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Performance stability of photoperiod sensitive *vs.* insensitive Dolichos bean (*Lablab purpureus* L. var. Lignosus) cultivars under delayed sowing conditions

C.M. Keerthi*[1], S. Ramesh[1], M. Byregowda[2], A. Mohan Rao[1], G.A. Mary Reena[3] and Chandrakant[1]

[1]Department of Genetics and Plant Breeding, University of Agricultural Sciences (UAS), GKVK, Bangalore-560 065, India
[2] All India Coordinated Research Project (AICRP) on Pigeonpea, Zonal Agricultural Research Station (ZARS), UAS, Bangalore-560065, India

***Corresponding author: cm_keerthi@rediffmail.com**

Abstract

Gradual shift in onset of monsoon driven by climate change, has forced farmers to unpredictably delay the sowing to match the crop growth period to distribution of rainfall. Sowing date is one of the most important factors which have tremendous effect on biological yield of a crop species. This is specifically true in highly photoperiod sensitive crops such as Dolichos bean. Theoretical considerations and farmers' belief are in favour of photoperiod sensitive cultivars under delayed sowing environments. The photoperiod sensitive (PS) and photoperiod insensitive (PIS) genotypes were planted during August, September and October months (representing delayed sowing environments) in randomised block design in two replications. The data were recorded on days to 50% flowering, primary branches plant^{-1} and fresh pod yield plant^{-1}. The performance stability of five PS and five PIS Dolichos bean grown in delayed sowing dates was compared based on three criteria namely *per se* performance, regression (b_i) of environment indices on crop response and deviation from regression (s^2d_i) to examine theoretical consideration and farmers' belief. The *per se* performance of PS genotypes was superior to PIS genotypes although they displayed greater sensitivity (b_i>1) to sowing date environments. On the other hand, performance of PIS genotypes was lower than that of PS genotypes but displayed least sensitivity (b = 1) and higher stability (S^2d_i non-significant) to sowing date environments. If farmer choose PS/PIS cultivars, they need to be planted not later than September to harness their complete genetic potential. The study provided preliminary evidence to support theoretical hypotheses and farmers experience-based view that PS cultivars perform better across delayed sowing date environments although they may not be as stable as PIS cultivars.

Key words: Photoperiod insensitivity, photoperiod sensitivity, stability, Dolichos bean.
Abbreviations: PS_photoperiod sensitive, PIS_photoperiod insensitive.

Introduction

Climate change is a threat to crop productivity in the most vulnerable regions of the world, especially the tropics and the semi-arid regions where higher temperatures and rainfall variability could have substantially negative impacts (Parry et al., 2004). The 21st century is projected to experience rise in surface air temperature from 1.8 - 4.0^{0}C with very likely occurrence of unpredictable droughts and floods (IPCC, 2007). Light and temperature are the two important environmental factors that affect plant growth and development (Masaya and White, 1991). There is a gradual shift in onset of monsoon driven by climate change. It has become inevitable for the farmers to delay the sowing to match the crop growth period to onset and cessation of rainfall pattern. However, crop grown in delayed dates experience different environmental variables. Sowing date is one of the most important factors which have tremendous effect on growth, development and biological yield of a crop species (Fagnano et al., 2009; Compant et al., 2010).
Houssmann et al. (2012) have opined that photoperiod sensitive (PS) cultivars (compared to photoperiod insensitive (PIS) cultivars) have greater ability/flexibility to match their growth and development cycle to prevailing rainfall duration in production regions where sowing dates are highly variable, despite fairly fixed dates for end-of-season moisture availability. Farmers also believe that PS cultivars fair better under such variable and/or delayed sowing environments. However, there is paucity of experimental evidence to examine theoretical hypothesis and farmers' belief in crop plants, especially so in Dolichos bean. Dolichos bean is one of the indigenous grain legumes widely cultivated in southern parts of Karnataka state in India. Traditionally farmers sow Dolichos bean by August. Most of traditional varieties of Dolichos bean are highly sensitive to photoperiod for flowering time. Several PIS advanced breeding lines and pure-line varieties have been developed by University of Agricultural Sciences (UAS), Bangalore, India. The present study was carried out to assess performance stability of PIS vs PS cultivars of Dolichos bean var. lignosus under different sowing dates. The study seeks to elicit the information that help farmer to decide about the choice of cultivar type and maximum limit of sowing date to maximise productivity of Dolichos bean in a given production environment.

