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Effect of spacing, nutrient and plant growth regulators on growth, yield and economics of Indian mustard (*Brassica juncea* L.)

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Abstract
A field experiment entitled "Effect of spacing, nutrient and plant growth regulators on growth, yield and economics of Indian mustard (*Brassica juncea* L.)" was conducted at the Instructional Farm, Dau Kalyan Singh College of Agriculture and Research Station, Bhatapara (C.G.) during the *rabi* season of 2024-25. The study was laid out in a split-split-plot design with three replications. The treatments consisted of three row spacings (45 cm, 60 cm, and 75 cm) in main-plots, two nutrient levels (100% RDF and 125% RDF) in sub-plots, and three plant growth regulators (GA_3 at 125 ppm, NAA at 100 ppm, and control) in sub-sub-plots.
The results revealed that the widest row spacing (75 cm) significantly enhanced growth parameters such as plant height, number of branches per plant and dry matter accumulation, along with yield parameters including seed yield, stover yield and harvest index compared to narrower spacings. Application of 125% RDF resulted in significant improvement in growth and yield traits over 100% RDF. Among the growth regulators, GA_3 at 125 ppm produced superior growth and yield performance, while the control consistently exhibited the lowest results. No significant interactions were observed among spacing, nutrient management, and plant growth regulators for growth and yield parameters.
From an economic standpoint, the maximum returns were achieved with 75 cm row spacing (gross returns: ₹95,763/ha; net returns: ₹63,617/ha; B:C ratio: 2.98), 125% RDF (gross returns: ₹92,623/ha; net returns: ₹59,602/ha; B:C ratio: 2.80), and GA_3 at 125 ppm (gross returns: ₹95,367/ha; net returns: ₹62,622/ha; B:C ratio: 2.91). These findings suggest that optimizing row spacing along with appropriate nutrient management and plant growth regulator application can significantly enhance the growth, yield, and economic returns of Indian mustard cultivation.

Keywords: Mustard, siliqua, brassica, nutrient, RDF and yield.

Introduction

Brassica is a genus of the Brassicaceae (Cruciferae), commonly known as the Cruciferae family. The family Brassicaceae, includes about 3,500 species and 350 genera, is one of the ten most economically important plant families (Warwick *et al.*, 2000) [25]. Brassica contains about 100 species, the different species are, Indian mustard (*Brassica juncea* (L.) Czern. & Coss.), toria (*B. rapa* L. ssp. toria), yellow sarson (*B. rapa* L. ssp. yellow sarson), brown sarson (*B. rapa* L. ssp. brown sarson), gobhi sarson (*B. napus* L.), karan rai (*B. carinata* Braun.) and taramira (*Eruca sativa* Mill.) (Willis, 1973) [26]. Brassicas plays an important role in the world agriculture as oilseeds, vegetables, forage and fodder, green manure and condiments.

A large proportion of mustard oil is used directly in cooking, the oil is also used in the manufacture of salad dressage and table oils, confectionery fats etc. It is used in manufacturing of cakes, biscuits, pastries and many other products. It is also of great importance in the manufacture of margarine. The fatty acids and their derivatives are widely used for industrial purpose. It is also used in production of rubber, tanning industries, as lubricants, and manufacture of soaps, detergents and bonding compounds (Kumar *et al.*, 2004) [10]. The economically most important product is oil. The mustard oil contains substantial amount of unsaturated fatty acid and the low concentration (around 7%) of saturated fatty acid. In unsaturated fatty acid it contains oleic acid (8-40%), lenolenic acid (5-10%), linoleic acid (10-29%), eicosinoic acid (5-12%) and erucic acid (40-55%).

The Brassica seed meal (oil cake) contains: protein (36-38%), carbohydrate (14-16%), fiber (10-15%), moisture (6-8%), ash (4-6%), mineral (3-4%), vitamins (0.7-0.9%) glucosinolate (2-3%), phytic acid (3-6%), sinapine (1-1.5%) and 1.6-3.1% of tannin (Agnihotri and Kumar, 2004) [1].

