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Path Coefficient Analysis of Bambara Groundnut Pod Yield Components at Four Planting Dates

[1]Itai Makanda, [1]Pangirayi Tongoona, [2]Rosalia Madamba, [3]David Icishahayo and [1]John Derera

[1]African Centre for Crop Improvement, University of KwaZulu-Natal, P/Bag X01 Scottsville, South Africa
[2]Crop Breeding Institute, P. O. Box CY550 Causeway, Harare, Zimbabwe
[3]Department of Crop Science, University of Zimbabwe P.O. Box MP167 Mt Pleasant, Harare, Zimbabwe

Abstract: Little is known on the relationship between yield and its components in bambara groundnuts outside the traditional growing season in Zimbabwe, information that is important when selecting cultivars for off-season planting. To study these relationships, correlation and path coefficient analyses were performed on yield traits in bambara groundnuts cultivars planted at four planting dates in Zimbabwe during 2000 – 2001. A split-plot arrangement in a randomised complete block design with planting date as main plot factor and cultivar as subplot factor was used. Moisture was supplied through irrigation during off-season cultivation and supplementary irrigation was applied during the rainy season. Days to 50% emergence, days to 50% flowering, days to 95% physiological maturity, plant count at harvest, pod count plant^{-1}, and dry pod yield plot^{-1} were measured and data were analysed using GenStat. Correlation and path coefficient analyses were performed for the traits for each planting date. Most of the correlation coefficients were significant (P<0.05) and dry pod yield was more dependent on the direct effects of its components compared to the indirect effects through other components, suggesting that direct selection is more effective. All the direct effects showed contrasting influences on dry pod yield for the same traits, but at different planting dates except for the number of plants plot^{-1} on which they were all positive. The contrast could be attributed to different photothermal conditions between the growing conditions associated with the planting dates. Indirect effects through number of plants plot^{-1} were high, suggesting the possibility of correlated response in selection. The experiment showed plant establishment and number of pods plant^{-1} to be the important traits in bambara cultivar development.

Key words: Bambara groundnut, correlation, path coefficients

INTRODUCTION

Little information on bambara groundnut research and cultivar development is available, although there is a shift in the crop's importance from a subsistence crop to a commercial crop. It is now canned in the same way as beans, peas and maize and its market value has increased. More farmers are now starting to grow the crop and an early crop fetches a high market price compared to a normal season crop. It also escapes foliar diseases associated with increased humidity at favourable temperatures during the main rainy season as reported for *Ascochyta* blight on chickpea [1,2]. There are no suitable varieties for early planting in Zimbabwe. Farmers are therefore at risk when unsuitable cultivars are planted early so as to have a competitive edge on the market. This emphasises the need to develop cultivars for off-season planting to meet the farmers' needs.

Cultivar development requires an understanding of the responses and relationships between yield-determining traits under the conditions in which the cultivars are to be deployed. Such relationships have been studied using correlation coefficients. Correlation coefficients alone may still not be reliable in selection as they represent simple linear relationships between traits [3]. Further studies have used non-linear connecting paths of influence between traits through further breaking down of correlation coefficients [3]. These influences have been termed path coefficients attributable to direct and indirect causes [3,4]. Path coefficients give the relative contribution of various yield-determining traits, enabling breeders to decide between direct and indirect selection [5,6]. Therefore, correlation and general relationships studies between yield-determining traits give an indication of the responses due to selection based on individual traits [7].

Corresponding Author: Itai Makanda, African Centre for Crop Improvement, University of KwaZulu-Natal, P/Bag X01 Scottsville, South Africa

Wide variations in the extent of direct and indirect effects revealed through path coefficient analyses have been reported for yield in various crops including sorghum [7], groundnuts [8], bambara groundnut [5], soybean [9,10], linseed [11], safflower [3] and many other crops. The primary components of seed yield in legumes are number of pods $plant^{-1}$, number of seeds pod^{-1}, and seed weight [5]. Singh and Yidava [9] and Iqbal *et al.* [10] confirmed this assertion.