Results and Discussion

Effect of sowing date environment:

The estimate of environment index which is a reflection of crop environment quality suggested sowing in August and latest by October provide favourable crop environment for

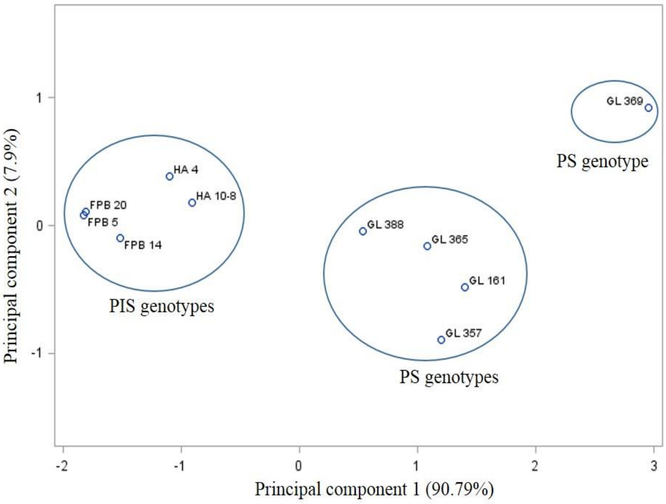

Fig 1. Scatter plot of five PS and five PIS Dolichos bean genotypes based on first two principal components.

realising higher productivity in Dolichos bean (Table 1). PS genotypes displayed greater reduction in days to flowering, primary branching and fresh pod yielding abilities compared to those of PIS genotypes with delayed sowing. Marginal variations in pod yielding ability of PIS genotypes across different dates of sowing could be obviously attributable to little variation in days to flowering and primary branching ability. Despite substantial traits variation among PS genotypes across sowing dates, their primary branching and fresh pod yielding abilities were greater than those of PIS genotypes irrespective of sowing dates. However, if farmer choose PS varieties, they need to be planted not later than September to ensure harnessing their complete genetic potential. The results provide evidence to support farmer's views of superiority of PS genotypes in delayed sowing environments.

Detection of genetic differences and PS/PIS genotype × sowing date interaction

Analysis of variance indicated significant differences among PS genotypes for all the three traits, while PIS genotypes, as expected were comparable for days to 50% flowering and primary branches plant^{-1}. However, PIS genotypes differed significantly for fresh pod yield plant^{-1} (Table 2). Significant mean squares due to the contrast PS *vs* PIS genotypes suggested that on an average, PS genotypes differed from those of PIS genotypes for all the three traits. Significant mean squares due to sowing dates are suggestive of substantial differences in crop environment contributed by differences in weather variables that prevailed during growth and development of PS and PIS genotypes sown in different dates. Significant mean squares due to PS genotypes × sowing date interaction but non-significance of those due to pooled deviation indicated predictability of flowering time, primary branches and pod yielding ability of all the PIS and PS genotypes across sowing dates despite their differential performance. These results further suggested that variation in flowering time, primary branching and pod yielding potential of PS genotypes across environments represented by different sowing dates is attributable to regression alone (Table 2). Unlike significant genotype × location interaction, which could be exploited by breeding for specific adaptation, significant genotype × sowing date environment interaction cannot be exploited. This is because, variations in climate conditions driven by changes in weather variables that prevail in different sowing date environments' are not known *a priori*. However, a wise decision by a breeder is to evaluate the genotypes over representative locations in target production environment across years to identify most suitable PS genotype to a particular sowing date environment (Annicchiarico, 2012). PIS genotypes as expected displayed consistent performance as indicated by non-significant mean squares due to PIS genotypes × sowing date interaction for all the three traits. On the other hand, PS genotypes interacted significantly with sowing date environments for days to flowering and fresh pod yield plant^{-1} (Table 2). Failure of detection of PIS genotypes × sowing dates interaction does not necessarily indicate true absence of interaction as large number of degrees of freedom makes interaction mean squares non-significant in F-test, which is not a sensitive test (Fisher, 1918). Thus, further analysis of genotype × sowing date interaction to estimate parameters to assess the stability of genotypes is justified. Breeders will benefit from information that indicates performance stability/otherwise of genotype across test environments. Scatter plot based on first two principal components which captured >97% variation, clearly indicated distinction between PS and PIS genotypes and they could be classified into different clusters (Fig 1).

