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Correlation and Path Coefficient Analyses of Yield and Yield Components in Pigeonpea

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Abstract: Growth and yield components on which selection for high grain yield could be based among early maturing pigeonpea varieties were investigated in field trials conducted in the Guinea savannah zone of Ghana. Ten genotypes were tested during the 1996, 1997 and 1998 cropping seasons for their yield performance. The trial for each year was arranged in a randomised complete block design with 4 replications. Significant differences ($P \leq 0.05$) were found among genotypes for grain yield for each of the years. Relative yield ranking of genotypes did not shift significantly between years. Investigation of yield differences between genotypes using phenotypic correlation and path coefficient analyses have shown that crop growth rate, harvest index and number of pods per plant are the most effective secondary traits to select for high grain yielding varieties in Northern Ghana. A significant positive linear correlation ($P \leq 0.05$) was found between each of these traits and grain yield and between pairs of traits. Each of these traits showed a large positive direct effect on grain yield as well as large positive indirect effects through each other on grain yield.

Key words: Pigeonpea, path coefficient analysis, crop growth rate, harvest index

INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp) is the third most important food legume in Ghana and the bulk of pigeonpea production occurs in the Guinea savannah ecology. Although it is usually a minor crop in the traditional crop mixtures, it is an important component of the traditional farming systems with its fodder creating forage potential for domestic livestock during the critical dry months of December - May. The grains are consumed in many households as green peas or dry grain. In its major production areas, a considerable quantity of the crop is grown on homesteads, borders and hedges, a factor which tends to underestimate its production area and production figures. The main constraint to its widespread production has been that of low yields, with average farm-level yields estimated at 120 kg ha^{-1} (Runge-Metzger and Diehl, 1993). This is the result of the use of low-yielding long-duration landraces, damage from pod-sucking bugs and soils of low fertility. The role the crop plays in the traditional farming systems makes it imperative that research is focussed on identifying or developing early maturing genotypes with high grain and vegetative biomass yields to be integrated into organised and compatible cropping systems.

To ensure high and stable yields and to increase the crop's production areas, current research efforts are directed at determining the traits that will increase the crop's adaptation to its harsh production regions. An understanding of the quantitative effects of yield components on grain yield of pigeonpea and their mutual compensatory effects could provide options for formulating selection indices in improvement of the crop. These selection indices have often been arrived at by relying on crop morphological and physiological characteristics (Rodomiro and Langie, 1997). Earlier work done in other ecogeographical regions to identify genetic attributes of pigeonpea which strongly influence grain yield have found high yield to be associated with large number of pod clusters per plant (Singh and Malhotra, 1973; Veeraswany *et al*., 1973), or high numbers of secondary branches per plant and a high harvest index (Sandhu *et al*., 1995) or high crop growth rate and total dry matter production (Nam *et al*., 1998) as reliable and stable predictors of grain yield. With the existence of genotype x environment interaction it is necessary to establish which traits will be most important for specific ecological zones (Lin *et al.,* 1986)

The objectives of this study were to define the relationships of morphological and physiological traits affecting grain yield in early maturing pigeonpea by means of path coefficient analysis so as to determine the most effective traits for selecting high grain yielding pigeonpea genotypes in northern Ghana.

MATERIALS AND METHODS

Study location and site features: During the 1996, 1997 and 1998 cropping seasons, field evaluations of the performance of 10 pigeonpea genotypes were conducted at Nyankpala in the Guinea Savannah zone of Ghana. The site is located in latitude 9°25′4″N and longitude

$0°58^{I}42^{II}$W; 183 m above sea level. The zone is characterised by erratic rainfall and poor soils. The topsoil has a coarse loamy structure and is locally referred to as the Nyankpala series, derived from sandstone or shale and falls into the Chromic Luvisol group (FAO classification). Organic matter content is generally low, usually less than 1%, cation exchange capacity between 3-4 $cmol_c\ kg^{-1}$. Average N, P and K contents are 400 ppm, 2-3 ppm and 60 ppm, respectively. The soils are generally of acidic reaction (pH of 5.5-6.0).

