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Agronomic Evaluation of Sowing Time and Row Spacing for Yield Attributes and Productivity of Indian Mustard (*Brassica juncea* L. Czern and Coss)

Parveen [a], Neeraj [a*], Ashish Shivran [a] and Smita Kumari [b*]

[a] *Department of Agronomy, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana 125004, India.*
[b] *Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara-144411, Punjab, India.*

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

Indian mustard is an important oilseed crop cultivated widely under diverse agro-climatic conditions in India. Among various agronomic practices, optimum sowing time and appropriate row spacing play a crucial role in improving growth, yield attributes and productivity of mustard under semi-arid environments. The present investigation was carried out during the *Rabi* season of 2024-25 at the experimental farm of Krishi Vigyan Kendra (KVK), Mahendergarh under CCS Haryana Agricultural University, Hisar, Haryana. The objective of the study was to evaluate the effect of different sowing times and row spacings on yield attributes and yield of

**Corresponding author: E-mail: neerkaushik97@gmail.com, Smitasingh25398@gmail.com;*

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Indian mustard. The experiment was laid out in a split plot design with four sowing times (25 September, 5 October, 15 October and 25 October) assigned to main plots and three row spacings (30 cm, 45 cm and 60 cm) to sub-plots. The mustard variety RH-1424 was used for the study. Data were recorded and statistically analyzed for yield attributes viz., primary branches per plant, secondary branches per plant, siliquae per plant, siliqua length, seeds per siliqua and yield parameters including seed yield, stover yield, biological yield and harvest index. The results revealed that sowing on 15 October significantly improved the yield attributes and yield of mustard. This treatment recorded the highest number of primary branches per plant (6.7), secondary branches per plant (16.7), siliquae per plant (314.6), siliqua length (7.26 cm) and seeds per siliqua (16.5). The same treatment also produced the maximum seed yield (2172 kg ha^{-1}), stover yield (6412 kg ha^{-1}), biological yield (8584 kg ha^{-1}) and harvest index (25.3%). Among different row spacings, 45 cm spacing proved superior by recording higher values of yield attributes including primary branches per plant (6.1), secondary branches per plant (15.3), siliquae per plant (289.4), siliqua length (6.69 cm) and seeds per siliqua (16.2). The 45 cm row spacing also resulted in the highest seed yield (2012 kg ha^{-1}), stover yield (6003 kg ha^{-1}), biological yield (8015 kg ha^{-1}) and harvest index (25.1%). Based on the findings of the study, it may be concluded that sowing mustard around 15 October with 45 cm row spacing was the most suitable combination for obtaining higher yield and better yield attributes under the semi-arid conditions of Mahendergarh, Haryana.

Keywords: Indian mustard; sowing time; row spacing; yield attributes; seed yield.

1. Introduction

Indian mustard (*Brassica juncea* L. Czern and Coss.) is one of the most important oilseed crops cultivated in India and plays a significant role in the agricultural economy due to its contribution towards edible oil production and nutritional security. Oilseed crops occupy an important place after cereals and contribute substantially to the gross agricultural output of the country. Among the major oilseed crops, rapeseed-mustard is widely cultivated because of its adaptability under diverse agro-climatic conditions and its multiple uses as edible oil, condiment, vegetable and livestock feed. India is one of the leading producers as well as importers of edible oils and ranks fourth in the global vegetable oil economy after the United States, China and Brazil. Rapeseed-mustard contributes significantly to the total oilseed production of the country and occupies a prominent position among winter season oilseed crops. In India, rapeseed-mustard is cultivated over approximately 10.6 million hectares with a production of 13.2 million tonnes and an average productivity of 1443 kg ha^{-1} (Datanet India Pvt. Ltd., 2024). Major mustard growing states include Rajasthan, Haryana, Madhya Pradesh, Uttar Pradesh and Gujarat. Haryana is one of the major mustard-producing states with high productivity due to favourable climatic conditions and improved agronomic practices.