Relative stability of PS and PIS genotypes

PIS genotypes compared to PS genotypes were relatively less sensitive to crop environment represented by different sowing dates and manifested greater stability for all the traits as indicated by bi = <1 and non-significant S^2d_i (Table 3). However, the average primary branching ability and fresh pod yielding potential of PIS genotypes were far below those of PS genotypes. All the PIS genotypes were significantly early to flower but manifested consistent flowering time across the three sowing date environments compared to PS genotypes as indicated by least b_i and S^2d_i estimates. It is thus evident that all the PIS genotypes displayed static stability (analogous to biological concept of homeostasis) by maintaining consistent performance across the three sowing date environments. Static stability is generally regarded as useful in a range of rainfed production environments, especially in developing countries like India (Ceccarelli, 1994; Tigerstedt, 1994). In general, PS genotypes were late to flower and produced greater number of primary branches plant^{-1} and fresh pod yield plant^{-1} compared to PIS genotypes (Table 1). The performance differences between PS and PIS genotypes could be due to differences in duration of vegetative phase vs. reproductive phase. This is because, it has been well established that economic product yield potential is positively correlated with maturity duration of crop plants. In Dolichos bean, maturity duration is harvest (market) maturity which is the period from sowing to the day on which most of the individuals in a genotype produce well-filled fresh seeded pods, which fetch premium price. Among PIS genotypes, the released cultivar, HA 4 and advanced breeding line, HA 10-8 was found desirable with good primary branching ability and fresh pod yielding potential across all the three sowing date environments. However, PS genotypes compared to PIS genotypes displayed greater sensitivity to environments represented by sowing dates and were less stable for all the traits. The PS genotype, GL 369 with delayed flowering and profuse primary branching and highest pod yielding abilities was highly sensitive to variation in crop growth and development environment represented by sowing dates. Nevertheless, it could be opined that GL 369 is specially adapted and performs better when planted

Table 1. Estimates of trait means and sowing date environmental indices of PS and PIS genotypes of Dolichos bean

