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Assessment of growth, physiological traits, and yield stability of Indian mustard in response to varying sowing dates and sulphur levels

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Abstract
The study assesses the growth, physiological traits, and yield stability of Indian mustard (*Brassica juncea*) in response to varying sowing dates and sulphur levels. The research evaluates growth patterns, physiological responses, and yield outcomes across different treatments. Results indicate significant variations in growth and yield based on sowing dates and sulphur levels. Optimal sowing dates and sulphur levels were identified, enhancing yield stability and overall crop performance. Early sowing combined with adequate sulphur levels improved photosynthetic efficiency, nutrient uptake, and stress tolerance, leading to higher yields. The findings underscore the importance of precise agronomic practices in maximizing the productivity and stability of Indian mustard. This study provides valuable insights for farmers and agricultural policymakers aiming to optimize cultivation strategies, improve crop resilience, and ensure food security.

Keywords: Sowing dates, sulphur levels, growth assessment, yield stability

Introduction
Rapeseed mustard (*Brassica juncea*L.) is the most widely grown edible oilseed crop in India, accounting for 28.6% of total oilseed output, comparably with other seven oil seed crops. Rapeseed mustard is the second-most important oilseed crop in India, next only to soybean, with almost one-fourth share in both area and production (Jat *et al*., 2019; Singh *et al*., 2017) [3, 4, 17, 18]. It is cultivated in an area of 7.58 million hectares with a production of 10.1 million tonnes yielding 1324 kg/ha. There exists a huge gap between the global productivity (20.47 q/ ha) and India's productivity (13.24 q/ ha) which need to be bridged with the expansion of area under high yielding varieties (hybrids) due to their improved genetic potential (Mondal *et al*., 2011; Kumari *et al*., 2012) [10, 8]. Rapeseed-mustard crops are grown in diverse agro-climatic conditions ranging from north-eastern/ north-western hills to down south under irrigated/rainfed, timely/ late-sown, saline soils and mixed cropping. Production potentiality of Indian mustard can be fully exploited under these conditions with suitable agronomic practices and varieties. Among the different agronomic practices, optimum sowing time is very important for mustard production (Shah *et al*., 2022; Jha *et al*., 2012) [16, 5]. Mustard oil contains omega fatty acids, saturated fats, thiamine, ascorbic acid, iron, potassium, calcium, riboflavin, and β-carotene, which make it more valuable than other edible oils. The green leaves of this herb are commonly used as a vegetable. The seeds of mustard are used for making pickles, soups, stews, and hair oil throughout the world (Afroz *et al*., 2011; Rakesh and Chandra, 2016) [1, 11]. Due to the commercial importance of mustard, increasing its production is highly desirable. In this regard, mineral nutrients and plant hormones/plant-growth promoters may have roles in enhancing mustard growth and oil production. Mustard cultivation is profitable, but the productivity is currently insufficient to meet the needs of the people. Efforts are currently being made by scientists to enhance the cultivation and production of edible oilseed crops, including mustard (Shah *et al*., 2021; Singh *et al*., 2017) [15, 17, 18]. Of these efforts, supplementation of plant growth regulators (PGRs) has been recognized as an efficient approach that has been shown to improve several crop plants growth, physicochemical characteristics, yield, and quality (Waraich *et al*., 2022; Ray *et al*., 2015) [22, 14]. The sulphide that is not converted into protein is stored in the leaves and, to a smaller extent, in the seeds where it can be mobilised as needed. Protein, lipids, and vitamins must be synthesised, and this requires the S.

The protein needs about 90% of the reduced sulphur since it contains the amino acids methionine (21% S), cysteine (26% S), and cystine (27% S). Methionine makes up about 50% of all the sulphur in proteins (Ghassemi *et al*., 2019) [2]. Although there are numerous sources of S fertilisers today, only a small number of researchers have examined how different S sources affect oilseeds. Ammonium sulphate (24% S), single superphosphate (12% S), gypsum (13% S), pyrite (22-30% S), and elemental S (85-100% S) are the most used S fertilisers. The additional S sources are potassium sulphate (18% S), magnesium sulphate (13% S), pressmud (2-3% S), and sulphur sludge (10-16% S). Phosphorus gypsum is one of the sources of S, with 16% S content (Meena *et al*., 2020) [9]. For the majority of oilseed crops, the S fertiliser containing SO_4^{-2} were effective.

