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Performance of Extra Early Pigeonpea Genotypes under Different Planting Geometries in Rainfed *Kharif* Conditions in Coastal Odisha, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted over three years (2019-20 to 2021-22) to evaluate the performance of extra early pigeonpea genotypes with varying planting geometry under rainfed *kharif* upland condition of coastal Odisha at the Nutri-Crops Research Station (OUAT), Berhampur-761001. Altogether 04 genotypes (AL-882, PA-16, ICPL-20338 and ICPL-11255) were taken in three planting geometry arrangements *i.e*. 30cm×10cm; 30cm×20cm and 45cm×10cm. The trial was laid out in Factorial Randomized Block Design (FRBD) with three replications. The pooled data revealed that pigeonpea variety PA-16 recorded plant height (103.3cm), significantly highest

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number of primary fruiting branch plant^{-1} (5.54), effective pods plant^{-1} (40.59), seeds pod^{-1} (3.44), seed index (10.55) and ultimately the highest grain yield (873 kg ha^{-1}). Stover yield, chaff yield and biological yield followed the same trend as the grain yield. Significantly maximum harvest index (HI) was recorded with PA-16 (34.27) followed by AL-882 (33.66). Among planting geometry 45cm×10cm registered maximum grain yield (863 kg ha^{-1}). The treatment combination of variety PA-16 sown with 45cm×10cm spacing recorded maximum grain yield of 1044 kg ha^{-1}, highest yield day^{-1} (8.82kg), net monetary return (Rs.31,971 ha^{-1}), B:C ratio (2.03) and return per day (Rs. 532 day^{-1}). Thus it is recommended to grow extra early genotype of pigeonpea (PA-16) with planting geometry of 45cm××10cm under *kharif* rainfed upland situation of coastal Odisha, especially to fulfil the demands for utilization of a narrow growing window.

Keywords: Extra early pigeonpea; planting geometry; harvest index; net return; B:C ratio; return per day; genotype.

1. INTRODUCTION

Pulses are miracle crops, being climate smart, low duty, having higher nutrient and water use efficiency. They are primary dietary staple for vegetarians in Indian subcontinent. India, a global leader for pulse production contributes 80% of global production and area. India ranks first in annual pigeonpea production with 4.2mt (FAO, 2022). Pigeonpea (*Cajanus cajan* L.) is most important *kharif* pulse of India. It is a cost-effective source of protein as compared to various animal sources. It accounts for 15% of total pulses produced in the country (Project coordinators report, 2024-25 of AICRP). Present pulse production is inadequate to meet the requirement resulting in exacerbating malnutrition especially among vegetarian population (Mallikarjun *et al*., 2014). Due to longer duration, pigeonpea always face challenges from natural calamities, aberrant weather condition, severe attack of pod borer complex and competitive shorter duration remunerative rainfed crops during *kharif* season and does not accommodate in a cropping sequence (Panda *et al*., 2019). *Kharif* pigeonpea within four month duration may be preferred under narrow *kharif* growing window for facilitating suitable short duration low duty *rabi* crops. Medium duration pigeonpea grown in rice bund and near mono-cropped rice field faces threats from stray cattle after harvest of rice. These areas demands shorter duration pigeonpea, that could be harvested before rice to escape grazing menace. Varieties with shorter duration life cycle (seed to seed) be chosen so as to cut down water requirement of crops and be accommodated in wide range of cropping sequences. Success rate of short duration crops is greater than long duration crops. Early maturing crops have advantage of greater chances of escape natural calamity, biotic and abiotic stresses and also have competitive yield per day. Need for horizontal expansion of pigeonpea encouraged for searching new niche. Pigeonpea is one of the most versatile plants, fits very well in various production niches and can be grown in diverse agro-ecological conditions. Panda *et al.* (2018) reported suitability of early duration varieties like manak and UPAS-120 in Odisha. Thus enhancing the area of pigeonpea in shorter *kharif* growing window condition encourages for searching suitable extra early genotypes of pigeonpea (≤ 120 days) and standardise the planting geometry. As plant height and canopy growth of extra early pigeonpea reduced as compared to early and medium duration pigeonpea in *kharif*, it become pertinent to standardize the planting geometry of extra early pigeonpea genotypes for higher production. Bansal *et al*. (2023) tested PA-16 and AL-882 with six planting geometry under Ludhiana condition and recommended AL-882 with 50cm*25cm as the best combination. Planting geometry has significant effect on productivity of pigeonpea (Kaur & Saini, 2018, Kuri *et al*., 2018). Hence effort has been made to find out suitable extra early pigeonpea genotypes and the best planting geometry to accommodate in an *kharif* rainfed upland agro-ecosystem in coastal Odisha.

