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Physics and Chemistry of the Earth 29 (2004) 1029–1034
PHYSICS and CHEMISTRY of the EARTH
www.elsevier.com/locate/pce

Constitutive traits and selective indices of Bambara groundnut (*Vigna subterranea* (L) Verdc) landraces for drought tolerance under Botswana conditions

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Abstract

Constitutive traits of 12 landraces of Bamabra groundnut (*Vigna subterranea* (L) Verdc) were studied during the 1999/2000 and 2000/2001 at the Botswana College of Agriculture, for traits which relate to the crop's adaptation to drought. The objective was to estimate the degree of phenotypic and genotypic variation of traits whose selection would lead to earliness in maturity and drought tolerance through drought escape. The landraces showed significant diversity. Low environmental variability was recorded for days to maturity, root:shoot ratio, canopy spread, number of seeds per pod, 100-seed weight and shelling percentage. Genotypic correlation coefficients and path coefficient of number of pods per plant and seed size on yield were significantly high.

The results of this experiment indicate that, canopy spread, root:shoot ratio, 100-seed weight and number of seeds per pod are among parameters that could be used for indirect selection for drought tolerance in Bambara groundnut in Botswana and other areas where drought is a common occurrence.
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1. Introduction

Bambara groundnut (*Vigna subterranea* (L) Verdc) is an important pulse crop in semi-arid Africa (Doku and Karikari, 1971a; Poulter and Caygill, 1980; Brough and Azam-Ali, 1992; Karikari et al., 1999). It tolerates a wide range of agroecological conditions and displays traits conferring drought tolerance (Collinson et al., 1996). It is therefore a crop suited to low input cropping systems that makes it popular amongst farmers with limited resources. However, the problem of securing consistent, satisfactory yield in is of practical importance to the grower. Linnemann and Azam-Ali (1993) had associated low yields with poor germination and late establishment but later evidence by Squire et al. (1996) has indicated that variability in growth and development of individual plants is the main cause of low yields.

Bambara groundnut is predominantly autogamous (Doku and Karikari, 1971b). Therefore, it is amenable to genetic improvement through pure line or mass selection and other conventional breeding methods (Allard, 1960; Kang, 1994). In order to achieve rapid improvement through hybridization, large numbers of progeny will be required for a reasonable probability of recovering desirable recombinations from segregating populations. The success of such a breeding programme depends largely on the identification of landraces within segregating populations that would give high yields in pure stands. The characteristics contributing to yield are governed by polygenes on which the environment has modifying effects. Furthermore, yield is a complex character determined by a number of components that follow a developmental sequence. The organs developed earlier can have a profound influence on those produced

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1474-7065/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pce.2004.08.002

later (Adams, 1967; Grafius et al., 1976; Grafius, 1978; Hamid and Grafius, 1978). Therefore, selection for yield requires manipulation of quantitative characters that may be correlated among themselves as well as with others.

Characterisation of germplasm collected in Botswana (Appa Rao et al., 1986; DAR, 1990; Karikari, 1996) indicated that landraces are phenotypically heterogeneous but no genetic analysis of yield components has been made. There have been a few studies to correlate yield with agronomic characters in Bambara groundnut. One such study by Karikari (1972) indicated that, number of pods per plant was highly correlated with yield and the best criterion for selection. Linnemann (1994) has shown that an important factor affecting harvest index and crop duration is time of planting as a result of daylength sensitivity for pod initiation. These traits may thus serve as criteria for indirect selection for grain yield. However, the heritabilities of these traits are unknown.

The objective of this study was to estimate the degree of phenotypic and genotypic variation of quantitative characters influencing seed yield and their interrelationships and to determine the component characters whose selection would lead to earliness in maturity and hence drought escape.

2. Materials and methods

2.1. Location, rainfall and soil characteristics

The experiments were conducted in the field at the Botswana College of Agriculture garden at Sebele (24°33′S, 25°54′E, 994 m above sea level) during the 1999/2000 and 2000/2001. The climate of Sebele is semi-arid with an average annual rainfall (30-year mean) of 538 mm (Bekker and de Wit, 1991). Most rain falls in summer, which generally starts in late October and continues to March/April. Prolonged dry spells during the rainy season are common and rainfall tends to be localized (Baker, 1987). The soils are shallow, ferruginous tropical soils, mainly consisting of medium to coarse grain sands and sandy loams with a lower water holding capacity and subject to crusting after heavy rains. They are deficient in phosphorus, have low levels of mineral nitrogen and low organic matter content (Baker, 1987).

