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Full Length Research Paper

Evaluation of five bambara groundnut (*Vigna subterranea* (L.) Verdc.) landraces to heat and drought stress at Tono-Navrongo, Upper East Region of Ghana

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The need to obtain crop varieties that are tolerant to heat and drought cannot be overemphasised especially with the threat of climate change to agricultural productivity in sub-Saharan Africa. Bambara groundnut has been identified as a drought tolerant crop; however, variations exist among landraces with respect to drought tolerance. An experiment was therefore conducted to evaluate the performance of five bambara groundnut landraces: Black eye, Burkina, NAV 4, NAV Red and Tom, to drought and heat stress, at the Irrigation Company of Upper East Region (ICOUR) at Tono-Navrongo in the Upper East Region of Ghana. The experiment was arranged in a Randomized Complete Block Design with three replicates. The heat trial was irrigated once weekly to field capacity until crop maturity. The drought trial was irrigated once weekly until 30 DAS, after which irrigation ceased. Burkina, a landrace from Burkina Faso produced the highest pod yield of 1.2 t/ha under the heat treatment. Tom did not produce any pod yield. Under drought, Burkina exhibited the greatest root dry weight and leaf area at 120 DAS, and had the longest leaf area duration (LAD). Burkina exhibited bunch canopy architecture, while NAV 4, NAV Red, and Black eye had an intermediate canopy type and Tom a spreading type. Burkina proved the most drought and heat tolerant among the five landraces evaluated. Though a drought tolerant crop, temperatures beyond 38°C and low relative humidity can negatively affect pod yield of bambara groundnut even when irrigation is provided. It is important to test the performance of a crop under a new environment before money is invested into its production in that environment.

Key words: Bambara groundnut, drought, heat stress, irrigation, pod yield.

INTRODUCTION

Bambara groundnut (*Vigna subterranea* (L) Verdc.) is a crop, which is adapted to a wide range of conditions, and is popular with African farmers for its ability to yield on poor soils. The crop has been identified as a drought tolerant crop that can produce some yields where other crops, such as groundnut, fail (Harris and Azam-Ali, 1993). The crop is an indigenous African legume, which is mainly grown for food. Given this and its drought tolerance, bambara groundnut has the potential as a crop to provide food security in the dry areas of Africa. With the potential risk of drought associated with climate change, drought tolerance is likely to become even more important in African agriculture. Unfortunately, until recently, very little research has been done on the crop, it being described as underutilized and under researched. Unlike peanut and soybean, bambara groundnut is not a commercial crop because it has very low lipid content (Azam-Ali et al., 2001). Doku (1996) described the story

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of bambara groundnut in the following paradox; "The story of *V. subterranea*, until fairly recently, has been one of neglect, decline and relegation". He considered it a paradox that an indigenous African crop which is almost a complete food, drought tolerant, easy to cultivate and does not make much demand on the soil, would be given little research attention and, be described as a poor man's crop. Azam-Ali et al. (2001) also reported that until recently, bambara groundnut has been ignored by international agricultural scientists and funding agencies because of its status as a 'poor man's crop', grown for subsistence rather than money.

The Upper East Region of Ghana is one of the hottest regions in Ghana recording the highest temperatures in the country (Ghana Meteorological Services Report, 2007). The presence of a major irrigation project at Navrongo in the Upper East Region of Ghana enables the cultivation of some crops during the dry season. However, even with irrigation, high temperatures may affect the productivity of some plant genotypes. Reddy et al. (2003), in a review of physiological responses of groundnut (*Arachis hypogea* L.) to drought stress, reported that low rainfall and prolonged dry spells during the crop growth period are the main reasons for the low average yields in India. Dadson et al. (2005) reported that drought resistant cowpea genotypes, better suited to the Delmarva Region of the United States, could play an important role in filling the gap in the shortfall of yields and sustain crop production in this area.