2. MATERIALS AND METHODS

2.1 Experimental Site and Weather Conditions

A field experiment was conducted over three consecutive years during *kharif* season of 2019-20, 2020-21 and 2021-22 under AICRP on Pigeonpea at the Nutri-Crops Research Station (previously Centre for Pulses Research), OUAT, Berhampur, Odisha, India (GPS location 19.36° north latitude, 84.76° east longitude and 34 MSL altitude). The experimental site comes under East coast plains & hills agro-climatic zone of India and East & South Eastern Coastal Plain zone of Odisha. The objective of the investigation was to find out suitable extra early pigeonpea genotypes and standardize proper planting geometry for higher production. The soil was sandy loam with pH 6.2, medium organic carbon (0.53 %), medium available phosphorus (21.67 kg ha^{-1}, Bray) and medium potassium (292 kg ha^{-1}). There were 1046mm (48 rainy day), 735.4 mm (31 rainy day) and 819.1 mm (37 rainy day) rainfall during crop period (27th standard week to 45th standard week) in three years respectively.

2.2 Experimental Design and Treatments

The trial was laid out in Factorial Randomized Block Design (FRBD) with three replications having 12 treatment combinations. *viz*.

Factor A (Spacing-3):

- S_1: 30cm×10cm (0.33 million plants ha^{-1}) ;
- S_2: 30cm×20cm (0.17 million plants ha^{-1});
- S_3: 45cm×10cm (0.22 million plants ha^{-1})

Factor B(Genotype-4):

- G_1: AL-882;
- G_2: Pusa Arhar 16 (PA-16);
- G_3: ICPL-20338;
- G_4: ICPL-11255.

The trial was sown during first fortnight of July each year with 22.68m^2 (5.4m×4.2m) plots under *kharif* rainfed upland condition. A common recommended fertilizer dose of 20:40:20 N, P_2O_5, K_2O kg ha^{-1} was applied at basal to each treatment. Recommended package of practices along with need based plant protection measures was followed for maintaining a healthy crop.

2.3 Observations, Data Collection and Analysis

Observations on 50% flowering was recorded for each treatment combination. Data on growth parameters like plant height (cm), primary and secondary fruiting branch per plant, dry matter accumulation (g plant^{-1}) and total dry matter production (g m^{-2}) were recorded at harvest, tabulated and analysed. The overall crop growth rate (OCGR) value (g m^{-2} day^{-1}) that represent the average rate of dry matter accumulation per unit of land area per day throughout the entire growing season was computed by the formula,

$$OCGR = \frac{biological\ yield\ at\ harvest}{duration\ of\ the\ crop} \quad (\text{g m}^{-2}\ \text{day}^{-1})$$

Yield attributes such as number of effective pod plant^{-1}, number of effective seed pod^{-1} and seed index (100 seed weight in g) were recorded at harvest. The grain yield (kg ha^{-1}), chaff yield (kg ha^{-1}), Stover yield (kg ha^{-1}) and duration of the genotype (days) were taken at harvest and analysed as per the statistical procedure described by Panse and Sukhatme (1985) and using online analysis by OPSTAT. The biological yield (total dry matter production of above ground parts viz. grain, Stover and chaff), harvest index [(grain yield ×100)/ biological yield] and grain yield day^{-1} (kg ha^{-1}day^{-1}) were also computed and analysed.

2.4 Economics

The economic feasibility of the treatments was computed based on market price of inputs and minimum support price (MSP) of the produce. The grain yield (kg ha^{-1}) multiplied with MSP (Rs kg^{-1}) gives the gross monetary return (GMR) per hectare. Treatment wise cost of production (COP) were worked out basing on cost of inputs. The net monetary return (NMR) was derived by deducting COP from GMR. The benefit cost ratio was computed as ratio of GMR and COP. Return per day (Rs. day^{-1}) were calculated by GMR/ duration of the genotype and compared for economic feasibility.