2.2. Landraces, cultural practices and experimental design

Twelve landraces representing the range in the Botswana collection were planted each season. Land preparation involved uniform cultivation to make a fine seedbed and application of basal fertilizer consisting of 26 kg N ha^{-1} from urea and 140 kg P_2O_5 ha^{-1} from single super phosphate. Sowing of seeds was done on the flat at a spacing of 30 cm within and 50 cm between rows. Each landrace occupied three rows on 1.5 m × 10 m plots and plots were replicated four times. Two seeds were sown per hill at 5 cm depth and seedlings thinned to one, 10 days after emergence. Irrigation was supplied to all plots to ensure that the soil was at field capacity from sowing until crop establishment (21 days after emergence). Thereafter, all plants were left to grow on moisture stored in the soil profile plus any rain that fell during the season.

2.3. Sampling size and data collection

Twenty plants (five from each replication), selected were analysed for yield components and other associated characters. The sampling sequence was pre-determined on a row/plant matrix to avoid bias in selecting plants. The final harvest consisted of a sample of 10 plants taken from the central area of each plot in contrast to the sequential harvests of five plants distributed throughout the plot. Maturity periods for each landrace were recorded. Plants were carefully dug out. Roots and pods were separated from the stem and leaves. Pods were said to be mature when the parenchymatous layer surrounding the embryo had disappeared and there were brown patches on the pods (Doku and Karikari, 1970). Pod numbers, number of seeds per pod and seed mass were recorded. Pods were dried for 7 days before shelling. Number of seeds per pod, total and 100-seed mass and shelling percentage were recorded.

2.4. Data analysis

The average response of data over the two years were analysed based on the method of McIntosh (1983). Variances and covariances for the characters combined were computed and correlation coefficients at the genotypic, phenotypic and environmental levels were calculated from mean values of the characters using the method of Miller et al. (1958). A path-coefficient analysis was done to discern the direct influence of yield components on seed yield and separation of the correlation coefficients into components of direct and indirect effects. The direct and indirect effects of root:shoot ratio, number of pods per plant, number of seeds per pod and 100-seed mass on yield were computed by the method of Dewey and Lu (1959).

3. Results and discussion

3.1. Growth parameters

The means and variability of growth parameters of the 12 landraces are shown in Table 1. Days to maturity varied between 80 and 165 days, but there was little dif-

Table 1
Average performance of nine quantitative characters of 12 Bambara groundnut landraces evaluated at Sebele, Botswana across two growing seasons (1999/2001)

Landraces	Grain yield ($kg\,ha^{-1}$)	100-Seed weight (g)	Shelling percentage	Dry matter (g)	Days to maturity	Days to emergence	Days to flowering	Canopy spread	Root/shoot ratio
BOTR	566.57	57.33	48.57	31.68	115.52	22.44	50.61	45.03	0.18
GABC	1208.28	80.17	40.27	41.74	88.50	17.50	41.38	22.80	0.26
DIPC	1477.36	77.22	46.06	40.81	113.25	14.25	38.20	27.04	0.24
TSHC	914.94	75.91	58.44	40.61	87.66	16.88	39.05	28.80	0.21
OM1	718.31	63.74	54.30	31.90	122.25	21.20	50.98	35.60	0.15
OM2	782.13	69.08	67.92	32.68	129.90	20.80	41.94	40.15	0.19
OM6	695.68	60.33	53.06	34.07	136.73	22.55	48.25	34.08	0.17
NTSR	449.20	67.26	65.19	36.33	131.25	22.38	57.10	43.09	0.22
DOR	407.25	51.51	61.50	38.61	164.50	23.45	51.88	46.61	0.16
JBPop2	630.45	61.33	42.31	32.44	130.75	15.55	45.36	38.55	0.18
JBPop4	805.27	64.28	50.56	31.90	133.80	15.20	46.25	38.00	0.21
BOTM	422.30	60.42	55.05	34.51	110.50	16.80	52.50	40.50	0.17
Mean	756.48	66.20	53.60	35.61	122.04	19.08	46.96	36.69	0.13
SD±	307.83	8.23	8.29	3.70	20.27	3.21	5.68	7.05	0.14
CV%	40.69	12.44	15.47	10.39	16.61	16.85	12.10	19.22	9.20
F test	**	**	**	*	*	ns	ns	ns	**

Key: BOTR = Botswana Red; GABC = Gaborone Cream; DIPC = Diphiri Cream; TSHC = Tshesebe Cream; OM1, 2 and 3 = Omotswasele 1, 2 and 3; NTSR = National Tested Seed Red; DOR = Dodoma Red; JBPop2; JBPop4 = Jackals Brown Popular 2 and 4; BOTM = Botswana Mottled. Significant at the 0.05 level (*), 0.01 (**) or not significant (ns).