Mustard is cultivated in mostly under temperate climates. It is also grown in certain tropical and sub-tropical regions as a cold weather crop. Indian mustard is reported to tolerate annual precipitation of 500 to 4200 mm, annual temperature of 6 to 27ºC and pH of 4.3 to 8.3.

The global estimated area, production and yield of rapeseed-mustard stand at 43.31 million hectares, 89.89 million tonnes and 2080 kg/ha, respectively. India contributes 14.74% of the total cultivated area and 7.0% of global production (USDA). In India, rapeseed-mustard is cultivated on 9.18 million hectares, yielding 13.26 million tonnes with an average productivity of 1444 kg/ha. About 86.01% of the cultivated area is irrigated. Rajasthan is the leading producer, contributing 48.28% of the total production, followed by Uttar Pradesh (8.63%) and Madhya Pradesh (14.13%) (Anonymous, 2023) [3]. In Chhattisgarh, rapeseed-mustard is grown on 47,542 hectares, with a total production of 26,999 metric tonnes (Anonymous, 2022) [4].

Among the various factors influencing mustard productivity, plant spacing is also a crucial agronomic practice that significantly impacts crop growth and yield by modifying competition dynamics. The competitive ability of Indian mustard is strongly influenced by plant density and soil fertility status (Singh *et al.*, 2020) [22]. Although spacing is a non-monetary input, it plays a vital role in optimizing resource utilization. Proper row spacing ensures adequate light interception at different leaf strata, enhancing the rate of photosynthesis and dry matter accumulation, ultimately improving yield. Uniform plant distribution facilitates efficient utilization of space, nutrients, and moisture while suppressing weed growth, leading to higher productivity (Shekhawat *et al.*, 2022) [18].

Among the various agronomic factors influencing crop production, fertilizers play a crucial role and are considered one of the most impactful inputs in agriculture. Indian mustard has a high nutrient requirement and inadequate fertilization often results in low productivity. The major nutrient elements, which are generally deficient in most Indian soils, significantly affect the growth and yield of *Brassica juncea* (Solanki *et al.*, 2023) [23]. The fertilizer use efficiency in Indian soils is relatively low, with nitrogen at 40-50%, phosphorus at 15-20% and sulfur at 10-12%. However, these efficiencies can be improved through the optimal and efficient application of inputs (Potdar *et al.*, 2019) [14]. Macronutrients such as nitrogen, phosphorus and potassium play a vital role in enhancing crop yield. Among them, nitrogen is the most essential, with urea being the most widely used nitrogen source globally. The efficiency of nitrogen use in most crops ranges from 20-26%. Its significance in achieving higher mustard yields is well recognized, as nitrogen is a key metabolic element necessary for plant growth and development. It plays a crucial role in protein metabolism and the synthesis of essential biochemical compounds such as nucleic acids, chlorophyll and protoplasm, making it fundamental to plant life. Additionally, nitrogen promotes vegetative growth and facilitates the utilization of other nutrients (Singh *et al.*, 2017) [19, 21].

Plant Growth Regulators (PGRs) are naturally occurring organic substances that regulate plant growth and development in very low concentrations. While plants synthesize their own PGRs, their production is influenced by biotic and abiotic factors, which can hinder normal physiological processes and restrict growth. When applied externally in low concentrations, PGRs compensate for deficiencies and have beneficial effects on plant growth (Sumi *et al.*, 2021) [24]. Depending on their function, they can either promote or inhibit specific processes (Ijaz *et al.*, 2019) [9], ensuring that physiological activities proceed at optimal rates. Thus, the application of synthetic PGRs in crops has been shown to produce positive results.