Materials and Methods

In a field experiment at the Agricultural Research Farm of the faculty of Agricultural Science, Aligarh Muslim University Aligarh, Uttar Pradesh, Assessment of growth, physiological traits, and yield stability of Indian mustard in response to varying sowing dates and Sulphur levels in the winter (rabi) season of 2022-2023 was investigated. Aligarh situated at 27.88°N 78.08°E. About 178 meters (587 feet) above sea level, that's where it is. A city is located in the doab, a region that connects the Yamuna and Ganges rivers. The climate in the area is tropical moist sub-humid, with significant seasonal variation in temperature and precipitation. The mean maximum and minimum temperatures during the crop time vary from 32.2 to 36.2, with an average of 24.25 and 12.41, respectively. The testing location had soil of the sandy-clay loam texture. The soil's pH was 7.30, its level of organic carbon was low (0.35 percent), its availability of nitrogen was low (192.50 kg ha^{-1}), its availability of phosphorus was average (17.30 kg ha^{-1}), and its availability of potassium was average (212.15 kg ha^{-1}). The experiment was set up using a split plot design (SPD), with sixteen treatment combinations and three replications, taken into consideration the nature of the elements being studied as well as the practicality and efficiency of agricultural operations. The field was once more tilled by a cultivator to produce healthy soil tilth. For healthy mustard germination and growth, a field must be properly prepared for sowing and have a fine seed bed. To regularly record biometric observations, two sampling areas one for destructive execute and the other for non-destructive behavior were demarcated. At 30, 60, and 90 days after sowing (DAS), as well as at harvest, five randomly selected plants from the net plot area were tagged and monitored to record growth characteristics. Yield and factors that influence yield were documented after harvest. By multiplying the seed nitrogen content (%) by 6.25, the protein content of the seed was calculated. The cost of cultivation was worked out by taking into consideration all the expenses incurred.

Results and Discussion

Plant height

In the current investigation, mustard's growth is examined in terms of germination, plant height, dry matter accumulation, crop growth rate, relative growth rate, leaf area per plant, relative leaf growth rate, and net assimilation rate. The crop planted on October 5 exhibited a greater germination percentage than the other two days in the data. Delay in planting reduced plant height, with a maximum height of 201.3 cm at harvest recorded in the data of the crop sown on October 5th, and a minimum height of 172.6 cm in the 5th November sowing. Crops sown on 5th October had considerably greater plant height (201.3 cm) than crops sown on 20 Sep. (180.1 cm) and 5 October than crops sown on 20 October (180.1 cm), but the plant height reported in 20 October and 5 November sowing (177.7 cm) was statistically equal (Table-1). Plant height reduced with planting delay, according to Waraich *et al*., (2022) [22]. In contrast, delayed planting reduces plant growth, resulting in inferior development when compared to timely and early sown crops. In the data (Table-1), crops seeded on October 5th had greater sulphur content in plant at 60 DAS (0.69%) and in stover at harvest (0.60%).

Dry matter accumulation

The trend in dry matter accumulation was similar to that in plant height, with 5 October followed by 20 October outperforming the remaining two sowing dates. A plant's dry matter is determined by its vertical and horizontal growth. Horizontal growth is the formation of branches, whereas vertical growth is the height of the plant. That is why there was a positive link between plant height and dry matter accumulation. In the analysis only, sulphur application showed a significant interaction with sowing dates in terms of dry matter accumulation at 60 DAS (Table-1). The crop sown on 5th October produced more growth and, as a result, better development due to favourable weather conditions, particularly the maximum and minimum limits of atmospheric temperature available to this crop; thus, crop response to sulphur varied with these growth, development, and yield attributes (Kumar *et al*., 2020) [7].