Table 2
Descriptive statistics of 12 landraces of Bambara groundnut landraces in Botswana

Variable	Minimum	Maximum	Mean	SD	CV%
Maturity period (days)	88	165	110.0	20.27	16.61
Total pod number	24	202	56.0	97.0	57.7
Total pod weight (g)	16.4	137.5	82.0	10.7	13.0
Total seed weight (g)	6.58	89.28	58.0	27.0	40.0
Number of seeds per pod	1.00	3.00	1.08	0.07	7.00
100-Seed weight (g)	51.5	80.2	66.2	8.23	12.44
Shelling percentage	40	68	53.60	8.29	15.47

SD = standard deviation; CV = coefficient of variation.

ference in time of flowering as all landraces had some plants flowering within 40 days after sowing at a day-length of 13.5 h. Overall, grain yield were high and highly variable with 41% coefficient of variation (VC). This high CV was due to heterogeneity of the landraces (Table 2).

The best single plant selections yielded over 200 pods and had seed mass as high as 89 g. The regression of seed mass on pod mass was highly significant ($p < 0.0001$) and the slope gave an average shelling percentage of 53.40 (SE ± 0.05). There was phenotypic and therefore utilisable genetic variation for seed mass and number of seeds per pod. The number of seeds per pod varied between 1 and 3 with most pods producing one seed while 100-seed mass varied between 52 and 80 g. The genotypic variability of quantitative characters compared with their respective environmental variability indicated a higher degree of genotypic component in root:shoot ratio, 100-seed mass and number of seeds per pod, $CV_e > CV_g$ (Table 3).

Table 3
Performance summary, environmental (CV_e%) and genotypic (CV_g%) variability of characters in 12 Bambara groundnut landraces in Botswana

Character	CV_e%	CV_g%
Maturity period (days)	–	–
Shelling percentage	9.4	6.2
Total pod number	44.7	41.6
Total pod weight (g)	48.9	51.5
Total seed weight (g)	42.2	45.6
Number of seeds/pod	13.1	11.7
100-Seed weight (g)	14.6	12.9
Root:shoot ratio	15.3	14.8

The small environmental variability (<20%) for number of seeds per pod and seed size, suggests that selection for these two characters would be more effective than for others. The pod mass and seed mass have a high level of environmental variability (>40%). Therefore, other characters may be more useful in selection for yield improvement than these two.

Table 4
Genotypic correlations ($r_g \pm S_e$) of seed yield per plant and shelling percentage and yield components

Character	Seed yield per plant	Shelling percentage
Root/shoot ratio	0.398*** ± 0.018	0.296** ± 0.084
Shelling percentage	0.587*** ± 0.045	–
No. of seeds per pod	0.202* ± 0.091	0.553** ± 0.088
100-Seed mass (g)	0.415*** ± 0.080	0.518** ± 0.072
No. of pods per plant	0.764*** ± 0.127	0.312* ± 0.112
No. of seeds per plant	0.882*** ± 0.031	0.464*** ± 0.094
Pod mass per plant (g)	0.991*** ± 0.022	0.452*** ± 0.090

*, **, *** Significant at 5%, 1% and 0.1%, respectively.

3.2. Correlations

The selection of a genotype requires manipulation of many characters, which are correlated. Therefore, knowledge on both variability and interrelations among characters is essential for successful selection. Genotypic correlation coefficients indicated that the number of pods, number of seeds and seed weight per plant had profound influence on final seed yield (Table 4). The correlations of seed size (100-seed mass), shelling percentage and root/shoot ratio (which quantifies the crop's ability to absorb moisture), with seed yield were also positive and statistically significant but were not as high as the former group. The number of seeds per pod also showed positive but relatively low correlation with seed yield.

3.3. Importance of seed size

Seed size is an important crop yield index. In groundnut (*Arachis hypogea*) for example, seed size is an important quality criteria in the international market (Duncan et al., 1978; Pathirana, 1993). According to Pathirana (1993), a premium price is paid for cultivars with larger seeds in Japanese, European and American markets. Therefore, the positive correlations of seed yield with 100-seed mass gives a scope for further improvement of yield by selecting for this character. One hundred seed mass in Bambara groundnut has also been found to exhibit high heritability (Karikari, 2000). Indeed, in Botswana, a limited amount of farmer selection for larger seed size has taken place in the landraces with cream pericarp (Brink et al., 1996; Manthe et al., 2001).