Mustard seeds contain about 38-46 percent oil and 28-36 percent protein, making the crop nutritionally and economically important. Besides oil extraction, mustard is utilized for various purposes including medicinal applications, preparation of condiments and as a source of organic manure through oil cake (Kumari et al., 2023). The crop performs well under cool and dry climatic conditions and is highly responsive to agronomic management practices such as sowing time and crop geometry. Among various production factors, optimum sowing time and appropriate row spacing are considered highly important for obtaining higher yield and better crop performance. Proper sowing time ensures that the crop receives favourable environmental conditions during vegetative and reproductive growth phases which ultimately improves productivity (Chouhan et al., 2023).

Sowing time significantly influences crop growth, phenological development and yield formation in mustard through its effect on temperature, solar radiation and moisture availability. Delayed or early sowing often exposes the crop to adverse environmental conditions during flowering and seed development stages, resulting in poor siliqua formation and reduced seed yield. Singh and Singh (2002) reported that appropriate sowing time plays a crucial role in achieving higher productivity in Indian mustard by ensuring favourable conditions for crop growth and development. Likewise, Gupta et al. (2004) observed that temperature conditions prevailing during flowering significantly affected the incidence of Sclerotinia stem rot in mustard crops. Delayed sowing also increases the infestation of insect-pests, especially mustard aphid (*Lipaphis erysimi*), which adversely affects crop productivity. Bhuiyan et al. (2008) reported that sowing on 30 October resulted in maximum plant height and number of primary branches per plant, whereas Alam et al. (2015) observed higher siliquae per plant,

seeds per siliqua and seed yield with optimum sowing time. These findings clearly indicate that suitable sowing dates are essential for achieving better growth and yield in mustard.
Plant geometry or row spacing is another important agronomic factor influencing mustard productivity because it directly affects plant population, resource utilization and canopy development (Nisar et al., 2024). Appropriate spacing helps in efficient utilization of sunlight, moisture and nutrients while minimizing inter-plant competition. Very close spacing increases competition among plants for nutrients, moisture and light, whereas excessively wider spacing may lead to underutilization of available resources and lower productivity. Shekhawat et al. (2012) reported that spacing plays a vital role in determining mustard productivity by influencing crop competition and growth environment. Proper crop geometry creates favourable conditions for vegetative and reproductive growth and enhances interception of solar radiation throughout the crop growth period. Rathi et al. (2019) also reported that suitable spacing significantly improved seed yield, straw yield and biological yield of mustard. Therefore, maintenance of optimum plant population through proper row spacing is essential for maximizing yield and yield attributes in mustard.

The interaction of sowing time and row spacing greatly affects the yield attributes such as number of branches per plant, siliquae per plant, seeds per siliqua and ultimately seed yield. Under suitable sowing conditions and optimum spacing, mustard plants receive better environmental conditions for growth and reproductive development, resulting in enhanced yield potential. Proper sowing time allows synchronization of critical growth stages with favourable temperature and moisture conditions, whereas optimum row spacing ensures efficient utilization of growth resources and reduces intra-specific competition among plants. Thus, optimization of these agronomic practices is necessary for improving mustard productivity under semi-arid conditions.

Keeping these facts in view, the present investigation was conducted during the *Rabi* season of 2024-25 at the research farm of Krishi Vigyan Kendra (KVK), Mahendergarh under CCS Haryana Agricultural University, Hisar. The study was undertaken to evaluate the effect of different sowing times and row spacings on yield attributes and yield of mustard under semi-arid conditions of Haryana.

2. Materials and Methods

2.1 Location of Experimental Field

The field experiment was conducted during the *Rabi* season of 2024-25 at the experimental farm of Krishi Vigyan Kendra (KVK), Mahendergarh under CCS Haryana Agricultural University, Hisar, Haryana, India. Geographically, the experimental site is situated at 27°47′ N latitude and 76°51′ E longitude with an altitude of about 262 m above mean sea level.

2.2 Climate and Weather Conditions

The experimental site falls under the semi-arid climatic region of Haryana characterized by hot summers and cold winters. The climate of the region is generally dry except during the monsoon season, when humid air from the ocean enters the region. The winter season usually commences in late November and extends up to the first week of March. Meteorological data pertaining to maximum and minimum temperature, morning and evening relative humidity, rainfall, sunshine hours and evaporation during the crop growth period were recorded from the meteorological observatory of CCS Haryana Agricultural University, KVK, Mahendergarh.