Auxins and gibberellic acids are among the most commonly used plant growth regulators (PGRs) in agriculture. In oilseed crops, PGRs have demonstrated significant effects on growth and yield. Their application has been successfully utilized to enhance the productivity of economically important oilseed crops (Rastogi *et al.*, 2013) [15]. For instance, the application of NAA has shown positive effects on sesame seed yield by modifying plant architecture and improving biomass production (Nizamani *et al.*, 2018) [13]. Similarly, GA_3 application has been beneficial for mustard growth and yield, reducing yield losses by 17.7% (Devi *et al.*, 2018) [8].

Materials and Methods

A field experiment was conducted during *rabi* season 2024-25 at the Instructional Farm, Dau Kalyan Singh College of Agriculture and Research Station, Bhatapara, Chhattisgarh (21.73° N latitude, 81.98° E longitude, and 262 m above mean sea level). The experimental soil was sandy loam in texture, slightly alkaline in reaction (pH 7.20), low in organic carbon (0.48%), low in available nitrogen (226 kg/ha), low in available phosphorus (13.1 kg/ha), and high in available potassium (210 kg/ha). The experiment comprised 18 treatments, having three row spacing *viz.*, 45 cm (S_1), 60 cm (S_2) and S_3 75 cm (S_3) in main-plots. Two nutrient management practices *viz.*, 100% RDF (F_1) and 125% RDF (F_2) in sub-plots and three plant growth regulators *viz.*, GA_3 (125 ppm) (G_1), NAA (100 ppm) (G_2) and Control (G_3) in sub-sub-plots and laid out in a split-split-plot design with 3 replications. Weather data during the crop growth period were recorded at the meteorological observatory of DKS CARS, Bhatapara. No rainfall was received during the crop period. Relative humidity ranged from 37.2% (7th Standard Meteorological Week, 2025) to 94.6% (48th SMW, 2024). The mean weekly maximum temperature varied from 22.9 °C (6th SMW, 2025) to 32.0 °C (44th SMW, 2025). Bright sunshine hours ranged between 2.58 and 9.32 hrs/day. The test crop was mustard (*Brassica juncea* L.) variety Chhattisgarh Sarson 01, sown on 8th November 2024 with a seed rate of 5 kg/ha.

The recommended dose of fertilizers (RDF) was 80:60:40 kg $N:P_2O_5:K_2O$/ha, applied through urea, diammonium phosphate (DAP), and muriate of potash (MOP), respectively. Half of the nitrogen along with the entire dose of phosphorus and potassium was applied as a basal dose at sowing, while the remaining half of nitrogen was top-dressed at 21 days after sowing (DAS). The gross plot size for each treatment was 9.0 m × 2.25 m. Standard and recommended agronomic practices were followed uniformly to raise a healthy crop. The crop was harvested manually at physiological maturity. Observations recorded included growth, seed yield, stover yield and estimated using standard procedures and formulae. The economics of treatments was assessed by calculating gross and net returns based on prevailing market prices of mustard seed and stover. The benefit-cost ratio (B:C ratio) was derived as the ratio of gross returns to total cost of cultivation. The data obtained were subjected to statistical analysis using appropriate methods for split-split plot design, and results have been presented accordingly.

Results and Discussion

- **Growth parameters:** Significant variation was observed in plant height, number of branches per plant, and dry matter accumulation (g/plant) under different row spacing, nutrient management, and plant growth regulator treatments (Table 1).

- **Row spacing:** Wider row spacing of 75 cm recorded the maximum plant height (166 cm), number of branches (19.2/plant), and dry matter accumulation (48.5 g/plant) at harvest, which were significantly higher than those observed under 60 cm spacing (158 cm, 18.6 branches, 47.6 g/plant) and 45 cm spacing (147 cm, 16.8 branches, 46.5 g/plant). The enhanced growth under wider spacing could be attributed to reduced inter-plant competition for light, moisture, and nutrients, thereby facilitating better resource utilization and photosynthetic efficiency. These findings are in line with the results of Lalruatfeli *et al.* (2021) [12], who reported that wider relative spacing (45 × 10 cm) in mustard promoted higher plant height, greater number of branches, and improved dry matter accumulation compared to closer spacing.