Uarrota (2010) observed that reduction in cowpea growth observed as a result of water shortage may partly arise from poor nutrition. Comparing differences in soybean genotypes to drought, Angra et al. (2010) reported that water deficit during seed development considerably limited crop yield, with Genotype Bragg experiencing greater reduction in yield than PB 1, indicating differences in sensitivity to stress between the two genotypes. Vurayai et al. (2011) observed that growth in bambara groundnut reduced under water stress resulting in smaller leaf area which transpired less water, which they considered as a first line of defense against drought. Jongrungklang et al. (2008) observed that drought reduced total dry matter, pod yield and leaf area in peanut. Screening of tolerant spring barley genotypes to terminal heat stress, Bavei et al. (2011) observed that genotypes responded differently to different environmental conditions, suggesting the importance of evaluating genotypes under different conditions in order to identify the best genotype for a particular condition.

Food security in the Guinea savannah agro-ecology of Ghana faces a threat due to poor and erratic rainfall and the high temperatures during some parts of the year. However, the need to obtain crop varieties that are tolerant not only to drought but also heat stress cannot be overemphasised. Not much study however, has been undertaken to identify bambara groundnut genotypes tolerant to heat and drought in Ghana. The objective of this study was to evaluate the differences in response of five bambara groundnut landraces 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.

MATERIALS AND METHODS

This trial was conducted at Tono near Navrongo, on the field of the Irrigation Company of the Upper East Region of Ghana (ICOUR). The location is in the Guinea savannah agro-ecology of Ghana, and is one of the hottest regions in Ghana according to Ghana Meteorological data, 2007. Mean maximum monthly temperatures for the period of this study were; 38.7, 40.2, 37.6 and 34.7 degrees Celsius for February, March, April and May respectively. Total monthly rainfall for the site were 0.0 mm, Traces, 155.0 and 92.0 mm for February, March, April and May respectively. The region also experiences a unimodal rainfall (May-September). The high temperatures and the long spell of drought during the experiment were ideal conditions for the heat and drought trial.

Five bambara groundnut landraces: Burkina from Burkina Faso, Black eye NAV 4 and NAV Red from Navrongo and Tom from the Brong Ahafo Region of Ghana were evaluated under heat and drought conditions. The land was ploughed, harrowed and ridged. Soil samples were analysed to determine the NPK levels and soil nutrient levels were maintained at 50 kg/ha of N, 25 Kg/ha of P and 25 kg/ha of K. The soil type was a sandy loam. Plot size was 6 m x 6 m (13 rows and 31 hills). The design used was a Randomised Complete Block Design (RCBD) with three replicates. The heat trial was sown on the 10^{th} of February 2007 and irrigated once weekly to field capacity using furrow irrigation until maturity. Seeds for the drought trial were sown on the 11^{th} 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 5^{th} day to the 18^{th} 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 when fields were weedy. Plant height and canopy spread were measured using a ruler at 90 DAS, when the crops on the irrigated plots had almost attained full canopy cover.

Ten plants were randomly selected for each measurement at 20, 45, 60, 105 and 120 DAS. These days fell within the days to thinning and developmental stages like days to flowering pod initiation, physiological maturity and pod harvest, respectively. Ten plants within the central harvest area were not removed. They were used for the final harvest data. Leaf area was measured using a leaf area meter (Li-3100, USA). Plants were harvested using a hand fork. Roots were carefully removed and root dry weights were taken for the drought plot at 105 and 120 DAS. Plant dry weights were obtained by drying samples in an oven at 80^oC for 48 h.

Data analysis

Data were subjected to statistical analysis using the GENSTAT 12.1 (VSN International Ltd) edition. Treatment means were compared by the Least Significance Difference (LSD) at 5% probability level.

RESULTS

Tono heat trial

Leaf dry weight was significantly different at 45 DAS

Table 1. Leaf dry weight, plant height, canopy spread and pod dry weight for five bambara groundnut landraces at Tono (Heat trial).

Landrace	Leaf dry wt. (g/m^2) 45 DAS	Leaf dry wt. (g/m^2) 120 DAS	Plant height (cm)(90 DAS)	Canopy spread (cm)(90 DAS)	Pod dry weight (g/m^2) (120 DAS)
Black eye	11.36^{b}	123.00^{a}	20.45^{b}	38.15^{a}	48.70^{b}
Burkina	13.18^{b}	110.00^{a}	20.45^{b}	30.90^{b}	118.50^{a}
NAV 4	17.16^{ab}	138.00^{a}	21.32^{b}	39.95^{a}	54.00^{b}
NAV Red	12.54^{b}	104.00^{a}	22.52^{b}	36.55^{ab}	52.50^{b}
Tom	19.71^{a}	90.00^{a}	25.30^{a}	40.15^{a}	0.00^{c}
CV %	26.1	41.50	7.2	10.7	20.50

Figures in a column bearing the same letters are not significantly different (P=0.05).

