Selection criteria for early maturing cowpea (*Vigna unguiculata* L. Walp.) genotypes in northern Ghana

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Abstract

Growth characteristics on which selection for seed yield could be based in early maturing cowpea were investigated in multilocational trials during the 1997 cropping season using representative samples of 14 cowpea genotypes. Th trial locations were Damongo, Manga, Nyankpala and Wa, representing the diverse agroecologies within northern Ghana. Differences in days to flowering between locations which affected timing and rates of subsequent physiological processes resulted in yield differences between locations. Cause-effect investigations of genotypic yield differences in each location using path analysis have shown that crop growth rate and harvest index are the two most important characteristics on which selection for seed yield could be based, irrespective of location. For the Sudan savanna ecology, the reliance on these two traits has the potential of developing dual-purpose cowpea varieties with high seed and biological yields. The efficiency of crop growth rate and harvest index in explaining the variability in seed yield assessed through regression analyses showed highly significant R_2 values ($P \leq 0.05$) for each location.

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Introduction

Early maturing cowpea varieties are important as sole crops in the northern savanna zones of Ghana. Reliance on these early maturing types has been with the aim of obtaining up to three crops within the monomodal rainy season. The crop is, however, rarely grown under optimum conditions as rate and time of specific developmental processes conditioned by location-specific conditions of temperature, rainfall and soil factors determine the final seed yield. High yielding cultivars developed in specific locations fail to show the same yield superiority in other locations due to the differential response of cultivars to the environment.

In the genetic improvement of a crop, two approaches, empirical and analytical, are commonly used. The empirical approach to the genetic improvement of a crop for a particular trait usually consists of selecting against attributes that adversely affect the trait whilst selecting for those that favour its expression (Hamblin, 1993). In the analytical approach, crop models or ideotypes are established for each specified environment which aims at increasing productivity in that specific location (Rodomiro & Langie, 1997). These ideotypes are often arrived at by relying on crop morphological and physiological characteristics. Thus, selection based on growth characteristics rather than on yield *per se* could be an effective pathway to maximize yield potentials of cowpea.

Research at identifying genetic attributes of cowpea which strongly influence seed yield have established that high yield potentials are associated with high harvest indices (Hall *et al.*, 1997a), increasing length of the seed filling period (Ranalli *et al.*, 1997), or high crop growth rates and high harvest indices (Marfo *et al.*, 1997). The authors established these relationships with the aid of correlation and regression analyses. However, correlation analysis could have detected significant associations that are not necessarily causal (Austin, 1993). Therefore, an effective statistical tool such as path analysis (Wright, 1934) should be used to describe direct and indirect effects of growth characteristics on the yield potential of cowpea.

The objectives of the study were (i) to determine the most effective growth characteristics affecting cowpea seed yield using representative samples of early maturing cowpea lines in four locations, and (ii) to establish whether the relative contributions of each established causal trait on seed yield would vary significantly depending on location.

Materials and methods

Fourteen early maturing cowpea genotypes, most of them developed at the International Institute of Tropical Agriculture (IITA), Nigeria, were grown at Damongo, Manga, Nyankpala and Wa during the 1997 cropping season. Damongo, Nyankpala and Wa are in the Guinea savanna zone whilst Manga is in the Sudan savanna ecology of Ghana. Damongo is located within latitute 09° 01' N and longitude 01° 36' W, 260 m above sea level. Manga is located within latitude 11°, 01' N and longitude 00° 16' W, 249 m above sea level. Nyankpala is located within latitude 09° 25' N and longitude 00° 58' W, 183 m above sea level. Wa is located within latitude 10° 04' N and longtitude 02° 30' W, 323 m above sea level. At each location the design used was a randomized complete block with four replications. Sowing was done at the spacing of 60 cm between rows × 20 cm within rows, with two plants per hill. Each plot was 4 m long with five rows. Data was collected on only the two inner rows.