Physiological traits (CGR & RGR)

Sulphur levels increased the number of different types and total branches per plant numerically up to 75 kg and considerably up to 50 kg S/ha. Higher sulphur levels enhanced crop growth rate at the early development stage (5.88 with 50 kg and 6.20 with 75 kg S/ha), however control (8.65) and 20 kg Sha (8.17) showed higher crop growth rate values during 60-90 days after sowing. Sulphur application at various levels did not improve the second relative growth rate over the control, but rather resulted in a considerable decline, notably up to 50 kg S/ha. With no sulphur application, the maximum ratios were 59.21 and 32.06 between 30-60 and 60 90 DAS, respectively, while the leaf area ratio dropped with increasing sulphur levels. Sulphur application had a substantial effect on the initial relative leaf growth rate, as well as in the alone, but not in any of the years. By-enlarge, increasing sulphur levels reduced relative leaf growth rates (Tandayu *et al*., 2022) [19]. Sulphur concentrations enhanced and lowered the first and second net assimilation rates, respectively. A maximum of 7.53 CGR was computed between 30-60 days after sowing from a crop planted on October 5th with the application of 75 kg S/ha, which was comparable to 50 kg S/ha given to the same crop (7.07) as well as the 20th October sowed crop getting either 50 kg (645) or 75 kg S/ha (6.86). Crop duration was reduced due to delayed sowing. Sulphur had no effect with any of the sowing dates. Crop sowed on September 20 took much longer to mature with 75 kg/S (127.6 days), closely followed by crop sown on the same date with 50 kg S/ha.

Straw yield & Stover yield

Following increases in all of the aforesaid yield features, the seed yield of the crop sown on October 5th was higher than the previous three dates throughout 2022-2023 (2445 kg/ha). In the data, there was a 9.67%, 23.91%, and 33.67% drop in the 20th September, 20th October, and 5th November sowings, respectively (Table-3). A similar pattern was seen in the oil yield, harvest index, straw yield, stover yield, and above ground biomass of the crop sown on October 5th (Table-3), with the values being 966.5 kg oil per hectare and 32.41 harvest index. Each had received 733-kilogram straw, 5163 kg stover, and 8093 kg above ground biomass. The maximum and minimum atmospheric temperatures, relative humidity (morning and after midday), rainfall, daily evaporation, sun shine hours, and wind speed were all favorable for the crop sowed on October 5. These findings are consistent with the work of (Rana *et al*., 2021; Kumar *et al*., 2020) [13, 7] and others. Although no clear pattern emerged in the content and intake of sulphur in the hole plant at various stages, as well as in seed and stover at harvest, delaying seeding reduced the content and uptake of sulphur. Because of the fast growth and development of the plants, the crop sowed on 5 October or 20 September removed more sulphur from the soil. In contrast, delayed planting reduces plant growth, resulting in inferior development when compared to timely and early sown crops. In the data (Table-3), crops seeded on October 5th had greater sulphur content in plant at 60 DAS (0.69%) and in stover at harvest (0.60%). Similarly, crops sown on 5 October had higher sulphur renewal at 60 DAS (20.21 kg/ha) and at harvest (54.40 kg/ha) than crops grown on other dates.

Seed yield, Oil yield & Harvest index

The crop sown on October 5th (45.16 kg/ha) had significantly higher sulphur uptake at 90 DAS, closely followed by the crop sowed on September 20th (44.88 kg/ha). 5.25 Quality Impact The oil content of seed reduced with delay in sowing in the current trials. The crop sowed on September 20 had a much greater oil content (41.65%), followed by 5 October (39.52%) than the other two dates (Table-3). Crops planted on October 20 had a greater protein content in seed (22.98%), closely followed by 5th November (23.10%) and 5th October (22.98%) in the results. On the other hand, protein yield was higher (539.3 kg/ha) of the crop sown on 5 October than the remaining three dates (Table-3). Crude fiber content declined with sowing delay and was highest in the crop sowed on November 5th (18%), closely followed by 20 October (Table-3). It is clear from the above results that early sown crops benefit from more favourable weather conditions for increasing oil content in seed, but too early sowings (20 September & 5th October) were not better for protein content in seed, but the protein yield of the crop sown on 5th October was higher as a result of higher seed yield. Crude fiber content appears to be negatively linked with early or timely crop planting. Many sulphur compounds are found in the plant's vegetative portions as well as the seed. As a result, sulphur has a direct impact on growth, yield, and quality. Increasing sulphur levels increased seed oil content, protein content, protein yield, and glucosinolate content up to 50 kg S/ha, while erucic acid content responded up to 1" level, i.e., 25 kg S/ha, but crude fiber content did not follow a systematic trend, with no sulphur closely followed by 25 kg S/ha. Crops sown on 5 October had the highest harvest index (32.41), followed by 20 September (30.23), and produced significantly more straw (690 kg/ha) than the remaining three sowing dates as well as maximum stover yield (5371 kg/ha), which was significantly higher than the remaining three sowing dates. The Aboveground biomass was much higher than the crop seeded on 5 October ($419 kg/ha).

