Journal of Applied and Natural Science 9 (4): 2377 - 2384 (2017)

Thermal requirements, growth and yield of pigeonpea [*Cajanus cajan* (L.) Millsp.] genotypes under different agroclimatic zones of Punjab

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Received: April 12, 2017; Revised received: June 11, 2017; Accepted: October 30, 2017

Abstract: A field experiment was carried out at four locations i.e. Ludhiana, Bathinda, Faridkot and Gurdaspur to study the influence of diverse environments on symbiotic traits, thermal requirements, growth in terms of plant height (cm) and yield (kg/ha) of pigeonpea [*cajanus cajan* (L.) Millsp.] genotypes under different agroclimatic zones of Punjab. Results indicated that crop sown on 15 May recorded the higher grain yield than later sowing dates of 1 June and 15 June at all the locations; 15 May sowing provided 23.3, 22.1 and 46.7% higher grain yield over 1 May, 1 June and 15 June sowing, respectively. Early sown crop acquired higher agro-climatic indices than delayed sowings. The crop sown on 15 May provided the maximum gross returns, net returns and B:C ratio as evident from the additional income of Rs 13599, 13040 and 22865 Rs/ha over 1 May, 1 June and 15 June sowing, respectively. Among the genotypes, AL 201 at Ludhiana and Gurdaspur, AL 1578 at Bathinda and PAU 881 at Faridkot resulted in the highest grain yield and maximum returns. The genotype AL 201 took more days to 50% flowering and maturity at all the locations. It can be concluded that 15 May is the optimum sowing date and AL 201 and PAU 881 are the promising genotypes for providing high productivity of pigeonpea under different agroclimatic zones of Punjab.

Keywords: Genotype, Grain yield, Pigeonpea, Sowing date, Thermal requirements

INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important legume crop widely cultivated in the world. In India, during 2014 pigeonpea was grown on 5.60 million ha with total production of 3.29 million tonnes and productivity of 587 kg/ha (FAOSTAT 2017). Its grains are rich in high digestible protein (21.7 g/100 g), low in fat (1.49 g/100 g) with no cholesterol and high dietary fibres. Being a non-monetary input, sowing time significantly influences the growth and grain yield of pigeonpea (Wilson *et al*., 2012; Egbe *et al*., 2013; Singh *et al.,* 2016). Delayed sowings beyond the optimum period result in low grain yields of pigeonpea (Kumar *et al*., 2008). Genotypes may vary in productivity (Egbe and Vange, 2008; Bhavi *et al*., 2013; Umesh *et al*., 2013; Singh *et al.,* 2016) and the yield potential of the genotypes can be fully exploited through providing appropriate microclimate temperature between 18 and 29 ^{o}C at different growth and development phases.

All biological processes of crops respond to temperature and all responses can be summarized in terms of three cardinal temperatures: a base or minimum, an optimum and a maximum temperature. The crop needs moist and warm weather. The temperature requirement during germination, active vegetative growth, flowering and pod setting and maturity ranges between 30-35 ^{o}C, 20-25 ^{o}C, 15-18 ^{o}C and 35-40 ^{o}C, respectively. However, the nature of the response to temperature between these cardinal points is important for calculating the phenology, adaptation and yield of a crop (Singh and Singh 2011). Air temperature based meteorological indices viz. growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) are used to describe changes in phenology and growth parameters (Prakash *et al*., 2015). The progress in terms of growth is estimated by integrating a developmental rate, which is usually a function of temperature and photoperiod. Besides, heat use efficiency i.e. efficiency of utilization of heat in terms of dry matter production or grain yield is another important aspect which has practical utility. Efficiency of heat energy conversion for dry matter production depends on genetic factors, crop and the growing environment. Several phenological models have been prepared to predict

ISSN : 0974-9411 (Print), 2231-5209 (Online)

the duration required to attain different phenophases by using growing degree-days (GDD), photothermal units (PTU) and other crop thermal units (Esfandiary *et al*., 2009). GDD and PTU are good estimators of growth stages in different crops like sorghum (Prakash *et al*., 2017) and wheat (Pandey *et al*., 2010) and finally to predict the yield in view of different climatic changes.