3. RESULTS AND DISCUSSION

3.1 Growth Parameters

3.1.1 50% flowering and duration (days)

The 50% flowering stage did not differ due to varying planting geometry, but varies due to genotypes (Table 1). The genotype ICPL-20338 and ICPL-11255 have initiated flower early and 50% plants started flowering at 53.3 DAS (mean). Both matured simultaneously with mean duration of 112.7 days. The genotype AL-882 and PA-16 attained 50% flowering stage at 62.7 DAS (mean) and matured simultaneously having mean duration of 118.3 days.

3.1.2 Plant height (cm)

Plant height of pigeonpea genotypes were recorded at harvest and the pooled data

Table 1. Growth parameters of extra early pigeonpea genotypes as influenced by varying planting geometries (mean and pooled data for three years, 2019-22)

S.N.	Treatment	Days to 50% flowering	Duration (day)	Plant height (cm)	Primary branch plant^{-1}	Secondary branch plant^{-1}	DMA (g plant^{-1})	TDMP (g m^{-2})	OCGR (g m^{-2} day^{-1})
	Spacing(cm)								
S_1	30×10	58	115.5	85.4	4.30	11.60	7.42	244.7	2.12
S_2	30×20	58	115.5	80.8	5.07	13.18	11.09	188.6	1.63
S_3	45×10	58	115.5	85.5	5.13	13.06	11.21	246.7	2.13
	Sem (±)	-	-	NS	0.19	0.46	0.17	4.2	0.04
	CD (p=0.05)	-	-		0.55	1.35	0.49	12.4	0.11
	Genotypes								
G_1	AL-882	62.7	118.3	105.5	5.36	14.24	10.88	246.4	2.08
G_2	PA16	62.7	118.3	105.5	5.54	15.09	11.16	252.9	2.14
G_3	20338	53.3	112.7	64.0	4.24	10.33	8.67	200.6	1.78
G_4	11255	53.3	112.7	62.8	4.19	10.78	8.91	206.7	1.84
	Sem (±)	-	-	2.71	0.22	0.53	0.19	4.5	0.04
	CD (p=0.05)	-	-	7.98	0.64	1.56	0.57	14.3	0.12
	Interaction (A×B)								
	Sem (±)	-	-	NS	NS	NS	0.33	8.4	0.07
	CD (p=0.05)						0.99	24.8	0.21
	Treatment combination								
T1	S_1G_1	62.7	118.3	109.8	4.71	12.39	7.56	249.4	2.11
T2	S_1G_2	62.7	118.3	104.2	4.81	13.73	7.82	257.9	2.18
T3	S_1G_3	53.3	112.7	64.2	3.84	9.95	7.02	231.6	2.06
T4	S_1G_4	53.3	112.7	63.5	3.82	10.33	7.27	240.0	2.13
T5	S_2G_1	62.7	118.3	99.4	5.58	15.14	12.38	210.5	1.78
T6	S_2G_2	62.7	118.3	98.8	5.90	16.01	12.84	218.3	1.85
T7	S_2G_3	53.3	112.7	62.9	4.46	10.50	9.53	162.0	1.44
T8	S_2G_4	53.3	112.7	61.8	4.33	11.06	9.63	163.7	1.45
T9	S_3G_1	62.7	118.3	107.2	5.78	15.21	12.70	279.3	2.36
T10	S_3G_2	62.7	118.3	106.8	5.90	15.54	12.84	282.4	2.39
T11	S_3G_3	53.3	112.7	65.0	4.42	10.57	9.47	208.4	1.85
T12	S_3G_4	53.3	112.7	63.1	4.42	10.94	9.84	216.6	1.92
	Sem (±)			4.68	0.37	0.91	0.33	8.39	0.07
	CD (p=0.05)			13.7	1.10	2.67	0.98	24.60	0.21
	CV (%)			9.67	13.42	12.48	5.85	6.41	6.31

presented in Table 1. The data revealed that plant height of pigeonpea did not differ significantly due to varying planting geometry. However, there are significant differences observed among genotypes (Table 1). Pigeonpea genotype AL-882 was observed to be the tallest (105.3 cm) among all genotypes and at par with PA-16, but significantly taller than ICPL-20338 and ICPL-11255. The interaction effect among two factors was found not significant (Table 1). Significant variations in plant height was observed due to the treatment combination and the maximum plant height (109.8 cm) was recorded with AL-882 sown with 30cm×10cm planting geometry (Table 1). These observations are in consistent with the findings of Mallikarjun and Hulihalli (2015).

