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Comparative Performance Assessment of Determinate and Indeterminate Dolichos Bean (*Lablab purpureus* L. Sweet) Recombinant Inbred Lines

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Abstract

The *per se* performance of two bi-parental crosses-derived determinate and indeterminate recombinant inbred lines (RILs) belonging to early, medium and late maturity groups in dolichos bean were compared for eight quantitative traits. Based on days to 50% flowering, the HA 4 × CPI 31113 (HACPI 3)-derived RILs and HA 4 × CPI 60125 (HACPI 6)-derived RILs were classified into early, medium and late maturity groups. Early and late maturing HACPI 3-derived and early maturing HACPI 6-derived determinates and indeterminate RILs differed significantly in favour of indeterminate RILs for pods plant^{-1}, dry pod yield plant^{-1} and dry seed yield plant^{-1}. For rest of the traits, in all the maturity groups, determinate and indeterminate RILs derived from both the crosses were comparable. However, medium maturity group determinates and indeterminate RILs derived from both the crosses were comparable for all the traits. The results suggested that it is desirable to breed determinate dolichos bean varieties of medium maturity group (50–55 days to flowering) to maintain their economic product yield comparable to indeterminate varieties.

Keywords: Determinate, indeterminate, maturity, RILs, variance

Dolichos bean is an under-exploited food legume crop widely distributed in many tropical and subtropical countries. It is a self-pollinated crop (Kukade and Tidke, 2014) with 2n=22 chromosomes (She and Jiang, 2015). It is believed that dolichos bean is originated in India (Nene, 2006), as it is documented in archeo-botanical findings in India from 2000 to 1,700 BC at Hallur, the earliest Iron-age site in Karnataka to 1200 to 300 BC at Veerapuram excavation site in Andhra Pradesh (Fuller, 2003). In India, it is predominantly grown in southern districts of Karnataka state and adjoining districts of Tamil Nadu, Andhra Pradesh and Maharashtra (Ramesh *et al.,* 2016). It is grown mostly as a rainfed crop for its fresh immature beans for use as a vegetable (Keerthi *et al*., 2014a; Keerthi *et al*., 2014b; Keerthi *et al.,* 2016 and Ramesh *et al.,* 2016).

Most cultivars grown by farmers are land races which display indeterminate growth habit (Keerthi *et al*., 2014a; Keerthi *et al*., 2014b; Keerthi *et al.,* 2016 and Ramesh *et al.,* 2016). Indeterminacy is advantageous for subsistence production and consumption of dolichos bean, as it enables harvesting of pods in multiple pickings ensuring continuous availability of pods for a longer time (Keerthi *et al*., 2014a: Keerthi *et al*., 2014b; Keerthi *et al.,* 2016 and Ramesh *et al.,* 2016). However, of late, due to market economy, there is an increased demand for varieties with a determinate growth habit. The varieties with determinate growth habit exhibit synchronous flowering and maturity and thus enable single harvest of all the pods on a commercial scale, which in-turn facilitates economical transportation of the produce to the markets (Keerthi *et al*., 2014a; Keerthi *et al*., 2014b; Keerthi *et al.,* 2016 and Ramesh *et al.,* 2016). Determinate types compared to their indeterminate counterparts produce larger number of branches, exhibit greater economic product yield (EPY) potential and EPY stability (Keerthi *et al.,* 2014b and Keerthi *et al.,* 2016). Due to their compact growth, determinates facilitate high density planting to maximize their EPY (Keerthi *et al*., 2014a; Keerthi *et al*., 2014b; Keerthi *et al.,* 2016 and Ramesh *et al.,* 2016). Keerthi *et al.* (2014b) based on a random sample of unrelated determinate and indeterminate genotypes opined that performance stability of determinate genotypes was better than that of their indeterminate counterparts in dolichos bean. However, these studies are based on a limited number of genotypes with a particular maturity group. Considering that performance is directly related to crop duration, any such comparative performance studies should be based on a large number of determinate and indeterminate genotypes belonging to a range of maturity groups. The objective of the present investigation was to compare the pod and seed yield and their component traits between the determinate and indeterminate recombinant inbred lines (RILs) belonging to a range of maturity groups in dolichos bean.