During the *Rabi* season of 2024-25, the weekly average maximum temperature ranged from 16.6°C (52nd standard meteorological week) to 36.8°C (40th standard meteorological week), whereas the weekly average minimum temperature ranged from 4.0°C (50th standard meteorological week) to 25.3°C (39th standard meteorological week). Morning relative humidity ranged between 76–96%, while evening relative humidity varied from 25–75% during the crop growth period. A total rainfall of 94.7 mm was received during the season, with maximum rainfall (32.2 mm) recorded during the 52nd meteorological week. Maximum evaporation was observed during the 40th standard meteorological week.

2.3 Soil Analysis

Prior to sowing, soil samples were collected randomly from five different locations of the experimental field at a depth of 0–15 cm. The collected samples were thoroughly mixed to prepare a composite sample and analyzed for physicochemical properties using standard laboratory procedures. The soil of the experimental field was sandy loam in texture with mildly alkaline reaction (Ahmad et al., 2025). The soil contained 80.7% sand, 11.0% silt and 8.3% clay. The electrical conductivity of the soil was 0.24 dS m^{-1} with soil pH of 8.0. The soil was low in organic carbon (0.28%) and available nitrogen (141 kg ha^{-1}), whereas available phosphorus (18 kg ha^{-1}) and available potassium (169 kg ha^{-1}) were in medium range.

2.4 Variety Used

The mustard variety RH-1424 was used for the experiment. The variety is suitable for timely sown conditions under semi-arid environments and possesses good yield potential. It matures in approximately 130 days and contains about 40.5% oil content. The variety is widely cultivated under Haryana conditions due to its adaptability and stable performance.

2.5 Experimental Details and Crop Management

The experiment was laid out in a split plot design with three replications. Four sowing times viz., 25 September, 05 October, 15 October and 25 October were assigned to the main plots, whereas three row spacings viz., 30 cm, 45 cm and 60 cm were allocated to the sub-plots. The gross plot size was 5.4 m × 4.0 m.

The crop was sown using recommended agronomic practices for the region. Fertilizers were applied through urea, diammonium phosphate (DAP) and muriate of potash (MOP). A recommended fertilizer dose of 80 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1} and 20 kg K_2O ha^{-1} was applied. Half dose of nitrogen along with full doses of phosphorus and potassium were applied as basal at the time of sowing, while the remaining nitrogen was top dressed at the first irrigation stage.

2.6 Observations Recorded

Observations on yield attributes and yield parameters were recorded at harvest stage. Five competitive plants were randomly selected from each net plot excluding border rows for recording observations on yield attributes. The observations included number of primary branches $plant^{-1}$, number of secondary branches $plant^{-1}$, number of siliquae $plant^{-1}$, siliqua length (cm) and number of seeds $siliqua^{-1}$.

Yield parameters including seed yield, stover yield, biological yield and harvest index were recorded on plot basis. Seed yield obtained from each net plot was converted into kg ha^{-1} after adjusting the seed moisture content to standard safe moisture level. Biological yield was calculated as the sum of seed and stover yield.

Harvest index was calculated using the following formula:

Harvest Index (%) = Economic yield / Biological yield x 100

2.7 Statistical Analysis

The experimental data recorded for various yield attributes and yield parameters of mustard were statistically analyzed by using the Analysis of Variance (ANOVA) technique appropriate for split plot design as described by Cochran and Cox (1957). The significance of treatment effects was tested at the 5% level of significance. Whenever the treatment effects were found significant, the critical difference (CD) was calculated to compare the treatment means.

The critical difference (CD) was computed using the following formula:

$$CD = \frac{\sqrt{2 \times \text{Error mean sum of square}}}{N} \times t\ (\text{error d.f.}, 5\%)$$

Where, CD= critical difference, EMS= error mean sum of square, N= number of replications, t= value of t-distribution at the 5 % level of error degree of freedom

3. Results and Discussion

3.1 Yield Attributes and Yield

The data pertaining to yield attributes *viz.,* primary branches per plant, secondary branches per plant, siliqua length, number of siliquae per plant and number of seeds per siliqua as influenced by different sowing times and row spacings are presented in Table 1. Fig. 1 illustrates the influence of different sowing times and row spacings on yield attributes viz., primary branches per plant, secondary branches per plant, siliqua length, number of siliquae per plant and number of seeds per siliqua in Indian mustard. The data regarding seed yield, stover yield, biological yield and harvest index are presented in Table 2.