Days to 50 per cent flowering, reproductive duration, crop and pod growth rates, biological and seed yields and harvest index were obtained for each of the plots at each location. The reproductive duration and growth rates were estimated as RD = DM - DFF, CGR = (BY + PY)/DM, and PGR = PY/RD, where RD = reproductive duration, DM = days from sowing to maturity, DFF = days from sowing to 50 per cent flowering, CGR = crop growth rate, BY= biological yield, PY = pod yield, PGR = pod growth rate, and SY = seed yield. The harvest idex (HI) was calculated as the ratio of the seed yield to the total above ground biological yield expressed as a percentage. The reproductive duration was estimated as the time from 50 per cent flowering to physiological maturity. The pod growth rate was defined as the increase in pod biomass per day.

Anaylses of variance were performed for the various data taken following a two-factor randomized complete block design with genotype and location as the factors. Treatment mean comparisons were made using Duncan's multiple range test when *F*-values were significant ($P \leq 0.05$). The contribution of each causal factor to seed yield was established by means of path analysis as follows:

$$\begin{vmatrix} r_1 \\ r_2 \\ r_N \end{vmatrix} = \begin{vmatrix} 1 & r_{12} \cdots\cdots r_{1N} \\ r_{12} & 1 \cdots\cdots r_{1N} \\ r_{1N} & r_{2N} \cdots\cdots 1 \end{vmatrix} \times \begin{vmatrix} P_1 \\ P_2 \\ P_N \end{vmatrix}$$

The r_i are the correlation coefficients between the dependent variable (seed yield) and its component traits r_{ij} are the correlation, coefficients between the component traits and the P_i are the path coefficients. If X is defined as the column vector for r_i, Y as the correlation matrix and Z as the column vector of path coefficients, then X = YZ. The path coefficients were calculated by solving the equation $Z = Y^{-1}X$. The residual (ε) for each analysis was calculated as

$$\varepsilon = [1-(P_1^{\,2} + P_2^{\,2} + \ldots\ldots P_N^{\,2} + 2r_{12}P_1P_2 + \ldots\ldots 2r_{1N}P_1P_N + \ldots 2r_{(N-1)N}P_{N-1}P_N)]^{1/2}$$

Regression analysis

Seed yield was regressed on crop growth rate and harvest index for each of the locations according to the equation $y = c + \alpha X_1 + \beta X_2$, where y = seed yield, X_1 = harvest index, X_2 = crop growth rate, and C = intercept.

Results and discussion

Climatic differences between the locations during the study period were as follows: Damongo received 380 mm of rain with a mean temperature ($T_{min/max}$ °C) of 20.2/30.4. Manga received 410 mm rain with a $T_{min/max}$ °C of 23.4/32. At Nyankpala, total rainfall received was 495.5 mm with a $T_{min/}$

$_{max}$°C of 22.6/31. Rainfall and temperature values were not available for Wa.

Significant differences were observed between genotypes and between locations for all the traits studied except for genotypic differences in biological yield (Table 1). Flowering occurred earliest in IT93K-2045-29 and IT93K-634 at all locations. There was significant delay in flowering at Nyankpala and Manga compared to Wa and Damongo with a corresponding significant decrease in reproductive duration at Nyankpala and Manga compared to Wa and Damongo (Fig.1). These location effects could be important causes of yield differences between locations, as evidenced by the significant r^2 values ($P \leq 0.05$) between the mean grain yield of locations and the days taken to 50 per cent flowering and reproductive duration. Hall *et al* (1997b) noted that in locations where environmental factors act to shorten the reproductive duration, seed yield is reduced in proportion owing to the reduced time available for dry matter partitioning into seeds.

