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IS MICRO-ENVIRONMENT A HURDLE IN GENETIC ENHANCEMENT OF YIELD IN PIGEONPEA?

Agricultural Science

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ABSTRACT

Yield stagnation in pigeonpea remains a serious concern. Since most cultivars in the past were bread using pedigree method, it seems that this method was ineffective in increasing the crop productivity. To get insight into this failure, 10 highly inbred parents and their F2 bulks were examined by comparing their single plant yield variances. Surprisingly, the inbred parents exhibited high inter-plant variability; and their F2s were less variable than their one or both the parents. These unusual observations were attributed to the interaction of individual plants with unspecified micro-environmental factors prevailing in their vicinity, both below and above the ground. Under such circumstances, the selections had low heritability and unpredictable performance in the subsequent generation. Since these factors cannot be targeted through breeding, it is suggested that the breeders should try other breeding approaches such as bulk, composites, and single pod descent. The pedigree method of breeding, however, will continue to have its utility in the genetic enhancement of qualitative traits like yield.

KEYWORDS

Cajanus cajan, G x E interaction, Inbred and F2 variance, Pedigree breeding, Yield/plant.

INTRODUCTION

Pigeonpea is a popular high-protein food for the masses living in south Asia and Africa. Despite decades of breeding efforts globally, the productivity of this crop has remained unacceptably low at around 700 kg/ha. For a long time, it has been a matter of concern, particularly in view of population growth and role of pigeonpea in nutritional security of rural families. Pigeonpea breeders in the past have produced over 200 pure line cultivars, but with no significant reward in terms of productivity gains. This raises a logical question about the efficiency of pedigree breeding method in increasing the crop yield. The authors, in this research, have tried to examine this issue by studying the variability for per plant yield within the inbred parents and their F_2 populations.

MATERIALS AND METHODS

Ten diverse genotypes were randomly selected from the breeding programme at ICRISAT. Their inbred lines were developed by self-pollination for five successive generations using plant-to-progeny method of generation advance. In S_6 generation, all the plants within a progeny were self-pollinated and their seeds bulk harvested. To study the F_2 generation, 18 single crosses were made by crossing these inbred lines and their F_1 plants were bagged for generation advance. All the 10 inbreds and 18 F_2 bulks were sown in non-replicated 9 m x 9 m plots, and allocation of these entries was done randomly. A basal doze of fertilizer @100 kg/ha DAP was applied, and for good drainage, ridges were constructed along the slope. Each plot accommodated 9 m long 12 rows, spaced 75 cm apart. The seeds were dibbled at 2-3 cm depth with inter-hills spacing of 30 cm. The experimental area was irrigated as and when required. For harvesting, first the border rows of each plot and border plants at either end of each row were removed. In the inbred plots,10 consecutive plants from the middle of each row were harvested, while in the F_2 plots, all the plants in the net area were harvested. Yield data (g/plant) on the inbred parents (87- 100 plants) and F_2 bulks (247- 279 plants) were recorded and for each entry, estimates of phenotypic variances were calculated.

RESULTS AND DISCUSSION

Since the quantitative traits like yield are controlled by polygenes, their expression is prone environmental influences. Therefore, the inbreds and F_2 populations were characterized and compared for their uniformity by estimating their "variances" – a simple statistical tool. In the present study, phenotypic variances recorded in the most uniform (inbreds) and the most diverse (F_2) populations, were compared for the observed variability with respect to single plant yield.