3.1.3 Primary and secondary fruiting branch plant $^{-1}$

The primary and secondary branches are the important determinant for crop canopy, stover yield, number of pods and ultimately the grain yield in pigeonpea. More branches leads to a higher number of pods resulting in higher grain yield per plant. Wider the spacing better the solar light interception and higher the canopy development including branch and foliage. Data presented in Table 1 revealed that wider row spacing of 45cm registered maximum number of primary fruiting branch plant^{-1} (5.13). However, the planting geometry with lowest plant population (30cm×10cm spacing) registered maximum secondary branch (13.18) per plant. Among genotypes, PA-16 recorded highest primary and secondary branch plant^{-1} (5.54 and 15.09 respectively). Treatment combination of PA-16 sown with 45cm×10cm planting geometry registered maximum number of primary and secondary fruiting branch plant^{-1} (5.9 and 15.54 respectively). Increased availability of horizontal space by wider inter-row and intra-row spacing enhance primary and secondary branching in pigeonpea. Kaur and Saini (2018), Chandrakar *et al*. (2015) and Bansal *et al*. (2024) reported similar findings.

3.1.4 Dry matter production (g plant^{-1}) and overall crop growth rate (g m^{-2}day^{-1})

Dry matter accumulation (DMA) per plant and total dry matter production (TDMP) per square meter at harvest (cumulative dry weight of grain, chaff and stover) was computed and presented in Table 1. The data revealed that the dry matter accumulation per plant was found lowest (7.42 g plant^{-1}) with high density planting geometry (30cm×10cm) which might be due to more plants per unit area leading to more competition among plants for resources like nutrient, moisture, space and solar radiation. Per plant dry matter production was statistically at par among S_2 (30cm×20cm) and S_3 (45cm×10 cm) and maximum (11.21g plant^{-1}) being registered with S_3 (45cm×10 cm) ie. 0.22million plants ha^{-1}. Among genotypes AL-882 and PA-16 produced at par dry matter (10.88 and 11.16 g plant^{-1} respectively), but significantly superior than other two genotypes (ICPL-20338 and ICPL-11255). This might be due to the inherent genetic potential of genotypes. ICPL-20338 and ICPL-11255 due to their dwarf nature registered lower dry matter with each planting geometry and failed to gain more dry weight with wider spacing as compared to AL-882 and PA-16. Maximum dry matter production from unit area was recorded with 45cm×10cm spacing (246.7g/m^2) and PA-16 (252.9 g m^{-2}). The result was in conflict with the findings of Bansal *et al.* (2023) who registered more growth of AL- 882 as compared to PA-16 under Ludhiana condition. They also registered higher biological yield with narrow spacing due to more number of plants. Significantly maximum overall crop growth rate (g m^{-2}day^{-1}) were computed with 45cm×10cm spacing (2.13 g m^{-2} day^{-1}), genotype PA-16 (2.14 g m^{-2}day^{-1}) and the combination of these treatments ((2.39 g m^{-2} day^{-1}).

3.2 yield Attributes and Yield

3.2.1 Number of effective pod plant^{-1}

Yield attributes and yield data (pooled for three years) presented in Table 2. The data revealed that the number of effective pod plant^{-1} was higher with lower planting density. High density planting with 30cm×10cm spacing recorded lowest pod per plant (28.72) and the maximum (37.61) being recorded with 30cm×20cm spacing. This may be due to higher interception of solar radiation, availability of more space, nutrient and moisture in thin populated planting geometry. Among genotypes PA-16 registered significantly higher number of effective pod per plant (40.59) closely followed by AL-882 (37.05) and the lowest (28.78) being recorded with ICPL-20338. Interaction of both factors was found non-significant. Among treatment combinations PA-16 sown with 30cm×20cm planting geometry registered maximum number of effective pod plant^{-1} (44.3).

