International Journal of Plant & Soil Science

Volume 38, Issue 9, Page 551-559, 2026; Article no.IJPSS.165369
ISSN: 2320-7035

Quality and Productivity of Mustard (*Brassica juncea L.*) through Optimum Sowing Dates with Sulphur Management under Open and Mango-based Agroforestry Systems

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Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i96317

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/165369

Original Research Article

Received: 25/06/2026
Accepted: 31/08/2026
Published: 10/09/2026

Abstract

The current study was conducted to assess their effects on mustard growth, productivity and quality under open and mango-based agroforestry systems. A field experiment was conducted during the rabi season of 2024–25 at the AICRP Research Farm, Department of Forestry, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, to

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Cite as: *Katara, A., Solanki, V. K., Sarvade, S., Khare, A. K., Shah, A. K., Jain, S., & Katara, P. (2026). Quality and Productivity of Mustard (Brassica juncea L.) through Optimum Sowing Dates with Sulphur Management under Open and Mango-based Agroforestry Systems. International Journal of Plant & Soil Science, 38(9), 551–559. https://doi.org/10.9734/ijpss/2026/v38i96317*

evaluate the effects of sowing date and sulphur level on Indian mustard (*Brassica juncea* L.) under open and mango (*Mangifera indica* L.)-based agroforestry systems. The factorial randomised block design comprised two cropping systems, three sowing dates (15 October, 5 November and 25 November), four sulphur levels (0, 20, 30 and 40 kg S ha^{-1}) and three replications. The open cropping system produced higher seed, straw and biological yields than the mango-based agroforestry system and also recorded greater oil and protein attributes. Sowing on 15 October resulted in the highest seed yield (1032.99 kg ha^{-1}), whereas delayed sowing reduced yield and quality attributes. Sulphur application progressively improved crop performance, with 40 kg S ha^{-1} recording the highest seed yield (1108.72 kg ha^{-1}), oil content (34.70%), oil yield (386.20 kg ha^{-1}), protein content (17.54%) and protein yield (194.89 kg ha^{-1}). Harvest index was not significantly affected by cropping system, sowing date or sulphur level. Under the study conditions, timely sowing and adequate sulphur nutrition improved the productivity and quality of Indian mustard in both open and mango-based agroforestry systems.

Keywords: Indian mustard; Brassica juncea L.; sowing date; sulphur nutrition; mango-based agroforestry; open cropping system; seed yield; oil content; protein content; harvest index.

1. Introduction

Indian mustard (*Brassica juncea* L.) is one of the most important winter (*rabi*) oilseed crops and occupies a significant position in the oilseed economy of India. After soybean, rapeseed-mustard is India's second most important oilseed crop and makes a significant contribution to edible oil production (Jat *et al*., 2019; Singh *et al*., 2018). The majority of India's mustard is grown in Rajasthan, Uttar Pradesh, Madhya Pradesh, Haryana, Punjab, Gujarat, Bihar and other states. The crop is a significant source of edible oil, while the residual oil cake provides valuable protein for cattle (Kumbhare *et al.,* 2025). According to Kumar, Singh, *et al.* (2018), the notable oil and protein contents of mustard seed make it nutritionally significant. However, climatic conditions and appropriate agronomic management, specifically sowing time and fertiliser availability, affect mustard yield and quality (Parveen *et al.,* 2026).

Recent studies further indicate that sowing date and nutrient management influence Indian mustard productivity, while heat stress remains an important constraint under unfavourable thermal conditions (Sharma & Kumar, 2023; Gupta et al., 2024; Pillai & Walia, 2024).