MATERIAL AND METHODS

The material consisted of 124 F_{10} RILs derived from HA 4 × CPI 31113 (HACPI 3) and 112 RILs derived from HA 4 × CPI 60125 (HACPI 6). The seeds of these RILs derived from HACPI 3 and 112 RILs derived from HACPI 6 and three check entries [HA 3, HA 4 and kadalavare (KA)] are being maintained at All India Co-ordinated Research Project (AICRP) on pigeonpea, University of Agricultural Sciences (UAS), Bengaluru, India.

Layout of the experiment: The seedlings of all the RILs and the checks were raised in polythene covers and maintained for 20 days for proper rooting. Subsequently, the seedlings of two RIL populations and those of the three check entries were transplanted separately to field in an augmented design in twelve compact blocks during 2016 rainy season at the experimental plots of Department of Genetics and Plant Breeding, UAS, Bengaluru. Each block consisted of 18-20 RILs, three checks and two border entries. The seedlings of each entry were transplanted in a single row of 2.5 m length, with a row spacing of 0.45 m. A basal dose of 25:50:25 Kg ha^{-1} of NPK (nitrogen : phosphorous : potassium) was applied to the experimental plots. Recommended management practices were followed during the crop-growing period to raise a healthy crop.

Sampling of plants and data collection: Out of 124 HACPI 3-derived RILs and 112 HACPI 6-derived RILs planted, only 117 and 109 RILs, respectively, survived till the maturity. Data were recorded on survived RILs on one qualitative trait (growth habit) based on visual observation and eight quantitative traits (QTs) (days to 50 % flowering, primary branches $plant^{-1}$, racemes $plant^{-1}$, raceme length, pods $plant^{-1}$, dry pod yield $plant^{-1}$, dry seed yield $plant^{-1}$ and 100 seed weight) based on counting / measurement using appropriate scale depending on the trait in each RIL and check entries following the descriptors (Byregowda, *et al.,* 2015).

As is true in most grain legumes, in dolichos bean also, the period from days to flowering to days to maturity is by and large remain constant. Taking cue from this, based on days to 50 per cet flowering, the HACPI 3- derived and HACPI 6- derived RILs were classified into three maturity groups such as early (<50 days to 50% flowering), medium (51-60 days to 50% flowering) and late (>61 days to 50% flowering).

Statistical analysis: The eight QTs mean values computed based on data on five plants in each RIL and check entries were used for statistical analysis. ANOVA was performed following Augmented design using WINDOSTAT 9.5 version. Adjusted trait value of each of the individuals in RIL were estimated by subtracting observed trait value of the individuals of RILs from the adjustment factor 'a_j' of j^{th} block; 'a_j' was estimated as 'a_j'= (x_j – x…), x_j = trait mean of checks in the j^{th} block and x… = the overall QTs mean of checks in the experiment.

Descriptive statistics to assess genetic variability: Adjusted means were used for estimating eight QTs mean. Genetic variability among the RILs for all the QTs was assessed at the level of first degree statistics such as absolute range (AR) and standardized range (SR) and at second degree statistics such as, phenotypic co-efficient of variability (PCV) and genotypic co-efficient of variability (GCV). AR was estimated as (QTs Max – QTs Min), while SR was estimated as (QTs Max – QTs Min)/ $\bar{X}$ (QTs mean).

PCV was estimated as,

$$\mathrm{PCV}(\%) = \frac{\sqrt{Phenotypic\ variance}}{Experimental\ mean} \times 100$$

GCV was estimated as,

$$\mathrm{GCV}(\%) = \frac{\sqrt{Genotypic\ variance}}{Experimental\ mean} \times 100$$