- **Nutrient management:** Application of 125% RDF recorded the maximum plant height (165 cm), number of branches (19.0/plant), and dry matter accumulation (48.1 g/plant), which were superior to those obtained under 100% RDF (150 cm, 17.3 branches, and 47.0 g/plant). The improvement in growth attributes with higher fertilizer dose could be ascribed to enhanced nutrient availability during the entire crop growth period, leading to greater cell division, cell elongation, and biomass production. Similar beneficial effects of higher nutrient levels on mustard growth have been reported by Singh and Verma (1993) [20].

- **Plant growth regulators (PGRs):** The maximum plant height (165 cm), number of branches (19.4 /plant), and dry matter accumulation (48.5 g/plant) were observed with GA_3 application, which were distinctly superior to NAA at 100 ppm (159 cm, 18.2 branches, 47.5 g/plant) and the control (148 cm, 17.0 branches, 46.5 g/plant). The superiority of GA_3 may be attributed to its role in stimulating cell elongation, reducing apical dominance, and promoting vegetative growth, which ultimately increased branching and dry matter accumulation. These findings corroborate the results of Akter *et al.* (2007) [2], who also reported that exogenous application of GA_3 significantly improved mustard growth parameters compared to untreated control.

- **Interaction effects:** None of the interactions (S × F, S × G, F × G and S × F × G) were found significant, indicating that the effects of spacing, nutrient management and growth regulators were independent of each other.

Table 1: Effect of spacing, nutrient and plant growth regulators on plant height, number of branches and dry matter accumulation at harvest stage of Indian mustard

Treatments	Plant height (cm)	Number of branches /Plant	Dry matter accumulation (g/plant)
	At harvest		
Row spacing (S)			
S_1 - 45 cm	147	16.8	46.5
S_2 - 60 cm	158	18.6	47.6
S_3 - 75 cm	166	19.2	48.5
SEm (±)	1.01	0.28	0.25
CD (P = 0.05)	3.99	1.10	0.97
Nutrient management (F)			
F_1 - RDF	150	17.3	47.0
F_2 - 125% RDF	165	19.0	48.1
SEm (±)	1.74	0.20	0.26
CD (P = 0.05)	6.02	0.69	0.91
Plant Growth Regulators (G)			
G_1 - GA_3 (125 ppm)	165	19.4	48.5
G_2 - NAA (100 ppm)	159	18.2	47.5
G_3 -Control	148	17.0	46.5
SEm (±)	2.56	0.32	0.34
CD (P = 0.05)	7.47	0.94	**0.98**
Interaction (S×F)			
SEm (±)	3.01	0.35	0.45
CD (P = 0.05)	NS	NS	NS
Interaction (S×G)			
SEm (±)	4.43	0.56	0.58
CD (P = 0.05)	NS	NS	NS
Interaction (F×G)			
SEm (±)	3.62	0.46	0.47
CD (P = 0.05)	NS	NS	NS
Interaction (S×F×G)			
SEm (±)	6.27	0.79	0.82
CD (P = 0.05)	NS	NS	NS

Yield

Significant variation was observed in seed yield and stover yield due to the influence of row spacing, nutrient management, and plant growth regulators, whereas harvest index did not exhibit statistically significant differences under these treatments (Table 2).

Row Spacing: Among the three row spacings tested, the highest seed yield (1624 kg/ha), stover yield (4019 kg/ha), and harvest index (28.9%) were recorded under the widest row spacing of 75 cm. These findings are in line with Saini *et al*. (2019) [16], who reported that wider row spacing promotes better crop growth by improving light penetration and reducing competition for nutrients and water. In contrast, the narrowest row spacing (45 cm) resulted in the lowest performance across all measured parameters, emphasizing the critical role of optimizing row spacing for achieving improved productivity in Indian mustard.