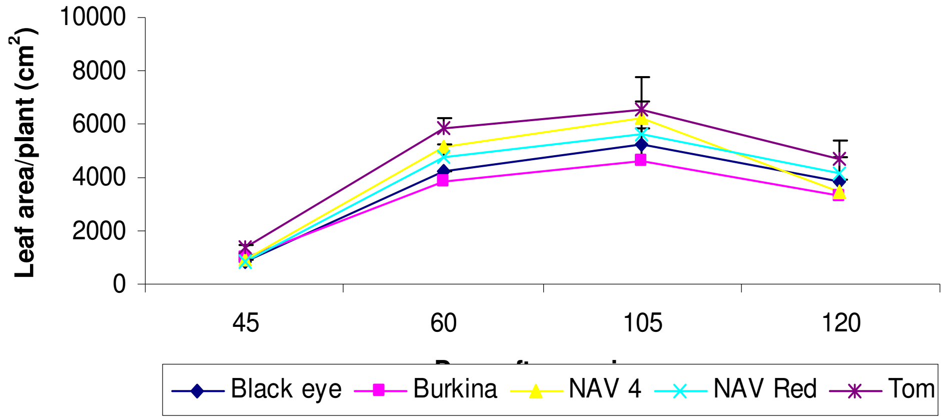

Figure 1. Leaf area per plant cm^2 against DAS (Tono heat trial). Bars indicate standard error of the mean.

($p<0.05$), with Tom having the highest leaf dry weight of 19.7 g/m^2. Black eye and NAV Red gave the lowest leaf dry weight of 11.4 g/m^2 at 45 DAS. No significant difference was subsequently observed in leaf dry weight among the landraces for the various sampled dates; however, Tom produced the least leaf dry weight (90.0 g/m^2) at 120 DAS (Table 1). Plant height was significantly different among the landraces ($p<0.05$). Significant difference was also observed among landraces with respect to canopy spread ($p<0.05$) (Table 1). Tom had the highest plant height and canopy spread of 25.30 and 40.15 cm, respectively. Burkina however, had the least plant height and canopy spread of 20.45 and 30.90 cm, respectively.

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 1).

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 this was not significantly different from the other landraces (Figure 1). Leaf area index followed a similar trend as the leaf area, with the highest leaf area index (6.5) being registered by Tom at 105 DAS. Tom maintained the highest leaf area index for all the sampled dates in the heat trial until harvest even though not significantly different from the other genotypes at 105 and 120 DAS (Figure 2).

Tono drought trial

No significant difference was observed among the landraces for canopy spread and plant height at 90 DAS. Tom however, maintained the highest canopy spread (37.7 cm) and plant height (21.2 cm) at 90 DAS. 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, 93.9 g/m^2 (Table 2). Root dry weight was significantly different at 120 days, with Burkina having the highest of 3.66 g m^{-2} ($p=0.017$) (Table 2).

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.