Comparative assessment of QTs means of determinate and indeterminate RILs: For reliable and unambiguous performance comparison of QTs means of determinate and indeterminate RILs, the QTs variances should be homogenous within determinate and indeterminate RILs of each maturity group. QTs variances within the determinate and indeterminate RILs of each maturity group were estimated using 'statistical analysis' option available in Microsoft excel. Homogeneity of QTs variances between determinate and indeterminate RILs was examined using Levene's test implemented using 'PROC Univariate' (SAS Institute, Cary, NC). Significance of differences in QTs means between determinate and indeterminate RILs derived from HACPI 3 and HACPI 6 in each maturity group was examined using two sample t-test assuming unequal variances as number of determinate and indeterminate RILs in each maturity group differed. The test statistic 't' was computed as,

$$t = \frac{(\overline{X}_D - \overline{X}_{ID})}{\sqrt{sp^2\left(\frac{1}{N_D} - \frac{1}{N_{ID}}\right)}}$$

Where,

$\overline{X}_D$= QTs mean of determinate RILs; $\overline{X}_{ID}$= QTs mean of indeterminate RILs; $sp^2 = (n_1-1)\, s_1^2 + (n_2-1)\, s_2^2/(n_1+n_2-2)$; n_1= number of determinate RILs; n_2= number of indeterminate RILs; s_1^2 = variance of determinate RILs; s_2^2 = variance of indeterminate RILs; N_D= number of determinate RILs; N_{ID}= number of indeterminate RILs.

Results and Discussion

Analysis of variance: Non-significance of mean squares due to blocks suggested poor evidence for detectable effect of edaphic factors and /or micro-environments associated with the blocks on the expression of RILs for all the QTs except primary branches plant^{-1}in both the populations and 100-seed weight in HACPI-6 derived RIL population (Table I). Mean squares attributable to RILs (determinate + indeterminate RILS) and determinate RILs derived from both the crosses were significant for all the QTs except racemes plant^{-1}, dry pod yield plant^{-1}, dry seed plant^{-1} and 100-seed weight in HACPI-3. Similarly, mean squares attributable to indeterminate RILs derived from both the crosses were significant for all the QTs except days to 50 per cent flowering, racemes plant^{-1}, dry seed plant^{-1} and 100-seed weight in HACPI-3. However, non-significant mean squares attributable to the contrast 'indeterminate RILs *vs*. determinate RILs' derived from both the crosses suggested that in general indeterminate and determinate RILs were comparable for all the QTs investigated.

Genetic variability: The estimates of QTs range, one of the measures of trait variation provide clues about the occurrence of RILs with extreme expression. The SR of the RILs was higher for the racemes plant^{-1}, raceme length, pods plant^{-1}, dry pod yield plant^{-1}, dry seed yield plant^{-1} and 100-seed weight compared to that for days to 50 per cent flowering and primary branches plant^{-1} which was amply reflected by the estimates of PCV in RILs derived from both the crosses. The narrow differences in the estimates of PCV and GCV for all QTs in HACPI-6 derived RIL population and wide differences in the estimates of PCV and GCV for all QTs except primary branches plant^{-1}and 100-seed weight in HACPI-3 derived RIL population suggested limited and greater influence of environment, respectively in the expression of QTs investigated (Table II).

Non-significance of Levene's test (Tables III and IV) indicated homogeneity of QTs variances within all the maturity groups determinate and indeterminate RILs derived from both the crosses for all the QTs (barring a few exceptions). Such homogeneity of QTs variances is a necessary prerequisite for reliable comparative performance assessment of determinate and indeterminate RILs of different maturity groups.

Comparative performance of determinate and indeterminate RILs: The HACPI 3-derived determinate RILs of early, medium and late maturity groups were significantly early to flower compared to those of indeterminate RILs, although the magnitude of differences were marginal to low to have any practical significance. HACPI 3-derived determinate and indeterminate RILs of early and late maturity groups differed significantly in favour of indeterminate RILs for racemes plant^{-1}, pods plant^{-1}, dry pod yield plant^{-1}, dry seed yield plant^{-1}. For rest of the QTs, the determinate and indeterminate RILs of all the maturity groups were comparable (Table V).