Many studies in bambara groundnuts have focused on agronomic performance and general correlation with little emphasis on the relationships between yield components. Further, no work has been reported on such relationships outside the traditional growing season in southern Africa. There is need to understand the relationships for the potential growing environments because the crop's phenology is dependent on temperature and photoperiod [12,13,14,15,16]. Linnemann [17] and Karikari *et al.* [18] showed that different growing conditions stimulated different trait responses among genotypes of bambara groundnut. The same scenario was reported for groundnut [19]. This may mean different trait emphasis during selection in different environments, as trait response may vary due to changes in the growing conditions. This paper reports on the relationships between yield-determining traits of bambara groundnuts planted at different planting dates in Zimbabwe based on correlations and path coefficients.

MATERIALS AND METHODS

Twenty bambara groundnut cultivars (Table 1) were evaluated at four planting dates (Table 2) at the Harare Research Station (17¾S 31E;1480 m.a.s.l.) in Zimbabwe. The fields have red clay soil classified as 5E.2 on the Zimbabwean classification system, Rhodic Paleustalf (USDA classification), or Chromic Luvisol on the FAO system [20]. The average annual rainfall is 815 mm and monthly temperature varies, is lowest during winter (May to July), and highest in summer (November to April). During this study, both minimum and maximum temperatures were lowest in July and highest in October (Table 2) during plant establishment period. Harare day lengths vary from the winter levels of below 11 h to summer values of up to 14 h [21]. The planting dates selected cover the entire range of off-season planting times until the onset of the summer season.

A split plot arrangement in a randomised complete block design with three replicates was used. Planting date was the main plot factor with four levels (Table 2) and cultivar was the subplot factor with 20 levels (Table 1). One seed was planted $station^{-1}$ at 0.20 m within-row and 0.45 m inter-row spacing giving a total of three rows of 3m in length $plot^{-1}$. Plots were spaced at 0.90 m giving a gross plot size of 3.2 m X 1.8 m. A compound fertiliser (Cottonfert) [N (5%): P_2O (17%): K_2O (10%); B (0.25%)] was broadcast at 150 kg ha^{-1} pre-plant. The field was kept weed free through hand weeding with adequate moisture supplied through perforate irrigation.

Days to 50% emergence; days to 50% flowering; days to 95% physiological maturity; number of pods $plant^{-1}$ at harvest (mean of ten randomly selected plants on either of the outer rows); and dry pod yield (g $plot^{-1}$) were measured. Whole plots were harvested and pods were left to sun-dry until no further weight change was recorded over a period of two week for all the plots. Data was analysed in GenStat [22]. Phenotypic correlations coefficients (r) were computed among all the measured traits and path coefficients (P) calculated using the simultaneous solutions of the equations below based on the work of Wright [23] and Dewey and Lu [4].

1. $r_{16} = P_{16} + r_{12}P_{26} + r_{13}P_{36} + r_{14}P_{46} + r_{15}P_{56}$
2. $r_{26} = r_{12}P_{16} + P_{26} + r_{23}P_{36} + r_{24}P_{46} + r_{25}P_{56}$
3. $r_{36} = r_{13}P_{16} + r_{23}P_{26} + P_{36} + r_{34}P_{46} + r_{35}P_{56}$
4. $r_{46} = r_{14}P_{16} + r_{24}P_{26} + r_{34}P_{36} + P_{46} + r_{45}P_{56}$
5. $r_{56} = r_{15}P_{16} + r_{25}P_{26} + r_{35}P_{36} + r_{45}P_{46} + P_{56}$
6. $1 = P^2X_6 + P^2_{16} + P^2_{26} + P^2_{36} + P^2_{46} + P^2_{56} + 2P_{16}r_{12}P_{26} + 2P_{16}r_{13}P_{36} + 2P_{16}r_{14}P_{46} + 2P_{16}r_{15}P_{56} + 2P_{26}r_{23}P_{36} + 2P_{26}r_{24}P_{46} + 2P_{26}r_{25}P_{56} + 2P_{36}r_{34}P_{46} + 2P_{36}r_{35}P_{56} + 2P_{46}r_{45}P_{56}$

Table 1: Bambara groundnut varieties that were evaluated during 2000/2001 season at the Harare Research Station