Inbred Parents

The variances for yield/plant in different inbreds, using 87- 100 competitive plant data, showed high values and huge differences among the inbred lines (Table 1). Also, the quantum of variance, as a group, appeared to be associated with their plant type. For example, in comparison to the spreading type inbreds (mean 853.3), the compact types (mean 304.5) exhibited 180% less variance for yield. Besides these, within each inbred group also, the genotypic differences for estimated variances existed. Within the spreading group, the phenotypic variance for yield in ICP 102 was the highest (1205); and it was followed by BDN 1 (882). The other two spreading type inbreds also recorded high variances for seed yield. In contrast, the variances in the compact group ranged between 166 (ICP 7086) and 393 (ICP 7977). Across both the groups, the difference between the least (166) and maximum (1205) variance-producing inbreds was a huge seven-fold. The data showed that the compact type pigeonpea plants are more resilient to inter-plant competition than their spreading counterparts. It may be because the compact type plants inherently have low plasticity and relatively fewer and straight branches which grow along the main stem.

F_2 Bulks

The intra-F_2 variability amongst the crosses also varied considerably. To get more insight into it, the F_2s bulks were grouped into the spreading x spreading, compact x compact, and spreading x compact types of crosses. In the spreading x spreading group (Table 1) there were four crosses. Among these, the highest variance (975) was found in cross ICP 102 x ICP1258 and its lowest value (665) was recorded in cross ICP 102 x BDN1. In the sole compact x compact cross (TTB 7 x ICP 7977) the variance for yield was quite low (202). There were 13 crosses in the compact x spreading group. The F_2 variances in this group ranged between 427 (KWR 1 x ICP 1258) and 975 (KWR 1 x ICP 102). It was noted that the crosses with ICP 102, the most sensitive line, generally had greater variances. Overall, there appeared to be no relationship between mean yields and mean variances.

Inbreds vs F_2 bulks

Theoretically, the genetic variation in F_2 generation of a cross, that is produced by crossing two diverse inbred lines, is maximum; and it should be greater than its parental values. A perusal of the comparative data of 18 crosses and their parents, however, showed that one or both the inbred parents had greater variance than their respective F_2s (Table 1) but their magnitude varied considerably from cross to cross. These observations were not only surprising, but also deviated from the classical theory of recombination and segregation.

Spreading X Spreading Crosses:

In this group of crosses the variances recorded in the inbred parents were much greater than their F_2 bulks. For example, in cross ICP 102 x BDN 1, the two parents had the variance values of 1205 and 882, respectively, while their F_2 bulk exhibited the variance of only 665. In the other three crosses also, one of the parents exceeded their F_2 variance.

Compact X Compact Cross:

In a sole compact x compact type cross (TTB 7 x ICP 7977), the magnitudes of variance in the parents and F_2s were comparatively low when compared with those of spreading x spreading and spreading x compact type crosses. Also in this case, the parents exhibited only marginal increases over the F_2. In this cross both the parents and their F_2 had compact phenotype, and it is believed that these were not so vulnerable to g x e effects as compared to the spreading types.

Spreading X Compact Cross:
In this group a total of 13 crosses were studied (Table 1). In these crosses also, the variances among different F_2 bulks varied considerably from 427 (KWR 1 x ICP 1258) to 975 (KWR 1 x ICP 102). The cross ICP 7086 x ICP 102, which involved the inbred parents with the least (166) and the highest (1205) variances, produced an F_2 with high variance (854); but less than the high variance parent.

Putative Role Of Micro- Environment
Since both spreading as well as compact inbreds lines were developed using the same method and they were evaluated under a single macro-environment with similar cultural practices with least external stresses, the observed intra-genotypic uniformity should not be high. But this was not the case and most inbreds exhibited high to very high inter-plant variability for yield/plant, despite six generations of selfing. Therefore, the observed high intra-population variances could only be attributed to some non-genetic factors, which affected the individual performances in one way or the other. It is believed that such factors created a sphere of micro-environment in the vicinity of individual plants, both below and above the ground. These factors then produce undetected direct and indirect effects on individual plant performance at different growth stages. These results in the production of variable inter-plant yields and finally, high variance within a genetically pure population. Since such factors cannot be identified and measured easily, The plastic nature of pigeonpea plants, which induce irreversible changes, also play a significant role in shaping its phenology and productivity.