In Punjab, the recommended time of sowing of pigeonpea was first fortnight of June (PAU 2011). However, with the changing climate, the optimum time of sowing is also subjected to changes. Furthermore, when the crop is sown during first fortnight of June, mostly the crop maturity is delayed, causing delayed harvesting and consequently late sowing of succeeding wheat crop also leads to low productivity. About 375 kg/ha wheat grain yield is reduced with a delay of one week in sowing (PAU 2011). In Northern India, only those genotypes of pigeonpea are required which may fit well in pigeonpea-wheat cropping system (Sekhon and Singh 2005). Based on different climatic conditions, Punjab state has been divided into six diverse agroclimatic zones and to draw conclusive inferences, experiments were conducted in 3 prime zones having pigeonpea acreage i.e. central plain zone (Ludhiana), submontane zone (Gurdaspur) and south-western plain arid zone (Faridkot and Bathinda). Keeping all these factors in mind, the present experiments were conducted at four places in three different agroclimatic zones of Punjab to study the influence of diverse environments on symbiotic traits, thermal requirements, growth and yield of pigeonpea genotypes.

MATERIALS AND METHODS

Field experiments were conducted during *kharif* (rainy season) 2011 at the research farm of the Punjab Agricultural University, Ludhiana (30° 54´N, 75° 48´E, altitude 247 m) and its Regional Research Stations at Gurdaspur (31°94´N and 75°24´E altitude 241 m), Bathinda (30°21´N and 74°94´E altitude 210 m) and Faridkot (30°40´N and 74°44´E altitude 211 m). Meteorological data during the crop season were recorded from the Meteorological Observatories and weekly mean of maximum & minimum temperature, total rainfall and sunshine hours are presented in Fig. 1.

The experiment comprised of four dates of sowing (1 May, 15 May, 1 June and 15 June) in main plots and four genotypes (AL 15, AL 201, PAU 881 and AL 1578) in sub-plots at Ludhiana, Gurdaspur & Bathinda whereas at Faridkot these genotypes were tested under three dates of sowing (15 May, 1 June and 15 June) . The experiment was laid out in split-plot design with four replications. Nutrients viz. 15 kg N/ha and 40 kg P_2O_5/ha were applied entirely as basal dose to the crop and the crop was sown in rows 50 cm apart using a seed rate of 15 kg/ha. Weeds were controlled by spraying pendimethalin (Stomp 30 EC) @ 0.45 a.i. kg/ha as pre-emergence by using 500 litres of water followed by hand weeding at six weeks after sowing. The crop was raised with the recommended package of practices (PAU 2011).

Days taken to 50% flowering and maturity were recorded for each genotype sown under different dates. The accumulated GDD for each phenophase were calculated by applying the following equation (Nuttonson 1955):

$$\text{Accumulated GDD} = \sum_{1}^{N} \frac{[T_{max}+T_{min}]}{2} - T_b \quad (1)$$

Where, T_{max}, daily maximum temperature (^oC), T_{min}, daily minimum temperature (^oC),

T_b, base temperature of 10.0 ^oC

1 = Start of phenophase or date of sowing, N = End of phenophase or date of physiological maturity

Photothermal units (PTU), the product of GDD and corresponding day length for that day were computed on daily basis as follows:

PTU = GDD × Day length

Where day length refers to maximum possible sunshine hours.

Heat use efficiency (HUE) was calculated as follows:

$$\text{Heat use efficiency (HUE)} = \frac{\text{Grain yield (kg/ha)}}{\text{Accumulated heat units (°C day)}} \quad (2)$$

Growing degree days and photothermal units were accumulated from the date of sowing to 50% flowering and maturity to give accumulated indices. Heat use efficiency was calculated after harvesting of the crop.

Data on plant height, branches/plant and pods/plant were recorded at harvest from five randomly selected plants from each plot excluding border rows. Biological yield (all above-ground plant parts) and grain yield were recorded on the whole plot basis and expressed in kg/ha. Grains/pod were recorded from average value of twenty pods per plot. The data on 100-grain weight were recorded after taking 100 randomly selected grains. Harvest index (%) was calculated by dividing grain yield by biological yield and multiplied by 100. Gross returns, net returns as well as Benefit: Cost (B:C) ratio was worked out by using prevailing prices of inputs and output. Data were subjected to analysis of variance (ANOVA) in a split-plot design as per the standard procedure (Cheema and Singh, 1991).