3.1.1 Primary Branches per Plant

The number of primary branches per plant was significantly influenced by sowing time and row spacing (Table 1 and Fig. 1). Among the sowing times, mustard sown on 15 October recorded the highest number of primary branches per plant (6.7), followed by 25 October (5.7) and 5 October (5.6), whereas the lowest number of primary branches per plant (4.9) was observed under 25 September sowing. The increase in primary branches under mid-October sowing might be due to favourable climatic conditions which promoted better vegetative growth and branching.

Among different row spacings, the highest number of primary branches per plant (6.1) was recorded under 45 cm spacing, which was followed by 60 cm spacing (5.9). The minimum number of primary branches per plant (5.3) was observed under 30 cm spacing. The improved branching under wider spacing may be attributed to reduced competition among plants for nutrients, moisture and sunlight, resulting in better plant growth and development.

3.1.2 Secondary Branches per Plant

Sowing time significantly affected the number of secondary branches per plant (Table 1 and Fig. 1). The maximum number of secondary branches per plant (16.7) was recorded under 15 October sowing, followed by 25 October (14.3) and 5 October (14.0), while the minimum number of secondary branches (12.2) was observed under 25 September sowing. The higher number of secondary branches under optimum sowing time might be due to favourable environmental conditions during crop growth which enhanced vegetative development and branching ability of plants.

Among the row spacing treatments, 45 cm spacing produced the highest number of secondary branches per plant (15.3), followed by 60 cm spacing (14.7). The lowest number of secondary branches per plant (13.2) was recorded under 30 cm spacing. The results indicated that moderate spacing favoured better plant architecture and branching due to lower inter-plant competition.

3.1.3 Number of Siliquae per Plant

The number of siliquae per plant varied significantly under different sowing times and row spacings (Table 1 and Fig. 1). Mustard sown on 15 October recorded the highest number of siliquae per plant (314.6), followed by 25 October (302.3) and 5 October (272.6), whereas the minimum number of siliquae per plant (245.0) was observed under 25 September sowing. The increase in siliquae production under mid-October sowing may be due to favourable temperature and moisture conditions during flowering and reproductive stages.

Among different row spacings, the highest number of siliquae per plant (289.4) was recorded under 45 cm spacing, followed by 60 cm spacing (283.7), whereas the lowest number of siliquae per plant (277.8) was observed under 30 cm spacing. The results suggest that optimum plant spacing provided favourable conditions for reproductive growth and siliquae formation.

3.1.4 Siliqua Length

Siliqua length was significantly influenced by sowing time and row spacing (Table 1 and Fig. 1). The maximum siliqua length (7.26 cm) was recorded under 15 October sowing followed by 25 October (6.48 cm) and 5

October (6.18 cm), while the minimum siliqua length (5.81 cm) was recorded under 25 September sowing. Better siliqua development under optimum sowing time might be due to favourable climatic conditions during siliqua formation and seed development stages.

Among row spacing treatments, the highest siliqua length (6.69 cm) was recorded under 45 cm spacing followed by 60 cm spacing (6.35 cm), whereas the minimum siliqua length (6.26 cm) was observed under 30 cm spacing. Wider spacing possibly provided better availability of growth resources leading to improved siliqua growth.

3.1.5 Number of Seeds per Siliqua

The number of seeds per siliqua was also significantly affected by sowing time and row spacing (Table 1 and Fig. 1). The highest number of seeds per siliqua (16.5) was recorded under 15 October sowing, followed by 25 October sowing (15.9) and 5 October sowing (14.4), while the lowest number of seeds per siliqua (13.8) was observed under 25 September sowing. The improvement in seed number under optimum sowing time might be due to better pollination and seed filling under favourable environmental conditions.

Among the row spacing treatments, 45 cm spacing recorded the highest number of seeds per siliqua (16.2), followed by 60 cm spacing (15.4), whereas the lowest number of seeds per siliqua (14.5) was recorded under 30 cm spacing. The results indicate that optimum row spacing improved reproductive efficiency and seed development in mustard.