Genotypes	Days to flowering			Primary branches plant^{-1}			Fresh pod yield plant^{-1} (g)		
	August	September	October	August	September	October	August	September	October
Photoperiod sensitive (PS) genotypes									
GL 369	91.00^{a}	89.50^{a}	52.50^{a}	7.00^{a}	7.17^{a}	4.72^{ab}	238.67^{a}	198.48^{a}	151.17^{a}
GL 357	77.50^{ab}	85.00^{a}	54.50^{a}	6.17^{abc}	6.59^{ab}	5.05^{a}	95.69^{cd}	93.45^{cd}	78.31^{b}
GL 161	86.50^{ab}	84.00^{a}	53.00^{a}	6.52^{ab}	6.00^{abc}	4.53^{ab}	122.61^{b}	110.31^{bc}	93.02^{b}
GL 388	66.00^{bc}	73.50^{ab}	52.50^{a}	5.04^{abdc}	5.50^{abcd}	4.00^{ab}	114.86^{bc}	105.14^{bc}	91.68^{b}
GL 365	80.00^{ab}	60.00^{abc}	51.50^{ab}	6.67^{ab}	5.59^{abcd}	4.95^{a}	121.66^{b}	117.15^{b}	98.54^{b}
Mean of PS genotypes	80.20	78.40	52.80	6.28	6.17	4.65	138.70	124.91	102.54
Photoperiod insensitive (PIS) genotypes									
HA 4	48.50^{c}	38.50^{c}	43.50^{ab}	4.25^{cd}	3.69^{cd}	3.21^{b}	81.85^{d}	78.79^{d}	80.62^{b}
FPB 20	45.50^{c}	37.00^{c}	32.50^{b}	3.57^{d}	3.00^{d}	3.50^{ab}	53.44^{e}	56.83^{e}	50.17^{b}
FPB 5	47.50^{c}	40.00^{c}	35.00^{ab}	3.00^{d}	3.55^{cd}	2.98^{b}	54.64^{e}	53.56^{e}	49.35^{b}
FPB 14	51.50^{c}	38.00^{c}	32.00^{b}	4.39^{cd}	4.00^{bcd}	3.00^{b}	54.73^{e}	53.04^{e}	50.49^{b}
HA 10-8	50.50^{c}	41.50^{bc}	37.00^{ab}	4.82^{bcd}	3.90^{bcd}	3.86^{ab}	81.99^{d}	78.34^{d}	70.73^{b}
Mean of PIS genotypes	48.70	39.00	36.00	4.01	3.63	3.31	65.33	64.11	60.27
Environmental index	8.60	2.85	-11.45	0.47	0.23	-0.69	9.37	1.87	-11.24
CD @ 5%	13.44	9.98	29.23	1.18	1.58	1.25	13.43	18.65	10.90
CD @ 1%	19.31	14.33	42.00	1.70	2.26	1.79	19.29	26.80	15.65

Estimates of traits means with same superscripts indicate comparable genotypic performance while those with different superscripts indicate differential genotypic performance.

Table 2. Analysis of variance for stability of PS and PIS genotypes of Dolichos bean across different sowing date environment

Source of variation	df	Days to flowering		Primary branches plant^{-1}		Fresh pod yield plant^{-1} (g)	
		MSS	Pr > F	MSS	Pr > F	MSS	Pr > F
Replication within environment	03	6.44	0.942	0.24	0.321	120.97	0.001
Genotypes (G) (PIS + PS genotypes)	09	770.42	0.000	4.10	0.000	5539.98	0.000
Photosensitive (PS) genotypes	04	236.12	<.01	1.45	<.01	10752.10	<.0001
Photo-insensitive (PIS) genotypes	04	26.05	>0.05	0.62	>0.05	1208.00	<.0001
PS vs. PIS genotypes	01	12818.82	<.0001	66.15	<.0001	51880.61	<.0001
Sowing dates (SD)	02	1065.93	0.000	3.75	0.000	1087.61	0.000
Sowing dates (SD) + (G × SD)	20	165.89	0.029	0.62	0.027	257.33	0.000
G × SD	18	65.89	0.347	0.27	0.274	165.08	0.000
SD (Linear)	01	2131.85	0.000	7.51	0.000	2175.23	0.000
G × SD (Linear)	09	75.22	0.275	0.34	0.184	320.47	0.000
PS genotypes × SD	08	114.47	<.05	0.35	>0.05	367.56	<.01
PIS genotypes × SD	08	17.25	>0.05	0.16	>0.05	45.44	>0.05
Pooled deviation (PS + PIS genotypes)	10	50.90	0.033	0.19	0.434	8.72	0.990
Pooled deviation (PS genotypes)	05	51.28	0.28	0.18	0.37	11.27	0.93
Pooled deviation (PIS genotypes)	05	5.87	0.72	0.12	0.65	3.24	0.97
Pooled error (PS + PIS genotypes)	27	21.07	-	0.18	-	36.96	-
Pooled error (PS genotypes)	12	35.68	-	0.16	-	44.92	-
Pooled error (PIS genotypes)	12	10.43	-	0.18	-	21.63	-