Nutrient Management: The application of 125% RDF significantly improved seed yield (1569 kg/ha), stover yield (3956 kg/ha), and harvest index (28.6%) compared to 100% RDF, which recorded seed yield of 1445 kg/ha, stover yield of 3823 kg/ha, and harvest index of 27.7%. The superior yield under higher nutrient application can be attributed to improved nutrient availability, resulting in enhanced physiological processes such as photosynthesis, cell division, and assimilate translocation (Kumar *et al.*, 2020) [11]. These results confirm that increasing nutrient supply beyond the recommended dose can further stimulate growth and productivity under optimal management conditions.

Plant Growth Regulators: Among the growth regulators, GA_3 at 125 ppm produced the highest seed yield (1617 kg/ha), stover yield (3987 kg/ha), and harvest index (28.9%), followed by NAA at 100 ppm. The untreated control consistently exhibited the lowest performance across all parameters. The enhanced yield performance under GA_3 treatment can be explained by its role in promoting cell elongation, increasing photosynthetic efficiency, and enhancing assimilate partitioning towards reproductive organs (Sharma *et al.*, 2018) [17]. These effects result in improved growth and greater seed production, indicating the importance of GA_3 application in improving Indian mustard productivity.

Interaction Effects: The interaction effects between row spacing, nutrient management, and plant growth regulators (S × F, S × G, F × G, S × F × G) on seed yield, stover yield and harvest index were found to be statistically non-significant at the 5% level of significance (P = 0.05). Similar findings were reported by Singh *et al.*, (2017) [19, 21], who observed that the individual main effects of agronomic practices had a predominant role in yield determination under Indian agro-climatic conditions.

Table 2: Effect of spacing, nutrient and plant growth regulators on seed yield, stover yield and harvest index of Indian mustard

Treatments	**Seed yield (kg/ha)**	**Stover yield (kg/ha)**	**Harvest index (%)**
Row spacing (S)			
S_1 - 45 cm	1414	3777	27.6
S_2 - 60 cm	1484	3874	28.0
S_3 - 75 cm	1624	4019	28.9
SEm (±)	31.0	35.8	0.44
CD (P = 0.05)	122	140	NS
Nutrient management (F)			
F_1 - RDF	1445	3823	27.7
F_2 - 125% RDF	1569	3956	28.6
SEm (±)	13.1	36.7	0.40
CD (P = 0.05)	45.4	127	NS
Plant Growth Regulators (G)			
G_1 - GA_3 (125 ppm)	1617	3987	28.9
G_2 - NAA (100 ppm)	1515	3899	28.0
G_3 - Control	1389	3783	27.7
SEm (±)	31.5	65.6	0.35
CD (P = 0.05)	92.2	191	NS
Interaction (S × F)			
SEm (±)	22.7	63.6	0.69
CD (P = 0.05)	NS	NS	NS
Interaction (S× G)			
SEm (±)	54.7	113	0.60
CD (P = 0.05)	NS	NS	NS
Interaction (F × G)			
SEm (±)	44.6	92.7	0.49
CD (P = 0.05)	NS	NS	NS
Interaction (S × F × G)			
SEm (±)	77.3	160	0.85
CD (P = 0.05)	NS	NS	NS

Economics

Significant variation was observed in cost of cultivation, gross returns, net returns and benefit: cost ratio under different row spacing, nutrient management, and plant growth regulator treatments (Table 3).

Row spacing: The highest cost of cultivation (32,348 ₹/ha) was incurred under the narrow row spacing of 45 cm. In contrast, the maximum gross returns (95,763 ₹/ha) and net returns (63,617 ₹/ha) were obtained with the wider spacing of 75 cm, which also recorded the highest benefit-cost (B:C) ratio of 2.98. Conversely, the lowest gross returns, net returns, and B:C ratio were observed under 45 cm spacing. Yadav *et al.* (2018) [27] similarly noted that balanced plant geometry reduces competition and ensures better photosynthate partitioning, which translates into higher net economic gains.

