



RESEARCH ARTICLE

Performance of green gram (*Vigna radiata* L.) as influenced by varietal selections and land configurations under trans gangetic plains of Punjab (India)

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Abstract

This research was conducted during kharif season of 2024 in the agricultural research farm of Lovely Professional University, Phagwara, Punjab, to evaluate the effects of varietal selection and planting geometry on the growth and production of green gram (*Vigna radiata* L.) in Punjab region. The experiment was formulated in factorial randomized block design (FRBD) where by 3 types of the seeds (V_1 - ML 2056, V_2 - MH 421 and V_3 - SML 1827) were utilised and three landscape arrangements (S_1 - Flat sowing, S_2 - Raised bed sowing and S_3 - Ridge furrow sowing) were multiplied thrice. It was discovered that variety SML 1827 grown under raised bed sowing resulted in a marked increase in growth, physiological traits, yield traits and economics. Seed yield of raised bed sowing was found 9.9 % higher than seed yield of flat sowing and SML 1827 seed yield was found 6.7 % higher than that of ML 2056. Variety V_3 (SML 1827) and planting geometry S_2 (Raised bed sowing) had the highest seed yield (1089.40 kg ha⁻¹) and Variety V_1 (ML2056) and planting geometry S_1 (Flat sowing) had the lowest seed yield (1020.89 kg ha⁻¹). It was observed that SML 1827 achieved the highest yield with a higher number of pods per plant (33.3) and a higher amount of dry matter accumulation (25.8 g). The highest gross ₹ 94863 ha⁻¹ net returns B:C ratio (2.10) were achieved with SML 1827 in the raised beds, with the highest net returns of ₹68261 ha⁻¹. Overall Variety V_3 (SML 1827) under planting geometry S_2 (Raised bed sowing) obtained higher growth, crop productivity and economic in kharif green gram. The conclusion is that, a higher productivity and profitability of kharif green gram in Punjab environment may be enhanced provided that the raised bed sowing technique is implemented using better varieties.

Keywords: economics; green gram; planting geometry; varieties; yield

Introduction

The kharif green gram (*Vigna radiata* L.), commonly known as green gram or moong bean, is a warm-season legume widely cultivated across South Asia, Southeast Asia and other regions of the world (1). Due to its high nutritional value (20–25 % protein) and a great source of protein, adaptability to diverse agro-climatic conditions and vital role in cropping systems as a cash crop, inter-crop, or cover crop, it is highly significant to agriculture (2). One hundred grams of dried mungbean have been found to have vitamin A (94 mg), iron (7.3 mg), calcium (124 mg), zinc (3 mg) and folate (549 mg) (3). Its versatility in cultivation and consumption contributes to both food security and sustainable agricultural practices (4). It is a small, circular-shaped green bean that is widely cultivated across Asia, including India, Pakistan, Bangladesh, Sri Lanka, Thailand, Laos, Cambodia, Vietnam, Indonesia, Malaysia, South China and the Republic of Formosa (5). Apart from being a primary source of food for humans and feed for animals, it also contributes significantly to soil fertility by improving soil structure and fixing atmospheric nitrogen, thereby playing a crucial role in sustainable agriculture (6, 7). While the central stem is generally erect, the side branches are semi-erect (8). In India, mungbean is cultivated on an average of 4.5 million ha with 2.5 mt yield and

5.48 q ha⁻¹ productivity (9). In Punjab and West Bengal, more than 95 % of the food grain production area of these states is now under rice and wheat cultivation.

Planting geometry refers to the spatial arrangement of crops in a field, including row planting geometry, plant planting geometry and planting patterns, all of which play a crucial role in crop establishment, growth and overall productivity (10). In kharif green gram (*V. radiata* L.) cultivation, optimal planting geometry depends on factors such as soil type, climate conditions and available resources (11). Optimal planting geometry for kharif green gram varies depending on factors such as soil type, climate conditions and available resources. However, common planting configurations include row planting geometry ranging from 30 to 45 cm and plant planting geometry within rows ranging from 5 to 15 cm. These configurations facilitate efficient use of space, light and nutrients, promoting uniform plant growth and maximising yield potential. Plant planting geometry plays a crucial role in minimising competition among crops (10). Proper planting geometry ensures optimal plant population density, minimises intra-plant competition and promotes better canopy development, which collectively enhances physiological processes and yield attributes (1). Therefore, a test was carried out to

measure both suitable variety and planting geometry on morpho-physiological and yield parameters of green gram on sandy loam with the aim of establishing the impact of alternative varieties and planting arrangement on green gram production and profitability under the trans gangetic plains of Punjab.