TABLE 1

Analysis of Variance of Various Cowpea Traits Studied

Parameter[δ]	*Probability level*			*Mean*
	Location (L)	*Genotype (G)*	*L × G*	
DFF	**	*	NS	45.0
DR (days)	**	*	*	23.0
CGR (kg/m²/day)	**	*	**	78.0
PGR (kg/m²/day)	*	**	*	83.2
BY (t/ha)	**	NS	*	3.64
SY (t/ha)	*	*	*	1.20
HI	**	**	**	22.4

* Significant at 5% ; ** Significan at 1%; NS Not significant
[δ]Abbreviations defined under Materials and methods

Seed yield response of the genotypes to increasing reproductive duration was, however, not significant for all locations (Table 6). The path coefficient analyses showed weak direct effects of days to 50 per cent flowering and reproductive duration on seed yield (Table 7). The indirect effects of each of these two traits through the other (on seed yield) were negative for all locations (indirect effects not shown). In addition, almost all the indirect effects of other independent traits through these two traits were negative. These illustrate that in these ecologies, where the trials were conducted, selection for increasing length of the reproductive period would not be effective in increasing seed yield. Marfo *et al.* (1997) reported non-significant associations between reproductive duration and seed yield in a range of cowpea varities evaluated in northern Ghana.

Significant genotype × location interaction were obtained for all traits except for number of days to 50 per cent fflowering (Table 1). The significant genotype × location interaction for seed yield may be mainly due to the lower yields of Sul × 518 and IT89KD-374-56 at Damongo compared with other

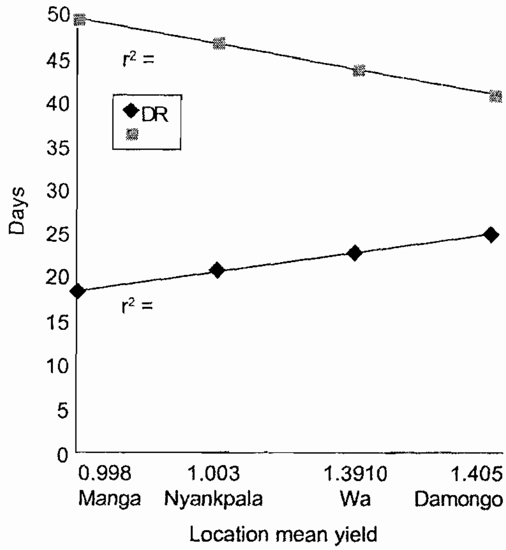

Fig. 1. Location effects on the mean number of days to 50% flowering (DFF) and reproductive duration (DR)

TABLE 2

Growth and Yield Characteristics of 14 Early Maturing Cowpea Genotypes Tested at Damongo

Genotype	*Days to 50% flowering*	*Reproductive duration (days)*	*Crop growth rate (kg/ha/day)*	*Pod growth rate (kg/ha/day)*	*Biological yield (t/ha)*	*Seed yield (t/ha)*	*Harvest index (%)*
IT87D-885	42	26	63.6	78.1	2.29	1.35	31.2
Vallenga	42	22	90.3	124.3	3.05	1.96	33.9
IT87D-1951	42	26	68.2	85.1	2.42	1.25	26.9
IT89KD-374-57	45	24	66.0	81.2	2.60	1.21	26.5
SuI × 518	43	26	72.8	72.9	3.13	1.15	22.8
IT87D-829-5	46	24	94.2	110.7	3.75	1.52	23.7
IT87D-719	45	24	105.3	99.8	4.87	1.39	19.1
IT87D-879-1	43	25	95.7	121.9	3.46	2.04	31.4
Benglia	44	21	61.8	86.8	2.19	1.21	26.4
IT92KD-370	43	26	79.3	77.1	3.46	1.17	21.3
IT × P-257	46	23	76.2	87.2	3.26	1.26	23.9
IT86D-719	44	24	95.7	96.6	4.19	1.55	24.1
IT93K-2045-29	40	24	90.7	93.3	3.57	1.34	23.1
IT93K-634	40	24	94	87.9	3.91	1.29	21.4
Mean	43	24	82.4	93.1	33.0	1.41	25.4
CV (%)	2.2	2.1	17.4	21.8	29.7	21.5	3.4
LSD $(P \leq 0.05)$	14	1.1	16.2	23.5	1.2	0.39	1.6