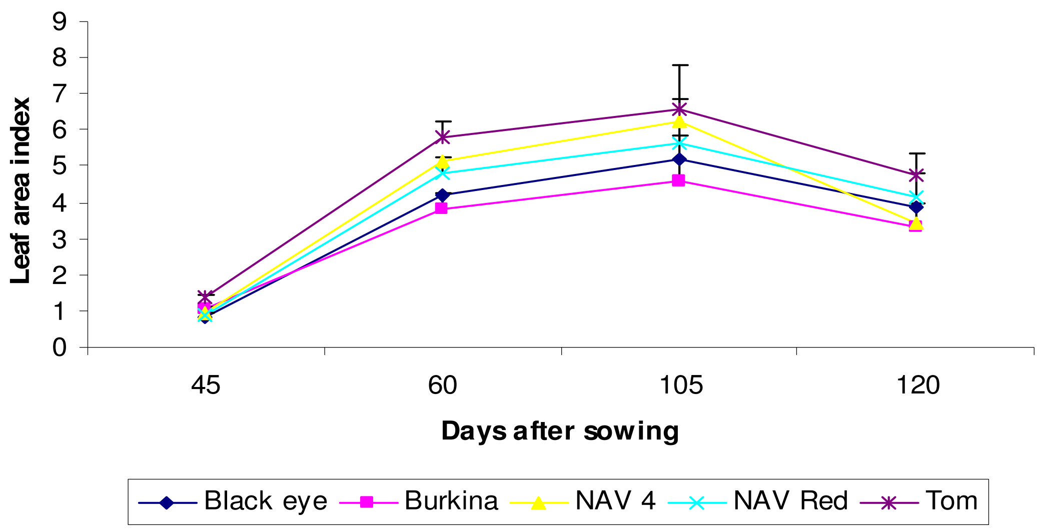

Figure 2. Leaf area index against DAS (Tono heat trial). Bars indicate standard error of the mean.

Table 2. The effect of drought on canopy spread, plant height, root and leaf dry weights of bambara groundnut landraces (Tono drought trial).

Landrace	Canopy spread (cm) 90 DAS	Plant height (cm) 90 DAS	Root dry weight ($g\ m^{-2}$)105 DAS	Root dry weight ($g\ m^{-2}$) 120 DAS	Leaf dry weight ($g\ m^{-2}$) 105 DAS	Leaf dry weight ($g\ m^{-2}$) 120 DAS
B. eye	35.73[a]	18.93[a]	2.01[a]	2.10[b]	142.00[a]	103.80[b]
Burkina	31.33[a]	17.00[a]	3.78[a]	3.66[a]	159.30[a]	196.30[a]
NAV 4	32.84[a]	19.40[a]	2.19[a]	2.30[b]	146.70[a]	106.40[b]
NAV Rd.	36.53[a]	19.80[a]	2.31[a]	1.84[b]	154.70[a]	132.70[b]
Tom	37.67[a]	21.20[a]	2.06[a]	2.17[b]	162.00[a]	93.90[b]
CV%	10.9	9.4	27.0	21.3	22.1	22.40

Figures in a column bearing the same letters are not significantly different (P=0.05).

Significant difference was observed in 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. At 120 DAS however, it was Burkina that had the significantly highest mean leaf area per plant (3692 cm^2). A similar trend was observed in the leaf area index (Figures 3 and 4). The highest leaf area indices were attained for the landraces at 105 DAS. This was reflected in the leaf dry weights, which were greatest for all the landraces except Burkina at 105 DAS. Leaf area index at 105 DAS was 4.7 for Tom and 2.5 for NAV Red. At 120 DAS, Burkina had the highest LAI of 4.5.

DISCUSSION

Tom appeared to have both greater canopy spread and plant height than any of the other landraces. Tom is a more spreading landrace while the other landraces are more bunched. Even though leaf dry weight was not significantly different after 60 DAS for the heat trial, Tom appeared to be the most vegetative landrace among all the landraces. Burkina expressed a more erect plant morphology. Pod yields were generally low among all the landraces for the heat trial with Tom producing no pods at all. Plants were sown on February 2007 when maximum mean temperature was high (38.7°C) and mean relative humidity low (20.7%). Furthermore, the monthly maximum mean temperature for March 2007 was 40.2°C and the minimum was 25.4°C. The monthly mean relative humidity for March was 28.3%. This period coincided with the commencement of flowering and it is possible that, despite the irrigation provided, the high temperatures and low relative humidity might have resulted in the drying up of flowers. This could have affected pollen germination and tube growth and resulted in poor pod yield. It is also possible that pegs got dried before penetrating into the soil to develop into pods. This finding is in agreement with that of Nielson and Hall (1985) and Patel and Hall (1990) who reported that the combination of high temperatures, drought and long days can slow down or