Agroforestry integrates woody perennials with agricultural crops, promoting resource-use efficiency, farm diversification and environmental sustainability, including climate-change mitigation through carbon sequestration (Newaj *et al.,* 2016). Wider spacing and sufficient light penetration during early orchard development make mango (*Mangifera indica L.*)-based systems suitable for intercrop production (Musvoto & Campbell, 1995). According to Mirjha and Rana (2016), mango-based intercropping can increase productivity and resource utilisation, but interactions between trees and crops can change light, soil moisture and nutrient availability, thereby affecting crop development and production. Mustard performance under tree-based agroforestry is also influenced by crop suitability and management practices (Pervin *et al.,* 2015).

Recent evaluations of mustard under poplar- and citrus-based agroforestry systems also demonstrate the relevance of tree-associated production conditions when assessing crop performance (Kumbhare & Daniel, 2023; Deshmukh et al., 2023).

Sowing time is an important non-monetary input influencing the growth, development and productivity of Indian mustard. Optimum sowing provides favourable temperature, light, humidity and moisture conditions for better crop performance (Shekhawat *et al*., 2012; Singh *et al*., 2017). According to Shekhawat *et al.* (2012), mustard follows the C_3 pathway and shows its greatest photosynthetic response at 15–20°C. Delayed sowing exposes the crop to unfavourable conditions during reproductive growth, resulting in reduced assimilate production, a shortened siliqua-filling period and lower seed yield (Kumar, Lal, *et al.,* 2018). Awasthi *et al.* (2007) and Singh and Singh (2002) observed higher seed and stover yields under early sowing, respectively. The importance of the optimum sowing period for increasing mustard yield was also highlighted by Patel *et al.* (2017) and Meena *et al.* (2022).

Improving mustard quality and productivity requires balanced nutrient management. Sulphur is especially important in oilseed crops because it contributes to protein and oil synthesis and other metabolic processes (Singh & Pal, 2011). Oilseed crops generally require more sulphur than cereals because of their greater demand for oil and protein synthesis (Hegde & Sudhakara Babu, 2009). Sulphur also contributes to chlorophyll formation and oil synthesis and supports improved mustard growth, yield and quality (Dubey et al., 2013). However, rising crop yields, continuous removal of sulphur and the substitution of high-analysis fertilisers for sulphur-containing fertilisers have contributed to sulphur deficiency in agricultural soils (Scherer, 2001; Aulakh, 2003; Singh, 2001).

Sulphur significantly influenced biological, seed and straw yields and harvest index (Piri & Sharma, 2006), while nitrogen application also improved major yield attributes and seed yield (Saud et al., 2016). Significant effects of sulphur on seed yield, stover yield and sulphur uptake were reported by Sharma *et al*. (2009). Adequate sulphur nutrition also enhances seed development and oil and protein contents, thereby improving mustard quality (Kumar & Yadav, 2007).

Tree-crop interactions under mango-based agroforestry can modify light availability and intercrop performance as the tree canopy develops (Rathore et al., 2013). Mango-based intercropping can increase productivity and resource-use efficiency, according to Mirjha and Rana (2016), while wider mango spacing and a sparse canopy during the juvenile stage allow sufficient light for intercrops (Musvoto & Campbell, 1995). However, the combined effects of sulphur nutrition and sowing dates on mustard under

mango-based agroforestry are not well understood. Therefore, the current study was conducted to assess their effects on mustard growth, productivity and quality under open and mango-based agroforestry systems.

2. Materials and Methods

2.1 Experimental Site and Climatic Conditions

The field experiment was conducted during the rabi season of 2024–25 at the AICRP Research Farm, Department of Forestry, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India. The experimental site was situated at an altitude of 391 m above mean sea level (23°12′50″ N latitude and 79°57′56″ E longitude) and falls within the hot sub-humid (dry) eco-region of the Central Highlands. The experiment was conducted in a mango (*Mangifera indica* L.)-based agri-silviculture system. Meteorological observations, including maximum and minimum temperatures, relative humidity, sunshine hours, rainfall and rainy days, were recorded during the crop season at the observatory of the College of Agricultural Engineering, JNKVV, Jabalpur.