Table 1. Effect of sowing time and row spacing on the yield attributes in Indian mustard

Treatments	Yield attributes				
	Primary branches/plant	Secondary branches/plant	Length of siliqua (cm)	Siliquae/Plant	Seeds/Siliqua
Sowing time					
25 September	4.9	12.2	5.81	245	13.8
05 October	5.6	14	6.18	272.6	14.4
15 October	6.7	16.7	7.26	314.6	16.5
25 October	5.7	14.3	6.48	302.3	15.9
SEm±	**0.05**	**0.04**	**0.05**	**1.52**	**0.09**
CD (P= 0.05)	**0.18**	**0.14**	**0.19**	**5.36**	**0.32**
Row spacing					
30 cm	5.3	13.2	6.26	277.8	14.5
45 cm	6.1	15.3	6.69	289.4	16.2
60 cm	5.9	14.7	6.35	283.7	15.4
SEm±	**0.04**	**0.04**	**0.03**	**2.08**	**0.13**
CD (P= 0.05)	**0.12**	**0.13**	**0.1**	**6.3**	**0.4**

SEm ± = Standard error of mean; CD (P = 0.05) = Critical difference at 5% level of significance

3.2 Yield Parameters

The data pertaining to seed yield, stover yield, biological yield and harvest index as influenced by different sowing times and row spacings are presented in Table 2. Fig. 2 illustrates the influence of different sowing times and row spacings on seed yield, stover yield, biological yield and harvest index of Indian mustard.

3.2.1 Seed Yield

Seed yield of mustard was significantly influenced by different sowing times and row spacings (Table 2 and Fig. 2). Among the sowing times, the crop sown on 15 October recorded the highest seed yield (2172 kg ha^{-1}), followed by 25 October (1975 kg ha^{-1}) and 5 October (1964 kg ha^{-1}), whereas the lowest seed yield (1789 kg ha^{-1}) was observed under 25 September sowing. The higher seed yield under mid-October sowing might be attributed to favourable climatic conditions during vegetative and reproductive growth stages which enhanced growth and yield contributing characters.

