morphology

Visually, not much difference could be seen between plants exposed to 20 days of drought and the irrigated treatment. Effect of drought stress could, however, be seen on the drought plants 25 days after the imposition of the drought treatment. Effect of drought was most severe 30 days after the imposition of drought treatment. Tan One and Tan Two from Tanzania exhibited spindle shaped leaflets to reduce leaf surface area. Leaflets of some of the landraces showed paraheliotropic movement and showed erect leaf orientation to drought. Response to drought was also exhibited reduced canopy size relative to the irrigated treatment. Plates 5.8-5.15 show responses of bambara groundnut landraces to drought and irrigated treatment. Tan One showed the greatest recovery after rewatering 30 days after drought treatment (Plate 5.15).

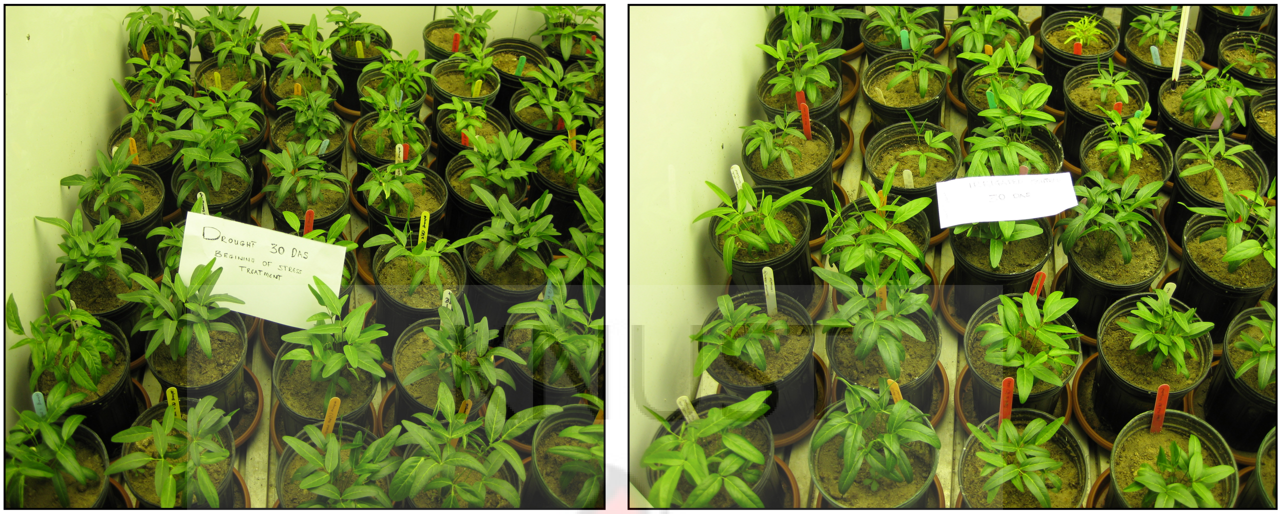

Plate 5.8. **Beginning of drought trial 30 DAS (Drought Left, Irrigated Right)**

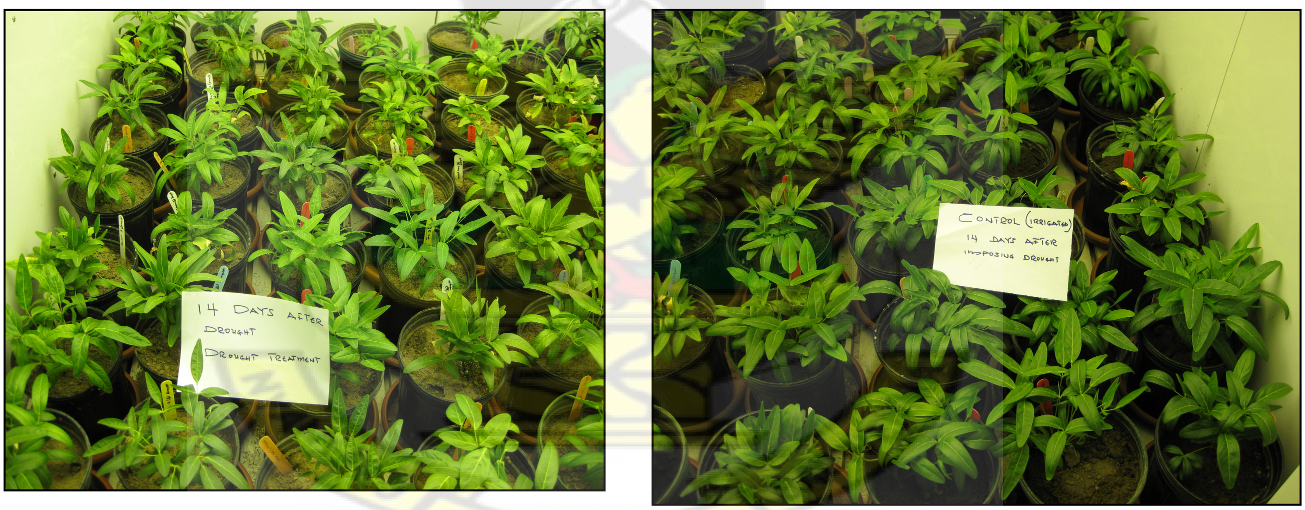

Plate 5.9. **14 days without irrigation, 44 DAS (Drought Left, Irrigated Right)**

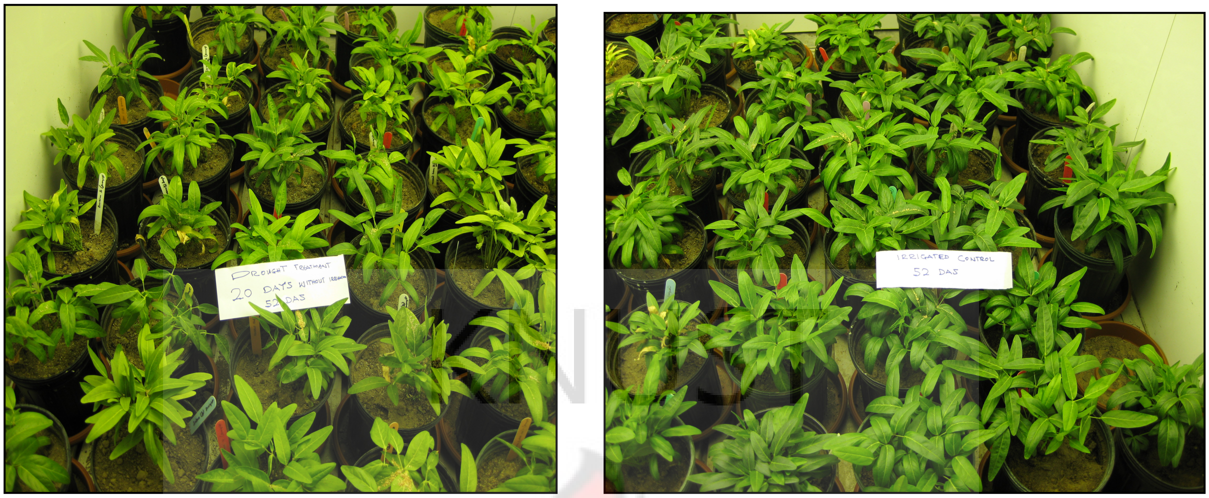

Plate 5.10. **20 days without irrigation Drought Left. Irrigated Right (50 DAS)**