Materials and Methods

A field experiment was conducted at Research Farm, Lovely Professional University, Phagwara, Punjab, India, situated at 31.81° N and 75.38° E, 252 meters above sea level. The texture of the experimental field soil was sandy loam and had a pH of 7.4, an EC value of 0.32 dS m⁻¹, available nitrogen of 215 kg ha⁻¹, phosphorus of 18.6 kg ha⁻¹ and potassium of 162 kg ha⁻¹ when it was sown. The experiment was carried out in a FRBD with three replications. The experiment consisted of three varieties (V): V₁ - ML2056, V₂ - MH 421, V₃ - SML 1827, representing factor A and three planting geometries (S): S₁ - Flat sowing, S₂ - Raised bed, S₃ - Ridge-furrow as factor B. Each combination (e.g., V₁S₁, V₂S₂, V₃S₃) was replicated three times. The recommended dose of fertilisers (RDF) of green gram, as per Punjab Agriculture University (PAU) recommendations (5 kg N and 16 kg P₂O₅ per acre), was used evenly. Normal agronomic practices were used. After a 30-day interval, hand weeding was conducted for each treatment. Additionally, all necessary practices were implemented to maintain optimal plant conditions.

Observation data recording of green gram

Plant height was calculated as the mean of five plants randomly selected in each row of the middle of the plots. The height of the plant was recorded from the base (above the ground) to the peak. After the process outlined in another research, plant information, including fresh weight (g) and dry weight (g), was measured (12). The quantity of chlorophyll in leaves (mg g⁻¹) was measured by the absorbance at 645 and 663 nm using a blank made of high accuracy and dependability (wavelength range: 340–960 nm, 4-digit 7-segment LED display) with a digital spectrophotometer (Systronics Model 105). The technique to compute the total chlorophyll was a previous study (13).

$$\text{Chlorophyll index (CI)} = \log \left[\frac{\frac{I_{940}}{I_{650}}}{\frac{T_{940}}{T_{650}}} \right] \quad (\text{Eqn. 1})$$

To calculate the mean leaf area of the plants, the green leaf segments were disconnected from the stems (14).

$$\text{Leaf area index (LAI)} = \frac{\text{Total leaf area}}{\text{Ground area}} \quad (\text{Eqn. 2})$$

Relative growth rate (RGR) represents the increase in plant biomass per unit time. It was expressed in g g⁻¹day⁻¹ (15). Net assimilation rate (NAR) measures the rate of dry matter accumulation per unit leaf area (16).

$$\text{RGR} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1} \quad (\text{Eqn. 3})$$

$$\text{NAR} = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{\ln L_2 - \ln L_1}{L_2 - L_1} \quad (\text{Eqn. 4})$$

Soil pH was determined using the glass electrode method, while electrical conductivity was assessed with an EC meter (12, 17). All yield data were recorded at the net plot at harvest and were

converted to a per-hectare basis. These measures comprised the number of pods per plant, pod length, number of seeds per pod, pod dry weight (g) and test weight seed yield. The yield parameter data were collected as per the conventional methods defined in previous studies (18). The calculation of the cost of cultivation and gross income (ha⁻¹) of different treatments was done based on the approved market rate of inputs and outputs set by the Agriculture Research Farm, Lovely Professional University, Phagwara, Punjab, within the year of experimentation.

Benefit: Cost ratio =

$$\frac{\text{Gross returns (₹ ha}^{-1}\text{)}}{\text{Total cost of cultivation (₹ ha}^{-1}\text{)}} \quad (\text{Eqn. 5})$$

Statistical analysis

Data of an experimental nature were handled, put in a position input inventory sheet in MS Excel and then processed. statistical analyses, which are based on web-based OPSTAT software in the FRBD experimental design. The ANOVA was constructed to make additional inferences. At the 0.05 level of probability, appropriate LSDs were procured for each case to compare the treatment means.