RESULTS AND DISCUSSION

Effect of date of sowing: Data clearly revealed that days to 50% flowering and maturity were reduced with delay in sowing (Table 1). The earliest sown crop took more number of days to 50% flowering and maturity at Ludhiana as well as Faridkot. The crop sown on 15 May also took slightly higher number of days to 50% flowering and maturity than later sowings of 1 or 15 June. Early sown crop during May also matured earlier

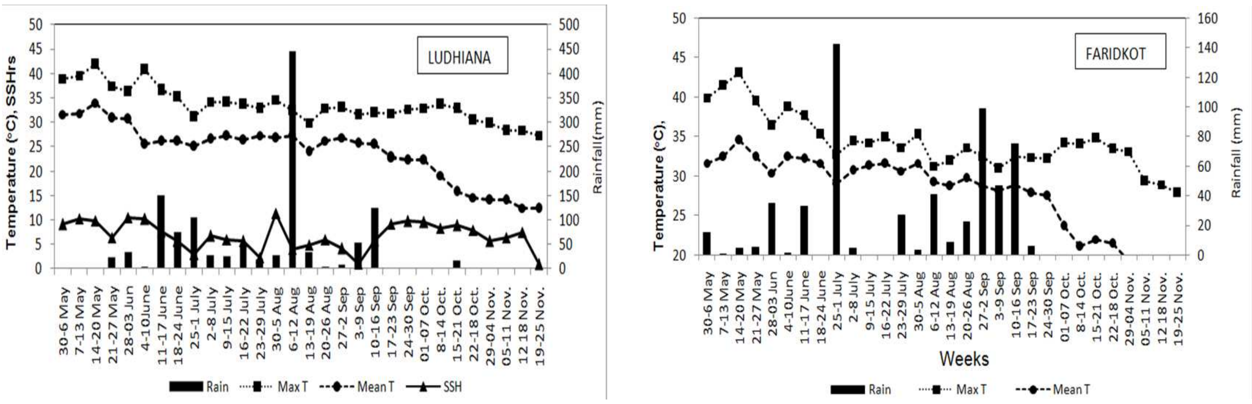

Fig. 1. *Weekly mean weather conditions of maximum annd minimum temperature, rainfall and sunshine hours during crop season (2011) at Ludhiana and Faridkot.*

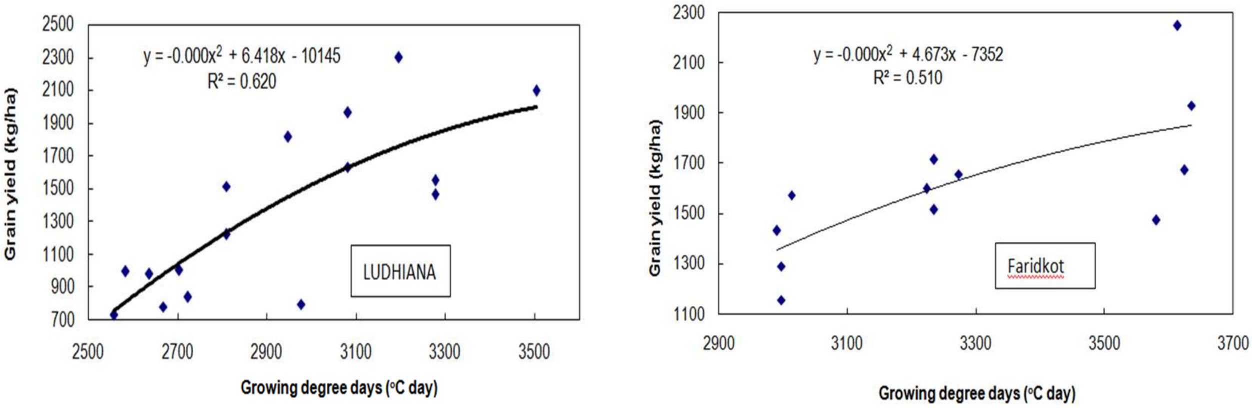

Fig.2. *Relationship between accumulated growing degree days and grain yield in pigeonpea at Ludhiana and Faridkot.*