Plate 5.11. **25 days without irrigation Drought Left. Irrigated Right (55 DAS)**

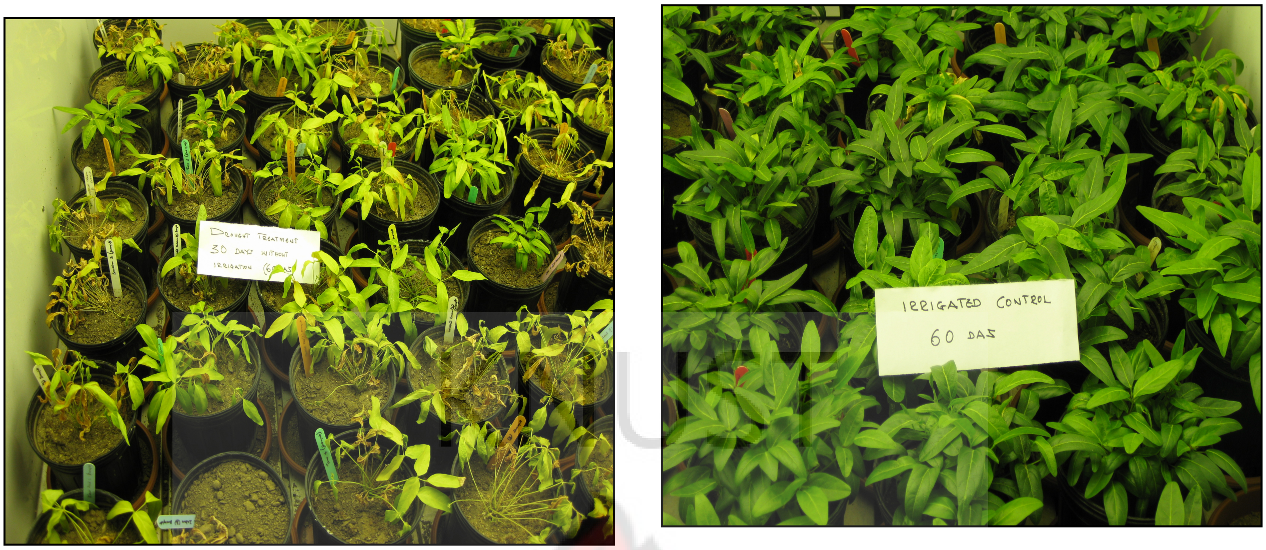

Plate 5.12 30days without irrigation Drought Left. Irrigated Right. (60 DAS)

Plate 5.13 (i) Reduced canopy size under drought (Left) and (ii) Spindle shaped leaflets under drought (Right) compared to irrigated control.

Plate 5.14 Recovery and resumption of flowering one week after re-irrigation after drought treatment (Tan One)

Plate 5.15 Recovery and resumption of flowering one week after re-irrigation after drought treatment (Black eye)

5.4.5 Discussion

5.4.5.1 Days to flowering

Dadson *et al*. (2005) studying the effect of water stress on the yield of 10 cowpea genotypes noted that six of the genotypes flowered 2-3 days earlier under water stressed conditions than under non-water stressed conditions. In the present study, four of the landraces flowered earlier under water stress than under irrigated conditions. It is however, interesting to note that all the three landraces which flowered earlier under drought than under irrigated conditions are the early maturing landraces. Malhotra and Saxena (2002) observed that drought tolerance is the ability of a crop variety to remain relatively more productive than others under limited water conditions and plants usually adapt to drought stress through three major mechanisms namely; escape, avoidance and resistance. Early flowering by the three early maturing bambara groundnut genotypes under stress may be a drought escape mechanism to enable the genotypes produce pod early under limited water conditions.

5.4.5.2 Leaf chlorophyll content

Leaf chlorophyll content was significantly lower in the drought treatment than in the irrigated treatment. This was visually observed in the yellowing of leaves of the drought treatment. Plant nutrients are absorbed by the roots in a solution form. Under drought, uptake of nutrients like nitrogen which affects leaf chlorophyll content is impaired. Nitrogen deficiency under drought conditions was observed in the yellowing of leaves under the drought conditions relative to the green colour of the of leaves under irrigated conditions. This gave a visual presentation of reduced chlorophyll content in the drought treatment. Nitrogen assimilation is also affected by moisture stress due to reduction in nitrate reductase activity (Reddy *et al.,* 2003). It is possible this could have accounted for the reduced leaf chlorophyll content. Reddy and Rao (1968) observed that severe drought stress decreased the levels of chlorophyll a, b and total chlorophyll. This was attributed to the inhibition of chlorophyll synthesis as well as accelerated turnover of chlorophyll already present.

5.4.5.3 Stomatal conductance

Stomatal conductance indicates the ability of the stomata to transport water. Low stomatal conductance indicates closed stomata and high stomatal conductance indicates open stomata or low resistance to gaseous transport. In the present study, stomatal conductance was lower under water stressed than under the irrigated treatment. Stomatal closure under drought is therefore one means by which bambara groundnut is able to reduce the amount of water in the leaf and thus regulate plant leaf water content especially under stress conditions. Wien *et al.* (1979) observed that drought avoidance by cowpea is achieved by partial stomatal closure of the leaves under moisture stress. Ekanayake and De Jong (1992) reported of differences in stomatal resistance in potato cultivars.

Pinheiro *et al.* (2005) and Serrano and Peneulas (2005) observed that drought tolerant crops are characterized by low stomatal resistance, that is, high stomatal conductance under irrigated conditions and high stomatal resistance, that is, low stomatal conductance under water stressed conditions. Turk and Hall (1980) observed that drought avoidance by cowpea is due to avoidance of water loss through reduction in leaf area; partial stomatal closure and changes in leaflet orientation. Reddy *et al.* (2003) observed that as moisture stress increases, stomata starts closing as a mechanism to reduce transpiration which also results in reduced entry of carbon dioxide into the leaves.

CHAPTER SIX

YEAR THREE EXPERIMENTS

The following experiments were undertaken during the year 2009:

6.1 Experiment 9: Yield Evaluation of Three Early Maturing Bambara Groundnut Landraces at the CSIR-Crops Research Institute, Fumesua-Kumasi.

6.2 Experiment 10: Effect of spacing on Performance of Tom

6.3 Experiment 11: Seed Priming on Seedling Emergence and Establishment of Four Bambara Groundnut Landraces

6.1 Experiment 9: Yield Evaluation of Three Early Maturing Bambara Groundnut Landraces at the CSIR-Crops Research Institute, Fumesua-Kumasi.

6.1.1 Introduction

Three early maturing bambara groundnut landraces were identified during the study at the University of Guelph in Canada. These are Burkina which had been identified as an early maturing variety in the 1st and 2nd year field studies in Wenchi and Kumasi. The additional two early maturing landraces identified are Mottled cream and Zebra coloured. The three landraces showed a relatively neutral response to daylength producing pods under both short day (12h) and long day (14h) at the controlled environment trial at the University of Guelph, Canada. Hall and Patel (1985) reported that early maturing cowpea varieties have proved more useful in some dry environments and years because of their ability to escape drought. Singh *et al.* (1997) observed that earliness in maturity of cowpea genotypes is a desirable trait so that cowpeas can be grown in the niches of cereal-based cropping system. The objective of this study was to determine the field performance of the three early maturing landraces identified at the controlled environment study at the University of Guelph, Canada.