TABLE 3

Growth and Yield Characteristics of 14 Early Maturing Cowpea Genotypes Tested at Manga

Genotype	*Days to 50% flowering*	*Reproductive duration (days)*	*Crop growth rate (kg/ha/day)*	*Pod growth rate (kg/ha/day)*	*Biological yield (t/ha)*	*Seed yield (t/ha)*	*Harvest index (%)*
IT87D-885	50	19	57.4	85.0	2.34	0.94	23.7
V allenga	50	16	60.8	97.7	2.45	0.83	20.8
IT87D-1951	48	19	77.8	98.7	3.49	1.20	22.3
IT89KD-374-57	53	17	65.5	122.5	2.50	1.29	26.9
SuI × 518	49	20	73.2	93.8	3.18	1.35	26.8
IT87D-829-5	53	16	52.8	87.9	2.24	0.94	25.7
IT87D- 719	51	19	58.8	76.7	2.66	1.04	25.3
IT87D-879-1	50	19	84.6	117.9	3.59	1.51	25.9
Bengpla	48	16	36.4	48.8	1.51	0.47	20.5
IT92KD-370	51	19	55.1	79.5	2.34	1.15	29.7
IT × P -257	48	20	58.2	65.1	2.66	0.73	18.4
IT86D-719	50	20	62.5	80.8	2.76	0.99	22.6
IT93K-2045-29	44	25	55.9	45.8	2.71	0.68	17.6
IT93K-634	44	24	44.4	45.6	1.93	0.73	24.1
Mean	49	19	60.2	81.8	2.6	0.99	23.6
CV (%)	2.2	2.1	17.4	21.8	29.7	21.5	3.4
LSD $(P \leq 0.05)$	1.4	1.1	16.2	23.5	1.2	0.39	1.6

TABLE 4

Growth and Yield Characteristics of 14 Early Maturing Cowpea Genotypes Tested at Nyankpala

Genotype	*Days to 50% flowering*	*Reproductive duration (days)*	*Crop growth rate (kg/ha/day)*	*Pod growth rate (kg/ha/day)*	*Biological yield (t/ha)*	*Seed yield (t/ha)*	*Harvest index (%)*
IT87D-885	46	22	124.6	123.1	4.97	1.74	22.9
Vallenga	46	20	109.6	96.1	5.31	1.25	17.0
IT87D-1951	46	22	85.7	80.1	4.07	1.14	19.3
IT89KD-374-57	49	21	81.9	86.6	3.92	0.99	17.1
Sul ×518	46	20	79.4	80.3	3.79	1.01	18.4
IT87D-829-5	47	21	92.3	80.0	4.60	1.15	16.0
IT87D-719	47	21	106.3	89.4	5.35	0.96	11.8
IT87D-879-1	49	19	102.9	100.3	5.09	1.17	19.2
Bengpla	45	20	64.2	30.4	4.57	0.39	7.4
IT92KD-370	46	22	79.6	67.5	3.93	0.82	9.8
IT × P-257	47	21	76.9	88.9	3.36	0.96	15.4
IT86D-719	47	20	119.5	101.8	7.09	1.06	12.7
IT93K-2045-29	43	22	74.9	58.4	3.58	0.65	9.4
IT93K-634	42	23	90.5	56.8	4.58	0.76	11.2
Mean	46	21	92.1	75.0	4.6	1.0	14.8
CV (%)	2.2	2.1	17.4	21.8	29.7	21.5	3.4
LSD ($P \leq 0.05$)	1.4	1.1	16.2	23.5	1.2	0.39	1.6

TABLE 5

Growth and Yield Characteristics of 14 Early Maturing Cowpea Genotypes Tested at Wa