Results and Discussion

Germination percentage and plant height

The highest germination percentage was observed in variety (V₃) SML 1827, which implies its seed vigour and ability to emerge better. The highest germination rate was recorded in the raised bed sowing method (S₂), achieving 89.68 %. Among the evaluated varieties, V₃ (SML 1827) exhibited the highest germination rate at 76.26 %. Germination percentage of green gram was significantly influenced by sowing method and varietal differences (Tables 1 and 2). Raised bed sowing (S₂) recorded a higher germination percentage, indicating better crop establishment compared to flat sowing (S₁), which recorded the lowest germination (67.93 %). Among the varieties, ML 2056 (V₁) exhibited the lowest germination percentage (58.84 %). The superior germination under raised bed sowing can be attributed to improved soil structure, uniform moisture distribution and better soil-seed contact, which collectively facilitate rapid imbibition and oxygen diffusion required for seed germination. In contrast, flat sowing may result in surface crusting or uneven moisture conditions, thereby restricting seedling emergence. Varietal differences in germination may be related to inherent seed vigour and genetic potential. Similar improvements in germination and early crop establishment under raised bed planting have been reported in green gram and other pulse crops grown under irrigated conditions (12).

The height of the plants was notably influenced by the various sowing methods and varieties assessed at different intervals after sowing. In all stages of plant height, the highest plant height (69.02 cm and 71.14 cm) was observed in V₃ (SML 1827) and S₂ (Raised bed sowing) followed by S₃ (ridge furrow) 69.42 cm with variety V₂ (MH 421) 67.92 cm at all the growth stages (30, 45, 60 and at harvest (Table 1). The minimum height of plants was 63.54 cm and 65.78 cm was recorded in treatment (S₁V₁). The interaction effect of V₃S₂ (SML 1827) under raised bed sowing) produced the maximum plant height of 69.25 cm at harvest. The result obtained from the present study was similar to the findings of previous studies. The highest plant height (47.50 cm) was observed in a 43

Table 1. Effect of different sowing methods and varieties on plant height, germination %, fresh weight and dry weight of green gram crop

Treatments	Plant height (cm)				Germination %	Fresh weight			Dry weight			
	15 DAS	30 DAS	45 DAS	60 DAS		At harvest	15 DAS	60 DAS	At harvest	15 DAS	60 DAS	At harvest
	Main plot treatments (planting geometry)											
S ₁ - Flat sowing	8.94	28.43	51.79	62.93	63.54	67.93	10.59	68.14	85.12	2.70	16.29	21.51
S ₂ - Raised bed sowing	12.59	42.69	57.18	70.27	71.14	89.68	15.14	94.25	111.75	3.79	25.06	27.94
S ₃ - Ridge furrow sowing	10.63	36.59	55.38	68.28	69.42	72.28	12.75	89.57	95.06	3.09	22.64	24.71
SEm(±)	0.27	0.31	1.11	0.81	0.83	1.06	0.41	2.01	3.58	0.09	0.48	0.89
C.D. at 5 %	NS	0.95	3.32	2.46	2.49	3.20	NS	6.04	10.78	NS	1.48	2.67
Sub plot (varieties levels)												
V ₁ - ML2056	9.91	33.96	54.04	65.06	65.78	58.84	11.96	79.30	92.44	2.99	18.39	23.40
V ₂ - MH 421	10.78	35.84	54.74	67.70	67.92	65.57	12.75	84.88	97.06	3.13	20.66	24.78
V ₃ - SML 1827	11.46	37.91	55.56	68.72	69.02	76.26	13.77	91.79	102.43	3.44	22.95	25.98
SEm(±)	0.15	0.31	1.18	0.84	0.89	0.96	0.47	2.08	3.64	0.12	0.52	0.94
C.D. at 5 %	NS	0.94	3.36	2.52	2.54	3.16	NS	6.26	10.91	NS	1.56	2.82
Interaction (S × V)												
SEm(±)	0.15	0.54	1.93	1.46	1.49	1.85	0.82	3.61	6.30	0.21	0.29	1.63
CD at 5 %	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
G.M.	10.72	35.90	54.78	67.16	69.25	67.26	12.82	85.32	97.31	3.19	2.71	24.72

Note: NS= Non significant, * Significant at 5%, SE= Standard error mean.

cm × 7 cm planting geometry in mungbean (19). The observed variation in plant height may be linked to genetic factors.