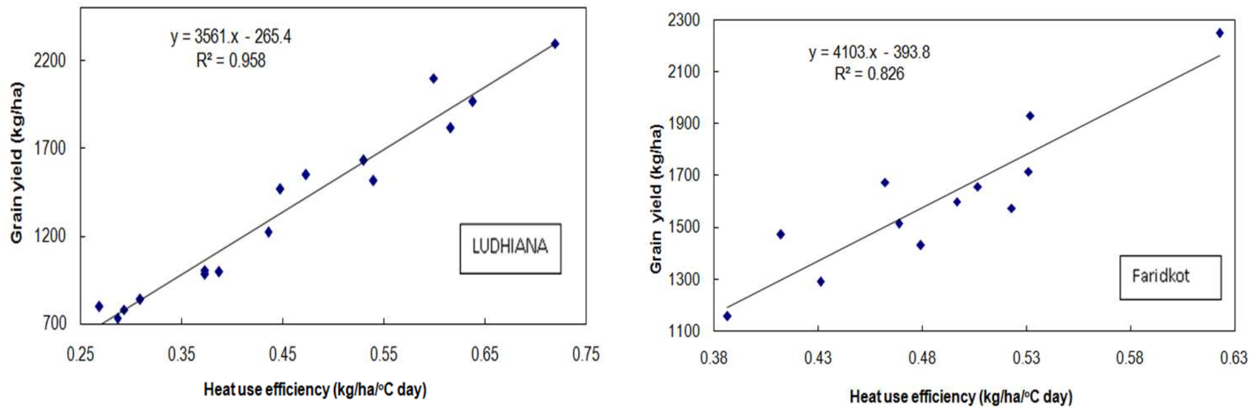

Fig.3. *Relationship between heat use efficiency and grain yield in pigeonpea at Ludhiana and Faridkot.*

than sowing in June, resulting in early harvest of the pigeonpea crop and thereby vacating the field earlier for timely sowing of the succeeding *rabi* season crop like wheat. The late sown crop took less number of days for maturity possibly due to completion of its various growth stages in a short period owing to decreasing temperatures.

The data on accumulated agroclimatic indices i.e. growing degree days, photothermal units and heat use efficiency computed for pigeonpea genotypes under varying dates of sowing from sowing to 50% flowering and physiological maturity at two different agroclimatic zones have been presented in Table 1. The accumulated growing degree days from sowing to maturity ranged from 2620-3259 ^oC days for Ludhiana and 3000-3613 ^oC days for Faridkot. It clearly elucidated that early sown crop accumulated higher heat units (3259, 3613^oC day) as compared to late sown crop (2620, 3000^oC day). Lower growing degree days for late sown crop were due to reduction in growing period. Khichar and Niwas (2007) also reported that the requirement of heat units decreased for different phenological stages with delay in sowing of wheat. The timely sown crop utilized heat more efficiently than late sown crop, resulting in highest grain yield under 15 May sowing and it showed a significant re-

Table 1. Effect of date of sowing and genotypes on variousagroclimatic indices (GDD, PTU and heat use efficiency) of pigeon-pea crop at Ludhiana and Faridkot.

Location	Treatment		50% flowering			Physiological maturity			
			DAS	AGDD (^oC day)	APTU (^oC day)	DAS	AGDD (^oC day)	APTU (^oC day)	HUE (kg/ha/^oC day)
Ludhiana	Date of sowing	1 May	100	2088	28980	165	3259	43629	0.45
		15 May	99	2040	28260	155	3020	40265	0.55
		1 June	97	1934	26493	150	2808	36893	0.47
		15 June	94	1837	24768	146	2620	33893	0.35
	Genotype	AL 15	80	1644	22843	141	2731	36433	0.29
		AL 201	106	2139	29231	166	3087	40467	0.58
		PAU 881	102	2058	28213	155	2951	38962	0.51
		AL 1578	102	2058	28213	154	2938	38818	0.45
Faridkot	Date of sowing	15 May	96	2025	27941	188	3613	46335	0.51
		1 June	85	1760	23961	174	3241	41141	0.50
		15 June	83	1678	22555	166	3000	37597	0.45
	Genotype	AL 15	76	1611	22048	175	3271	41561	0.46
		AL 201	97	2007	27095	178	3307	41916	0.52
		PAU 881	86	1807	24570	175	3280	41633	0.52
		AL 1578	91	1885	25563	176	3282	41654	0.45

Table 2. Effect of sowing dates and genotypes on plant height of pigeonpea at different locations.