3.2.2 Number of effective seed pod^{-1}

The data presented in Table 2 revealed that the number of effective seed per pod was influenced by varying planting geometry and genotypes. Significantly higher seed pod^{-1} (3.41) was recorded with 45cm×10cm spacing. High density planting with 30cm×10cm spacing recorded lowest seed pod^{-1} (3.3). Among genotypes PA-16 registered significantly higher number of effective seed per pod (3.44) closely followed by AL-882 (3.36) and the lowest (3.28) being recorded with ICPL-20338. Interaction of both factors was found non-significant. Among treatment combinations PA-16 sown with 30cm×20cm planting geometry registered maximum number of effective seed pod^{-1} (3.47).

3.2.3 Seed index (100 seed weight in g)

The seed index (100 seed weight in g) was estimated with high resolution electronic balance and presented in Table 2. The data revealed that the seed index was not influenced by varying planting geometry. Though the maximum seed index (10.15 g) was recorded with 45cm×10cm spacing, but the values from other two planting geometry were found at par. Nevertheless, the seed index differs significantly due to varying genotypes. Among genotypes PA-16 registered significantly higher seed index (10.55g) closely followed by AL-882 (10.10g) and the lowest (9.73 g) being recorded with ICPL 20338. Interaction of both factors was found non-significant. The variation due to treatment combinations of planting geometry and genotype did not reach statistical significance, but PA-16 sown with 45cm×10cm planting geometry registered maximum seed index (10.73g).

3.2.4 Grain yield (kg ha^{-1} and kg ha^{-1} day^{-1})

The data on grain yield (pooled for three years) presented in Table 2 revealed that there was significant variations in grain yield of extra early pigeonpea genotypes due to varying planting geometry. The maximum pooled grain yield was recorded with 45cm×10cm spacing (863 kg ha^{-1}) closely followed by 30cm×10cm spacing. Wider spacing of 30cm×20cm recorded lowest grain yield (591 kg ha^{-1}). Despite higher pod per plant this planting geometry failed to achieve higher yield per hectare due to low plant population. It was observed that genotype PA-16 registered significantly higher grain yield (873 kg ha^{-1}) closely followed by AL-882 (836 kg ha^{-1}) and the lowest (655 kg ha^{-1}) being recorded with ICPL-20338. Higher grain yield obtained from PA-16 was attributed to higher branch and pod per plant, seed per pod and seed index. Maini and Sandhu (2022) also found maximum grain yield from PA-16 with wider spacing. Interaction of both factors was found significant. Among treatment combinations PA-16 sown with 45cm×10cm planting geometry registered maximum grain yield (1044 kg ha^{-1}). Grain yield (kg ha^{-1}) per day followed the same trend as grain yield (kg ha^{-1}).

The maximum yield of 7.44 kg ha^{-1} day^{-1} and 7.37 kg ha^{-1} day^{-1} were obtained from 45cm×10cm spacing and PA-16 respectively. Manjunatha *et al.* (2025) also found maximum per day yield from PA-16. The treatment combination of these two factors recorded the maximum (8.82 kg ha^{-1} day^{-1}) grain yield. From farmer point of view, they could get an equivalent yield of 1588 kg/ha from a medium duration pigeonpea with 180days maturity and have the land free in November for a *rabi* crop. The result was in conflict with the findings of Bansal *et al*. (2023), who reported higher yield from lower spacing (30cm×12.5cm) and significantly higher grain yield from AL-882 than PA-16 at Ludhiana.