2.2 Experimental Design and Treatments

The experiment was laid out in a factorial randomised block design with three factors, 24 treatment combinations and three replications. Factor A consisted of two cropping systems, viz., open conditions (sole cropping) and a mango-based agroforestry system (under-tree conditions). Factor B comprised three sowing dates, viz., D_1 (15 October), D_2 (5 November) and D_3 (25 November), while Factor C consisted of four sulphur levels, viz., S_0 (control), S_1 (20 kg ha $^{-1}$), S_2 (30 kg ha $^{-1}$) and S_3 (40 kg ha $^{-1}$).

The tree component consisted of seven-year-old *Mangifera indica* trees planted at 5.0 × 5.0 m spacing. Mustard (*Brassica juncea* L.) cv. RH-725 was used as the crop component. The recommended dose of 80:40:40 kg N:P:K ha^{-1} was applied through urea, single superphosphate and muriate of potash, respectively, while sulphur was applied through gypsum according to the respective treatments. The crop was sown at 30 cm row spacing in plots with a gross size of 5.0 × 5.0 m and a net plot size of 4.20 × 4.20 m.

The experimental data were analysed using procedures appropriate for a factorial randomised block design (RBD), as outlined by Gomez and Gomez (1984). Treatment effects were tested at the 5% probability level ($p \leq 0.05$) to determine statistical significance.

2.3 Yield and Quality Estimations

At maturity, the crop was harvested manually from the net plot area and sun-dried for 2–3 days. The harvested material was threshed and winnowed, and the cleaned seed was weighed plot-wise. Seed and stover yields were recorded and expressed in kg ha^{-1}, while biological yield was determined from the total crop biomass.

Harvest Index (%) = Seed yield (kg ha^{-1}) / Biological yield (kg ha^{-1}) × 100

Oil content was determined by the Soxhlet extraction method (Azmir et al., 2013) using ethyl ether and expressed as a percentage: Oil content (%) = Weight of extracted oil / Weight of seed sample x100

Oil yield was calculated from seed yield and oil content: Oil yield (kg ha^{-1}) = Oil content (%) x seed yield (kg ha^{-1})/100

Protein content was expressed as a percentage, whereas protein yield was calculated from seed yield and protein content: Protein content (%) = Nitrogen content (%) × 6.25 and the Protein yield (kg ha^{-1}) = Protein content (%) × Seed yield (kg ha^{-1}) / 100

3. Results and Discussion

3.1 Yield Parameters

Seed yield, straw yield and biological yield of mustard were significantly influenced by cropping system, date of sowing and sulphur level, whereas harvest index was not significantly affected by the treatments (Table 1). Among the cropping systems, the open cropping system recorded significantly higher seed yield (983.99 kg ha^{-1}), straw yield (1716.33 kg ha^{-1}) and biological yield (2700.32 kg ha^{-1}) than the mango-based agroforestry system (AFS), which recorded 894.64, 1551.00 and 2445.64 kg ha^{-1}, respectively. Harvest index did not differ significantly between the two cropping systems, with values of 36.45% and 36.59%, respectively.

The higher seed, straw and biological yields under the open cropping system may be attributed to greater availability of solar radiation and reduced competition for moisture and nutrients, which enhanced crop growth and assimilate translocation. The lower yield under the mango-based agroforestry system might be due to partial shading and resource competition between trees and crops. A similar reduction in mustard yield under *a Eucalyptus tereticornis*-based agri-silviculture system was reported by Kumar *et al.* (2013) and Deswal and Nandal (2008).