Table 1: Plant height (cm) and Dry matter accumulation (g/plant) at different growth stages as influenced by dates of sowing during 2022-2023

Treatment	Plant height			Dry matter accumulation		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Date of sowing						
20 September	20.0	133.4	180.1	2.90	17.5	65.32
05 October	24.9	137.8	201.3	3.90	22.49	67.63
20 October	17.6	124.2	180.1	3.29	19.52	67.26
05 November	14.6	114.2	172.6	3.15	14.15	45.43
SE±	0.38	0.12	0.36	0.04	0.44	0.27
CD at 5 %	0.25	0.41	1.18	0.15	1.46	0.88
Sulphur levels						
0 kg ha $^{-1}$	17.2	113.4	172.3	2.93	13.25	54.33
25 kg ha $^{-1}$	18.1	119.7	184.6	2.99	15.98	57.35
50kg ha $^{-1}$	20.6	136.2	190.1	3.22	22.30	65.63
75 kg ha $^{-1}$	22.1	142.8	192.4	3.27	21.26	66.50
SE±	0.40	0.24	0.40	0.17	0.29	0.32
CD at 5%	1.32	0.78	1.34	0.5	0.95	1.04

Table 2: Crop growth rates (g day^{-1}) and relative growth rates (g g^{-1} day-1) at various growth stages as affected by various sowing sulphur application dates in 2022-2023.

Treatment	CGR		RGR	
	30-60 DAS	60-90 DAS	30-60 DAS	60-90 DAS
Date of sowing				
20 September	5.35	8.95	6.83	3.95
05 October	7.53	9.27	6.32	3.32
20 October	6.50	10.07	6.40	3.86
05 November	4.92	7.32	5.67	3.75
SEm+-	0.58	0.57	0.23	0.13
CD at 5 %	0.97	0.92	NS	NS
Sulphur levels				
0 kg ha $^{-1}$	4.67	9.94	5.84	4.32
25 kg ha $^{-1}$	5.61	9.44	6.35	3.89
50kg ha $^{-1}$	7.07	8.43	6.81	3.29
75 kg ha $^{-1}$	8.86	8.22	6.94	3.17
SEm±	0.26	0.40	0.06	0.22
CD at 5 %	0.85	NS	0.22	0.73

Table 3: Straw yield, Stover yield, Seed yield, Oil yield and Harvest index as influenced by dates of sowing and sulphur application during 2022-2023

Treatment	Straw yield (kg/ha)	Stover yield (kg/ha)	Seed yield (kg/ha)	Oil yield (kg/ha)	Harvest index
Date of sowing					
20 September	690	4818	2248	899.1	32.56
05 October	733	5163	2445	966.5	32.41
20 October	629	4355	1872	721.6	30.47
05 November	581	3949	1641	623.8	29.95
SE±	1.01	5.20	4.30	1.40	0.51
CD at 5 %	3.30	16.97	14.3	4.72	NS
Sulphur levels					
0 kg ha $^{-1}$	613	4308	1894	711.1	26.88
25 kg ha $^{-1}$	653	4533	1991	769.7	27.29
50kg ha $^{-1}$	681	4730	2155	855.5	27.56
75 kg ha $^{-1}$	683	4710	2166	870.6	27.63
SE ±	2.85	4.61	13.97	2.02	0.5
CD at 5%	9.30	15.27	45.2	6.59	NS

Conclusion

Based on the results of experiments conducted during the consecutive Rabi seasons of 2022-2023, it can be concluded that mustard (*Brassica juncea* L.) Cv. Pusa Kranti should be sown in the first week of October preferably on October 5th, in semi-arid climates like western UP like Aligarh for improved crop performance, including yield and quality. As an alternate option, early sowing may be preferable over delayed sowing. In sandy loam alluvial soils, sulphur at 50 kg/ha should always be administered in addition to the uniform dose of 80:40:40 kg N:P: K/ha.

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