Code	Genotype	Type	Pod colour
1	Tulimara S1	Improved	Purple/White
2	Tulimara S2	Improved	White
3	Ndebvu	Landrace	White
4	Misodzi	Landrace	White
5	Chipofu	Landrace	Purple/White
6	Variety 10	Improved	White
7	BS 545	Improved	White
8	BS 599	Improved	Purple
9	BS 520	Improved	White
10	BS 544	Improved	Purple
11	BS 537	Improved	White
12	BS 534	Improved	White
13	BS 564	Improved	Purple/White
14	BS 28	Improved	Purple
15	3806/90	Improved	Purple
16	IND-1	Improved	White
17	V2-17	Improved	White
18	BG-MIA	Improved	White
19	3804/90	Improved	White
20	Mbare	Landrace	Purple/White

Table 2: Planting dates and their respective temperatures at planting

Code	Planting date	Season	Temperature (°C)	
			Minimum	Maximum
1	17 July, 2000	Off-season	5.8	20.5
2	28 August, 2000	Off-season	7.3	21.8
3	15 September, 2000	Off-season	11.2	26.8
4	22 October, 2000	Beginning of season	13.0	28.1

Where1 = Days to 50% emergence; 2 = Days to 50% flowering; 3 =Number of pods plant-1; 4 = Number of plants plot-1; 5 = Days to 95% physiological maturity; 6 = dry pod yield (g plot-1); X= Residual factor representing unaccounted for variation calculated by making X the subject of the formula in equation 6.

Taking equation (1) above for example, r_{16} is the correlation coefficient between 1 (days to 50% emergence) and 6 (dry pod yield plot^{-1}); P_{16} is the direct effect of days to 50% emergence to pod yield plot^{-1}; $r_{12}P_{26}$ is the indirect effect of days to 50% emergence to yield through days to 50% flowering: $r_{13}P_{36}$ is the indirect effect of days to 50% emergence to yield through number of pods plant^{-1}; $r_{14}P_{46}$ is the indirect effect of days to 50% emergence to yield through number of plants plot^{-1}; and $r_{15}P_{56}$ is the indirect effect of days to 50% emergence to yield via days to 95% physiological maturity.

Results: Significant differences ($p<0.05$) were observed between planting dates for days to 50% emergence, days to 50% flowering, days to 95% physiological maturity, number of plants plot^{-1}, and dry pod yield plot^{-1} (Table 3). This paper is focused on the correlation and path coefficients between the traits and detailed reports and discussions on the planting dates and genotypes differences and interactions are not discussed.

Path coefficient analyses showed various relationships that can be useful for direct and indirect plant selection in bambara groundnuts (Table 4). Pod yield was more dependent on direct effects although few indirect effects were also important. Correlation coefficients between days to 50% emergence and dry pod yield was positive and significant ($p\leq0.05$) for the October planting (OP) (Table 4). The direct effects of the same trait to pod yield for the July planting (JP) and August planting (AP) were negative whereas those for the September planting (SP) and OP were positive (Table 4). High negative indirect effects were observed through number of plants plot^{-1} for the JP and via days to 50% flowering for the OP (Table 4). A high positive indirect effect was observed through number of plants plot^{-1} at harvest for the OP.

Days to 50% flowering had a negative and significant ($p\leq0.05$) correlation coefficient to dry pod yield for the SP whereas it was positive and significant ($p\leq0.05$) for the OP (Table 4). Days to 50% flowering had positive direct effects to pod yield for the JP and AP whereas the SP and OP had negative direct effects for the same traits (Table 4). A high and positive indirect effect was observed for the OP through number of plants plot^{-1} whereas it was negative for the JP through the same trait (Table 4). Days to 50% emergence had a weak positive direct effect and a high negative indirect effect through number of plants plot^{-1} for the JP (Table 4). The AP had a high and positive direct effect and a negative indirect effect through number of pods plant^{-1}. High and negative direct effects were observed for both the SP and the OP (Table 4). The OP had high positive indirect effects through number of plants plot^{-1} and days to 50% emergence (Table 4).