Date of sowing significantly affected seed, straw and biological yields. The crop sown on 15 October (D_1) recorded the highest seed yield (1032.99 kg ha^{-1}), straw yield (1792.50 kg ha^{-1}) and biological yield (2825.49 kg ha^{-1}), which were significantly superior to those obtained with sowing on 5 November (D_2) and 25 November (D_3). The lowest seed yield (871.13 kg ha^{-1}), straw yield

(1503.50 kg ha^{-1}) and biological yield (2374.63 kg ha^{-1}) were recorded under 25 November (D_3) sowing. However, harvest index was not significantly influenced by date of sowing; the highest value was recorded under D_3 (36.70%), followed by D_1 (36.55%) and D_2 (36.32%).

The superiority of early sowing (15 October) may be associated with favourable environmental conditions during crop growth, which enhanced vegetative development, yield attributes and efficient translocation of assimilates towards reproductive parts. Similar observations were reported by Kumar, Lal, *et al*. (2018), who observed higher biological and seed yields under optimum sowing time due to favourable temperature conditions. Comparable results were reported by Tripathi *et al.* (2021), who found that harvest index was not significantly influenced by different sowing dates. Singh *et al.* (2017) showed that sowing date influenced mustard seed and stover yields, with significant reductions under delayed sowing.

Table 1. Effect of cropping systems, sowing dates and sulphur levels on yield and harvest index of mustard under open and mango-based agroforestry systems

Treatments	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Open	983.99	1716.33	2700.32	36.45
AFS	894.64	1551.00	2445.64	36.59
SEm±	4.66	7.39	9.68	0.14
CD (P=0.05)	13.28	21.05	27.55	0.39
Date of sowing				
D_1	1032.99	1792.50	2825.49	36.55
D_2	913.83	1605.00	2518.83	36.32
D_3	871.13	1503.50	2374.63	36.70
SEm±	5.71	9.06	11.85	0.17
CD (P=0.05)	16.26	25.78	33.74	0.48
Sulphur level (kg ha $^{-1}$)				
S_0	703.38	1214.00	1917.38	36.69
S_1	912.97	1612.67	2525.64	36.18
S_2	1032.19	1786.00	2818.19	36.63
S_3	1108.72	1922.00	3030.72	36.59
SEm±	6.60	10.46	13.69	0.19
CD (P=0.05)	18.78	29.77	38.96	0.55

Note: Open (Open cropping system) AFS (agroforestry system), Date of sowing dates; D_1 (15 October), D_2 (5 November) and D_3 (25 November), sulphur levels, viz., S_0 (control), S_1 (20 kg ha $^{-1}$), S_2 (30 kg ha $^{-1}$) and S_3 (40 kg ha $^{-1}$)

Sulphur application significantly influenced seed, straw and biological yields. Application of 40 kg S ha^{-1} (S_3) produced the highest seed yield (1108.72 kg ha^{-1}), straw yield (1922.00 kg ha^{-1}) and biological yield (3030.72 kg ha^{-1}), followed by 30 kg S ha^{-1} (S_2) with corresponding values of 1032.19, 1786.00 and 2818.19 kg ha^{-1}, respectively. The lowest seed yield (703.38 kg ha^{-1}), straw yield (1214.00 kg ha^{-1}) and biological yield (1917.38 kg ha^{-1}) were recorded under the control treatment (S_0). Harvest index ranged from 36.18 to 36.69% and did not differ significantly among sulphur levels.

The increase in seed, straw and biological yields with sulphur application may be attributed to improved yield-contributing characters and greater vegetative biomass production. Nayak *et al*. (2025) reported higher seed and stover yields with increasing sulphur application. Similarly, Rahangdale *et al.* (2022) observed increased seed yield with higher sulphur levels, while Piri and Sharma (2006) reported higher seed and straw yields due to improvements in yield attributes and vegetative growth.

The non-significant effects of cropping system, date of sowing and sulphur levels on harvest index indicate that these treatments influenced seed yield and biological yield proportionally, resulting in similar partitioning efficiency of assimilates towards economic yield. Similar non-significant effects of sulphur application on the harvest index of mustard were reported by Kumar *et al*. (2022) and Prajapati *et al*. (2023).