Fresh weight and dry weight

The fresh weight was notably influenced by the various sowing methods and plant varieties at 15-day intervals post-sowing. The raised bed sowing method (S_2) yielded the highest fresh weights of 15.14 g, 94.25 g and 111.75 g at 15 days, 60 days after sowing and at harvest, respectively. Among the different varieties, V_3 (SML 1827) also demonstrated commendable fresh weights of 13.77 g, 91.79 g and 102.43 g at the same intervals (Table 1). The elevated values noted in V_3 and S_2 appear to be associated with effective nutrient and water absorption, which facilitates biomass accumulation. The increased fresh weight with raised bed sowing and in variety SML 1827 could be due to the enhanced soil aeration and effective availability of moisture and nutrients that boosted biomass generation, as it was also earlier reported under green gram in the Trans-Gangetic Plains sandy loam soils (20).

At harvest, the highest dry weight was recorded in V_3 (SML 1827) 25.98 g and S_2 (Raised bed sowing) 27.94 g and the lowest dry weight was observed in variety V_1 (ML2056) as 2.99 g, 18.39 g and 23.40 g and planting geometry S_1 (Flat sowing) as 2.70 g, 16.29 g and 21.51 g at 15, 60 Day after sowing (DAS) and at harvest (Table 1). This variation in dry weight may be attributed to genetic diversity and various environmental factors affecting the cultivated varieties; however, the interaction between the different varieties and sowing methods does not appear to have a substantial effect on dry weight. Research has demonstrated that the uradbean U-31 variety produced significantly higher dry matter than the rest of the varieties in their studies on the green gram crop (21). The higher amounts of accumulation of the fresh and dry matter under raised bed sowing could be due to better physical conditions of the soil and to effective use of moisture and nutrients under irrigated sandy loam soil, which has also been previously reported in mungbean.

Chlorophyll index and leaf area index

Sowing techniques and variety variations at harvest had significant effects on the chlorophyll index, though the extent of variation was rather low. The elevated rate of chlorophyll index was also registered in raised bed sowing (S_2) 119.10 and varieties, which could be explained by the enhanced root zone aeration and efficiency of nitrogen uptake, leading to favourable soil moisture regimes. The content of chlorophyll has a close relationship with the nitrogen status of leaves and not the direct impact of management and this is why there are marginal differences in the sowing methods. The differences in varietal chlorophyll index might be attributed to genetic differences in the leaf morphology and nitrogen utilisation efficiency with SML 1827 (V_3) 116.56, having a higher level of leaf greenness at maturity. Other previous studies have also observed similar differences of little but significant differences in chlorophyll index with different management practices (22).

Table 2 illustrates the impact of the varietal selection and the geometry of the planting on the LAI of the green gram during various growth stages. The type with the highest LAI during the crop growth stage was SML 1827 (V_3), whereby the LAI was very high, especially after 60 days of sowing, followed by MH 421 and the lowest LAI was recorded in ML 2056 (V_1). The active vegetative growth and canopy development during a 30–60 day period are demonstrated by the progressive rise of LAI between 30 and 60 days after sowing. The high LAI of SML 1827 could be explained by the advantage of an active

growth habit, high leaf production, as well as improved spatial distribution of leaves, which improved canopy cover compared to other varieties. Better geometry of planting also allowed the optimum growth of leaves by lowering the inter-competition of plants in terms of light and space. These results are consistent with previous observations in green gram, where varietal effects had a great impact on LAI because there was an inherent genetic difference in the growth and leaf morphology (23).