during August (Table 3). On the contrary, the PS genotypes, GL 161 with relatively delayed flowering and profuse primary branching and fresh pod yielding ability performed better in all the three sowing date environments. It is worth recommending GL 161 for cultivation in delayed sowing as well. This augurs well with the practice of identifying and/or breeding appropriate cultivars adapted to prevailing production environment to maximise productivity (Ceccarelli, 1994; Tigerstedt, 1994). Broadening crop cultivar genetic base and introducing a number of such cultivars into specific production environments would stabilise crop production as it is expected to reduce the risk of disasters arising due to vulnerability of only one or a few recommended cultivar(s) to unforeseen biotic and abiotic stresses. This is particularly relevant in highly self-pollinated crops like Dolichos bean where cultivars are pure-lines which are genetically homogeneous (Simmonds, 1991). Performance stability and performance *per se* potential of PIS genotypes is higher and lower, respectively than those of PS genotypes. The reverse was true with respect to PS genotypes. Rattunde et al. (2013) have also reported superiority of photoperiod sensitive guinea-race sorghum hybrids under farmers' field condition in Mali in Africa. Such results could be attributed to involvement of different sets of genes controlling *per se* performance and stability, which has been amply demonstrated in Drosophila (Caligari and Halther, 1975). It could also be due to genetically-based trade-offs between performance and stability (Ludlow and Muchow, 1990) and need to choose between incompatible levels of a the key adaptive trait, such as earliness of flowering (Wallace et al., 1993).

Table 3. Estimates of parameters to assess stability of PS and PIS genotypes under different sowing date environments in Dolichos bean.

Genotypes	Days to flowering			Primary branches plant^{-1}			Fresh pod yield plant^{-1} (g)		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
Photoperiod sensitive (PS) genotypes									
GL 369	77.67^{a}	2.05	37.61	6.30^{a}	2.16	0.07	196.10^{a}	4.18	-0.27
GL 357	72.33^{ab}	1.34	105.29*	5.94^{ab}	1.16	0.08	89.15^{cd}	0.88	-34.47
GL 161	74.50^{ab}	1.77	12.14	5.68^{ab}	1.68	-0.18	108.65^{b}	1.42	-43.86
GL 388	64.00^{b}	0.83	61.67*	4.85^{cb}	1.10	0.09	103.89^{bc}	1.11	-44.30
GL 365	63.83^{b}	1.26	68.31*	5.73^{ab}	1.26	0.13	112.45^{b}	1.16	-35.41
Photoperiod insensitive (PIS) genotypes									
HA 4	43.50^{c}	0.14	26.51	3.71^{d}	0.79	-0.12	80.42^{d}	0.04	-40.92
FPB 20	38.33^{c}	0.59	-5.30	3.36^{d}	-0.11	-0.002	53.48^{e}	0.20	-31.70
FPB 5	40.83^{c}	0.57	-9.97	3.18^{d}	0.18	0.000	52.52^{e}	0.26	-44.89
FPB 14	40.50^{c}	0.87	19.70	3.80^{d}	1.16	-0.18	52.75^{e}	0.20	-45.35
HA 10-8	43.00^{c}	0.60	-3.08	4.20^{cd}	0.61	0.13	77.01^{d}	0.55	-45.23

*Significant @ P = 0.05; ** Significant @ P = 0.01

Estimates of traits means with same superscripts indicate comparable genotypic performance while those with different superscripts indicate differential genotypic performance.

Table 4. Weather parameters prevailed during experimental period

Weather parameters	August 2013	September 2013	October 2013
Minimum temperature (^{0}C)	19.0	18.9	19.1
Maximum temperature (^{0}C)	27.9	27.4	27.8
Rainfall (mm)	58.8	362.3	81.9

Table 5. PS and PIS Dolichos bean genotypes used in the study

Sl. No.	Accession	Origin
PS genotypes		
1	GL 388	Dharwad, Karnataka, India
2	GL 365	Ananthapuram, Andhra Pradesh, India
3	GL 161	Unknown
4	GL 369	Mandya, Karnataka, India
5	GL 371	Bidar, Karnataka, India
PIS genotypes		
1	HA 4	UAS, Bangalore, India
2	HA 10-8	UAS, Bangalore, India
3	FPB 5	UAS, Bangalore, India
4	FPB 20	UAS, Bangalore, India
5	FPB 14	UAS, Bangalore, India

Materials and Methods

Experimental location

A field experiment was carried out at Zonal Agricultural Research Station (ZARS) of UAS Bangalore, Karnataka, India. Geographically, ZARS, Bangalore is located at 12°58' latitude North, 77°35' longitude East and an altitude of 930 meters above sea level. The annual average rainfall ranges from 679.1 mm to 888.9 mm. The data on average monthly minimum and maximum temperature and rainfall during experiment are furnished in Table 4.