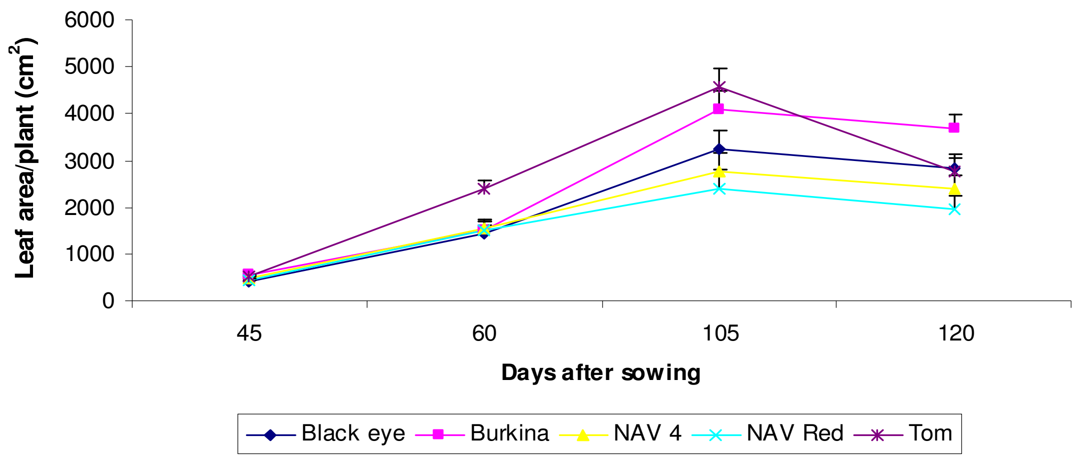

Figure 3. Leaf area per plant (cm^2) against DAS (Tono drought trial). Bars indicate standard error of the mean.

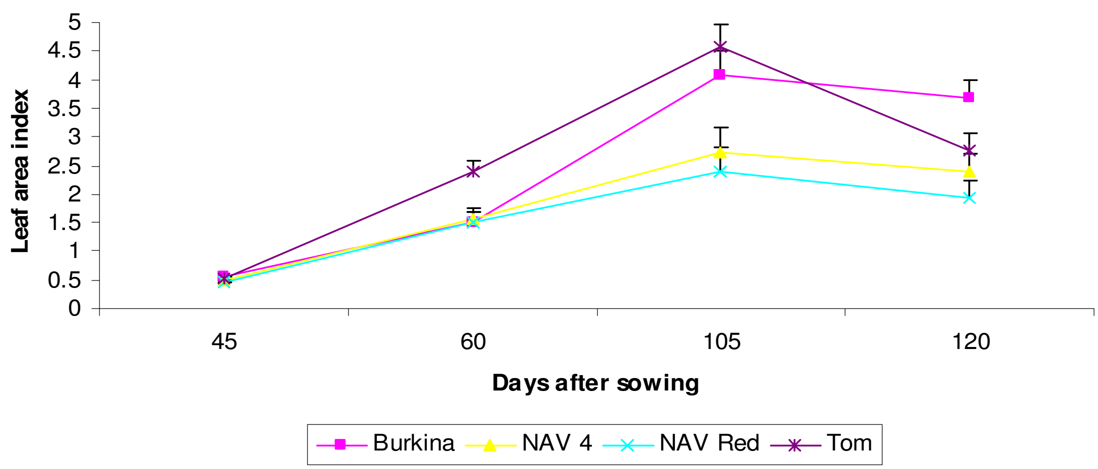

Figure 4. Leaf area index against DAS (Tono drought trial). Bars indicate standard error of the mean.

inhibit floral bud development, resulting in few flowers being produced and substantially reduce cowpea production. Doku and Karikari (1970) found that, where water could be provided, the dry season was better for the cultivation of bambara groundnut in Ghana. These findings were observed in a study conducted by the lead author in the Transition and Forest agro-ecologies in Ghana. In contrast, in the present study, in the Guinea savanna agro-ecology, the dry season cultivation of bambara groundnut under irrigation produced low yields. This was probably due to a combination of high temperatures and very low relative humidity during the experimental period.

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 have 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 drier environmental conditions than Ghana. It is therefore possible this landrace might have adapted to drier conditions than the other landraces. This attribute could have enabled Burkina to produce some pods under the harsh environmental conditions experienced in the course of this study. This finding also agrees with Malhotra and Saxena (2002) who 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.