6.1.2 Materials and methods

The three landraces were sown at the CSIR-Crops Research Institute, Fumesua-Kumasi in the Ashanti Region of Ghana at a spacing of 50cm by 20cm. The plot had been cultivated to cowpea in the previous year. The experiment was arranged in a Randomized Complete Block design with three replications. The plot was ploughed and harrowed. Sowing was done on 1st April 2009, at two seeds per hill and seedlings were thinned to one seedling per hill at 20 DAS. Other agronomic practices were undertaken as described in earlier experiments.

6.1.3 Data taken whose methodologies have been already described were;

Days to 50% emergence

Days to 50% flowering

Days to maturity

Plant stand at emergence and final harvest

Number of pods per plant

Number of seeds per 100 pods

Pod yield

100 pod dry weight

100 pod seed weight

Pod yield per plant

6.1.4 Data analysis

Data analysis was conducted using the Genstat statistical package. Means separation was undertaken using the LSD at 5% level of probability.

6.1.6 Results

6.1.5.1 Days to 50% emergence

Significant difference was observed in the days to 50% emergence of the three landraces (p=0.003). Mottled cream used the least number of days to emerge (6 days). This however, was not significantly different from Zebra coloured (6.3 days) with Burkina taking a mean of 7.5 days to emerge (Table 6.1).

6.1.5.2 Days to 50% flowering

Significant difference was also observed in the number of days to 50% flowering. Mottled Cream had the least number of days to 50% flowering (39.3) with Zebra coloured and Burkina taking 40.0 and 40.5 days to 50% flowering, respectively (Table 6.1)

6.1.5.3 Days to maturity

Significant difference was observed among the landraces with respect to days to maturity. Zebra coloured was the earliest maturing landrace (89.5 days) and Burkina maturing latest among the three landrace (112.5 days) (Table 6.1).

Table 6.1 Mean number of days to 50% emergence, 50% flowering and maturity

Landrace	**Days to 50% emergence**	**Days to 50% flowering**	**Days to maturity**
Mottled cream	6.0	39.3	98.2
Zebra coloured	6.3	40.0	89.5
Burkina	7.5	40.5	112.5
Mean	6.58	39.92	100.1
Cv (%)	5.7	0.9	2.2
LSD 0.05	0.6	0.6	3.8
P value	0.003	0.009	0.001

6.1.5.4 Plant stand at emergence and harvest

Significant difference was observed with respect to the plant stand at emergence among the three landraces with Burkina recording the least value at emergence (46.3) and Zebra coloured the highest (49.0). Plant stand at harvest however, was not significantly different among the three landraces with Burkina (31.0), Zebra coloured (30.0) and Mottled cream (34.0) plants at harvest.

6.1.5.5 Number of pods per plant

Significant differences were observed in number of pods per plant ($p=0.05$) among the landraces. Mottled cream produced the least number of pods per plant (25.0) with Burkina and Zebra coloured producing 36.0 and 43.3 pods per plant, respectively. Zebra coloured produced 72% and 20% more pods than Mottled cream and Burkina, respectively (Table 6.2).

6.1.5.6 Number of seeds/100 pods

There was no significant difference among the three landraces with respect to number of seeds per 100 pods. Mottled cream however, had the greatest number of seeds per 100 pods (132.5) and Burkina the least (121.2) (Table 6.2).

6.1.5.7 Hundred pod dry weight (g)

No significant difference was observed in the 100 pod dry weight for the three landraces. Mottled cream however, recorded the highest 100 pod dry weight of 71.8 g with Burkina recording the least 100 pod dry weight (65.5 g) (Table 6.2).

6.1.5.8 Pod yield/plant (g)

Significant difference was observed in pod dry weight per plant (p=0.05). Zebra coloured recorded the greatest pod dry weight per plant (23.6 g) followed by Burkina (17.7 g) and Mottled cream (12.5 g) (Table 6.2).

Table 6.2 Number of pods/plant, seeds/hundred pods, hundred pods seed weight and pod yield per plant as affected by landraces

Landrace	No. of pods per Plant	No. of seeds per 100 pods	100 pod dry weight (g)	100 pod seed weight (g)	Pod yield per plant (g)
Burkina	36.0	121.2	65.3	53.5	17.7
Zebra Col	43.3	124.5	67.3	49.0	23.6
Mot. Cream	25.0	132.5	71.8	48.5	12.5
Mean	34.8	126.1	67.9	50.3	17.9
LSD (0.05)	13.8	NS	NS	NS	10.23
P value	0.05				0.05

6.1.6 Discussion

6.1.6.1 Days to 50% emergence, 50% flowering and maturity

In the preliminary and second year field studies, Burkina was rated as the earliest maturing landrace among the landraces used. In this study however, Mottled cream and Zebra coloured took the least number of days to emerge 6.0 and 6.25 days, respectively. Mottled cream also took the least number of days to attain 50% flowering. Zebra coloured however, took the least number of days to maturity (89.50 days). From this study Zebra coloured and Mottled Cream can be regarded as early maturing landraces and Burkina a medium maturing landrace. Shumba-Mnyulwa (2002) reported that bambara groundnut cultivation in Zimbabwe occurs in agro-ecological zones where precipitation is sparse and erratic, heightening moisture stress and depressing yield. The best way of resolving this problem is to breed for early maturing bambara groundnut varieties (Shumba-Mnyulwa, 2002). Ehlers and Hall (1997) reported that in addition to escaping drought, early maturing cultivars can escape insect infestation and early erect types could be important for mechanized production to enable the easy movement of farm equipment when cultivating, spraying pesticide and harvesting. Practically results from this study provides bambara groundnut growers with early maturing bambara groundnut materials.

6.1.6.2 Number of pods/plant, seeds/pod and pod dry weight/plant

Zebra coloured produced the highest number of pods per plant and the highest pod dry weight per plant. Zebra coloured produced 89.2% more pod dry weight per plant than Mottled cream. The range of pod dry weight per plant (12.5-23.7 g/plant) equivalent to (1.3-2.4 t ha^{-1}) for an early maturing under utilized and under researched drought tolerant legume gives a great degree of motivation to work towards improving the productivity of the crop.

6.2 Experiment 10: Effect of Spacing on the Performance of Tom

6.2.1 Introduction

Field studies in 2007 and 2008 showed that Tom is a highly vegetative landrace. Performance of Tom over the different sowing dates for the two years showed that the harvest index is very low with poor pod yields. The landrace however, is known to be popular in Tom in the Nkoranza District of Ghana which is the locality where it is mostly grown. The positive attribute of Tom however, is the large pod size (100 seed weight) and its ability to produce two seeds per pod. Its poor yield has been shown in the few number of pods per plant in the two year study. Farmers are known however, to sow at lower plant population that is larger spacing on their fields. Within a crop, competition occurs between plants of the same species ie., intraspecific competition and between plants of different species i.e., interspecific competition (Halley and Soffe, 1994). The objective of this study was to determine whether larger spacing of Tom can result in a higher pod yield than the spacing (50cm x 20cm) used in the two year field trials.