Planting materials: Ten determinate short duration (95 - 100 days) pigeonpea genotypes were used in the study. The materials were received from the International Crops Research Institute for the Semi-Arid Tropics, (ICRISAT), Sahelian centre, Niger.

Land preparation and experimental layout: The land for each year has been under a maize-groundnut rotation. Land preparation was done by tractor ploughing and harrowing. For each year, planting followed a randomised complete block design (RCBD) with 4 replications. Each plot measured 3.2 x 5.6 m. Planting was done at three seeds per hill at a spacing of 80 cm between rows and 40 cm within rows in 5 row plots. Plants were thinned to 2 seedlings per hill after crop establishment.

Planting and crop management: Planting for each year was done during the second week of July. No soil agro-chemicals were applied. The crop was given two insecticidal sprays with Karate® (lambda cyhalothrin) at a rate of 20 g active ingredient per ha at first flower initiation and during peak pod initiation. Hand weeding of the plots was carried out using hoes at two different times during the growing seasons.

Environmental measurements: Mean daily minimum and maximum temperatures and rainfall amounts were recorded during the study period at the Savanna Agricultural Research Institute (SARI) meteorological main station at Nyankpala, 2 km away from the location of the trial.

Plant measurements: The field was monitored daily from day of sowing to record the number of days from sowing to first flower initiation, days to 50% flowering and days to first macroscopic pod initiation on 20 tagged plants on each plot, from the two middle rows. The number of days to 95% maturity of pods was also noted for each plot. All pods on the twenty tagged plants were counted for each plot at 95% maturity to obtain the mean number of pods per plant. At 95% maturity, all plants in the 3 middle rows of each plot were cut at ground surface and pods removed from the vegetative biomass into paper envelopes. All samples (pods and vegetative biomass) were placed in a ventilated drying oven set at 70°C immediately after separation of pods and vegetative biomass. Dry weights were taken after a constant weight was achieved. Pods were threshed and the grains weighed.

Mean growth rates of the crop and pods were estimated for each plot with the equations described by Williams and Saxena, (1991).

$$\text{Crop growth rate (CGR)} = \frac{\text{Total yield of above ground parts (kg ha}^{-1})}{\text{Days from sowing to maturity}}$$

$$\text{Pod Growth Rate (PGR)} = \frac{\text{Pod yield (kg ha}^{-1})}{\text{Reproductive duration (days)}}$$

Where, the reproductive duration is estimated as difference between days from sowing to maturity and days from sowing to appearance of first macroscopic pods. The harvest index was computed as the ratio of the weight of grains divided by the total above ground weight of plants, expressed as a percentage. For each plot, 100 grains were randomly selected and weighted to obtain the mean weight of 100 grains.

Statistical analyses: Analyses of variance were computed for each set of data taken in 1998 separately following a RCBD. Data on grain yield and days to 50% flowering was then grouped over the three-year period and analysed following a two-factor RCBD with genotypes and years 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 grain yield was established by means of path analysis (Dewey and Lu, 1959) as follows:

$$\begin{vmatrix} R_1 \\ R_2 \\ rN \end{vmatrix} = \begin{vmatrix} 1 & r12......r1N \\ r12 & 1......r1N \\ r1N & r2N......1 \end{vmatrix} \times \begin{vmatrix} P_1 \\ P_2 \\ P_N \end{vmatrix}$$

The r_i are the phenotypic correlation coefficients between the dependent variable (grain 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 (E_r) for each path analysis was calculated as

$$E_r = [1 - (P_1^2 + P_2^2 + ...P_N^2 + 2r_{12}P_1P_2 + ...2r_{1N}P_1P_N + ...2r_{(N-1)N}P_{N-1}P_N)]^{1/2}$$

Based on the results of the Genotype x Year interaction after performing the ANOVA, only the 1998 data was used to calculate the correlation and path coefficients.

RESULTS

The climatic data at the study location (Table 1) during the growing periods indicate that 1997 was the most favourable year for grain yield production in pigeonpea. The 1996 and 1998 growing seasons recorded much lower rainfall totals and higher mean night and day temperatures compared with the 1997 growing season.