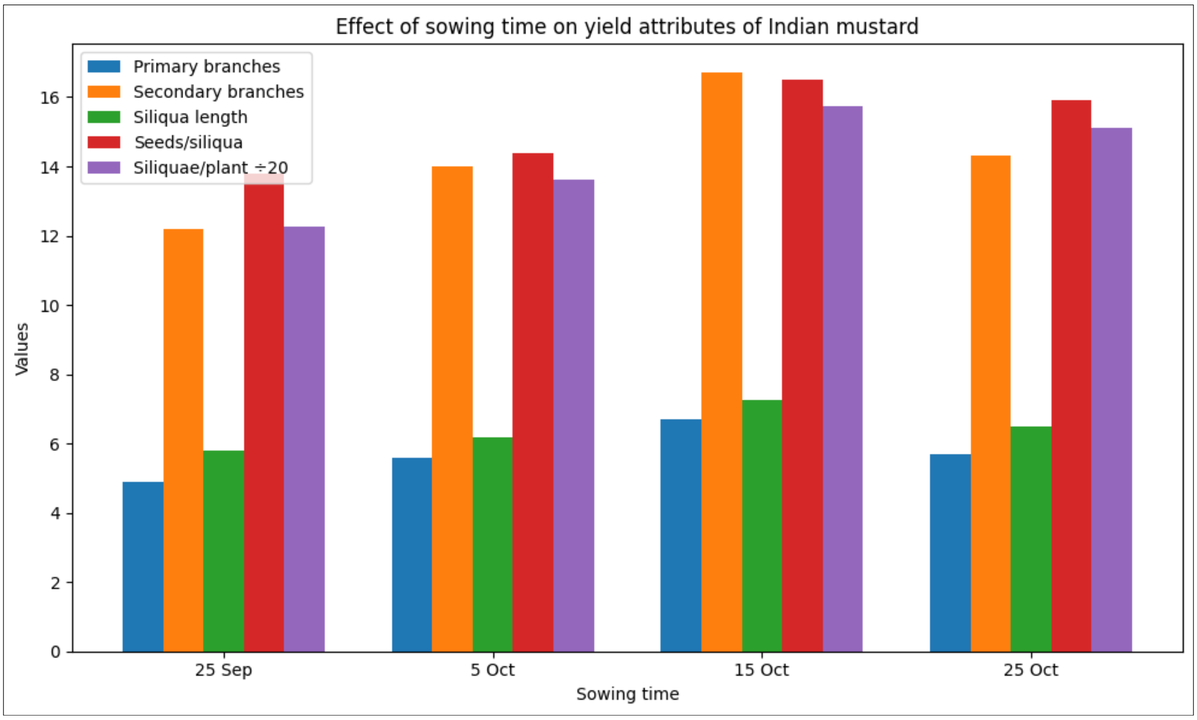

Fig. 1. Graph showing Effect of sowing time and row spacing on yield attributes of Indian mustard

Among the row spacing treatments, 45 cm spacing recorded the highest seed yield (2012 kg ha^{-1}), followed by 60 cm spacing (1975 kg ha^{-1}), while the lowest seed yield (1917 kg ha^{-1}) was recorded under 30 cm spacing. Better seed yield under 45 cm spacing may be due to optimum plant population and efficient utilization of nutrients, moisture and sunlight resulting in better growth and yield attributes.

3.2.2 Stover Yield

Stover yield was significantly affected by sowing time and row spacing (Table 2 and Fig. 2). Among the sowing times, mustard sown on 15 October produced the highest stover yield (6412 kg ha^{-1}), followed by 25 October (6020 kg ha^{-1}) and 5 October (6019 kg ha^{-1}), whereas the lowest stover yield (5696 kg ha^{-1}) was recorded under 25 September sowing. The increased stover yield under optimum sowing time may be attributed to enhanced vegetative growth and dry matter accumulation under favourable environmental conditions.

Among different row spacings, the highest stover yield (6003 kg ha^{-1}) was obtained under 45 cm spacing followed by 60 cm spacing (5956 kg ha^{-1}), while the lowest stover yield (5571 kg ha^{-1}) was recorded under 30 cm spacing. The improved biomass production under moderate spacing may be due to reduced competition among plants and better utilization of available resources.

3.2.3 Biological Yield

Biological yield was significantly influenced by sowing time and row spacing (Table 2 and Fig. 2). Among the sowing dates, the highest biological yield (8584 kg ha^{-1}) was recorded under 15 October sowing, followed by 25 October (7995 kg ha^{-1}) and 5 October (7983 kg ha^{-1}), whereas the lowest biological yield (7485 kg ha^{-1}) was recorded under 25 September sowing. The increase in biological yield under optimum sowing time might be due to favourable climatic conditions which promoted better crop growth and dry matter accumulation.

Among row spacing treatments, 45 cm spacing produced the highest biological yield (8015 kg ha^{-1}), followed by 60 cm spacing (7931 kg ha^{-1}), whereas the lowest biological yield (7488 kg ha^{-1}) was observed under 30 cm spacing. The results indicated that optimum spacing enhanced vegetative growth and total biomass production in mustard.

3.2.4 Harvest Index

Harvest index was significantly influenced by sowing time, whereas the effect of row spacing was found to be non-significant (Table 2 and Fig. 2). Among the sowing times, the highest harvest index (25.3%) was recorded under 15 October sowing followed by 25 October (24.7%), while the lowest harvest index (23.9%) was recorded under 25 September sowing. The improved harvest index under mid-October sowing indicates better partitioning of assimilates towards economic yield.

Among the row spacing treatments, 45 cm spacing recorded the highest harvest index (25.1%) followed by 60 cm spacing (24.9%) and 30 cm spacing (24.6%). However, the differences among row spacings were statistically non-significant.

Table 2. Effect of sowing time and row spacing on the yield parameters in Indian mustard

Treatments	Yield studies			
	Seed yield (kg ha^{-1})	**Stover yield (kg ha^{-1})**	**Biological yield (kg ha^{-1})**	**Harvest index (%)**
Sowing time				
25 September	1789	5696	7485	23.9
05 October	1964	6019	7983	24.6
15 October	2172	6412	8584	25.3
25 October	1975	6020	7995	24.7
SEm±	**18.9**	**30.97**	**65.61**	**0.17**
CD (P= 0.05)	**66.68**	**109.26**	**231.48**	**0.62**
Row Spacing				
30 cm	1917	5571	7488	24.6
45 cm	2012	6003	8015	25.1
60 cm	1975	5956	7931	24.9
SEm±	**14.39**	**45.09**	**48.47**	**0.19**
CD (P= 0.05)	**43.52**	**136.34**	**146.6**	**NS**