The highest gross returns (₹92,623/ha) and net returns (₹59,602/ha) were obtained under 125% RDF, which also recorded the highest benefit-cost (B:C) ratio of 2.80. In contrast, the lowest gross returns (₹85,462/ha), net returns (₹54,006/ha), and B:C ratio (2.72) were observed under 100% RDF. The improvement in profitability under higher nutrient supply is attributed to increased yield resulting from improved nutrient availability, which offset the slightly higher cost of cultivation (Chauhan *et al.*, 2014) [6].

The highest cost of cultivation (₹32,745/ha), gross returns (₹95,367/ha), and net returns (₹62,622/ha) were recorded under GA_3 at 125 ppm application. The highest B:C ratio (2.91) was also obtained with GA_3 treatment. In contrast, the minimum gross returns (₹82,283/ha), net returns (₹50,830/ha), and B:C ratio (2.62) were observed in the control treatment (without growth regulator). These results are in agreement with Choudhary *et al.* (2016) [7], who reported higher economic returns in mustard cultivation following GA_3 application due to enhanced growth and yield parameters.

The interaction effects of row spacing × nutrient management (S × F), row spacing × plant growth regulators (S × G), nutrient management × plant growth regulators (F × G), and the three-way interaction (S × F × G) were found to be statistically non-significant for gross returns, net returns, and the B:C ratio. This indicates that the individual effects of row spacing, nutrient management, and plant growth regulators predominantly influenced economic performance, without significant synergistic or antagonistic interaction effects.

Table 3: Effect of spacing, nutrient and plant growth regulators on Economics of Indian mustard

Treatments	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
Row spacing (S)				
S_1 - 45 cm	32348	83658	51311	2.58
S_2 - 60 cm	32222	87707	55485	2.72
S_3 - 75 cm	32146	95763	63617	2.98
SEm (±)		1748	1748	0.05
CD (*P* = 0.05)		6864	6864	0.20
Nutrient management (F)				
F_1 - RDF	31456	85462	54006	2.72
F_2 - 125% RDF	33021	92623	59602	2.80
SEm (±)		717.0	717.0	0.02
CD (*P* = 0.05)		2482	2482	0.07
Plant Growth Regulators (G)				
G_1 - GA_3 (125 ppm)	32745	95367	62622	2.91
G_2 - NAA (100 ppm)	32517	89478	56961	2.75
G_3 -Control	31453	82283	50830	2.62
SEm (±)	-	1811	1811	0.05
CD (*P* = 0.05)	-	5287	5287	0.15
Interaction (S × F)				
SEm (±)	-	1242	1242	0.03
CD (*P* = 0.05)	-	NS	NS	NS
Interaction (S × G)				
SEm (±)	-	3138	3138	0.09
CD (*P* = 0.05)	-	NS	NS	NS
Interaction (F × G)				
SEm (±)	-	2562	2562	0.07
CD (*P* = 0.05)	-	NS	NS	NS
Interaction (S × F × G)				
SEm (±)	-	4437	4437	0.12
CD (*P* = 0.05)	-	NS	NS	NS

Conclusion

The 75 cm row spacing significantly enhanced growth, yield and economic returns in Indian mustard, followed by 60 cm spacing. Among nutrient treatments, 125% RDF outperformed 100% RDF in all parameters. GA_3 at 125 ppm as a plant growth regulator consistently produced superior results compared to control. Combined interactions of spacing, nutrient, and growth regulators showed mostly non-significant effects. The highest economic returns were observed with 75 cm spacing (gross returns: ₹95,763/ha; net returns: ₹63,617/ha and B:C ratio: 2.98), 125% RDF (gross returns: ₹92,623/ha; net returns: ₹59,602/ha and B:C ratio: 2.80), and GA_3 at 125 ppm (gross returns: ₹95,367/ha; net returns: ₹62,622/ha and B:C ratio: 2.91).

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