Relative growth rate and Net assimilation rate

The data of the RGR, depending on varietal selection and the geometry of planting (Table 2). SML 1827 (V_3) had a higher RGR at the active vegetative stage (30 to 60 days after planting) and this was $0.11 \text{ g g}^{-1} \text{ day}^{-1}$ and later reduced down to $0.09 \text{ g g}^{-1} \text{ day}^{-1}$ at harvest among the varieties. This was at the same trend of raised bed planting (S_2), where RGR rose between 30 and 60 days after sowing and fell before harvest. The increase in the SML 1827 RGR in the middle of the growth phase shows that the biomass was growing rapidly with increased photosynthetic activity and efficient assimilate partitioning. The treatment reduction in RGR at harvest could be due to a decrease in vegetative development and an increase in the distribution of assimilates to reproductive structures. These observations support previous studies in green gram, whereby increased RGR in the vegetative stage and consequent decrease in the maturity stage had previously been reported as a result of physiological growth dynamics (12).

The varietal selection had a significant effect on the NAR (Table 2). In all varieties, net assimilation rate rose continuously to 60 days after germination and then decreased to harvest, or variations in physiological activity as the crop grew. As the variety, SML 1827 had a steadily higher net assimilation rate at 30, 45 and 60 days after sowing and also at harvest than the other varieties. This increased net assimilation rate of SML 1827 at the vegetative and early reproductive stages could be ascribed to its increased efficiency in photosynthesis and efficient use of the assimilates in growth to biomass. The resulting fall in net assimilation rate at later growth phases could be linked with the process of leaf senescence and the decrease in the photosynthetically active leaf area. This form of net assimilation rate fluctuation with crop development is not new in the green gram and other legume grains (24).

Yield attributes and yield

Table 3 indicates that the selection of the varietal and planting geometry of green gram had a significant effect on the number of pods per plant. SML 1827 (V_3) was the one that generated a much larger number of pods per plant (33.33) and the pod number was lowest in ML 2056 (V_1) (25.22). On the same note, raised bed sowing (S_2) gave a higher number of pods per plant (41.22) than flat sowing (31.00). The reason for the increased pod number under raised bed planting could be due to better spatial organisation of the plants, lower competition among the plants and better aeration of the root zone, which all lead to increased retention of the flowers and pod set. The number of pods can vary among varieties and this could be linked to natural genetic capacity, branching capacity and the ability to allocate assimilates efficiently to reproductive organs. The same reactions of the pod number to better planting geometry and varietal traits have been observed in green gram cultivated under irrigated conditions on sandy loam soils (25).

The combination of varieties and planting geometry significantly affected the pod length. Wherein, the maximum pod

Table 2. Effect of different sowing methods and varieties on chlorophyll index, leaf area index, relative growth rate and net assimilation rate of green gram crop

Treatments	Chlorophyll index				Leaf area index				Relative growth rate (g g ⁻¹ day ⁻¹)				Net assimilation rate (g m ⁻² day ⁻¹)			
	15 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	At harvest	0-30 DAS	30-60 DAS	60-at harvest	0-30 DAS	30-60 DAS	60-at harvest	0-30 DAS	60-at harvest
Main plot treatments (planting geometry)																
S ₁ - Flat sowing	38.37	84.10	117.97	113.85	0.39	1.04	1.47	1.95	0.11	0.09	0.07	0.08	0.06	0.04	0.06	0.04
S ₂ - Raised bed sowing	51.58	96.01	126.14	119.10	0.50	1.19	1.66	2.22	0.14	0.11	0.09	0.11	0.08	0.06	0.08	0.06
S ₃ - Ridge furrow sowing	44.59	88.92	122.00	117.14	0.45	1.11	1.52	2.03	0.12	0.10	0.08	0.10	0.07	0.05	0.07	0.05
SEm(±)	0.48	0.49	0.51	0.33	0.04	0.03	0.02	0.10	0.02	0.05	0.03	0.02	0.03	0.02	0.03	0.02
C.D. at 5 %	NS	1.47	1.55	0.99	NS	0.09	0.07	0.31	NS	0.15	0.10	NS	0.09	0.06	0.09	0.06
Sub plot (varieties levels)																
V ₁ - ML2056	30.92	76.58	113.35	111.45	0.35	0.96	1.39	1.83	0.10	0.08	0.06	0.08	0.05	0.03	0.05	0.03
V ₂ - MH 421	41.45	84.44	116.85	113.13	0.38	1.10	1.52	2.03	0.12	0.10	0.09	0.09	0.06	0.04	0.06	0.04
V ₃ - SML 1827	43.93	87.87	120.32	116.56	0.43	1.12	1.56	2.10	0.13	0.11	0.08	0.10	0.07	0.05	0.07	0.05
SEm(±)	0.42	0.41	0.48	0.29	0.02	0.02	0.04	0.08	0.02	0.03	0.02	0.03	0.02	0.01	0.02	0.01
C.D. at 5 %	NS	1.42	1.51	0.92	NS	0.06	0.12	0.24	NS	0.09	0.06	NS	0.06	0.03	0.06	0.03
Interaction (S × V)																
SEm(±)	0.83	0.85	0.89	0.57	0.08	0.04	0.04	0.02	0.05	0.06	0.03	0.03	0.02	0.02	0.02	0.02
CD at 5 %	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
G.M.	42.47	87.49	119.94	116.37	0.42	1.09	1.52	2.03	0.12	0.09	0.08	0.09	0.06	0.04	0.06	0.04