In general, early germination, wide spacing, and sufficient moisture facilitate large canopy in pigeonpea. These environment-induced responses lead to irreversible correlated changes in plants; and their quantum is greater in the spreading types and less in the compact types. Since, the seed yield in pigeonpea is reported to be positively correlated with the biomass, number of primary and secondary branches, plant height and pods/plant (see review by Sawargaonkar and Saxena, 2020), their variable expression in plants produce variable yield. Also, since the expression of these plant traits is sensitive to both micro- and macro-environmental factors, they induce significant phenotypic variability in growth and yield. For example, the late sown plants of pigeonpea always lag in various development processes and experience reduction in flowering time, plant height and number of primary / secondary branches and yield/plant (Roy Sharma et al., 1981; Byth et al., 1981). These changes are quantitatively linked to the reduction in the day light hours.

A similar situation of high variability for yields in the pure lines was also encountered by Hamblin (1977) in *Phaseolus* beans. Cannell et al. (1977) also reported that the non-genetic inter-plant competition affected the inherent abilities of individual plants to produce tea crop. Using a spatial analysis, they further demonstrated that the interactions among the immediate orthogonal neighbours generated the inter-plant competition. In such situations the individual plants from segregating or non-segregation populations are likely to have poor heritability from one generation to the other. Rossini et al. (2011) demonstrated that the suppressed or stressed young plants present within the maize stands failed to recover from the initial stress shock; and the inter-plant differences were carried throughout their life cycle. A similar situation also exists in pigeonpea; but such shocks are more frequent due to it being a rainy season long duration rainfed crop.

CONCLUSIONS
This study concludes that under field grown pigeonpea, certain undefined micro-environmental factors operate and interact differentially with individual plants, and thereby, affect their growth and productivity. Since these factors vary within and over the seasons and cannot be targeted through breeding, they remain a major hurdle in response to selections (heritability), the breeding of high yielding pure line pigeonpea cultivars has not shown positive results in the past. Since pigeonpea is highly sensitive to environmental influences, their effects are large, it is suggested that for yield enhancement, the breeders should not rely solely on pedigree breeding in future; but the alternate breeding approaches such as bulk, composites, single pod descent, and hybrids should be tried. The pedigree method of breeding, however, will continue to have its utility in the genetic enhancement of qualitative traits like yield.

Table 1. Comparative Variances And Means For Yield G /plant In The Inbred Parents And Their F_2 Bulks

S No.	Cross	Variance			Mean yield (g/plant)		
		P_1	P_2	F_2	P_1	P_2	F_2
Spreading x Spreading Crosses							
1	ICP 102 x BDN1	1205	882	665	65	66	66
2	ICP 102 x ICP1258	1205	646	975	65	36	36
3	BDN1 x ICP 1258	882	646	696	66	36	36
4	PS 66 x BDN1	680	882	746	29	66	66
Compact x Compact Cross							
5	TTB 7 x ICP 7977	214	393	202	29	30	26
Compact x Spreading Crosses							
6	NPWR 15 x ICP 102	344	1205	769	40	65	57
7	NPWR 15 x BDN 1	344	882	680	40	66	61
8	NPWR 15 x ICP 1258	344	646	538	40	36	39
9	Gw 3 x ICP 1258	318	646	612	35	36	45
10	ICP 7086 x ICP 102	166	1205	854	22	65	59
11	ICP 7977 X BDN1	393	882	690	30	66	63
12	ICP 7086 x BDN 1	166	882	845	22	66	65
13	ICP 7086 x ICP 1258	166	646	511	22	36	37
14	KWR 1 x ICP 102	392	1205	975	32	65	52
15	KWR 1 x ICP 1258	392	646	427	32	36	37
16	ICP 7977 x ICP 102	393	1205	799	30	65	55
17	TTB 7 x ICP 102	214	1205	942	29	65	57
18	TTB7 x ICP 1258	214	646	615	29	36	45

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