3.2.5 Stover and chaff yield (kg ha^{-1})

The data presented in Table 2 indicates the impact of different spacing and genotypes on stover, chaff and biological yield. They followed almost the same trend as observed in grain yield. The maximum stover dry weight (1214 kg/ha) was recorded with 45cm×10cm spacing, closely followed by 30cm×10cm spacing (1209 kg/ha). The result was in conflict with the findings of Bansal *et al*. (2024), who reported higher yield from lower spacing (30cm× 12.5cm) and significantly higher biological yield from AL-882 than PA-16 at Ludhiana. However, the chaff yield recorded maximum (416 kg ha^{-1}) with closer spacing (30cm×10cm) followed by 45cm×10cm spacing (390kg ha^{-1}). This may be due to higher number of pod per unit area (m^2) and reduced grain filling. Dwarf type has limited canopy expansion resulting in lower biomass accumulation. Among genotypes PA-16 registered significantly higher yield of both stover (1246 kg ha^{-1}) and chaff (409 kg ha^{-1}) followed by AL-882 (1233 and 395 kg ha^{-1} respectively). The lowest yield of stover (1028 kg ha^{-1}) and chaff (323 kg ha^{-1}) were recorded with ICPL-20338. Interaction of both factors was found non-significant for stover yield and significant for chaff yield. The variation due to treatment combinations of planting geometry and genotype found statistically significant and PA-16 sown with 45cm×10cm planting geometry registered maximum chaff yield (452kg ha^{-1}). Nonetheless, AL-882 sown with 45cm×10cm planting geometry registered maximum stover yield (1335 kg ha^{-1}).

Table 2. Effect of planting geometry on yield attributes and yield of extra early pigeonpea genotypes (mean and pooled data for three years, 2019-22)

S.N.	Treatment	Pod plant^{-1}	Seed pod^{-1}	Seed index (g)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Chaff yield (kg ha^{-1})	Biological yield (kg ha^{-1})	HI (%)	Yield (kg ha^{-1}day^{-1})
	Spacing(cm)									
S_1	30×10	28.72	3.30	9.95	823	1,209	416	2,447	33.59	7.12
S_2	30×20	37.61	3.38	10.09	591	1,005	290	1,886	31.38	5.11
S_3	45×10	36.22	3.41	10.15	863	1,214	390	2,467	34.71	7.44
	Sem (±)	0.77	0.03	NS	15.6	20.4	7.7	41.9	0.22	0.13
	CD (p=0.05)	2.28	0.08		46.2	60.3	22.8	123.8	0.66	0.39
	Genotypes									
G_1	AL-882	37.05	3.40	10.10	836	1233	395	2464	33.66	7.07
G_2	PA16	40.59	3.44	10.55	873	1246	409	2529	34.27	7.37
G_3	20338	28.78	3.28	9.73	655	1028	323	2006	32.62	5.82
G_4	11255	30.30	3.33	9.89	671	1064	333	2067	32.36	5.96
	Sem (±)	0.89	0.03	0.18	18.1	23.6	8.9	48.4	0.26	0.15
	CD (p=0.05)	2.28	0.09	0.54	53.3	69.6	26.4	142.9	0.76	0.45
	Interaction (A×B)									
	Sem (±)	NS	NS	NS	31.3	NS	15.5	83.9	0.44	0.26
	CD (p=0.05)				92.4		45.6	247.6	1.31	0.78
	Treatment combination									
T1	S_1G_1	30.71	3.36	9.97	852	1228	415	2494	34.14	7.20
T2	S_1G_2	34.04	3.40	10.34	883	1266	430	2579	34.23	7.46
T3	S_1G_3	24.34	3.19	9.68	762	1150	403	2316	32.87	6.77
T4	S_1G_4	25.77	3.26	9.82	794	1191	415	2400	33.09	7.05
T5	S_2G_1	41.10	3.39	10.14	641	1135	328	2105	30.48	5.42
T6	S_2G_2	44.30	3.47	10.56	691	1145	347	2183	31.64	5.84
T7	S_2G_3	31.80	3.31	9.73	520	861	239	1620	32.15	4.62
T8	S_2G_4	33.22	3.34	9.94	511	880	245	1637	31.26	4.54
T9	S_3G_1	39.33	3.44	10.18	1015	1335	443	2793	36.37	8.58
T10	S_3G_2	43.43	3.44	10.73	1044	1328	452	2824	36.93	8.82
T11	S_3G_3	30.19	3.33	9.78	684	1072	328	2084	32.83	6.07
T12	S_3G_4	31.91	3.40	9.92	708	1120	337	2166	32.72	6.29
	Sem (±)	1.55	0.05	NS	31.3	40.8	15.5	83.9	0.44	0.26
	CD (p=0.05)	4.54	0.16		91.8	119.8	45.3	245.9	1.30	0.77
	CV (%)	7.84	2.75	5.4	7.14	6.2	7.3	6.4	2.31	6.96