Note: NS= Non significant, * Significant at 5%, SE= Standard error mean.

Table 3. Effect of different sowing methods and varieties on yield parameters of green gram crop.

Treatments	Yield parameters											Harvest index (%)
	No. of pods per plant	Pod length (cm)	No. of seeds per pod	Pod dry weight (g)	1000 seed weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)			
Main plot treatments (planting geometry)												
S ₁ - Flat sowing	31.00	8.13	8.89	6.05	39.09	1068.11	1896.67	2964.78	34.70			
S ₂ - Raised bed sowing	41.22	8.64	12.67	7.51	41.42	1174.44	2446.00	3620.44	39.48			
S ₃ - Ridge furrow sowing	35.78	8.37	11.00	6.78	40.38	1130.00	2161.33	3291.33	36.35			
SEm(±)	0.08	0.20	0.47	0.09	0.60	35.01	35.13	54.64	0.07			
C.D. at 5 %	0.24	0.62	1.43	0.28	1.82	104.97	105.39	163.92	0.21			
Sub plot (varieties levels)												
V ₁ - ML2056	25.22	7.90	7.56	5.12	36.30	1020.89	1621.00	2641.89	31.61			
V ₂ - MH 421	31.00	8.20	9.56	6.36	38.74	1086.67	2018.56	3108.00	33.14			
V ₃ - SML 1827	33.33	8.24	9.85	6.57	39.49	1089.40	2027.56	3114.22	35.18			
SEm(±)	0.06	0.18	0.44	0.06	0.57	34.89	35.04	54.50	0.05			
C.D. at 5 %	0.18	0.58	1.38	0.18	1.71	104.56	106.58	162.50	0.15			
Interaction (S × V)												
SEm(±)	1.42	0.35	0.82	0.16	1.03	60.64	60.86	94.64	0.35			
CD at 5 %	NS	NS	NS	NS	NS	NS	NS	NS	NS			
G.M.	33.26	8.25	9.93	6.40	39.74	1094.93	2028.52	3123.44	35.41			

Note: NS= Non significant, * Significant at 5%, SE= Standard error mean.

length (8.24 cm and 8.64 cm) was produced in treatment V_3 SML 1827 and planting geometry S_2 (Raised based sowing) and the minimum (7.90 cm and 8.13 cm) seeds per pod were recorded in treatment V_1 -ML2056 and planting geometry S_1 , respectively. The SML 1827 variety demonstrated superior performance in terms of pod length, number of pod/plant, seed weight/plant and test weight when compared to the MH 421 and ML 2056 varieties. Crop geometry in green gram had a significant influence on pod length, number of seeds per pod, weight of seeds per plant and test weight. All these yield attributes showed the highest values in raised bed sowing (S_2), then ridge sowing (S_3) and the lowest values in flat sowing. The advantages of raised bed geometry may be explained by the better aeration of the root zone, equalisation of soil moisture distribution and decrease of the interplant competition, which contributed to the increase of assimilate production and its efficient translocation to the pods and seeds growing. Advanced spatial organisation beneath raised beds is also beneficial to enhanced photosynthetic rates and extended leaf behaviour throughout the reproductive stage, hence supporting high seed filling and test weight. The intermediate performance that is realised when using ridge sowing indicates that the physical conditions in the soil are partially improved relative to the case of flat sowing. Pod and seed properties have also responded similarly when the land configuration was improved in green gram, which is cultivated under an irrigation system on sandy loam soils (26).