6.2.2 Materials and methods

This study was conducted to evaluate Tom over three different spacings (50cm x 20cm, 50cm x 30cm, 50cm x 40cm). This was to determine whether at larger spacing Tom can exhibit its potential in terms of efficient capture of irradiance which may transform into better partitioning of dry matter into pods. The experiment was arranged in a RCBD with three replications of each treatment. NAV 4 was used as a check. The field was sown on 20th April, 2009 at the CSIR-Crops Research Institute, Fumesua-Kumasi.

6.2.3 Data taken

Data taken were the same as in experiment nine. Other data taken included 100 pod weight at the different spacings and the 100 seed weight.

Number of pods /plant

Pod dry weight per plant

100 pod dry weight

Haulm dry weight per plant

Data analysis was conducted using the Genstat statistical package. Means separation was undertaken using the Duncan's Multiple Range Test (DMRT)

6.2.5 Results

6.2.4.1 Haulm dry weight (g/plant)

Significant difference was observed in haulm weight with respect to spacing ($P<0.05$). Tom at 50cm x 40cm produced significantly highest haulm dry weight (33.4 g/plant). NAV 4 at 50cm x 20 cm produced the least haulm dry weight (14.0 g/plant) (Table 6.3).

6.2.4.2 Number of pods per plant

Significant difference was observed with respect to number of pods/plant ($p<0.05$). NAV 4 at 50cm x 40 cm produced the highest number of pods/plant (20.8). Tom at 50cm x 30cm produced the least number of pods /plant. Although not significantly different, Tom at 50cm x 40cm produced the highest number of pods/plant (9.75) at the three spacings with respect to Tom (Table 6.3).

Table 6.3. Effect of landrace and spacing on haulm dry weight and pod number/plant.

Landrace	Spacing	Plant population/hectare	Haulm dry Weight (g/plant)	No. of pods/plant
NAV 4	50cmx20cm	100,000	14..0.d	13.0b
	50cmx30cm	66,666	19.3c	15.5ab
	50cmx40cm	50,000	20.0bc	20.8a
Tom	50cmx20cm	100,000	24.3ab	6.8c
	50cmx30cm	66,666	25.6ab	6.1c
	50cmx40cm	50,000	33.4a	9.7c

Figures in a column bearing the same letters are not significantly different (p=0.05) by Duncan's Multiple Range Test (DMRT).

6.2.4.3 Hundred seed weight (g)

Hundred seed weight was significantly different (p=0.05) at the various spacings. Tom at 50cm x 40cm obtained the highest 100 seed weight of 48.8g (Table 6.4).

6.2.4.4 Pod weight per plant (g)

Pod weight per plant was significantly different at the various plant population. NAV 4 at 50 cm x 40 cm produced the highest pod weight per plant (26.5 g). This however, was not significantly different from NAV 4 at 50 cm x 20 cm. Tom at 50 cm x 40 cm produced a significantly higher pod yield per plant (10.8 g) among the three spacings for Tom (Table 6.4).

6.2.4.5 Pod yield (kg ha^{-1})

Pod yield in kg ha^{-1} was significantly different between the two landraces and among the three spacings (p=0.05). Nav 4 at 50cm x 20cm had the highest pod yield of 2025 kg ha^{-1}. Among the three spacings for Tom, 50cm x 30cm produced the highest pod yield per hectare (577 kg ha^{-1}) even though this was not significantly different from Tom at the other two spacings (Table 6.4).

Table 6.4 Effect of landrace and spacing on 100 seed weight, pod weight/plant and pod yield/ha.

Landrace	Spacing	100 Seed weight (g)	Pod weight per plant (g)	Pod yield/ha (kg)
NAV 4	50cmx20cm	43.0a	20.3a	2025.0a
	50cmx30cm	41.0a	17.0b	1133.0b
	50cmx40cm	41.0a	26.5a	1325.0b
Tom	50cmx20cm	31.2b	3.8d	375.0c
	50cmx30cm	40.5a	7.5c	577.0c
	50cmx40cm	48.8a	10.8c	537.5c

Figures in a column bearing the same letters are not significantly different (p=0.05) by Duncan's Multiple Range Test (DMRT).

6.2.5 Discussions

Where competition for resources by the plant is absent, individual plant yield will give an indication of the maximum yield possible per plant and with increasing plant population, individual yields per plant decrease, however, yields per unit area will increase (Halley and Soffe, 1994). This is because a more efficient use of the limiting resources for growth (light, nutrients and water) is being made by a community of plants (the crop) and the efficiency of utilization of light and the ability of the crop canopy to capture more light is improved (Halley and Soffe, 1994). Haulm dry weight (g/plant), number of pods per plant, and 100 pod weight decreased with increasing plant population in this study. Pod weight per plant also increased with decreasing plant population. Sesay and Yarmah (1996) reported that shoot dry weight expressed on per plant basis generally declined with increase in plant population for two bambara groundnut landraces. Pod yield per hectare in this study showed NAV 4 at 50 cm x 20 cm obtaining a significantly high pod yield even though the pod yield per plant for NAV 4 was highest at 50 cm x 40 cm. This shows the ability of bambara groundnut to compensate for low populations. The result is also in agreement with the findings of Halley and Soffe (1994) who reported that with increasing plant population, individual yields per plant decrease however, yields per unit area will increase.

Even though pod yield per plant for Tom was highest at 50 cm x 40 cm, the highest pod yield per hectare though not significantly different with the two other spacings was at 50 cm x 30 cm. Plant density affects the partitioning of assimilate within the plant with high densities resulting in a greater vegetative component and a lower, reproductive or storage component per plant (Halley and Soffe, 1994). This implies that below and above a certain plant population, crop yield reduces and there is an optimum plant population where crop yield is highest. It is therefore important to determine this population with respect to the environmental and other agronomic factors like availability of fertilizers and the cropping system being practiced.

6.3 Experiment 11: Effect of Seed Priming on Seedling Emergence and Establishment of Four Bambara Groundnut Landraces.

6.3.1 Introduction

Seedling emergence in bambara groundnut observed in the studies was not uniform. Within the same landrace seedling emergence was observed to begin from 7 days to as long as 15 days or more. This has a practical implication for days to flowering, podding and maturity. Delayed seedling emergence and establishment also has implication on early and efficient capture and use of resources such as light through timing of canopy development, nutrient uptake, weed control and hence final pod yield at harvest. Germination of bambara groundnut is hypogeal as the cotyledons remain in the ground. Bambara groundnut seed germination is slow and sporadic and on the field seedling emergence could take up to 21 DAS (Sesay and Yarmah, 1996).

This study was conducted to determine whether seed priming by soaking the seeds in water for 24 h or 48 h before sowing can have an effect on the rate and uniformity of seedling emergence relative to the control which is sowing without soaking seeds in water.

6.3.2 Materials and methods

Two hundred seed lot each of Burkina, NAV 4, NAV Red and Black eye were soaked separately in tap water for 24 hours and 48 hours in a well lighted barn with environmental temperature of $28\pm3^{o}C$. A control treatment was not soaked in water. Seeds were sown at 20 cm x 10 cm at one seed per hill on the field in a Randomized Complete Block Design with three replicates. Seeds were sown at approximately 5 cm depth using a measured dipper to minimise error due to the effect of sowing depth on seedling emergence. Data was taken on 40 predetermined hills per plot. Sowing was done on 18th September, 2009 at the CSIR-Crops Research Institute, Fumesua-Kumasi. Plot length was 100 centimetres (I metre).