Treatment	Plant height (cm) – Location				
	Ludhiana	Gurdaspur	Bathinda	Faridkot	Mean
Date of sowing					
1 May	229.5	239.6	293.7	-	254.3
15 May	230.1	240.5	294.5	298.5	265.9
1 June	209.2	223.4	273.0	277.5	245.8
15 June	173.0	223.6	271.3	238.4	226.6
CD (P=0.05)	8.5	10.5	14.1	8.2	
Genotype					
AL 15	171.8	187.7	243.4	230.8	208.4
AL 201	236.2	259.0	306.1	295.9	274.3
PAU 881	232.5	234.5	282.3	282.2	257.9
AL 1578	201.4	246.0	300.6	277.0	256.3
CD (P=0.05)	7.5	13.6	11.1	8.9	

duction with further delay in sowing from 1 June to 15 June. During the months of May and June, the maximum temperature and sunshine hours were higher as compared to July month (Fig. 1) and that is why the early sown crop acquired more heat units as compared to late sown crop.

Among dates of sowings, 15 May and 1 June sowings accumulated more heat units resulting in more heat use efficiencies than 15 June sowing. The highest heat use efficiency of 0.55 kg/ha/^{o}C day at Ludhiana and 0.51 kg/ha/^{o}C day at Faridkot was recorded when the crop was sown on 15 May (Table 1). While the lowest heat use efficiency of 0.35 kg/ha/^{o}C day at Ludhiana and 0.45 kg/ha/^{o}C day at Fraidkot was observed when the crop was sown on 15 June. A significant polynomial relationship was observed between grain yield and growing degree days (Fig. 2) for Ludhiana (R^2 = 0.62) and Faridkot (R^2 = 0.51) while a significant linear function was observed between grain yield and heat use efficiency (Fig. 3) with R^2 = 0.96 and R^2= 0.83 for Ludhiana and Faridkot, respectively.

The plant height was significantly (p=0.05) influenced by the date of sowing. The plant height at all the locations was highest under 15 May sowing which was, however at par with 1 May sowing. The plant height under May sowings (1 and 15 May) was more due to longer period of vegetative growth. A drastic reduction in plant height was recorded under delayed sowing compared to early date of sowing. It could be mainly attributed to the short growth period. Kumar *et al.* (2008) also reported reduced plant growth and yield attributes in case of delayed sowing in pigeonpea.

The pods/plant is an important yield attributing character. The crop sown on 15 May recorded significantly (p=0.05) higher number of pods/plant than other sowing dates at all the locations except Gurdaspur. The highest number of pods/plant in 15 May sown crop might be due to harmonic balance between vegetative and reproductive phase besides availability of sufficient time for pod setting. These findings are in agreement with those of Rani and Reddy (2010).The sowing dates did not affect the number of grains/pod at Ludhiana and Bathinda significantly (Table 3) whereas at Faridkot, it was significantly higher under 1 June sow-

Table 3. Effect of sowing dates and genotypes on the yield attributes of pigeonpea at different locations.

Treatment	Location				
	Ludhiana	**Gurdaspur**	**Bathinda**	**Faridkot**	**Mean**
Date of sowing			**Pods/plant**		
1 May	155.2	102.2	88.4	-	115.3
15 May	173.6	102.3	108.4	175.7	140.0
1 June	156.6	100.4	96.1	147.5	125.2
15 June	128.7	96.2	79.3	122.5	106.7
CD (P=0.05)	8.6	NS	10.8	10.9	
Genotype					
AL 15	88.1	84.7	74.1	156.1	100.8
AL 201	198.3	107.1	106.1	161.7	143.3
PAU 881	171.9	98.5	96.7	155.5	130.7
AL 1578	155.8	110.7	95.3	121.0	120.7
CD (P=0.05)	12.1	10.63	8.9	8.6	
Date of sowing			**Grains/pod**		
1 May	4.19		3.76	-	3.97
15 May	4.06		3.73	3.71	3.83
1 June	4.09		3.74	3.83	3.88
15 June	4.16		3.78	3.46	3.78
CD (P=0.05)	NS		NS	0.21	
Genotype					
AL 15	4.16		3.84	3.61	3.87
AL 201	4.15		3.73	3.74	3.87
PAU 881	4.09		3.66	3.32	3.69
AL 1578	4.10		3.79	3.86	3.92
CD (P=0.05)	NS		NS	0.17	
Date of sowing			**100-grain weight (g)**		
1 May	6.76	8.02	6.13	-	6.97
15 May	6.86	7.84	6.63	8.64	7.49
1 June	6.84	7.39	6.26	8.46	7.24
15 June	6.57	7.30	6.40	8.60	7.22
CD (P=0.05)	0.20	0.51	0.22	NS	
Genotype					
AL 15	6.58	7.19	6.19	8.72	7.17
AL 201	7.20	7.89	6.57	8.27	7.48
PAU 881	6.49	7.58	6.52	8.36	7.24
AL 1578	6.76	7.90	6.15	8.92	7.43
CD (P=0.05)	0.17	0.37	0.20	0.19	

ing than 15 June sowing. The 100-grain weight was the highest under May 15 sowing at all the locations except Gurdaspur.