Tom maintained the highest leaf area and leaf area index between 45 and 120 DAS in the heat trial. The highest leaf area was attained for all the landraces at 105 DAS, declining thereafter due to leaf senescence. Burkina maintained the lowest leaf area under the heat treatment 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.

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 the highest 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. Leaf area of all landraces in the drought experiment was lower than in the heat experiment. This could be due to reduced biomass production under drought compared to the heat treatment, which was irrigated.

Burkina maintained a significantly higher root dry weight under drought after 105 DAS. This attribute might have allowed the landrace to absorb the limited moisture available through the exploration of a greater soil volume or depth. This attribute might also have accounted for the landrace's ability to maintain longer leaf area duration under drought. Burkina might 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 has important effects on drought tolerance of bambara groundnut. Berchie et al. (2010a) observed in a study on yield of three early maturing bambara groundnut landraces at the CSIR-Crops Research Institute at Fumesua-Kuamsi, Ghana that Burkina is a medium maturing landrace. By contrast, Tom, is a landrace from Nkoranza in the Transition part of Ghana with a bimodal rainfall, which may not be as tolerant to drought as Burkina.

Even though data was not analysed, a few Burkina plants were able to produce some pods under the drought condition. This confirms the crop's 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. Berchie et al. (2010b) observed that farmers and consumers have a preference for white and cream coloured bambara groundnut landraces. Burkina was identified as having a cream seed colour, which gives the landrace an additional advantage in terms of consumer acceptability.

Vorasoot et al. (2003) observed that seed size of all peanut cultivars used in their study reduced with decrease in available water. They reported that 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 being aborted under severe water stress. Black eye, Burkina, NAV4 and NAV Red produced pod yields of over 4 t/ha in the Transition agro-ecology of Ghana under favourable conditions of moisture and relative humidity. However, these landraces produced low pod yields under the high temperature and low relative humidity during the period of this study. This agrees with Babiker (1989) who 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 the importance of testing the suitability of a crop to a range of environmental conditions prevailing at a particular site. In this study, despite the provision of irrigation, other dry season environmental conditions, namely heat and low humidity, proved unfavourable to the yield of the crop. Land preparation, seed, irrigation, labour and other agronomic interventions come at a cost and a farmer must be guaranteed of better returns for their investment in crop production.

Conclusion

Burkina, a landrace from Burkina Faso, a Sahelian country, was observed to be more tolerant to heat and drought in this study compared to Black eye, NAV 4, NAV Red and Tom. This drought tolerance may be a result of adaptation to environmental conditions in the source of the material. Even though bambara groundnut is a drought tolerant crop, temperatures beyond 38°C and low relative humidity can negatively affect pod yield even when irrigation is available. The high temperature 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 pod yield. It is also possible that pegs got dried before penetrating into the soil to develop into pods. Damage that can be caused by heat and drought can however, be minimized using a drought/heat tolerant genotype and Burkina in this study proved to be a good genotype.

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REFERENCES

Angra S, Kaur S, Singh K, Pathania D, Kaur N, Sharma S, Nayyar H (2010). Water-deficit stress during seed filling in contrasting soybean genotypes: Association of stress sensitivity with profiles of osmolytes and antioxidants. Int. J. Agric. Res., 5: 328-345.

Azam-Ali SN, Sesay A, Karikari SK, Massawe FJ, Aguilar-Manjarrez J, Bannayan M, Hampson KJ (2001) Assesing the potential of an underutilized crop- A case study using bambara groundnut. Exp. Agric., 37: 433-472.

Babiker AMA (1989). Growth, dry matter and yield of bambara groundnut (*Vigna subterranea*) and groundnut (*Arachis hypogaea*) under irrigated and droughted conditions. MSc Thesis, University of Nottingham, UK.

Bavei V, Vaezi B, Abdipour M, Kamali MRJ, Roustaii M (2011). Screening of tolerant spring barleys for terminal heat stress: Different importance of yield components in barleys with different row types. Int. J. Plant Breed. Genet., DO1: 10.3923/ijpbg.2011

Begemann F (1988). Ecogeographic Differentiation of Bambara Groundnut (*Vigna subterranea*) in the Collection of the International Institute of Tropical Agriculture (IITA). Wissenschaftlicher Fachverlag, Giessen, p. 153.