The significant interactions among cropping system, sowing date and sulphur levels indicated that the combined effects of these factors influenced mustard yield and harvest index under open and mango-based agroforestry systems (Table 2).

3.2 Quality Parameters

The quality attributes of mustard, including oil content, oil yield, protein content and protein yield, were significantly influenced by cropping system, sowing date and sulphur application (Table 3).

The open cropping system produced significantly superior quality attributes compared with the mango-based agroforestry system (AFS). It recorded the highest oil content (33.50%), oil yield (334.02 kg ha^{-1}), protein content (16.62%) and protein yield (165.35 kg ha^{-1}), whereas the corresponding values under AFS were 30.56%, 276.53 kg ha^{-1}, 15.32% and 139.47 kg ha^{-1}, respectively. The higher quality parameters under the open cropping system may be attributed to better seed development and greater accumulation of biochemical constituents, which enhanced oil biosynthesis and protein formation. In contrast, lower quality parameters under the mango-based agroforestry system might be associated with restricted accumulation of storage compounds due to tree influence. A

similar improvement in mustard performance under sole cropping compared with tree-based production systems was reported by Ramarao et al. (2020), Singh et al. (2023) and Kaur et al. (2021).

Table 2. Interaction effect of cropping system and sowing dates, sulphur levels and sowing date & sulphur level on yield parameter of mustard under open and mango-based agroforestry systems

Treatments	Interaction table			
	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
OD_1S_0	906.67	1576.00	2482.67	36.45
OD_1S_1	1092.00	1892.00	2984.00	36.59
OD_1S_2	1178.67	2040.00	3218.67	36.63
OD_1S_3	1260.00	2180.00	3440.00	36.63
OD_2S_0	650.22	1120.00	1770.22	36.74
OD_2S_1	937.33	1800.00	2737.33	34.24
OD_2S_2	989.67	1712.00	2701.67	36.64
OD_2S_3	1138.67	1976.00	3114.67	36.57
OD_3S_0	668.00	1140.00	1808.00	36.95
OD_3S_1	934.67	1620.00	2554.67	36.59
OD_3S_2	985.33	1700.00	2685.33	36.70
OD_3S_3	1066.67	1840.00	2906.67	36.71
AD_1S_0	687.11	1200.00	1887.11	36.43
AD_1S_1	884.93	1532.00	2416.93	36.61
AD_1S_2	1106.89	1920.00	3026.89	36.57
AD_1S_3	1147.66	2000.00	3147.66	36.47
AD_2S_0	673.41	1156.00	1829.41	36.81
AD_2S_1	851.05	1492.00	2343.05	36.31
AD_2S_2	984.82	1700.00	2684.82	36.70
AD_2S_3	1085.50	1884.00	2969.50	36.56
AD_3S_0	634.90	1092.00	1726.90	36.77
AD_3S_1	777.86	1340.00	2117.86	36.73
AD_3S_2	947.78	1644.00	2591.78	36.58
AD_3S_3	953.82	1652.00	2605.82	36.61
AXB				
Sem±	8.08	12.81	16.76	0.24
CD (5%)	23.00	36.46	47.72	0.67
AXC				
Sem±	9.33	14.79	19.36	0.27
CD (5%)	26.55	42.10	55.10	0.78
BXC				
Sem±	11.42	18.11	23.71	0.33
CD (5%)	32.52	51.56	67.48	0.95
AXBXC				
Sem±	16.16	25.61	33.52	0.47
CD (5%)	45.99	72.91	95.43	1.34

Note: Open cropping system (O), agroforestry system (A), Date of sowing dates; D_1 (15 October), D_2 (5 November) and D_3 (25 November), sulphur levels, viz., S_0 (control), S_1 (20 kg ha^{-1}), S_2 (30 kg ha^{-1}) and S_3 (40 kg ha^{-1})