3.2.6 Biological yield (kg ha^{-1})

The maximum biological yield was computed with 45cm×10cm spacing (2464 kg ha^{-1}); PA-16 (2529 kg ha^{-1}) and the combination of both treatments (2824 kg ha^{-1}). Notably, genotype AL-882 with the same spacing (45cm×10cm) produced 2793 kg ha^{-1} biological yield which was statistically at par with PA-16. Both ICPL-20338 and ICPL-11255 were dwarf genotypes and could not compete with PA-16 and AL-882 in each yield attributing parameters and yield. However, perusal of data on yield attributing parameters and yield presented in Table 2 indicate that both ICPL-20338 and ICPL-11255 were very much competitive figures under high density planting (30cm×10cm). ICPL-11255 recorded 794 kg ha^{-1} and 7.05 kg ha^{-1} day^{-1} grain yield as compared to PA-16 (883 kg ha^{-1} and 7.46 kg ha^{-1} day^{-1} respectively) and AL-882 (852 kg ha^{-1} and 7.20 kg ha^{-1} day^{-1}respectively). These genotypes could not perform well under higher spacing due to their low genetic potential.

3.2.7 Harvest index (%)

The study found that the highest harvest index of 34.71% achieved with the planting geometry of 45cm×10cm which may be attributed to higher photosynthate accumulation in grain as compared to stem, leaf and chaff of pigeonpea with this spacing. Higher grain weight may be attributed to higher number of pod per square meter, seed per pod, seed index with 45cm×10m spacing. The result was in conformity with the findings of Bansal *et al*. (2023) who reported maximum harvest index with wider spacing of 50cm×25cm. Similar results are also reported by Kashyap *et al*. (2003) and Umesh *et al*. (2013). Significant variation in harvest index observed among genotypes tested and the maximum (34.27%) computed with PA-16 followed by AL-882 (33.66%). This indicated higher potentiality of PA-16 for photosynthate partitioning towards grain as compared to other parts.

The findings align with previous study by Umesh *et al*. (2013), Kaur and Saini (2018) and Bansal *et al*. (2023). The difference in harvest index associated with varying potentiality of genotypes in yield attributes. Harvest Index was calculated on proportion of grain yield to biological yield ie, total dry matter production of above ground parts to find out the dry matter partitioning to grain or the reproductive efficiency of crop as influenced by varying genotypes of pigeonpea and planting geometries during *kharif* season (Table 2). Interaction of spacing and genotypes was found significant. Treatment combination of PA-16 with 45cm×10cm gave highest harvest index (36.93%) followed by AL-882 with 45cm×10cm spacing (36.37%). Low vegetative growth of extra early pigeonpea genotypes leads to lower stover yield and thus lower biological yield *i.e*. total dry matter production without reducing the per hectare grain yield proportionately. This results in higher harvest index of extra early pigeonpea (Panda *et al.* 2019).

3.3 Economics

Economics for each treatment combination was computed and presented in Table 3. The gross return was calculated by multiplying grain yield with mean minimum support price (MSP) for three years (Rs. 63.30 kg^{-1}) and cost of cultivation differed due to variation in seed rate in different planting geometries. The maximum gross return (Rs. 52,048 ha^{-1}), net return (Rs. 21,048 ha^{-1}), B:C ratio (1.68) and return per day (Rs. 449 $ha^{-1}day^{-1}$) was obtained from 45cm×10cm spacing. This might be due to proper balancing of plant density with biomass accumulation resulting in higher grain yield and harvest index. Among genotypes PA-16 outperformed other genotypes and registered maximum gross return (Rs. 52,648 ha^{-1}), net return (Rs. 21,315 ha^{-1}), B:C ratio (1.68) and return per day (Rs. 445 $ha^{-1}day^{-1}$). The treatment combination of PA-16 sown with 45cm×10cm spacing gave maximum gross return (Rs. 62,971 ha^{-1}), net return (Rs 31,971 ha^{-1}), B:C ratio (2.03) and return per day (Rs. 532 $ha^{-1}day^{-1}$). The technology has higher farmer's adoption potential. This was closely followed by AL-882 with 45cm×10cm planting geometry (Rs. 61,235 ha^{-1}, Rs 30,235 ha^{-1}, 1.98 and Rs.517 $ha^{-1}day^{-1}$ respectively). Similar results were reported by Tuppad *et al*. (2012), Kaur and Saini (2018) and Bansal *et al*. (2023).