The biological yield was significantly affected by date of sowing across all the tested agro-climatic locations (Table 4). Biological yields were highest at Bathinda and lowest at Ludhiana. The biological yield was significantly higher in 1 May sowing than the other sowing dates at Ludhiana and Bathinda. However, at Gurdaspur and Faridkot significantly higher values were observed under 15 May sowing than 1 June and 15 June sowing. Overall, biological yield was significantly reduced with delay in sowing due to shortening of growing season which in turn reduced the vegetative growth of the plant as reflected by the reduced plant height (Table 2).

At all the agro-climatic locations, the grain yield was significantly higher in 15 May sowing than other sowing dates (Table 4) due to more number of pods/plant, grains/pod and 100-grain weight. On the basis of means of all the locations, 15 May sowing gave 23.3, 22.1 and 46.7% higher grain yield over 1 May, 1 June and 15 June sowing, respectively. Our findings are in line with those of Ram *et al*. (2011) and Singh *et al.* (2016) who reported that 15 May sown pigeonpea crop produced significantly higher grain yield than 1 June and 15 June sown crop. The increased grain yield due to early sowing could be ascribed to the high leaf area index and its persistence, photosynthetically active radiation interception and absorption, leading to higher dry matter accumulation before the pigeonpea crop reached the reproductive stage (Patel *et al*. 2000). Other researchers also reported sharp decline in the grain yield of pigeonpea with delay in sowing time (Kumar *et al.* 2008; Singh *et al.* 2016). Contrarily, harvest index increased with delay in sowing (Table 4) primarily due to reduction in vegetative biomass. Owing to higher grain yield, crop sown on 15 May provided the highest gross as well as net returns and B:C ratio at all the test locations (Table 5). On the basis of means of all the locations, 15 May sowing gave an additional income of Rs 13599, 13040 and 22865 per

Table 4. Effect of sowing dates and genotypes on the biological yield, grain yield and harvest index of pigeonpea.

Treatment	Location				
	Ludhiana	**Gurdaspur**	**Bathinda**	**Faridkot**	**Mean**
Date of sowing	**Biological yield (kg/ha)**				
1 May	15679	17440	22979	-	18699
15 May	12688	18233	20750	16790	17115
1 June	7854	11703	17583	13200	12585
15 June	5000	11058	16917	9760	10683
CD (P=0.05)	840	3308	1211	1250	
Genotype					
AL 15	7354	9558	18750	12410	12018
AL 201	11917	19318	19896	13660	16197
PAU 881	11471	13223	18833	13380	14226
AL 1578	10479	16335	20750	13550	15278
CD (P=0.05)	876	1768	1235	NS	
Date of sowing	**Grain yield (kg/ha)**				
1 May	1479	1283	1303	-	1355
15 May	1685	1360	1807	1833	1671
1 June	1335	1058	1457	1622	1368
15 June	931	1103	1159	1365	1139
CD (P=0.05)	75	70	92	201	
Genotype					
AL 15	790	693	1240	1494	1054
AL 201	1806	1508	1380	1722	1604
PAU 881	1504	1155	1528	1733	1480
AL 1578	1331	1448	1577	1478	1458
CD (P=0.05)	91	92	108	154	
Date of sowing	**Harvest index (%)**				
1 May	9.4	7.3	5.6	-	7.4
15 May	13.9	7.5	8.7	10.9	10.3
1 June	19.3	9.0	8.3	12.3	12.2
15 June	19.0	10.0	6.9	14.0	12.5
Genotype					
AL 15	10.7	7.3	6.6	12.0	9.2
AL 201	15.2	7.8	6.9	12.6	10.6
PAU 881	13.1	8.7	8.1	13.0	10.7
AL 1578	12.7	8.9	7.6	10.9	10.0

ha over 1 May, 1 June and 15 June sowing, respectively.