Quality parameters were also significantly influenced by sowing date. The crop sown on 15 October (D_1) recorded the maximum oil content (32.62%), oil yield (341.16 kg ha^{-1}), protein content (16.60%) and protein yield (173.63 kg ha^{-1}). The oil content under D_1 remained statistically at par with that under 5 November (D_2), whereas both were significantly superior to 25 November (D_3). Oil yield, protein content and protein yield declined progressively with delayed sowing. The higher quality parameters under early sowing may be attributed to optimum temperature conditions and an extended crop duration during the reproductive phase, which favoured proper seed filling and improved quality attributes. A similar influence of sowing date on mustard productivity and oil yield was reported by Patel *et al*. (2017) and Tripathi *et al.* (2021).

Sulphur application significantly enhanced all quality characteristics of mustard. The highest sulphur dose, 40 kg S ha^{-1} (S_3), recorded the maximum oil content (34.70%), oil yield (386.20 kg ha^{-1}), protein content (17.54%) and protein yield (194.89 kg ha^{-1}). The oil content under S_3 (40 kg S ha^{-1}) was statistically comparable with that under S_2 (30 kg S ha^{-1}), whereas oil yield, protein content and protein yield increased significantly with each increment in sulphur level. The improvement in quality parameters with sulphur application may be attributed to the important role of sulphur in oil biosynthesis, protein formation and biochemical processes associated with mustard metabolism. Nayak *et al*. (2025) and Piri and Sharma (2006) reported that increasing sulphur levels significantly enhanced oil content, oil yield and quality parameters of mustard. A similar improvement in oil yield with sulphur application was also reported by Panda *et al*. (2000).

The significant interaction between cropping system × sowing date and cropping system × sulphur levels indicated that the combined effects of these factors played an important role in determining mustard quality under open and mango-based agroforestry systems (Table 4).

Table 3. Effect of cropping system, sowing dates and sulphur levels on quality parameter of mustard (*Brassica juncea* L.) under Open and Mango-Based Agroforestry Systems

Treatments	Oil content (%)	Oil yield (kg ha^{-1})	Protein content (%)	Protein yield (kg ha^{-1})
Open	33.50	334.02	16.62	165.35
AFS	30.56	276.53	15.32	139.47
SEm±	0.19	2.26	0.07	1.03
CD (P=0.05)	0.53	6.44	0.21	2.93
Date of sowing				
D_1	32.62	341.16	16.60	173.63
D_2	32.19	299.03	15.95	147.75
D_3	31.27	275.63	15.35	135.86
SEm±	0.23	2.77	0.09	1.26
CD (P=0.05)	0.65	7.89	0.26	3.59
Sulphur level (kg ha^{-1})				
S_0	28.63	202.00	14.38	101.86
S_1	31.46	288.22	15.33	140.72
S_2	33.33	344.68	16.63	172.17
S_3	34.70	386.20	17.54	194.89
SEm±	0.26	3.20	0.10	1.46
CD (P=0.05)	0.75	9.11	0.30	4.15

Note: Open (Open cropping system) AFS (agroforestry system), Date of sowing dates; D_1 (15 October), D_2 (5 November) and D_3 (25 November), sulphur levels, viz., S_0 (control), S_1 (20 kg ha^{-1}), S_2 (30 kg ha^{-1}) and S_3 (40 kg ha^{-1})

Table 4. Interaction effect of cropping system and sowing dates, sulphur levels and sowing date & sulphur level on quality parameter of mustard under open and mango-based agroforestry systems