3.3.1. Yield component compensation

Although in general, yield components individually correlated significantly with total yield, there can be negative relationships among yield components themselves due to compensation (Adams, 1967; Grafius et al., 1976). In improved crop species, the yield component compensation can be a barrier for further yield improvement. Yield components have a sequential developmental pattern (Karikari, 2000) and therefore their interrelations are of considerable interest. The genotypic correlations between number of pods per plant, number of seeds per pod and 100-seed mass were not significant (Table 5).

This is in contrast to the negative relationships commonly observed in field beans (*Phaseolus vulgaris*) (Adams, 1967; Duarte and Adams, 1972) and cereals; barley (*Hordeum vulgare*) (Bal et al., 1959; Grafius et al., 1976; Hamid and Grafius, 1978), wheat (*Triticum aestavum*) (Fonseca and Patterson, 1968), sorghum (*Sorghum bicolor*) (Ruben et al., 1998) and millet (*Pennisetum glaucum*) (Karikari and Mosekiemang, 2002). One reason for the absence of negative correlations between these yield components in the Bambara groundnut evaluated in this study is that much farmers' selection has been carried out for seed size, number of seeds per pod and seed yield as farmers claim that the landraces with cream pericarp yield higher and therefore such plants have been selected in favour of other colours (Brink et al., 1996; Manthe et al., 2001). Another reason may be the low planting density used as well as favourable agronomic factors such as adequate moisture and improved soil fertility resulting in the absence of intra-plant competition for these resources which are normally limited under traditional farmers' practices. Maphanyane (1994) made similar observations on intra-plant competition in groundnut in Botswana. Also, similar lack of negative correlations between yield components at wider than narrower spacing in soybean has been observed by Lehman and Lambert (1960), Ethredge et al. (1989), Board et al. (1990, 1997).

3.4. Path coefficient

The direct and indirect effects of yield components on seed yield are presented in Table 6. Path-coefficient analysis showed that number of pods per plant had the larg-

Table 5
Genotypic correlation coefficients between yield components in 12 Bambara groundnut landraces in Botswana

Character	No. of seeds per pod	100-Seed weight	Seed weight per plant
No. of pods/plant	0.205 ± 0.017	0.177 ± 0.014	0.764*** ± 0.014
No. of seeds/pod	–	0.105 ± 0.091	0.202** ± 0.088
100-Seed mass	–	–	0.415*** ± 0.081

, * Significant at 1% and 0.1% respectively.

Table 6
Path coefficients (direct effect, p) and indirect effects of yield components on seed yield in 12 Bambara groundnut landraces in Botswana

Type of relationship with seed yield	No. of pods per plant	No. of seeds per pod	100-Seed mass
Correlation coefficient (r)	0.764***	0.202**	0.415**
Direct effect (p)	0.621	0.061	0.286
Indirect effect by:			
No. of pods/plant	–	0.120	0.023
No. of seeds/pod	0.011	–	0.106
100-Seed mass (g)	0.132	0.021	–

, * Significant at 1% and 0.1% respectively.

est positive direct effect on seed yield. In all three parameters, direct effects (path coefficients) were lower than their respective correlation coefficients. The indirect effects were quite small and therefore did not contribute much to the correlation coefficients.

4. Conclusions and recommendations

In this study, path-coefficient analysis has been used to simultaneously capture the effects of intricate relationships among various yield traits in Bambara groundnut. The correlation coefficients obtained in earlier studies on landraces in Ghana (Karikari, 1972) and landraces in Botswana (Karikari, 2000) have been enhanced by partitioning them into direct and indirect effects for a set of a priori cause-and-effects interrelationships in Bambara groundnut.

The wide range of variability of quantitatively important characters offers good prospects for further yield improvement through recombination and selection. Root to shoot ratio, 100-seed mass and number of seeds per pod correlate positively with yield. These parameters are important selection criteria for earliness in maturity that enables the crop to escape drought. Early maturing landraces are desirable for growing in Botswana and other semi-arid areas in Africa where drought is of common occurrence.

Acknowledgments

The authors would like to express sincere gratitude to Dr. R.M. Sakia for his assistance in the statistical data analyses and Prof A. Panin for making useful suggestions in the draft manuscript.

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