Berchie JN, Adu-Dapaah HK, Dankyi AA, Plahar WA, Nelson-Quartey F (2010a). Practices and constraints in bambara groundnut production, marketing and consumption in the Brong-Ahafo and Upper-East Regions of Ghana. J. Agron., 9: 111-118.

Berchie JN, Sarkodie-Addo J, Adu-Dapaah H, Agyemang A, Addy S, Asare E, Donkor J (2010b) Yield evaluation of three early maturing bambara groundnut (*Vigna subterranean* (L) Verdc.) landraces at the CSIR_Crops Research Institute, Fumesua-Kumasi, Ghana. J. Agron., 9(4): 175-179.

Craufurd PQ, Prasad PV, Summerfield RJ (2002). Dry matter production and rate of change of harvest index at high temperatures in peanut. Crop Sci., 42: 146-157.

Dadson RB, Hashem FM, Javiad I, Joshi AL, Allen TE, Devine J (2005) Effect of water stress on the yield of cowpea (Vigna unguiculata L. Walp) genotypes in the Delmarva Region of the United States. J. Agron. Crop Sci., 191: 210-217.

Doku, E.V., 1996. Problems and prospects for the improvement of bambara groundnut. Proceedings of the International Bambara Groundnut Symposium, July 23-25, University of Nottingham, UK, pp. 19-27.

Doku EV, Karikari SK (1970). Flowering and pod production of bambara groundnut (*Voandzeia substerranea* Thours) in Ghana. Ghana J. Agric. Sci., 3(1): 17-26

Falconer DS (1990). Selection in different environments: Effects on environmental sensitivity (reaction norm) and on mean performance. Genet. Res., 56: 57-70.

Ghana Meteorological Services Report (2007). Upper East Region of Ghana.

Harris D, Azam-Ali SN (1993) Implication of daylength sensitivity in bambara groundnut (*Vigna subtarranea*) production in Botswana. J. Agric. Sci., 120:75-78.

Jongrungklang N, Toomsan B, Vorasoot N, Jogloy S, Kesmala T, Patanothai A (2008). Identification of peanut genotypes with high water use efficiency under drought stress conditions from peanut germplasm of diverse origins. Asian J. Plant Sci., 7(7): 628-638.

Malhotra RS, Saxena MC (2002). Strategies for overcoming drought stress in chickpea. ICARDA Caravan Issue No. 17, December, 2002.

Nielson CL, Hall E (1985). Responses of cowpea (Vigna unquiculataL. Walp) in the field to high night air temperatures during flowering II. Plant responses. Field Crops Res., 10: 181-191.

Patel PN, Hall AE (1990). Genotypes variation and classification of cowpeas for reproductive responses to high temperatures under long photoperiod. Crop Sci., 30: 614-621.

Patterson RM, Weaver DB, Thurlow DL (1983). Stability parameters of soybean cultivars in maturity groups VI, VII and VIII. Crop Sci., 23: 569-571.

Reddy TY, Reddy VR, Anbumozhi V (2003). Physiological responses of groundnut (Arachis hypogea L.) to drought stress and amelioration: a critical review. Plant Growth Regul., 41: 75-88

Squire GR (1990). The Physiology of Tropical Crop Production. Cab International, Wallingford.

Uarrota VG (2010) Response of cowpea (*Vigna unguiculata* L. Walp) to water stress and phosphorus fertilization. J. Agron., 9(3): 87-91.

Vurayai R, Emongor V, Moseki B (2011) Effect of water stress imposed at different growth and development stages on morphological traits and yield of bambara groundnut (*Vigna subterranea* (L) Verdc.). Am. J. Plant Physiol., 6(1): 17-27.

Vorasoot N, Songsri P, Akkasaeng C, Jogloy S, Patanothai A (2003). Effect of water stress on yield and agronomic characters of peanut (*Arachis hypogaea* L.). Songklanakarin J. Sci. Technol., 25(3): 283-288.