SEm ± = Standard error of mean; CD (P = 0.05) = Critical difference at 5% level of significance; NS = Non-significant

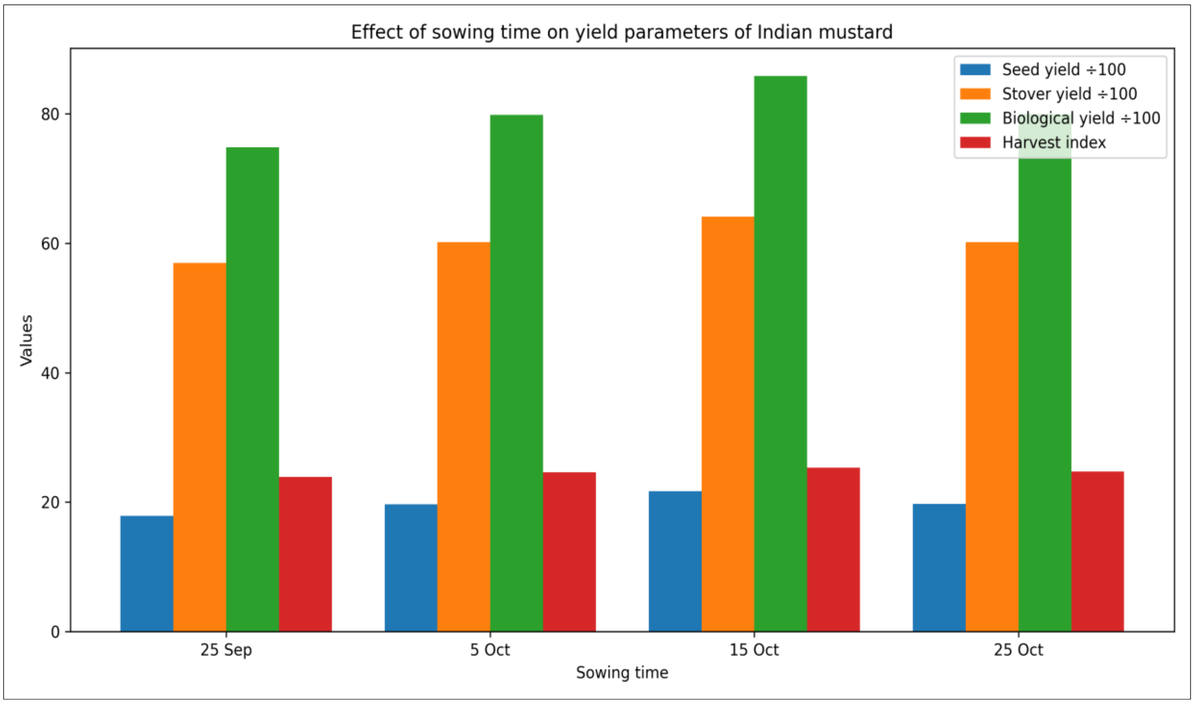

Fig. 2. Graph showing Effect of sowing time and row spacing on yield parameters of Indian mustard

3.2.5 Yield Attributes and Yield

Sowing time and row spacing significantly influenced the yield attributes and yield of Indian mustard. Among different sowing times, the crop sown on 15 October recorded the highest values for yield attributing characters viz., primary branches per plant (6.7), secondary branches per plant (16.7), siliquae per plant (314.6), siliqua length (7.26 cm) and seeds per siliqua (16.5). The improvement in yield attributes under mid-October sowing might be due to favourable environmental conditions, particularly optimum temperature and photoperiod during vegetative and reproductive growth stages, which enhanced plant growth and reproductive efficiency. In contrast, the lowest values were recorded under 25 September sowing, which may be attributed to unfavourable weather conditions during early crop growth resulting in poor reproductive development. A slight reduction in yield attributes was also observed under delayed sowing on 25 October, possibly due to shortened growth duration and exposure to terminal heat stress during reproductive stages. Similar findings were reported by Dey et al. (2025) for plant stress; Sharma and Kumar (2023), who observed higher growth and yield attributes in mustard under optimum sowing conditions. Alam et al. (2015) and Bhuiyan et al. (2008) also reported significant improvement in siliquae per plant, seeds per siliqua and branching under suitable sowing dates.