All the correlation coefficients between number of pods plant^{-1} and pod yield were positive and significant ($p\leq0.05$) for the JP, AP, and OP (Table 4). The direct effects for these dates were also positive. The OP and AP had high indirect effect through number of plants plot^{-1} and days to 95% physiological maturity, respectively (Table 4). The correlation coefficient and direct effect for the SP were both negative (Table 4). As was expected, the correlation coefficients between number of plants plot^{-1} and pod yield were positive and significant ($p\leq0.05$) for all the four planting dates and the direct effects were also positive (Table 4). High and positive indirect effect was observed via days to 95% physiological maturity for the JP and AP plantings, through days to 50% flowering for the SP, and through days to 50% emergence for the OP (Table 4). Although all the indirect effects via days to 50% flowering were negative, the negativity of the OP planting was exceptionally high.

Days to 95% physiological maturity was positively and significantly ($p\leq0.05$) correlated to grain yield for AP and the OP (Table 4). The direct effects were also positive. Both the correlation coefficient and direct effect for the JP and SP were negative. The AP and

Table 3: Trait means of the 20 genotypes over the four planting dates at the Harare Research Station during 2000 – 2001

Planting date	Days to 50% emergence	Days to 50% flowering	Number of plants plot^{-1}	Days to 95% maturity	Yield		
					g plot^{-1}	g plant^{-1}	t h^{-1}
17 July	46.60	85.60	19.90	186.20	440.80	22.15	0.77
28 August	29.00	60.80	35.10	158.50	1045.30	29.78	1.81
15 September	22.60	60.00	39.20	152.20	1129.00	28.80	1.96
22 October	20.90	55.00	41.60	133.70	1032.30	24.81	1.79
Mean	29.77	65.26	33.93	157.80	915.00		
SED	0.72	2.84	3.19	1.99	53.90		
CV	0.03	0.053	0.12	0.02	0.07		
p value	<0.001	<0.001	0.002	<0.001	<0.001		

Table 4: Total correlation, direct effects, and indirect effects to pod yield of the different traits of bambara groundnut evaluated at the Harare Research Station during 2000 – 2001

Planting date	Trait	Indirect effect to pod yield via: Days to 50% emergence	Days to 50% flowering	Number of pods plant-1	Number of plants plot-1	Days to 95% maturity	Total correlation to pod yield
17 July	Days to 50% emergence	**-0.029**	0.015	0.068	-0.146	-0.094	-0.187
	Days to 50% flowering	-0.008	**+0.051**	0.013	-0.147	-0.053	-0.144
	Number of pods plant^{-1}	-0.007	0.002	**+0.274**	0.013	0.083	0.365*
	Number of plants plot^{-1}	0.011	-0.020	0.009	**+0.376**	0.141	0.517*
	Days to 95% physiological maturity	0.006	-0.006	-0.049	-0.115	**-0.462**	-0.626*
28 August	Days to 50% emergence	**-0.065**	0.019	-0.032	0.094	0.065	0.081
	Days to 50% flowering	-0.010	**+0.123**	-0.068	-0.030	0.007	0.022
	Number of pods plant^{-1}	0.006	-0.024	**+0.346**	0.027	0.100	0.455*
	Number of plants plot^{-1}	-0.014	-0.008	0.021	**+0.443**	0.069	0.511*
	Days to 95% physiological maturity	-0.013	0.002	0.106	0.094	**+0.328**	0.517*
15 September	Days to 50% emergence	**+0.042**	-0.062	-0.026	-0.046	0.000	-0.092
	Days to 50% flowering	0.009	**-0.274**	-0.014	-0.072	-0.003	-0.354*
	Number of pods plant^{-1}	0.009	-0.029	**-0.128**	-0.037	0.018	-0.167
	Number of plants plot^{-1}	-0.006	0.060	0.014	**+0.330**	0.021	0.419*
	Days to 95% physiological maturity	-0.001	-0.010	0.023	-0.070	**-0.097**	-0.155
22 October	Days to 50% emergence	**+0.246**	-0.171	0.026	0.155	0.037	0.293*
	Days to 50% flowering	0.202	**-0.208**	0.048	0.194	0.036	0.272*
	Number of pods plant^{-1}	0.025	-0.040	**+0.250**	0.104	0.020	0.359*
	Number of plants plot^{-1}	0.127	-0.135	0.087	**+0.300**	0.041	0.420*
	Days to 95% physiological maturity	0.078	-0.063	0.043	0.105	**+0.117**	0.280*

* = significant at $P \leq 0.05$ level; May nrrd to give the direct effects (I have highlighted) in bold

OP had high positive indirect effects through number of plants plot^{-1} (Table 4). Indirect effect through number of pods plant^{-1} was high and positive for the AP. For the OP, high and positive indirect effects were observed through days to 50% emergence. High and negative indirect effects were observed through days to

50% flowering for the OP and via number of plants plot^{-1} for the JP (Table 4). A negative indirect effect was observed through number of plants plot^{-1} for the SP (Table 4). In general, direct effects were more important than indirect effects for all the four environments.