Plant material and experimental design

The experimental material consisted of five PS genotypes such as GL 388 (originated from Dharwad, Karnataka), GL 365 (originated from Ananthapuram, Andhra Pradesh), GL 161 (unknown origin), GL 369 (originated from Mandya, Karnataka) and GL 371 (originated from Bidar, Karnataka) collected and maintained at All India Coordinated Research Project (AICRP) on Pigeonpea, ZARS, Gandhi Krishi Vignana Kendra (GKVK), UAS, Bangalore and five PIS genotypes such as HA 4 (a released variety from UAS, Bangalore), FPB 5, FPB 20, FPB 14 and HA 10-8 (advanced breeding lines developed at UAS, Bangalore) (Table 5). The PS and PIS genotypes were planted in three sowing dates *viz.*, 8th August, 8th September and 8th October during 2013 rainy season in a randomised block design with two replications. The variation in weather variables during growth and development of PS and PIS genotypes created differential production environment and hence sowing dates were considered as sowing date environments in the present study. Each genotype was planted in a single row of 3 m length with a spacing of 0.6 m between rows and 0.3 m between plants within a row. The experiment was carried out at the experimental plots of ZARS, UAS, GKVK, Bangalore. The recommended agronomic practices were followed to raise a healthy crop.

Data collection

The data were collected on five randomly selected plants in each genotype on days to flowering (as number of days required to reach flowering in each of the cultivars), primary branches plant^{-1} and fresh pod yield plant^{-1} (g).

Statistical analysis

The means of data recorded on five randomly selected plants in each of the two replication were used for statistical analysis. Analysis of variance (Eberhart and Russell, 1966) was carried out to detect interaction between genotypes with sowing dates. Three parameters namely (1) trait mean of each genotype, (2) regression coefficient (b_i), which measures sensitivity or responsiveness of genotypes to environments representing different sowing dates and (3) deviation of the linear regression (S^2d_i) (Eberhart and Russell, 1966) were estimated to assess the performance stability of PIS and PS genotypes. Based on these parameters, relative performance *per se* and performance stability of PS vs PIS genotypes were interpreted. The significance of differences in traits means of PS and PIS genotypes was examined using Tukey's 't' test (Tukey, 1953). The principal component (PC) analysis (Pearson 1901; Hotelling 1933) was performed using data on traits means of PS and PIS genotypes across sowing data to extract the PCs that capture maximum variability among PS and PIS genotypes. The first two PCs which captured >97 *per cent* variation among PS and PIS genotypes were plotted in a graph. Based on the scattering pattern, PS and PIS genotypes were grouped into different clusters.

Conclusion

The present study provided preliminary evidence to support theoretical hypotheses and farmers' experiences-based view that PS cultivars perform better across delayed sowing date's environments although they may not be stable in statistical sense. However, confounding effects of relative performance and stability of PS and PIS genotypes cannot be discounted as they differ at loci controlling traits (especially, flowering and maturity duration) other than those controlling photoperiod sensitivity. The conclusive evidence on greater *per se* performance and performance stability of PS genotypes is possible only through evaluation of near isogenic lines that differ only at loci controlling photoperiod sensitivity to flowering time under delayed sowing dates in a range of locations. PS cultivars often are adopted to only a narrow range of latitudes as changes in latitudes are associated with day length and temperature changes in a manner that does not favour broad adaptation of a single PS cultivar. On the contrary, PIS cultivars have broad adaptation and if they are chosen, farmers can control date of flowering either by varying sowing time or choosing a cultivar with a different heat unit requirement. To authors knowledge, reported results in the present study are first of kind in Dolichos bean.

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