The combined analysis of variance for grain yield and days to 50% flowering for the 3 years shows significant genotype and year effects for grain yield and days to 50% flowering, (Table 2). Genotype response to the different years was the same among genotypes for both number of days to 50% flowering and grain yield as indicated by the non-significant genotype x year interaction for both traits. No significant differences were found between the grain yields of the 1996 and 1998 growing season. The 1997 cropping season recorded higher grain yields over those of the other two years. ICPL-89008 consistently produced the highest grain yields in each of the three years.

The analysis of variance for the 1998 set of data showed no significant differences ($P \leq 0.05$) between genotypes for reproductive duration, hundred grain weight and number of primary branches per plant, (Table 3). There were significant differences between genotypes for days to 50% flowering number of pods per plant, fodder yield, harvest index, mean crop and pod growth rates. ICPL-89008 produced the highest fodder yield although this level of yield was not significantly different from those of ICPL-151 and ICPL-88075. The genotypes ICPL-89008 and 88075 were the best in terms of number of pods per plant and mean crop and pod growth rates.

As there was no significant genotype x year interaction for grain yield, investigation into the observed grain yield differences was carried out using the 1998 data only by means of phenotypic correlation and path coefficient analyses, (Tables 4 and 5; Fig. 1).

Grain yield and days to 50% flowering: Significant positive correlation ($P \leq 0.05$) was obtained between the number of days to 50% flowering and grain yield. However, the direct effect of days to 50% flowering on grain yield was negligible. The high indirect effect of number of days to 50% flowering through crop growth rate modified the small direct effect of days to flowering on grain yield to a significant linear correlation. The indirect effects of other independent traits through the number of days to 50% flowering on grain yield were very small.

Table 1: Climatic conditions during the growth period, (July-October) of each year

		Mean temperature (°C)	
Year	Total rainfall (mm)	Night minimum	Day maximum
1996	418	25.1	31.0
1997	674	22.6	30.9
1998	468	25.8	31.7

Table 2: Summary of the analysis of variance of grain yield and days to 50% flowering for the 3-year period

	Degrees	Mean squares	
Source of variation	of freedom df	Grain yield	Days to 50% flowering
Replication	3	43259.45	0.55
Genotypes (G)	9	183509.60**	18.04**
Years (Y)	2	227164.30**	7.63**
G x Y	18	27861.55	0.45
Error	87	35305.73	1.02
Mean		588.43	54.00
CV (%)		31.93	1.88

**Significant at $P \leq 0.01$

Grain yield and number of primary branches/plant: A non-significant linear correlation ($P \leq 0.05$) was obtained between the number of primary branches per plant and grain yield. The direct effect of number of primary branches per plant on grain yield was positive and the least among all traits with direct effects on grain yield. The indirect effects of other independent traits through the number of primary branches on grain yield were negligible.

Grain yield and fodder yield: Fodder yield had a significant positive linear correlation ($P \leq 0.01$) with grain yield. The direct effect of fodder yield on grain yield was however negligible. The high indirect effects of fodder yield through crop growth rate, pods per plant and harvest index modified this small direct effect to a significant linear relationship with grain yield. The indirect effect of fodder yield on grain yield through pod growth rate was negative and large.

Grain yield and pods per plant: A highly significant linear correlation ($P \leq 0.01$) was obtained between the number of pods per plant and grain yield. The high positive indirect effects of pods per plant on grain yield through crop growth rate and harvest index accounted largely for the highly significant linear correlation between grain yield and pods per plant. However, the indirect effect of pods per plant on grain yield through pod growth rate was large and negative and this in addition to negligible positive indirect effects through days to 50% flowering, fodder yield and number of primary branches per plant resulted in a reduced direct effect on grain yield.