Treatments	Interaction table			
	Oil content (%)	Oil yield (kg ha^{-1})	Protein content (%)	Protein yield (kg ha^{-1})
OD_1S_0	30.26	274.09	16.09	145.78
OD_1S_1	33.73	368.32	16.23	177.19
OD_1S_2	36.18	426.28	18.10	213.33
OD_1S_3	36.62	461.41	18.52	233.35
OD_2S_0	29.53	191.92	15.16	98.54
OD_2S_1	32.16	301.45	16.07	150.67
OD_2S_2	36.49	361.12	17.59	174.08
OD_2S_3	37.33	425.18	17.19	195.79
OD_3S_0	28.98	193.64	14.51	96.90
OD_3S_1	31.90	298.14	15.92	148.80
OD_3S_2	33.27	327.89	16.29	160.49
OD_3S_3	35.51	378.76	17.75	189.34
AD_1S_0	28.80	197.69	14.29	98.22
AD_1S_1	30.40	268.87	15.52	137.46
AD_1S_2	31.61	349.77	16.45	182.06
AD_1S_3	33.35	382.86	17.57	201.61
AD_2S_0	27.42	184.66	13.68	92.16
AD_2S_1	29.00	246.99	14.39	122.55
AD_2S_2	31.23	307.55	15.88	156.39
AD_2S_3	34.39	373.38	17.67	191.83
AD_3S_0	26.77	169.97	12.53	79.54
AD_3S_1	31.55	245.54	13.83	107.66
AD_3S_2	31.18	295.45	15.48	146.68
AD_3S_3	30.99	295.61	16.51	157.46
AXB				
Sem±	0.32	3.92	0.13	1.78
CD (5%)	0.92	11.15	0.36	5.08
AXC				
Sem±	0.37	4.52	0.15	2.06
CD (5%)	1.06	12.88	0.42	5.87
BXC				
Sem±	0.46	5.54	0.18	2.52
CD (5%)	1.30	15.77	0.51	7.18
AXBXC				
Sem±	0.65	7.83	0.26	3.57
CD (5%)	1.84	22.30	0.73	10.16

Note: Open cropping system (O), agroforestry system (A), Date of sowing dates; D_1 (15 October), D_2 (5 November) and D_3 (25 November), sulphur levels, viz., S_0 (control), S_1 (20 kg ha^{-1}), S_2 (30 kg ha^{-1}) and S_3 (40 kg ha^{-1})

4. Conclusion

This study demonstrates that the productivity and quality of Indian mustard were influenced by cropping system, sowing date and sulphur application under the tested conditions. The open cropping system consistently recorded higher seed, straw and biological yields, together with greater oil and protein attributes, than the mango-based agroforestry system. Sowing on 15 October was superior to the two later sowing dates, indicating the importance of timely crop establishment for maintaining yield and quality. Among the sulphur treatments, 40 kg S ha^{-1} produced the highest seed yield and the highest oil and protein values. Harvest index did not differ significantly among the tested cropping systems, sowing dates or sulphur levels. These results indicate that sowing mustard on 15 October with 40 kg S ha^{-1} is a suitable treatment combination for improving mustard productivity and quality under the open and mango-based agroforestry conditions evaluated at Jabalpur. The findings should be interpreted within the specific environmental and management conditions of the experiment.

5. Limitation

The findings are specific to one rabi season, one experimental location, the mustard cultivar RH-725, a seven-year-old mango stand planted at 5.0 × 5.0 m spacing, three sowing dates and four sulphur levels. Consequently, the observed responses may vary under different seasons, agro-climatic conditions, mustard cultivars, tree ages or orchard configurations. Multi-season and multi-location evaluation would be useful for assessing the wider applicability and stability of the identified sowing date and sulphur treatment.

Acknowledgements

The advisor and committee members gratefully acknowledge the support, guidance and facilities provided by the AICRP Research Farm, Department of Forestry, College of Agriculture, Jabalpur, for successfully conducting the present study. The authors sincerely acknowledge the cooperation and assistance extended by the farm staff throughout the experimental period. Their valuable support in field preparation, sowing, application of treatments, intercultural operations, data collection and regular management of the experimental plots is gratefully acknowledged. The authors also express their sincere appreciation for the facilities and resources made available for conducting the field experimentation and completing the present research work successfully.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/165369