The interplay between different varieties and their planting geometry had a notable impact on the seed count per pod. Specifically, the highest average was observed in treatment V_3 SML 1827 and planting geometry S_2 (Raised based sowing), yielding 9.85 and 12.86 seeds per pod, respectively, while treatment V_1 -ML2056 and planting geometry S_1 recorded the lowest average of 7.56 and 8.89 seeds per pod, respectively (Table 3). A similar result was reported in the green gram crop (27). The observed differences in the number of seeds per pod may be attributed to the genetic diversity among various varieties and the inter-row planting geometry, both of which significantly influence seed yield.

The maximum 1000-seed weight (39.49 g) was recorded in treatment variety V_3 - SML 1827 at the planting geometry S_2 - Raised bed sowing (41.42 g), while the minimum 1000-seed weight in variety V_1 - ML2056 as (36.30 g) was obtained in treatment T_1 -variety SML 668 at planting geometry S_1 - Flat sowing as 39.09 g at harvest (Table 3). The difference in the weight of 1000 seeds of the sowing procedure and varieties can be explained by the difference in assimilate partitioning performance and seed filling period. The raised bed sowing enhances root activity and aeration of soil, which allows a quicker movement of photosynthesis to growing seeds and the difference in the variety is an inherent genetic capability of seeds to grow in terms of size and weight (12).

The varietal selection and the method of sowing affected the seed yield of green gram significantly (Table 3). Out of the varieties, SML 1827 (V_3) gave the best yield of seeds (1089.40 kg ha⁻¹), with the lowest yield being 1020.89 kg ha⁻¹ by ML 2056 (V_1). Similarly, the yield of seeds was far more in raised bed sowing (S_2) than in flat sowing (S_1), which registered the lowest yield (1068.11 kg ha⁻¹). The increased seed harvest with raised bed sowing may be explained by the fact that the physical condition of soil, the effective control of moisture and the increase of absorption of nutrients were improved and thus the yield, including characteristics (such as pod number, seed weight and test weight), were enhanced. The high genetic potential of SML 1827 to make assimilates and effectively partition to

reproductive organs in the conditions set by the existing agro-climatic conditions of the trans gangetic plains of Punjab has led to this high performance. These results show that varietal potential and sowing method complement each other to control the seed yield in irrigated green gram (12).

The varietal selection and method of sowing were found to contribute greatly to the biological yield of the green gram, as shown in Table 3. SML 1827 (V_3) cultivated in raised bed sowing (S_2) had the highest biological yield (3114.22 and 3620.44 kg ha⁻¹) at harvest. On the contrary, the least biological yield (2641.89 kg ha⁻¹) was recorded in ML 2056 (V_1) flat sown (S_1). The increased biological production realised during raised bed sowing could be explained by the positive physical maturity of the soil, better development of roots and effective use of moisture and nutrients, which together resulted in the increased biomass accumulation. The difference in the yield of different varieties is a legacy of genetic variation in the vigour of growth and the generation of dry matter. These findings show that elevated yield of biology with better sowing geometry and better varietal potential has a direct effect on the productivity of crops in the irrigated environment of the trans-gangetic plains (12).

The interaction between varietal selection and sowing method had a significant effect on the harvest index (HI) of green gram. The treatment of V_3S_2 (SML 1827 with raised bed sowing) showed the highest index of harvest with 39.48 and 35.18, which implies better use of total biomass to produce economic yield. Conversely, V_1S_1 (ML 2056 when sown in a flat) had the lowest harvest index (31.61 and 34.70). The increased index of harvest under raised bed sowing is an indication of enhanced assimilate partitioning to the reproductive organs as a result of good physical characteristics of the soils and low levels of interplant competition. The high performance of SML 1827 is also an indicator of a varietal advantage in the use of photosynthates on seed production instead of over vegetative production. On the other hand, reduced harvest index in the case of flat sowing can be explained by the increased competition for resources and the relative inefficiency of the translocation of assimilates to grains. This type of variation in harvest index, because of varietal differences and sowing geometry, has been well recorded in green gram and other grain legumes when planted under irrigated conditions (26).