Discussion and Conclusions: Correlations showed that plant stands and number of pods plant^{-1} were the most important yield components. This is consistent with Ofori [5] who reported number of pods per plant, among others, to be an important yield component in legumes. The all positive correlation coefficients for the number of plants plot^{-1} at harvest and dry pod yield indicated the importance of optimum plant stands if maximum pod yield is to be achieved. The improvement of pod yield from planting in July to planting in October (Table 3) can be attributed in part to improvement of plant establishment. This resulted in the positive correlation coefficients between the two traits and high direct effects to pod yield. This implies that selection for good plant establishment can improve pod yield. The same explanation can be put forward for number of pods plant^{-1} for the JP, AP, and OP based on correlation coefficients and direct effects to pod yield. As the number of pods plant^{-1} increased, pod yield also increased. Iqbal *et al.* [10] and Singh and Yidava [9] came to the same conclusion in soybean and Talebi *et al.* [6] in chickpea and Ofori [5] in bambara groundnut. However, this phenomenon occurs within a range after which negative competition for photo-assimilates impacts negatively on yield due to excessive podding. This can explain the negative correlation coefficient between yield and number of pods plant^{-1} for the SP which had the highest number of pods plant^{-1}. Significant interaction between time of planting and genotype on number of pods plant^{-1} may also have resulted from such competitions and differential tolerance to the competition by different genotypes. Podding capacity changed for the genotypes depending on the time of planting but for the last three planting dates, the overall yield remained the same. This suggested that, as reported for legumes [24], pod size and weight are inversely related and changed in a compensatory way such that the fewer the pods, the bigger or heavier they were and vice versa.

Negative correlation between time to 95% physiological maturity and pod yield for July can explain the significantly lower yields for that environment. Bashir *et al.* [25] also reported negative but not significant correlation between grain yield and days to maturity in forage legumes. Although this may seem to suggest a decrease in yield as the time the crop takes in the field increases, reduced plant stands due to poor crop germination and establishment under the cold July temperatures were the chief cause of a yield drop for the JP. However, this trend is not shown when pod yield is considered on a per plant basis in which the OP and the JP have slight but not significant differences (Table 4). This shows that, although legumes have the capacity to compensate for poor plant stand by increasing podding per plant [26], this does not translate to increased yields under very poor stands and therefore, poor plant stand was the chief cause of the low yield recorded for the JP.

The contrasting correlation coefficients observed between the SP and the OP on days to 50% flowering and dry pod yield give conflicting messages. While it may seem to suggest a yield penalty for the SP and a yield advantage for the OP as flowering is delayed, it was observed that both planting times had high negative direct effects. OP had high and positive indirect effects via number of plants plot^{-1} and days to 50% emergence, which masked the negative direct effect giving a net positive correlation coefficient between yield and days to 50% flowering. The trait analysed in this study did not cover all the pod yield components and therefore more experiments using more traits might be needed to ascertain the relationships between yield and secondary traits.

Overall, the study indicated that plant stand was the most important yield component in bambara groundnut because of its significant and positive correlation and positive high direct effects to pod yield in are all the four planting dates. This was followed by the number of pods plant^{-1} which also displayed a significant and positive correlation and positive direct effects on pod yield in three of the four environments. The indirect effects were generally low indicating that positive correlations between plant-stand establishment and number of pods plant^{-1} were largely due to the direct effects. Although less than the direct effects, the indirect influences via plant establishment and podding levels were also important for the significant correlation of pod yield with days to 50% emergence and days to 50% flowering, but only for the OP. These findings suggested that selection for high plant stand establishment and large number of pods plant^{-1} should be emphasised in all environments.

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