6.3.3 Data taken

- Days to 50% emergence of seedlings of the various treatments
- Final plant establishment of the various treatment

6.3.4. Data analysis

Data was analysed using GENSTAT statistical package. Data in percentage were transformed using ARCSINE transformation. Mean separation was done using the Duncans's Multiple Range Test (DMRT).

6.3.5 Results

6.3.5.1 Days to 50% emergence

Significant difference was observed with respect to seed priming treatment in number of days to 50% emergence. No significant difference was however, observed in days to 50% emergence with respect to landrace. Seeds soaked in water for 24 and 48 hours emerged earlier when sown (6.9 days) whereas the control took a mean of 9.3 days to attain 50% emergence (Table 6.5). Table 6.6 provides days to 50% emergence as affected by landrace and seed priming treatment.

Table 6.5 Effect of seed priming on mean number of days to 50% emergence

Seed Priming Treatment	Mean number of days to 50% emergence
Soaking seeds in water for 24 hours	6.9b
Soaking seeds in water for 48hours	6.9b
Control (No soaking in water)	9.3a

Figures in a column bearing the same letters are not significantly different (p=0.05) by Duncan's Multiple Range Test (DMRT).

Table 6.6 Days to 50% emergence as affected by landrace and seed treatment (Hours of soaking in water)

Landrace	Control (0 h)	24 h	48 h
	DAS	DAS	DAS
Black eye	9.3	6.7	7.0
Burkina	9.0	7.0	6.7
NAV 4	9.3	7.0	7.0
NAV Red	9.7	7.0	7.0
	NS	NS	NS

NS= Not significant

6.3.5.2 Percentage seedling establishment

Significant difference was observed among landraces with respect to final percentage seedling establishment (p=0.02) at 20 DAS. Significant difference was also observed in seed priming treatment in the final seedling establishment ($p<0.001$). No significant difference was observed in the seed priming by landrace interaction. Final percentage establishment was also highest under 24 hour soaking in water (85.6%) and least under the control (53.4%) (Table 6.7). NAV Red at the different seed priming treatment showed a high percentage seedling establishment than the other landraces (Table 6.8).

Table 6.7. Effect of seed priming on mean final percentage establishment

Seed Priming Treatment	Mean final percentage establishment
Soaking seeds in water for 24 hours	85.6a
Soaking seeds in water for 48hours	79.6a
Control (No soaking in water)	53.4b

Figures in a column bearing the same letters are not significantly different (p=0.05) by Duncan's Multiple Range Test (DMRT).

Table 6.8 Final percentage seedling emergence (20DAS) as affected by landraces and seed treatment (Hours of soaking seeds in water).

Landraces	**Percentage Establishment) (Control)**	**Percentage establishment (24h)**	**Percentage establishment (48h)**

Black eye	34.2c	86.7	71.7b
Burkina	49.2b	82.5	77.5ab
NAV 4	64.2a	82.5	84.2a
NAV Red	66.7a	90.8	85.0a
		NS	

Figures in a column bearing the same letters are not significantly different (p=0.05) by Duncan's Multiple Range Test (DMRT). NS= Not significant.

6.3.6 Discussions

Seedling emergence and final seedling establishment were highest with 24 hour soaking in water even though no significant difference was observed between the 48 hour treatment (Table 6.7). Zulu (1989) observed that seedling emergence in bambara groundnut seems to be more sensitive to moisture stress than groundnut. He attributed this to the restrictive uptake of water by bambara groundnut due to the hard seed coat. This was also observed in the earlier studies under drought when irrigation was not efficient, seeds could remain in the soil for almost 20 days before germination occurred with the availability of moisture. Mabika (1991) however, reported that scarification by scratching three openings did not hasten germination. Mabika (1991) also observed that seed priming by pre-soaking the seeds in distilled water at 21^{o}C for 24 hours did not affect the germination of the crop. The findings of this study however, did not agree with Mabika (1991) since soaking bambara groundnut seeds in water for 24 and 48 hours both affected days to seedling emergence and final percentage seedling establishment. The temperature, at which seeds were soaked in this study was 28±3^{o}C. This temperature was higher than that of Mabika (1991) and this could have facilitated the imbibition of water by the seeds and hence enhanced their germination. This temperature also pertains in most bambara groundnut growing areas in Ghana. Massawe (1997) however, observed that soaking bambara groundnut seeds in water for 24 to 72 h promoted initial germination by two to three days depending on the landrace, and also reduced the spread of germination. In the present study seed priming did not only facilitate seedling emergence but also reduced the spread of seedling emergence. The germination phase of planted seeds is critical because it directly determines the density of a crop stand especially under arid conditions where dry soil may impair imbibition of water and high temperature may affect seed viability and eventual density of a crop stand (Hadas and Russo, 1974). Hadas and Russo (1974) further observed that a good stand could be ensured by a complete and fast germination and if germinating seed is slow in taking up water, emergence is impaired and consequently the final stand is reduced.

Seeds soaked in water for 48 hours in this study became soft and the cotyledons easily split into two when not handled with care. It is possible the low seedling emergence and poor stand in the control treatment could be due to the relatively longer time for seeds to imbibe water. The practical significance of this findings is that with a simple soaking of bambara seeds in water for 24 hours the farmer does not only benefit from the early emergence of seedlings but also improved crop stand which has a positive implication on the more efficient utilization of resources such as light, nutrient and water, efficient control of weeds and improve crop yield. Soaking bambara seeds in water for 24 h has the possibility of improved bambara groundnut yield which is beneficial for bambara groundnut growers in terms of food security and poverty alleviation through income generation.

CHAPTER SEVEN

GENERAL DISCUSSIONS

7.1 Seedling emergence and establishment

The results of this study showed that drought at seeding stage resulted in delayed seedling emergence, delayed flowering, podding and maturity in bambara groundnut. This was observed in both the first and second year field studies. Drought also resulted in delayed seedling establishment. The practical implication of this finding is for bambara groundnut growers to manage the timing of application of irrigation if this is available and also to manage the date of sowing when irrigation is lacking and the crop is grown under rainfed agriculture. The importance of agro-meteorologist in predicting the period of sowing based on weather conditions is therefore very paramount. Good timing for the sowing of seed will enable the seed to take advantage of residual moisture to enhance imbibition of water for early seedling emergence. This will also save farmers from losing their seeds and the investments they have made on their farms.

Seed priming by soaking seeds in water for 24 hours before sowing enhanced seedling emergence and final seedling establishment. This finding is very relevant for bambara groundnut growers since early seedling emergence and establishment are necessary for obtaining an early ground cover to enable the crop to efficiently utilize crop growth resources like moisture, light and nutrients.

7.3 Pod yield and sowing dates

Pod yields during the February and March sowings in 2007 were relatively higher. Excluding Tom, the mean pod yields in Wenchi for the 2007 sowings was 3.50 t/ha. Similarly, in the 2008 sowings mean pod yields in the February, March and early April sowings was 4.5 t/ha. This period was towards the tail end of the dry season and the earlier part of the major season rains. Where irrigation is available, between February and March and before the onset of the major season rains, sowing of bambara groundnut in the Transition and Forest agro-ecologies of Ghana could produce good pod yield. This may be due to the fact that irradiance and temperatures are within the optimum for bambara groundnut cultivation in these agro-ecological zones of Ghana. This result is in agreement with findings of Doku and Karikari (1970) who reported that if water could be provided, the dry season would be better for the cultivation of bambara groundnut.