Economics

Table 4 showed that varietal selection and the way of sowing had a major impact on the economics of green gram cultivation. The species were SML 1827 (V_3) with gross return (₹ 94863 ha⁻¹) and net return (₹ 68261 ha⁻¹), the highest, whereas the raised bed sowing species (S_2) had the highest gross and net returns (₹ 96389 ha⁻¹ and ₹ 66099 ha⁻¹, respectively). As a result, the maximum ratio of benefit to cost (B: C) was found with V_3 and S_2 and the ratios are 2.10 and 2.18, respectively, which demonstrates a high level of economic efficiency because of the high yield of seeds and the capacity to obtain the market value. Conversely, ML 2056 (V_1) and flat sowing (S_1) had the most negative net returns (₹ 49945 ha⁻¹ and ₹ 56280 ha⁻¹, respectively) and a low B:C ratio (1.38) since they had lower productivity and gross income was lower. One of the previous green gram research has also indicated that with a better land and high-yielding varieties, higher net returns and better B:C ratios occur and the economic benefit of increased yield parameters and better use of resources under raised bed systems has been attributed (12, 25).

Table 4. Effect of different sowing methods and varieties on economic parameters of the green gram crop

Treatments	Economic parameters			
	Cost of cultivation (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B:C ratio
Main plot treatments (planting geometry)				
S ₁ - Flat sowing	30360	86840	56280	1.84
S ₂ - Raised bed sowing	31290	96389	66099	2.18
S ₃ - Ridge furrow sowing	30560	84580	54220	1.78
SEm(±)	—	67.12	67.12	0.16
CD at 5 %	—	201.36	201.36	0.48
Subplot treatments (variety level)				
V ₁ - ML2056	30160	66105	49945	1.65
V ₂ - MH 421	30314	93827	64273	1.74
V ₃ - SML 1827	30590	94863	68261	2.10
SEm(±)	—	17.46	17.46	0.12
CD at 5 %	—	52.38	52.38	0.36
Interaction (S × V)				
SEm(±)	—	1436.92	1245.12	0.26
CD at 5 %	—	4358.46	3818.26	0.74

Note: NS= Non significant, * Significant at 5%, SE= Standard error mean.

Conclusion

The current study has clearly shown that the method of sowing and choice of varieties is a decisive factor in deciding growth, yield characteristics, productivity and economic returns of green gram in the agro climatic conditions of the trans gangetic plain. Out of the sowing methodologies compared, the raised bed sowing (S₂) always performed better than the flat and ridge furrow sowing in terms of enhancing the parameters of plant growth, physiological indices, yield components and end seed yield. The higher success of raised bed sowing could be explained by the presence of better physical properties of soil, rapid root growth and efficient use of moisture and better absorption of nutrients, which in turn resulted in increased biomass and productivity in accumulating assimilates towards reproductive organs.

The level of varietal response was also quite diverse, with SML 1827 (V₃) showing better growth vigour, greater leaf area index, greater relative growth and net assimilation rates and better yield contributing characters, including pods per plant, seed weight and test weight. These benefits were expressed in better seed yield, biological yield, harvest index and better economic returns than ML 2056 and MH 421. SML 1827 interaction with raised bed sowing further maximised the productivity and profitability, hence the greatest gross returns, net returns and benefit cost ratio. Judging on the general performance, it is possible to conclude that cultivation of green gram variety SML 1827 in raised bed sowing is a technically efficient and economical process of pulse production in the Punjab in a sustainable manner. Such a combination can be adopted in order to increase efficiency of resource use, crop productivity and profitability of farms, which helps to diversify and sustain the current cropping systems in the area.

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Authors' contributions

HW and AK contributed to the conceptualization of the study, reviewed and edited the manuscript. AUSG performed experimentation;

conducted data analysis and drafted the manuscript. SP assisted in data analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

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