The HACPI-6 derived determinate RILs of medium group were significantly early to flower than those of indeterminate RILs. However, HACPI 6-derived indeterminate RILs produced significantly

TABLE I

Analyses of variance of determinate and indeterminate RILs derived from two bi-parental crosses for eight quantitative traits in dolichos bean

Sl. no.	Source of Variation	Df C - I	Df C - II	Dff C - I	Dff C - II	PB C - I	PB C - II	RP C - I	RP C - II	RL C - I	RL C - II
1	Block	05	05	02.89	49.38	00.17 **	00.18 *	05.60	01.55	04.58	02.42
2	Entries (RILs + Checks)	119	111	123.27	206.52 *	00.20 **	00.22 **	10.92	06.95 *	10.33	09.64 **
3	Checks	02	02	748.50 *	821.72 **	00.00	00.08	136.22 **	49.88 **	10.55	49.39 **
4	RILs	116	108	98.58 *	181.95 *	00.19 **	00.22 **	08.54	06.12 *	10.04	08.37 *
5	Checks vs. RILs	01	01	1736.74 **	1630.28 **	02.09 **	00.30 *	36.26	11.34 *	44.12 *	66.89 **
6	Determinate RILs	33	40	154.01	221.20 **	0.47 **	0.57 **	9.59	7.88 **	24.26 **	14.51 **
7	Indeterminate RILs	81	67	145.35	319.96 **	0.34 **	6.18 **	18.20	12.99 **	17.97 **	18.40 **
8	Determinate vs. indeterminate RILs	1	1	6019.50	9016.11	0.08	2.51	184.60	135.87	4263.15	959.76
9	Error	10	10	120.90	65.32	00.03	00.04	12.80	01.97	05.52	02.20

Continued TABLE 1

Sl. no.	PP C - I	PP C - II	DPY C - I	DPY C - II	DSY C - I	DSY C - II	TW C - I	TW C - II
1	144.74	27.45	103.88	25.12	42.77	05.22	01.04	01.06 *
2	340.37 *	320.34 ***	210.01	292.42 **	106.42	136.43 **	15.52	17.66 **
3	281.88	286.53 **	396.03	506.10 **	103.94	213.56 **	09.15	27.95 **
4	334.68 *	312.08 **	168.50	250.60 **	84.91	115.87 **	10.99 *	13.11 **
5	1116.92 **	1279.67 **	4653.09 **	4381.63 *	2606.15 **	2203.37 **	553.45 **	488.17 **
6	408.02 **	523.05 **	185.74	405.84 **	72.27	172.11 **	17.53	18.22 **
7	735.98 **	679.47 **	367.20 *	552.77 **	189.82	259.97 **	23.37	30.42 **
8	2840.37	916.33	1692.56	387.52	59.30	28.05		
9	85.98	22.55	104.09	21.52	50.64	09.99	03.13	00.21

Df = Degrees of freedom
C-I = HACPI 3
C-II = HACPI 6
DFF = Days to 50 % flowering
PB = Primary branches plant^{-1}
RP = Racemes plant^{-1}
RL = Raceme length (cm)
PP = Pods plant^{-1}
DPY = Dry pod yield plant^{-1} (g)
DSY = Dry seed yield plant^{-1} (g)
TW = 100- seed weight (g)

TABLE II

Descriptive statistics for quantitative traits in RIL populations derived from two bi-parental crosses in dolichos bean

Traits	Mean ± SE		Range				Standardized Range		Phenotypic coefficient of variation (%)		Genotypic coefficient of variation (%)	
			Min	Max	Min	Max						
	HACPI 3	HACPI 6	HACPI 3		HACPI 6		HACPI 3	HACPI 6	HACPI 3	HACPI 6	HACPI 3	HACPI 6
Days to 50% flowering	61.44 ± 1.01	59.55 ± 0.77	40	84	38	105	00.71	01.12	16.36	20.85	07.30	17.13
Primary branches $plant^{-1}$	02.75 ± 0.01	02.86 ± 0.02	02.00	03.80	01.60	03.80	00.65	00.76	15.31	15.94	13.89	14.44
Racemes $plant^{-1}$	10.74 ± 0.33	09.94 ± 0.13	05.00	20.80	04.20	16.20	01.47	01.20	27.89	23.95	18.22	19.33
Raceme length (cm)	13.08 ± 0.21	13.01 ± 0.14	04.24	22.58	07.38	23.72	01.40	01.25	23.70	21.34	15.42	18.03
Pods $plant^{-1}$	39.47 ± 0.85	38.08 ± 0.45	06.60	105.00	05.40	96.60	02.49	02.39	44.57	44.01	37.88	42.20
Dry pod yield $plant^{-1}$ (g)	25.14 ± 0.94	26.25 ± 0.44	02.00	64.76	02.48	72.28	02.50	02.85	50.64	57.24	30.28	54.45
Dry seed yield $plant^{-1}$ (g)	15.28 ± 0.65	16.03 ± 0.30	01.20	54.06	01.22	50.20	03.40	03.05	59.18	63.75	36.40	60.62
100- seed weight (g)	14.12 ± 0.16	14.22 ± 0.04	07.02	23.20	05.74	26.96	01.14	01.49	22.62	24.07	18.83	23.85