This result was confirmed in the minor season August 2007 sowing where the relatively moderate rainfall with abundant sunshine improved pod yields for all the landraces including Tom. Pod yield was however; relatively low with the June sowings. The relatively lower yield for the landraces during the June sowings could be due to the heavy major season rainfall which made the landraces more vegetative. Ameyaw and Doku (1983) observed grain yield of 892.06 kg ha^{-1} and 542.67 kg ha^{-1} for bambara groundnut landrace Legon No 3 given 40% and 50% available moisture, respectively. Yields of 186.23 kg ha^{-1} and 86 kg ha^{-1} were produced at moisture levels of 30 and 75% available moisture with field capacity considered as 100% available moisture (Ameyaw and Doku, 1983). Their results are in agreement with the results from the current study where under heavy rainfall pod yield was low.

The major effect of sowing date was highly observed in the 2008 sowings at the CSIR-Crops Research Institute, Kumasi. Mean pod yields for the 13th and 19th March sowings were 208.4 kg ha^{-1} and 233.3 kg ha^{-1}, respectively. Mean pod yield for the 1st and 18th June sowings were 33.5 Kgha^{-1} and 27.8 kg ha^{-1} , respectively. Fumesua, in the forest belt, had a higher rainfall than the Transition agroecology of Ghana. The major rainy season sowings showed some signs of fungal attack due to the high relative humidity. None of the field trials was sprayed. It is therefore possible the photosynthetic surface of the leaves might have been negatively affected resulting in reduced photosynthetic efficiency. Low irradiance due to cloud cover could also have affected the yield of pods sown in June.

7.4 Yield potential of bambara groundnut

Chrispeeles and Sadava (2003) reported that with very few prospect to sustainably expand the 1.5 billion hectares of crop land currently under cultivation, the only way to meet the increasing demand for food by the end of this century is through the doubling of productivity. Providing food security is one of the greatest challenges of our times and is a critical goal especially in the developing world where crop destruction by drought, diseases, and pests infestation swiftly place millions of lives at risk of hunger (UCR, 2007). Azam-Ali (2005) reported that if the yield of bambara groundnut and other indigenous African crops could be increased, the problem of food security and sustainability could be solved because these crops can grow in stressful environment and produce yields, something you get very rarely in the major crops.

Pod and seed yields of 5.5 and 3.8 tonnes per hectare respectively were obtained in this study. For an under developed and under researched legume, this figure may be considered as being high. Johnson (1968) reported of bambara groundnut grain yields of 3.9 tonnes hectare. Doku (1996) described the bambara groundnut as an architectural masterpiece designed for maximum production. The almost vertical leaves on a long thin petiole ensure maximum interception of solar radiation with minimal mutual leaf shading (Doku, 1996).

Long *et al.* (2006) also observed that one means of attaining the efficiency of interception of solar radiation is through canopy architecture. If for example the sun is overhead, then high leaf angles will distribute the light more evenly through the canopy and could reduce the proportion of leaves that become light saturated (Long *et al.*, 2006).

Doku (1996) again reported that the sink demand of the thin and much branched stem of bambara groundnut cannot offer any significant competition for assimilates relative to the developing pods. The almost vertical leaf architecture of the bambara groundnut described by Doku (1996) and observed in the present study creates a maximum potential for effective light interception by the crop and the potential of a high pod yield.

Unlike groundnut and soybean with high lipid contents of 20% and 45% repectively, bambara groundnut has a low lipid content (5-6%) (Poulter and Caygill, 1980). Penning de Vries *et al.* (1974) quoted product values (PV) of 0.37 g product g^{-1} glucose and glucose requirement (GR) of 2.71 g glucose g^{-1} product for lipids. The product value of carbohydrate however, is 0.83 g product g^{-1} glucose and a glucose requirement of 1.21 g glucose $g^{-1.}$ carbohydrate. With the high glucose requirement (2.71g) to produce one gram of lipid the potential yield of a crop with high lipid content stands to be lower than a crop with low lipid but high carbohydrate. Bambara groundnut has a relatively high carbohydrate content of up to 60% and low lipid content of 5-6%. Carbohydrate contents for soybean and peanut are 38% and 25% respectively (Loomis and Connor, 1992). Compared to soybean and groundnut, less glucose requirement is required to produce a unit of bambara groundnut than groundnut and soybean taking into consideration the protein contents of the three legumes. This gives bambara groundnut the potential of a high yield relative to the two crops if more research efforts and resources are put into the improvement of the crop.

It should be noted that the protein content of bambara groundnut (16-25% DM) combined with the low lipid and relatively high carbohydrate gives the seed of bambara groundnut a complete, balanced and nutritious meal when boiled and eaten or used to complement cereal, ripe plantain and other high carbohydrate meals.

Hay and Walker (1992) observed that the transformation of incident solar radiation into more useful forms of chemical potential energy located in the harvestable part of the crop is through the conversion of intercepted solar radiation to plant dry matter. Zhu *et al.* (2008) observed that one realistic opportunity to raise the theoretical maximum conversion efficiency is to convert C_3 crops to C_4 or by improving the specificity of Rubisco for carbon dioxide. This is to enable the C_3 plant to overcome photorespiration. Bambara groundnut is a drought tolerant crop and in most parts of Africa where the crop is cultivated, bambara groundnut is intercropped with millet and sorghum which are dry area crops. In the present study, bambara groundnut was able to produce good yields in areas with temperatures of 33^{o}C. Bambara groundnut is a C_3 leguminous plant. The ability of the crop to thrive and yield under conditions of relatively high temperatures where other legumes will not thrive gives the crop the potential to overcome the limitations of C_3 plants cropped under high temperature and in relatively dry areas due to photorespiration. This feature of bambara groundnut enables the crop to efficiently convert the intercepted solar radiation into dry matter and subsequently partitioned into pods. Differences were however, observed in the responses of bambara groundnut genotype to environmental stress.

7.4 Leaf morphology (Photoperiod trial)

Bambara groundnut has been described as a trifoliate crop bearing three leaflets on a single petiole. It was observed in this study that three plants from Tan One a landrace from Tanzania bearing three, four and five leaflets on the same petiole on the same plant (Plate 5.4). It is possible these landraces are wild types of the crop which have not been selected against by researchers and farmers. Interestingly, these landraces were relatively insensitive to photoperiod and produced some pods under 14 h photoperiod. The two landraces are also spreading types. This finding has not been reported in the literature to the best of the author's knowledge. In a personal communication as to whether the University of Nottingham a major centre for bambara groundnut research has observed the phenomenon of having the same plants having trifoliate, quadrifoliate and pentafoliate leaflet arrangement, Azam-Ali (2009) (Oral communication) mentioned that one scientist observed four leaflets on a plant at the

University of Nottingham, UK , however no report has been documented of the same plant showing three, four and five leaflets on different petioles of the same plant. It is possible farmers in Tanzania might have maintained these landraces because they might produce some pods under relatively long day which farmers unconsciously may not be aware and researchers might have also not observed. This finding provides a source of material for breeders to investigate the attribute of these landraces

Even though seedling emergence was earliest under 12 h than under 14 h photoperiod, canopy size at flowering was greater under 14 h than under 12 h. This continued till harvest at 130 DAS. Stems of landraces were more prominent under 14 h than under 12 h. At harvest, canopy size was lower under 12 h than 14 h which could be due to the fact that most of the landraces under 12 h photoperiod partititioned more assimilates to pods than to the vegetative parts like the leaves, stems and petioles. Leaf senescence was greater under 12 h than under 14 h and could be due to the fact that more assimilates were directed to the development of new leaves under 14 h. Fewer leaves however, were formed under 12 h at maturity which reflected in the lesser leaf area under under 12 h photoperiod as compared to 14 h photoperiod.