Among different row spacing treatments, 45 cm spacing recorded the highest values for primary branches per plant (6.1), secondary branches per plant (15.3), siliquae per plant (289.4), siliqua length (6.69 cm) and seeds per siliqua (16.2). The superiority of 45 cm spacing may be due to optimum plant population and reduced competition among plants for nutrients, moisture and sunlight, resulting in better growth and development. In contrast, the closest spacing of 30 cm recorded comparatively lower values for yield attributes due to increased inter-plant competition. These findings are in close agreement with the reports of Singh et al. (2017), Kamal et al. (2015a, b) and Husain (2008), who observed higher branching, siliquae formation and seed development in mustard under optimum row spacing conditions.

The yield parameters of mustard were also significantly affected by sowing time and row spacing. Among different sowing times, mustard sown on 15 October produced the highest seed yield (2172 kg ha^{-1}), stover yield (6412 kg ha^{-1}), biological yield (8584 kg ha^{-1}) and harvest index (25.3%). The higher productivity under mid-October sowing may be attributed to favourable climatic conditions during crop growth which enhanced photosynthetic activity, dry matter accumulation and efficient partitioning of assimilates towards economic yield. In contrast, the lowest seed yield, stover yield and biological yield were recorded under 25 September sowing due to comparatively less favourable environmental conditions during growth and reproductive stages. Delayed sowing beyond mid-October also resulted in a slight reduction in yield indicating that 15 October was the optimum sowing time under the prevailing agro-climatic conditions. Similar results were reported by Sharma and Kumar (2023), who observed higher seed yield and biomass production in mustard under timely sowing conditions.

Among row spacing treatments, 45 cm spacing produced the highest seed yield (2012 kg ha^{-1}), stover yield (6003 kg ha^{-1}) and biological yield (8015 kg ha^{-1}). The increase in yield under moderate spacing may be due to efficient utilization of available resources and reduced competition among plants which improved vegetative growth and yield contributing characters. Although the highest harvest index (25.1%) was also recorded under 45 cm spacing, the effect of row spacing on harvest index was statistically non-significant. The results suggest that 45 cm spacing maintained an optimum balance between plant population and resource utilization resulting in higher productivity. Similar findings were reported by Pandey et al. (2015), who observed significantly higher yield and yield attributes in mustard under optimum row spacing conditions.

4. Conclusion

The present investigation clearly demonstrated that sowing time and row spacing significantly influenced the yield attributes and yield of Indian mustard under the semi-arid conditions of Haryana. Among the different sowing times, mustard sown on 15 October recorded superior performance with respect to primary and secondary branches per plant, siliquae per plant, siliqua length and seeds per siliqua. The same treatment also produced the highest seed yield (2172 kg ha^{-1}), stover yield (6412 kg ha^{-1}), biological yield (8584 kg ha^{-1}) and harvest index (25.3%). Among the row spacing treatments, 45 cm spacing proved to be the most suitable by recording higher yield attributes and yield parameters compared to 30 cm and 60 cm spacing. The maximum seed yield (2012 kg ha^{-1}), stover yield (6003 kg ha^{-1}) and biological yield (8015 kg ha^{-1}) were obtained under 45 cm spacing, indicating that optimum spacing ensured better utilization of nutrients, moisture and sunlight resulting in improved crop growth and productivity. Therefore, it may be concluded that sowing mustard around 15 October with 45 cm row spacing is the most effective agronomic practice for achieving higher productivity of Indian mustard under the prevailing agro-climatic conditions of Haryana. Further research may be carried out by evaluating different mustard varieties under varying sowing times and crop geometries across diverse agro-climatic regions. Studies involving nutrient management, irrigation scheduling and climate-resilient agronomic practices in combination with optimum sowing time and spacing may also help in enhancing mustard productivity and sustainability under changing climatic conditions.

Disclaimer (Artificial Intelligence)

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

Competing Interests

Authors have declared that no competing interests exist.

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