TABLE III

Estimates of phenotypic variance within determinate (D) and indeterminate (ID) early (<50 days), medium (51-60 days) and late maturity (>61 days) group RILs derived from HACPI 3

Traits	Early maturity group Variance		Levene's Statistic	Medium maturity group Variance		Levene's Statistic	Late maturity group Variance		Levene's Statistic
	D	ID		D	ID		D	ID	
Days to 50% flowering	08.53	05.01	00.69	04.06	08.12	03.47	13.98	27.35	00.80
Primary branches plant^{-1}	00.31	00.01	03.38	00.17	00.23	00.68	00.26	00.16	01.43
Racemes plant^{-1}	03.35	15.13	07.49 **	04.88	04.04	00.14	08.23	09.06	00.09
Raceme length (cm)	12.67	06.81	00.89	17.80	10.24	00.96	08.00	08.65	00.11
Pods plant^{-1}	199.65	462.25	01.39	179.02	381.03	00.66	28.62	352.31	04.43 *
Dry pod yield plant^{-1} (g)	105.47	118.59	00.00	107.32	203.06	01.24	14.60	183.33	04.60 *
Dry seed yield plant^{-1} (g)	33.17	47.47	00.27	57.60	123.65	00.77	02.89	86.49	04.03 *
100- seed weight (g)	08.12	05.19	00.43	12.11	11.08	00.02	06.15	11.49	00.97

*= Significant at P=0.05 **=Significant at P=0.01

Table IV

Estimates of phenotypic variance within determinate (D) and indeterminate (ID) early (<50 days), medium (51-60 days) and late (>61 days) maturity group RILs derived from HACPI 6

Traits	Early maturity group Variance		Levene's Statistic	Medium maturity group Variance		Levene's Statistic	Late maturity group Variance		Levene's Statistic
	D	ID		D	ID		D	ID	
Days to 50% flowering	08.82	07.34	00.15	08.23	05.38	00.63	139.71	90.63	00.13
Primary branches plant^{-1}	00.36	00.17	03.04	00.26	00.18	00.63	00.04	00.20	01.09
Racemes plant^{-1}	03.88	10.30	05.06 *	02.10	05.38	01.24	07.34	06.81	00.02
Raceme length (cm)	07.67	08.94	00.02	04.00	05.06	00.41	13.61	10.43	00.02
Pods plant^{-1}	194.88	579.84	04.63 *	366.33	398.80	00.05	239.01	281.90	00.13
Dry pod yield plant^{-1} (g)	157.25	520.30	07.10 **	346.33	294.46	00.04	102.01	219.63	00.71
Dry seed yield plant^{-1} (g)	73.96	248.69	06.43 *	146.16	113.42	00.19	35.52	115.99	00.95
100- seed weight (g)	11.22	17.89	00.57	04.32	10.62	01.66	06.81	18.49	01.17

*= Significant at P=0.05 **=Significant at P=0.01

TABLE V

Comparative quantitative trait means of early (<50 days), medium (51-60 days) and late maturity group (>61 days) determinate (D) and indeterminate (ID) HACPI 3-derived RILs