Grain yield and crop growth rate: Grain yield and crop growth rate showed a significant positive correlation, ($P \leq 0.01$). The direct effect of crop growth rate on grain

Table 3: Performance of 10 pigeonpea genotypes tested in the Guinea savanna zone of Ghana in 1998

Genotype	Days to 50% flowering	Reproductive duration (days)	Primary branches/plant	Fodder yield (t ha^{-1})	Grain yield (kg ha^{-1})	Pods / plant	[A]CGR (kg ha^{-1} day^{-1})	[B]PGR (kg^{-1} ha^{-1} day^{-1})	Harvest index	100 grain weight (g)
ICPL-89008	55.8	42.3	9.6	1.68	772	48.7	29.05	27.76	25.53	8.77
ICPL-88001	53.0	41.0	9.1	1.37	462	30.9	23.11	19.53	20.56	8.77
ICPL-89027	51.5	42.5	8.1	1.15	447	28.1	19.85	16.77	23.20	9.30
ICPL-151	53.8	40.5	9.3	1.49	531	35.9	24.91	21.28	22.49	9.57
ICPL-83015	52.3	41.8	8.9	1.16	444	33.9	20.55	18.51	22.94	9.00
ICPL-4	54.3	41.8	9.1	1.31	471	36.2	22.55	20.32	22.20	7.70
ICPL-88003	51.8	42.3	8.4	1.20	524	37.1	22.44	21.53	24.99	8.17
ICPL-88075	52.8	41.3	9.2	1.47	641	44.3	27.02	25.94	25.40	9.37
ICPL-87015	52.5	41.5	8.6	1.04	409	27.4	18.55	16.84	23.44	8.97
ICPL-90008	52.0	42.0	7.4	1.19	450	28.5	20.45	17.59	23.26	8.80
Mean	53.0	41.7	8.8	1.31	511	34.1	22.85	20.61	23.50	8.84
LSD (5%)	1.6	NS	NS	0.30	241	11.2	5.57	6.11	4.11	NS
CV (%)	2.0	2.3	13.2	20.20	18.04	21.9	16.82	20.42	17.76	9.50

[A]CGR = Crop growth rate; [B]PGR = Pod growth rate. NS = Not significant

Table 4: Phenotypic correlation matrix of yield components and yield for 10 pigeonpea genotypes tested in the Guinea savannah zone of Ghana

	Dff	Fodder weight	100 grain weight	Pods/plant	Branches / plant	Crop growth rate	Pod growth rate	Harvest index
Dff	-							
Fodder weight	0.807**	-						
100 grain weight	-0.173	0.144	-					
Pods/plant	0.681*	0.828**	-0.044	-				
Branches / plant	0.744*	0.715*	0.066	0.693*	-			
CGR	0.730*	0.967**	0.113	0.926**	0.709*	-		
PGR	0.676*	0.876**	0.022	0.980**	0.680*	0.966**	-	
Harvest index	0.125	0.312	0.085	0.678*	0.116	0.507	0.677*	-
Grain yield	0.638*	0.865**	0.111	0.954**	0.585	0.949**	0.979**	0.744*

Dff = Days to 50% flowering CGR = Crop growth rate; PGR = Pod growth rate; RD = Reproductive duration
*Significant at $p \leq 0.05$; **Significant at $p \leq 0.01$

Table 5: Direct effects of seven independent traits on grain yield in pigeonpea

	Days to 50% flowering	Fodder yield	Pod growth rate	Crop growth rate	Branches/plant	Harvest index	Pods/plant
Grain yield	0.097	0.028	-0.719	1.084	0.009	0.519	0.208