Table 3. Effect of planting geometry and genotypes on economics of extra early pigeonpea (mean and pooled data for three years, 2019-22)

S.N.	Treatment	Grain yield (kg ha^{-1})	GMR (Rs.)	COP (Rs.)	NMR (Rs.)	B:C ratio	Return $ha^{-1}day^{-1}$ (Rs.)
	Spacing(cm)						
S_1	30×10	823	49,642	33,000	16642	1.50	429
S_2	30×20	591	35,655	30,000	5655	1.19	308
S_3	45×10	863	52,048	31,000	21048	1.68	449
	Sem (±)	15.6	944		940		
	CD (p=0.05)	46.2	2,786		2775		
	Genotypes						
G_1	AL-882	836	50436	31,333	19102	1.61	426
G_2	PA16	873	52648	31,333	21315	1.68	445
G_3	20338	655	39543	31,333	8210	1.26	351
G_4	11255	671	40499	31,333	9166	1.29	359
	Sem (±)	18.1	1090		1085		
	CD (p=0.05)	53.3	3217		3204		
	Interaction (A×B)						
	Sem (±)	31.3	1887.9		1880		
	CD (p=0.05)	92.4	5572.6		5549		
	Treatment combination						
T1	S_1G_1	852	51374	33000	18374	1.56	434
T2	S_1G_2	883	53292	33000	20292	1.61	450
T3	S_1G_3	762	45985	33000	12985	1.39	408
T4	S_1G_4	794	47915	33000	14915	1.45	425

S.N.	Treatment	Grain yield (kg ha^{-1})	GMR (Rs.)	COP (Rs.)	NMR (Rs.)	B:C ratio	Return ha^{-1}day^{-1} (Rs.)
T5	S_2G_1	641	38698	30000	8698	1.29	327
T6	S_2G_2	691	41681	30000	11681	1.39	352
T7	S_2G_3	520	31385	30000	1385	1.05	279
T8	S_2G_4	511	30855	30000	855	1.03	274
T9	S_3G_1	1015	61235	31000	30235	1.98	517
T10	S_3G_2	1044	62971	31000	31971	2.03	532
T11	S_3G_3	684	41259	31000	10259	1.33	366
T12	S_3G_4	708	42727	31000	11727	1.38	379
	Sem (±)	31.3	1888	-	1887.9		
	CD (p=0.05)	91.8	5573	-	5537.3		
	CV (%)	7.14	7.14	-	22.6		

4. CONCLUSION

With regards to the quantitative measure of seed yield and economics, the genotype PA-16 (Pusa Arhar16) exhibited significantly superior performance over other genotypes closely followed by AL-882. PA-16 showed consistent performance across all three years. Among planting geometry sowing with 45cm×10cm (0.22 million plants ha^{-1}) found better than 30cm×10cm (0.33 million plants ha^{-1}) and 30cm×20cm (0.17 million plants ha^{-1}). Combination of both factors PA-16 with 45cm×10 cm spacing produce maximum grain yield (1044 kg ha^{-1}), highest yield per day (8.82kg), net monetary return (Rs.31,971 ha^{-1}), B:C ratio (2.03) and return per day (Rs. 532 day^{-1}).

Therefore it can be concluded that extra early pigeonpea genotype PA-16 sown with 45cm×10cm spacing (0.22 million plants ha^{-1}) may be recommended to farmers for boosting pulse production for nutritional security, higher profitability and soil health. The technology may be adopted where the situation demands for narrow *kharif* growing window due to want of *rabi* crop sowing, higher possibility of terminal drought or cattle menace.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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