7.7 Leaf morphology under drought

Under drought conditions leaflets of some of the bambara groundnut landraces rolled into spindle shape and attained more erect characteristics. Canopy and leaflet size reduced under drought. Water loss can be reduced by greater cuticular resistance (Yoshida and Reyes, 1976), paraheliotropic leaf movement (Begg and Tarssell, 1974) and leaf rolling (O'Toole *et al.*, 1979). Reddy *et al.* (2003) reported that the long term effect of soil water deficit on canopy assimilation is a reduction in leaf area. Leaflets oriented in a more erect position with response to drought. This observation is in agreement with reports by Reddy and *et al.* (2003) who observed that during moisture stress in peanut, opposing leaflets of trifoliate leaf come together and orient themselves parallel to incident solar radiation in an effort to reduce solar radiation load on the leaf. Berchie *et al.* (2002) observed variation in paraheliotropic movement in three bambara groundnut landraces under drought. Ludlow and Bjorkman (1984) observed that paraheliotropic leaf movement protected leaves of Siratro from damage caused by excessive light and excessive heat to the photosynthetic system.

7.8 Recovery after re-irrigation

Tan One, Tan Two, Black eye and Burkina were able to show some recovery on resumption of irrigation after 30 days of drought. One week after resumption of irrigation, Tan One and Tan Two showed a high degree of recovery with leaflets which exhibited spindle shape opening fully and showing green colour. Flowering in Tan One which had ceased, resumed and there was virtually no difference between the drought and irrigated treatments on visual observation. Muchero *et al.* (2008) observed that within some cowpea genotypes, individual plants expressed varying levels of survival and ultimate recovery in response to drought stress. Such an observation was made in the present study where there was variation among the landraces with respect to their recovery after resumption in irrigation.

It is interesting to note that the percentage moisture content of the soil at the end of the drought study was 5.8% which is within the percentage coefficient described by

Brady (1990) as the permanent wilting point for a sandy loam soil. Some of the landraces were therefore able to survive even when soil moisture levels have reached the permanent wilting point for the sandy loam soil which was used in sowing of the seeds. This result confirms the potential of bambara groundnut as a drought tolerant crop. It also showed differences in the response of the various genotypes to drought stress. Practically, this result provides bambara groundnut growers in areas with very poor rainfall the opportunity to obtain genotypes that are relatively more drought tolerant.

7.7 Pod yield and photoperiod

The results of this study agreed with that of other workers who reported that long daylength negatively affected pod formation in bambara groundnut and favoured vegetative growth. Long photoperiod inhibited the partitioning of dry matter to seeds and increased assimilate partitioning to vegetative organs in common bean (*Phaseolus vulgaris* (L)) (Wallace and Yan, 1998). Azam-Ali (1998) observed that the continued leaf production under longer daylengths is associated with a corresponding decline in the fraction of dry matter allocated to pod structures. Eleven out of the 13 landraces produced pods under 12 h photoperiod. However, five out of the 13 landraces produced pods under 14 h photoperiod. For those landraces that produced pods under 14 h photoperiod, pod production was higher under 12 h. The five landraces could be described as relatively insensitive to daylength.

It is also interesting to note however, that the landraces that produced some pods can be described as early maturing in terms of their early emergence, and flowering. These landraces are Tan One, Tan Two, Mottled Cream, Burkina and Zebra coloured.

Subsequent field studies conducted at the CSIR-Crops Research Institute proved Zebra coloured and Mottled Cream as being early maturing 89.5 and 98.2 days, respectively, and Burkina as intermediate landrace (112.5 days). It is worth noting that Tan One and Tan Two originate from Tanzania and Burkina from Burkina Faso. Relative to Ghana these two countries lie in lower and upper latitudes where photoperiod can affect bambara groundnut production. It is possible these landraces are more adapted to their centres of origin and hence their being less sensitive to photoperiodic effect. The practical implication of this study is for researchers to identify bambara groundnut materials less sensitive to photoperiod from countries in the lower and upper latitudes. These materials can be introduced to farmers who record low bambara groundnut yields when sowing is delayed due to delayed onset of the rains. These materials can also be used as sources of genetic material for any improvement programme at introgressing photoperiod insensitivity to high yielding consumer accepted photoperiod sensitive materials.

Long photoperiod has been documented to delay pod formation or prevent pod formation. Where pod development is delayed due to photoperiod it is reasonable to sow an early maturing genotype. The early maturing genotypes can make up for the delay in pod development caused by using a full season landrace. Practically the identification of early maturing bambara groundnut landraces which are less sensitive to photoperiod provides a source of material for farmers in countries in Sub-saharan Africa and Asia where long days affect the yield of bambara groundnut.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

Eleven experiments were undertaken from 2007 – 2009 at four locations in Ghana (Tono, Navrongo, Wenchi and Kumasi) and the University of Guelph in Canada. Results of the study showed that time of sowing affected the yield of bambara in Ghana. The six series of sowings at Wenchi and Kumasi showed the potential of bambara to produce high pod yield under favourable conditions. Wenchi which is in the transition agro-ecology proved to be a better agro-ecology for bambara groundnut production relative to Kumasi in the forest agro-ecology. Pod yields of between 2 t/ha and 3 t/ha attained in the 13^{th} and 18^{th} March sowings in Kumasi however, showed that when the sowing date is selected so that it does not coincide with the period of heavy rainfall, bambara can yield relatively well in Kumasi in the forest agro-ecology. Where irrigation is available, bambara groundnut can be sown in February and March which falls within the dry season in Ghana to produce relatively high pod yields. Pod yields of 4-5 tonnes per hectare were obtained in the Transition agro-ecology when bambara was grown in February and March under irrigation before the commencement of the rains. Sowing of bambara in late April to June in the Forest and Transition agro-ecologies produced poor pod yield apparently as a result of the heavy rains which favoured vegetative development. Tom was observed to produce more vegetative biomass and few pods even though it possessed big seed size.

Minor season sowing of bambara in the Transition produced high pod yield. Tom which yielded poorly in the major season cropping produced pod yield of over 2.0 tonnes per hectare when cultivated in the minor season. Farmers will grow Tom despite its low yield. Tom has a dark cream colour with very large seed. These characteristics were prioritized as highly acceptable by farmers and consumers in an earlier survey in the Transition and Guinea Savannah agroecologies of Ghana.

Burkina, a landrace from Burkina Faso, was observed to be more heat and drought tolerant in the study conducted at Tono in the Upper East Region of Ghana during the dry season when temperatures could be as high as 42^{o}C. It was observed in the heat study that despite the fact that bambara groundnut is drought tolerant and performed well in areas of high temperatures, excessive heat even under irrigation greatly affected pod yield. Burkina however, could produce pod yield of about 1.2 tonnes per hectare with the other landraces producing below 600 kg ha^{-1}. Tom however, did not produce any pod in the heat study at Tono. The landrace Ada from the Coastal Savanna agro-ecology of Ghana seems to be similar to Burkina from Burkina Faso as shown by most of the phenological and the final pod yield of the two landraces.