Residual = 0.077

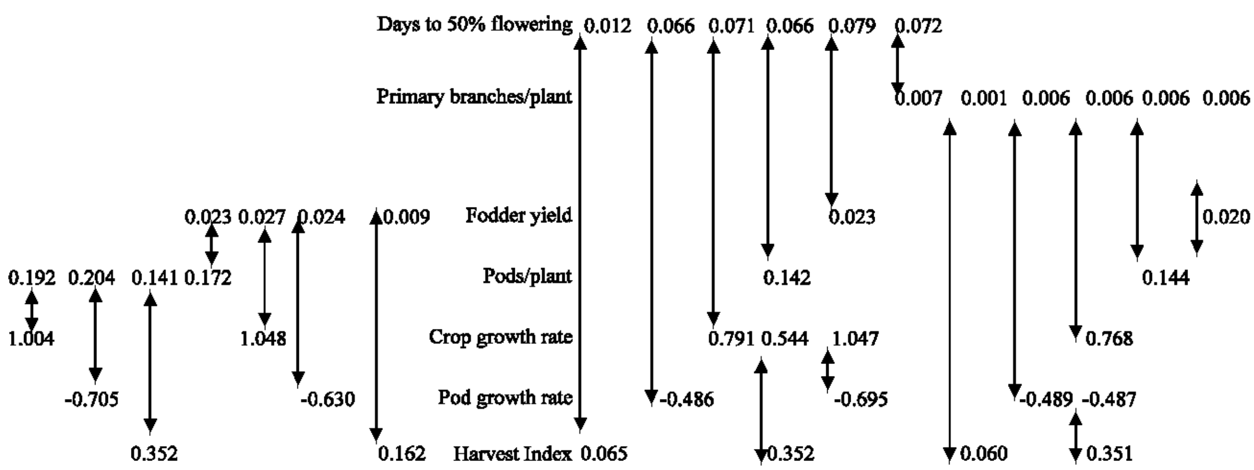

Fig. 1: Path diagram for indirect effects of 7 independent traits through each other on grain yield

In the path diagram, each coefficient represents a path such that, for example, the figure 0.012 on the arrow head of days to 50% flowering is the indirect effect of harvest index through days to 50% flowering on grain yield; the figure 0.065 at the bottom of the same arrow is the indirect effect of days to 50% flowering through harvest index on grain yield

yield was very large and positive. The indirect effects of all other independent traits through crop growth rate on grain yield were positive and large.

Grain yield and pod growth rate: A significant positive ($P \leq 0.01$) linear correlation between grain yield and pod growth rate was observed. The direct effect of pod growth rate on grain yield was however negative and large. The large positive indirect effects of pod growth rate through crop growth rate, harvest index and number of pods/plant modified this negative indirect effect to a positive correlation between pod growth rate and grain yield. All other independent traits showed large negative indirect effects through pod growth rate on grain yield.

Grain yield and harvest index: Harvest index and grain yield were positively correlated, ($P \leq 0.05$). The direct effect of harvest index on grain yield was positive and large. Except for the number of days to 50% flowering and number of branches per plant which showed negligible indirect effects through harvest index on grain yield, all other independent traits showed moderately high indirect effects through harvest index on grain yield.

DISCUSSION

Differences in grain yield between years could be attributed to differences in climatic conditions during the growing period. The high rainfall and relatively lower temperatures during the 1997 growing period favoured higher grain yields among genotypes. The ANOVA indicated however, that the relative sensitivity of a genotype's grain yield to different years did not shift significantly, as shown by the non-significant interaction between years and genotypes. This suggests that large genetic effects are responsible for observed differences in performance of genotypes.

Phenotypic correlation and path coefficient analyses have established a large genotypic dependence of grain yield on crop growth rate, harvest index and pods per plant, (in order of importance). The crop growth rate in addition to having the largest direct effect on grain yield, the indirect effects of all other independent traits through the crop growth rate were positive and large. Selection for a rapid crop growth rate would therefore not only impact positively on grain yield but also favour the relationship of the other independent traits in the formation of grain yield. A rapid crop growth rate has also been found to be an important trait for selecting high grain yielding genotypes in cowpea, (Marfo, *et al.*, 1997) and in groundnuts, (Williams, 1992). Conceivably, a rapid crop growth rate would provide adequate dry matter during the critical phenological phases of the crop and particularly for the pod and grain filling periods. This is evidenced by the large positive indirect effect of pod growth rate and number of pods per plant through the crop growth rate on grain yield.

Harvest index and number of pods per plant also showed positive direct effects on grain yield. The indirect effects of all other independent traits through the harvest index and pods per plant were also moderately large and positive. Ganesamurthy and Dorairaj, 1990, in a study of character association in pigeonpea observed that number of pods per plant is an important trait affecting final grain yield. It is conclusive from these observations that grain yield improvement in pigeonpea under the semi-arid conditions in the Guinea savannah zone should be rapid if selection is made for a rapid crop growth rate, high harvest index and high number of pods per plant. The path coefficient analysis has shown that the highly significant positive linear correlation between grain yield and the three independent traits; days to 50% flowering, fodder yield and pod growth rate, are not true direct associations.

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