Genotype	*Days to 50% flowering*	*Reproductive duration (days)*	*Crop growth rate (kg/ha/day)*	*Pod growth rate (kg/ha/day)*	*Biological yield (t/ha)*	*Seed yield (t/ha)*	*Harvest index (%)*
IT87D-885	41	27	74.6	79.1	2.94	1.48	27.2
Vallenga	40	23	79.1	88.3	3.10	1.35	25.7
IT87D-1951	40	27	73.9	79.1	2.96	1.49	27.4
IT89KD-374-57	43	24	81.7	99.8	3.08	1.64	30.4
Sul ×518	40	28	73.0	78.1	2.77	1.54	26.6
IT87D-829-5	42	24	83.4	95.5	3.21	1.50	27.1
IT87D- 719	43	25	80.3	91.7	3.17	1.39	24.3
IT87D-879-1	42	25	76.9	91.7	3.01	1.56	28.3
Bengpla	40	27	71.0	65.6	2.85	1.07	21.9
IT92KD-370	46	24	69.5	73.8	2.85	1.24	24.0
IT × P-257	41	25	74.3	77.7	2.97	1.25	23.8
IT86D-719	41	28	78.3	80.0	3.16	1.50	27.9
IT93K-2045-29	36	27	84.8	83.9	3.08	1.32	24.1
IT93K-634	35	26	82.2	73.1	3.11	1.17	21.3
Mean	41	26	77.4	82.7	3.02	1.39	25.7
CV (%)	2.2	2.1	17.4	21.8	29.7	21.5	3.4
LSD ($P \leq 0.05$)	1.4	1.1	16.2	23.5	1.2	0.39	1.6

TABLE 6

Correlation Coefficients between Growth Traits and Seed Yield for 14 Early Maturing Cowpea Genotypes Tested at Four Locations in Northern Ghana

	Location			
Growth trait	*Damongo*	*Manga*	*Nyankpala*	*Wa*
Days to 50% flowenng	-0.055	0.503	0.415	0.283
Reproductive duration	-0.208	-0.417	-0.038	-0.038
Harvest index	0.627*	0.704*	0.885*	0.952*
Biological yield	0.217	0.752*	0.285	0.301
Crop growth rate	0.551*	0.858*	0.774*	0.333
Pod growth rate	0.927*	0.844*	0.917*	0.770*

*Significant at ($P \leq 0.05$)

TABLE 7

Direct Effects of Growth Traits on Seed Yield as Estimated from Path Analysis for 14 Cowpea Genotypes Tested at Four Locations in Northern Ghana

	Location			
Growth trait	*Damongo*	*Manga*	*Nyankpala*	*Wa*
Days to 50% flowenng	0.035	0.035	0.080	0.178
Reproductive duration	0.062	0.086	0.077	0.245
Harvest index	0.690	0.483	0.501	0.757
Biological yield	0.179	0.035	-0.279	-0.199
Crop growth rate	0.357	0 593	0.728	0.421
Pod growth rate	0.350	0.132	0.012	0.172
Residual	0.279	0.088	0.179	0.093

locations, and the poor yield of Vallenga at Manga compared with it's performance at the other locations. These differences are attributable to the differential performance of these genotypes with respect to the crop growth rate and harvest index at the various locations. While Sul × 518 and IT89KD-374-56 maintained high crop growth rates and high harvest indices at Manga and Wa and were among the top seed yielding lines at these locations (Tables 3 and 5), they were among the lowest yielding lines at Damongo (Table 2) due to low crop growth rates (coupled with a low harvest index for Sul × 518).

Correlation and path coefficient analysis for each location have established a large genotypic dependence of seed yield on the crop growth rate and the harvest index (Tables 6 and 7). The crop growth rate and harvest index had significant positive correlations with seed yield in all locations except the relationship between seed yield and crop growth rate at Wa, due to the negative indirect effects through biological yield and days to 50 per cent flowering. The path coefficient analyses showed that crop growth rate and harvest index maintained the largest positive direct effects on seed yield. Selection for high crop growth rate and harvest index should be adequate for obtaining high seed yields in any particular location.