Controlled environment photoperiod study at the University of Guelph in Canada confirmed the findings of several workers that long photoperiod favoured vegetative production at the expense of pod production in bambara groundnut. Five bambara groundnut landraces; Tan One, Tan Two (both from Tanzania), Burkina, Mottled Cream and Zebra coloured were relatively less sensitive to photoperiod. They were able to produce some pods under 14 h photoperiod even though they produced more pods under 12 h photoperiod. It is however, interesting to note that these landraces were identified as early maturing landraces. Morphologically, Tan One produced some plants which produced three, four and five leaflets on different petioles on the same plant which should be of interest to plant breeders.

Tan One, Tan Two, Burkina, and Black eye were identified as relatively highly tolerant to drought. Leaflets of these genotypes showed spindle shape, erect orientation and reduced canopy size in response to drought. Effect of drought on plant was observed on the drought treated plants 25 days after the imposition of the drought treatment.

Bambara groundnut seeds soaked in water for 24 hours germinated earlier when sown than the control treatment where the seeds were not soaked in water. Seeds sown in water for 48 hours became soft and the cotyledons split into two when handled.

It is recommended that molecular studies to determine the relationship between Ada and Burkina be conducted to find out if the two landraces are the same. Further sociological studies to determine the movements of bambara seed between the Adas of Ghana and Burkinabes of Burkina Faso would also be of interest if it is established that the two landraces are the same. It is also recommended that the effect of bambara groundnut grown as an intercrop with maize, sorghum and millet be conducted to determine the land equivalent ratio (LER) and the sole crop yield of the subsequent cereal crop relative to a control and application of mineral fertilizer.

It is also recommended that nodulation studies be conducted to determine the effect of nodulation of the various landraces on pod yield. Additionally, on-farm trials can be conducted in bambara groundnut growing areas in the Nkoranza District using the high yielding landraces notably; Black eye, NAV 4, NAV Red, Mottled Red and Burkina with Tom as a check to enable farmers make a decision on the inclusion of these landraces in bambara groundnut cultivation.

It is also recommended that the early maturing landraces identified in Guelph and further tested on the field in Ghana be introduced to farmers in Ghana who would be interested in early maturing materials. These materials should also be introduced to bambara groundnut growers in countries within the sub-region where changes in photoperiod can negatively affect pod yields of bambara groundnut.

Effect of climate change is said to affect crop productivity in terms of drought. Developing countries have been projected to be greatly affected in terms of food security since irrigation facilities do not abound much in most developing countries. Agriculture in most developing countries south of the Sahara is mostly rainfed and in these areas water set the limit to crop productivity. It is important for researchers to identify and work on crops that have proven to be tolerant to drought and heat to increase the productivity of such crops if the fight towards attaining food security is to be won. Bambara groundnut (*Vigna subterranea* L. (Verdc) is one of such crops, moreso when nutritionally bambara seeds have been identified to form a complete meal.

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APPENDICES

Appendix 1: Meteorological data Wenchi (January-October,2007)

Month	Rainfall Monthly total (mm)	Temperature ^{o}C				Mean daily relative Humidity (%)	Mean daily sunshine duration (hours)
		Total Maximum	Total Minimum	Mean Max	Mean Min		
January	11.2	1022.9	635.7	33.0	20.5	33.5	6.3
February	24.4	977.8	632.2	34.9	22.6	60.0	6.3
March	62.8	1109.5	728.4	35.8	23.5	60.3	7.1
April	131.9	980.6	691.9	32.7	23.1	74.5	7.5
May	166.2	977.2	707.8	31.5	22.8	78.3	6.9
June	147.2	894.2	659.2	29.8	22.0	82.0	6.4
July	130.0	879.2	665.1	29.0	21.5	81.8	4.7
August	140.3	862.1	640.9	27.8	20.7	84.0	3.4
September	228.4	869.3	642.5	29.0	21.4	84.5	4.7
October	231.9	938.8	658.8	30.3	21.3	81.0	6.8

Appendix II: Meteorological data Tono near Navrongo (January-June, 2007)

Month	Rainfall Monthly total (mm)	Temperature ^oC				Mean daily relative Humidity (%)	Mean daily sunshine duration (hours)
		Total Maximum	Total Minimum	Mean Max	Mean Min		
January	0.0	1067	600	34.4	19.4	24.7	7.7
February	0.0	1082.2	628.6	38.7	22.5	20.7	9.5
March	Traces	1244.7	788.1	40.2	225.4	28.3	7.9
April	155.0	1111.8	780.8	37.6	26.0	57	6.3
May	92.0	1074.5	787.7	34.7	224.8	69.5	7.8
June	138.5	993.7	729.5	33.1	24.3	71.5	8.3

Source: Ghana Meteorological Service, 2007

Appendix III

Daylength hours, Northern and Southern sectors of Ghana.

Month	Northern Sector Brong Ahafo, Nothern, Upper Regions and Northern part of Volta	Southern Sector G. Accra, Ashanti, Eastern, Southern Volta, Central and Western Regions
January	11.6	11.8
February	11.8	11.9
March	12.1	12.1
April	12.3	12.2
May	12.6	12.3
June	12.7	12.4
July	12.7	12.3
August	12.4	12.1
September	12.2	12.1
October	11.9	12.0
November	11.7	11.9
December	11.5	11.8

Source Ghana Meteorological Service (2007).

APPENDIX IV: GROWTH CHAMBER AND PRESENTATION AT PLANT AGRICULTURE, RETREAT, NIAGARA FALLS, CANADA.

Growth chambers (Crop Science Dept, UoG) **Potted plants in a growth chamber**

Delivering a paper at the Sheraton Hotel Niagara Falls, Canada (18th February 2009)

Some members of Manish's lab., taken at the Sheraton of the Falls.

APPENDIX V: SAMPLE ANOVA for Leaf Dry weight, Total pod yield and Days to podding, Tono (2007), Wenchi (2008), and Kumasi (2008) respectively

ANOVA: Leaf dry weight (120 DAS), Tono (2007)
Variate: LW120DA

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	4981.2	2490.6	3.09	
rep.*Units* stratum					
entry					
Landrace	4	20688.3	5172.1	6.42	0.013
Residual	8	6448.3	806.0		
Total	14	32117.9			

ANOVA: Total pod yield Wenchi (2008) sowing

Variate: tyldupods

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	747954	373977	9.49	
rep.*Units* stratum					
pltdate	5	23801140	4760228	120.77	<0.001
variety	6	262827427	43804571	1111.32	<0.001
pltdate.variety	30	5664783	188826	4.79	<0.001
Residual	82	3232179	39417		
Total	125	296273483.			

ANOVA: Days to podding , Fumesua-Kumasi, 2008.

Variate: Dayspod

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	124.074	62.037	8.11	
rep.*Units* stratum					
pltdate	5	298.185	59.637	7.80	<0.001
variety	5	28.852	5.770	0.75	0.586
pltdate.variety	25	183.815	7.353	0.96	0.526
Residual	82	3232179	39417		
Total	107	1170.185.			