	Early maturity group			Medium maturity group			Late maturity group		
	D	ID	Difference	D	ID	Difference	D	ID	Difference
Number of RIL →	13	05		13	24		08	54	
Traits									
Days to 50% flowering	44.76	49.00	04.24 **	54.30	56.25	01.95 *	66.00	70.00	04.00 *
Primary branches plant^{-1}	02.78	03.08	00.30	02.86	02.76	00.10	02.55	02.71	00.16
Racemes plant^{-1}	09.29	12.44	03.15 *	09.24	10.52	01.28	09.57	11.34	01.77
Raceme length (cm)	13.18	11.93	01.25	13.86	13.27	00.59	13.37	12.70	00.67
Pods plant^{-1}	30.78	54.46	23.68 **	32.40	39.35	06.95	29.03	42.76	13.73 *
Dry pod yield plant^{-1} (g)	19.54	33.46	13.92 *	20.24	27.83	07.56	14.94	26.71	11.77 *
Dry seed yield plant^{-1} (g)	10.19	21.96	11.77 **	11.81	17.57	05.76	08.67	16.35	07.68 *
100- seed weight (g)	13.62	14.54	00.92	13.71	15.74	02.03	12.23	13.80	01.57

*= Significant at P=0.05 **=Significant at P=0.01

TABLE VI

Comparative quantitative trait means of early (<50 days), medium (51-60 days) and late maturity group (>61 days) determinate (D) and indeterminate (ID) HACPI 6-derived RILs

	Early maturity group			Medium maturity group			Late maturity group		
	D	ID	Difference	D	ID	Difference	D	ID	Difference
Number of RIL →	25	08		10	21		06	38	
Traits									
Days to 50% flowering	45.12	45.75	00.63	54.70	56.90	02.20 *	71.16	73.18	02.02
Primary branches plant^{-1}	02.80	02.72	00.08	02.82	02.80	00.02	03.06	02.94	00.12
Racemes plant^{-1}	08.75	10.65	01.90 *	08.68	10.47	01.79 *	10.06	10.56	00.50
Raceme length (cm)	13.23	13.59	00.36	12.75	11.56	01.19	12.85	13.60	00.75
Pods plant^{-1}	31.05	49.37	15.32 **	43.97	42.54	01.43	39.10	36.94	02.16
Dry pod yield plant^{-1} (g)	20.54	37.13	16.59 **	30.32	27.85	02.47	25.35	25.87	00.52
Dry seed yield plant^{-1} (g)	12.12	23.61	11.49 **	18.37	17.23	01.14	15.13	15.85	00.72
100- seed weight (g)	13.24	15.13	01.89	14.14	13.93	00.21	15.22	14.63	00.59

*= Significant at P=0.05 **=Significant at P=0.01

more racemes plant^{-1} compared to those of determinates RILs in early and medium maturity groups, although the magnitudes of differences were marginal. Further, HACPI 6-derived determinate and indeterminate RILs of early maturity differed significantly in favour of indeterminate RILs for pods plant^{-1}, dry pod yield plant^{-1} and dry seed yield plant^{-1}. For rest of the QTs, all maturity group determinate and indeterminate HACPI6-derived RILs were comparable (Table VI). In faba bean, Nadal *et al.* (2005) documented higher dry seed yield of the three indeterminate cultivars than that of three determinate cultivars. Kato *et al.* (2015) also reported superiority of indeterminate RILs over their determinate counterparts for number of seeds plant^{-1}, number of pods plant^{-1} and seed yield plant^{-1} in soybean.

The present study provides ample evidence for the superiority of only early maturity group indeterminate RILs over their determinate counterparts derived from both the crosses. The study also supports significant superiority of both early and late maturity group indeterminate RILs over their determinate counterparts derived from HACPI 3. On the contrary, medium maturity group determinate and indeterminate RILs derived from both the crosses were comparable for all the traits. These results clearly suggest that it is desirable to breed dolichos bean determinate varieties of medium maturity (51-55 days to flowering) so as to maintain their productivity level comparable to indeterminate varieties. To the best of our knowledge, the present results are based on a large number of determinate and indeterminate RILs with a range of maturity duration and comparable genetic background (as they are derived from bi-parental crosses) and comparable variation for the traits for which the RILs are compared.

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