Biological yield and crop growth rate were relatively lower for Manga and only at this location was a significant correlation obtained btweeen seed yield and the biological yield (Table 6). Also, the indirect effects of crop growth rate and harvest index on seed yield through biological yield were positive for only this location. These suggest that in the Sudan savanna ecology, selection based on high crop growth rates and harvest indices would lead to the development of dual-purpose cultivars high in seed and biological yields. The top two yielding lines in this ecology produced high biological yield of over 3.1 t/ha. As expected, high biological yields in the other three locations affected seed yield negatively. The direct effects of biological yield on seed yield were negative at Nyankpala and Wa. Also, the indirect effects of harvest index through biological yield were negative for all three locations (Damongo, Nyankpala and Wa), indicating that seed yield reduction was due to a decrease in the proportion of dry matter partitioned for seed filling, expressed as harvest index.

Biological yield and crop growth rate were relatively lower for Manga and only at this location was a significant correlation obtained between seed yield and the biological yield (Table 6). Also, the indirect effects of crop growth rate and harvest index on seed yield through biological yield were positive for only this location. These suggest that in the Sudan savanna ecology, selection based on high crop growth rates and harvest indeces, would lead to the development of dual-purpose cultivars high in seed and biological yields. The top two yielding lines in this ecology produced high biological yield of over 3.1 t/ha. As expected, high biological yields in the other three locations affected seed yield negatively. The direct effects of biological yield on seed yield were negative at Nyankpala and Wa. Also, the indirect effects of harvest index through biological yield were negative for all three locations (Damongo, Nyankpala and Wa), indicating that seed yield reduction was due to a decrease in the proportion of dry matter partitioned for seed filling, expressed as harvest index.

The path coefficient analyses have shown that the highly significant correlations between seed yield and pod growth rate are not true direct associations as the direct effects of pod growth rate on seed yield are mostly weak for all locations. The absence of inflated direct effects exceeding one in the path analyses indicates that multicolinearity was negligible or absent, and that numerical estimates of independent trait effects on seed yield reflect a true causal relationship. The low values for the residuals also indicate that most of the variation in seed yield has been accounted for by the independent traits used in the study.

The regression analyses showed highly significant ($P \leq 0.001$) portions of the total variation in seed yield explained by the crop growth rate and harvest index, with the efficiency of the equations ranging from 94 per cent at Nyankpala to 99 per cent at Manga (Table 8). The partial regression coefficients associated with both parameters were highly significant ($P \leq 0.001$) for each location. The results further illustrate that seed yield improvement in early maturing cowpea would be effective if selection is made for a rapid crop growth rate and high harvest index in each target ecology.

Conclusion

The results of the study indicated that high seed yield largely depends on a rapid crop growth rate and high harvest index suggesting that an ideal

TABLE 8

Parameters of the Regression of Harvest Index and Crop Growth Rate on Seed Yield

Dependent trait	*β values for independent trait*		*Intercept*	R^2	*Probability*
Seed yield	*Harvest index*	*Crop growth rate*			
Damongo	0.055	0.015	-1.26	0.96	***
Manga	0.044	0.017	-1.07	0.99	***
Nyankpala	0.046	0.079	-0.44	0.94	***
Wa	0.058	0.070	-0.77	0.95	***

*** Significant at 0.1%

cowpea cultivar for the northern savanna ecologies of Ghana should perform well in these two traits. With the existence of genotype × location interaction for harvest index and crop growth rate, it is important that selecting for these two traits should be done in the target ecologies for the crop; more so since yield differences between locations do not necessarily have the same underlying causes as genotypic yield differences at a particular location. Yield differences between locations were due to location-specific modification of the time genotypes took to initiate flowering which influenced the timing and duration of subsequent physiological processes.

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