Performance of genotypes: Among the genotypes, AL 201 showed edge over the other genotypes in terms of accumulated GDD and PTU and having highest HUE at Ludhiana and Faridkot (Table 1). The highest heat use efficiency in15 May sown crop might be due to higher production of grain yield per unit heat absorbed. Similar results were also reported by Tripathi *et al*. (2004). Any stress during anthesis and grain-filling is the major constraint of productivity so timely sown and thermo tolerant genotypes recorded higher grain yield by using accumulated heat units efficiently. The genotype AL 15 took least whereas AL 201 took highest days to 50% flowering and maturity both at Ludhiana and Faridkot.

The genotypes AL 201 and AL 15 attained the highest and lowest plant height, respectively at all the locations (Table 2).The number of pods/plant was recorded highest in AL 201 at all the locations except Gurdaspur where AL 1578 recorded highest value closely followed by AL 201 (Table 3). The grains/pod differed non-significantly at Ludhiana and Bathinda locations but at Faridkot, AL 1578 exhibited highest value. The genotype AL 201 recorded highest 100-grain weight at Ludhiana and Bathinda whereas at Gurdaspur and Faridkot it was highest in AL 1578.

The tested genotypes also differed significantly for biological yield at all the locations except for Faridkot location (Table 4). The biological yield of AL 201 was highest at Ludhiana and Gurdaspur whereas AL 1578 recorded highest biological yield at Bathinda. The grain yield also varied significantly as AL 201 performed best at Ludhiana and Gurdaspur while AL 1578 and PAU 881 resulted in highest yield at Bathinda and Faridkot locations, respectively. Several researchers have also reported genotypic variation with respect to growth and yield of pigeonpea (Mligo and Craufurd 2005; Egbe and Vange 2008; Singh *et al.* 2016). Differential response of different genotypes could be due to differences in growth, yield attributes, tolerance to insect pest and diseases etc. Similarly, harvest index was highest for genotype AL 201 at Ludhiana, AL 1578 at Gurdaspur and PAU 881 at Bathinda & Farid-

Table 5. Effect of sowing dates and genotypes on the monetary parameters of pigeonpea.

Treatment	Location				
	Ludhiana	**Gurdaspur**	**Bathinda**	**Faridkot**	**Mean**
Date of sowing	**Gross returns (Rs/ha)**				
1 May	63597	55169	56029	-	58265
15 May	72455	58480	77701	78819	71864
1 June	57405	45494	62651	69746	58824
15 June	40033	47429	49837	58695	48999
Genotype					
AL 15	33970	29799	53320	64242	39030
AL 201	77658	64844	59340	74046	68972
PAU 881	64672	49665	65704	74519	63640
AL 1578	57233	62264	67811	63554	62716
Date of sowing	**Net returns (Rs/ha)**				
1 May	36027	27599	28459	-	30695
15 May	44885	30910	50131	51249	44294
1 June	29835	17924	35081	42176	31254
15 June	12463	19859	22267	31125	21429
Genotype					
AL 15	6400	2229	25750	36672	11460
AL 201	50088	37274	31770	46476	41402
PAU 881	37102	22095	38134	46949	36070
AL 1578	29663	34694	40241	35984	35146
Date of sowing	**B:C ratio**				
1 May	2.31	2.00	2.03	-	2.11
15 May	2.63	2.12	2.82	2.86	2.61
1 June	2.08	1.65	2.27	2.53	2.13
15 June	1.45	1.72	1.81	2.13	1.78
Genotype					
AL 15	1.23	1.08	1.93	2.33	1.41
AL 201	2.82	2.35	2.15	2.69	2.50
PAU 881	2.35	1.80	2.38	2.70	2.31
AL 1578	2.08	2.26	2.46	2.31	2.28

kot. Among monetary parameters, maximum gross returns, net returns and B:C ratio primarily due to high grain yield were observed for AL 201 at Ludhiana and Gurdaspur, AL 1578 at Bathinda and PAU 881 at Faridkot location (Table 5).

Conclusion

Days to 50% flowering as well as maturity, growing degree days and photothermal units were reduced with delay in sowing of pigeonpea. The crop sown on 15 May recorded the highest plant height (265.9 cm), pods/plant (140.0), 100-grain weight (7.49 g), grain yield (1671 kg/ha), gross returns (Rs 71864 per ha) and net returns (Rs 44294 per ha). It can be concluded that 15 May is the optimum sowing date of pigeonpea and AL 201 and PAU 881 are the promising genotypes under diverse environments for providing high productivity of pigeonpea.

ACKNOWLEDGEMENTS

The authors are thankful to the Punjab Agricultural University, Ludhiana, India for providing facilities for conducting these trials.

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