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Response of mustard to sulphur and nutrient sprays in Northern Telangana zone

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Abstract

The field experiment entitled “Response of Mustard to sulphur and Nutrient sprays in Northern Telangana Zone” variety NRCHB- 101 was conducted at Regional Agricultural Research Station, Polasa, Jagtial, PJTAU during *rabi* 2025-26 to study the response of mustard to sulphur and nutrient sprays with respect to growth, yield, quality, soil nutrient status, nutrient content and uptake, soil biological properties and economics. The experiment comprised eleven treatments viz., T1: 100% RDF, T2: 100% RDF + 25 kg S ha⁻¹, T3: 100% RDF + 2% urea spray, T4: 100% RDF + nano plus urea spray, T5: 100% RDF + NPK multiplex spray, T6: 100% RDF + 25 kg S ha⁻¹ + 2% urea spray, T7: 100% RDF + 25 kg S ha⁻¹ + nano plus urea spray, T8: 100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray, T9: 75% RDF, T10: 75% RDF + nano plus urea spray and T11: 75% RDF + NPK multiplex spray. The treatments were evaluated in a randomized block design with three replications. The soil of experimental site was sandy clay loamy texture. The results revealed that the significantly higher plant height (175.5 cm), primary branches (20.7 branches plant⁻¹), secondary branches (7.6 branches plant⁻¹), tertiary branches (6.5 branches plant⁻¹), Dry matter yield (1502.79 kg ha⁻¹), number of siliquae plant⁻¹ (197.70), filled seeds siliqua⁻¹ (20.69), Test weight (5.99g), seed yield (1295.32 kg ha⁻¹), stover yield (2049.34 kg ha⁻¹) were recorded in T7 (100% RDF + 25 kg S ha⁻¹ + nano plus urea spray) which was also significantly on par with T6 (100% RDF + 25 kg S ha⁻¹ + 2% urea spray) and T8 100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray and the lowest plant height (125.9 cm), no of primary branches (8.9 branches plant⁻¹), no of secondary branches (5.6 branches plant⁻¹), no of tertiary branches (3.3 branches plant⁻¹), Dry matter yield (1502.79 kg ha⁻¹), no of siliqua plant⁻¹ (93.27), no of filled seeds per siliqua⁻¹ (7.83), test weight (4.90 g), seed yield (683.74 kg ha⁻¹), stover yield (1193.84 kg ha⁻¹).

Keywords: NPK Multiplex spray, Mustard, RDF, Urea, Urea plus, 25 kg S ha⁻¹, sulphur and Yield

1. Introduction

Mustard (*Brassica Juncea* L.) is an important oilseed crop belonging to the family Brassicaceae. The crop is grown both in tropical and subtropical countries. India stands third in terms of area and production after Canada and China, and fifth in terms of yield per hectare after Germany, France, Canada and China (Jat *et al.*, 2007) [17]. India stands as the third-largest global producer of rapeseed-mustard, contributing over 13% to worldwide output from 2020-21 to 2024-25, yet its average yield of 1,461 kg ha⁻¹ in 2024-25 lags at 60.7% of the global average of 2,070 kg ha⁻¹. As a pivotal oilseed crop, rapeseed-mustard ranks second in India's agricultural landscape, trailing only soybean, and accounts for 36% of the nation's edible oil production (Kumar *et al.*, 2025) [18]. India is the fourth largest vegetable oil economy accounting 7.4% oilseeds, 5.8% oils and 6.1% oil meal production, and 9.3% of edible oil consumption in the world. During the last two decades, the domestic consumption of vegetable oils increased at compound annual growth rate (CAGR) of 4.3%, and is expected to continue increasing with the growing population, changing demographic pattern and rising per capita consumption due to increased GDP growth. In India, rapeseed-mustard is the main oilseed crop growing in *rabi* season occupying more than 80 percent of the area under oilseeds crop. Indian mustard is predominantly cultivated in the states of Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat, Punjab and Bihar. Its cultivation is also being extended to non-traditional areas of southern states like Karnataka.

In India average Rapeseed-Mustard production is around 115.2 lakh tonnes and area under cultivation is around 92.15 lakh hectares (The solvent Extractors association of India (SEA) report- 2025) ^[46]. In India Mustard is a potential crop in winter (*rabi*) season due to its wider adaptability and suitability to exploit residual moisture.

In Telangana state mustard is cultivated in an area of approximately 7000 ha during 2024-25 (Madhukar *et al.*, 2025) ^[20]. The average productivity of 799 kg ha⁻¹ during 2024-25 (Department of Agriculture and Farmers Welfare, 2025) ^[4]. Mustard seed contains 30-33% oil, 17-25% protein, 8-10% fibre and 10-12% substances extractable (Mishra *et al.*, 2019) ^[22]. The cake obtained after extraction of oil can be used as cattle feed and manure. The oil cake contains 25-30% crude protein, 5% nitrogen, 1.8-2.0% phosphorus and 1.0-1.2% potassium (Reddy and Reddi, 2011) ^[36]. It is a major *rabi* crop which is taken up from October-November to February-March.

Mustard (*Brassica juncea* L.) is a significant oilseed crop, valued for its oil content and culinary uses. Mustard is one of prominent oilseed crops grown in the Northern Telangana Zone, grown in the area of nearly 3200 ha. But the productivity of mustard is lower than the world, approximately 1980 kg ha⁻¹. In India the productivity is approximately 1461 kg ha⁻¹. Hence, it is essential to study the possibility of increasing the growth and yield of mustard. Accordingly, a field experiment to study the effect of application of sulphur and nutrient sprays is proposed.

Soils of Jagtial district are deficient in available sulphur status as per results of Jagtial district soil fertility status and fertilizer use guidelines by PJTAU >50% soils of Jagtial district are deficient in available sulphur status content. Application of sulphur aids in improving the yield and quality of oilseed crops. The farmers, however, do not apply sulphur either directly or through S-containing primary nutrient fertilizers like SSP. Almost all the soils of the Zone are low in available nitrogen. Available phosphorus and potassium contents are medium to high. However, in the prevailing cold conditions in the *rabi* season the uptake of the soil nutrients which may be in sufficient quantities in soil, is hindered leading to slow growth.

Among oilseeds, Indian mustard noticeably responds to sulphur fertilization. The data with respect to optimum level and source of sulphur and its impact on the seed and quality of mustard is scanty/ pitiful. Presumably for these reasons the mustard crop needs a supplementary quantity of sulphur for absolute growth, development and yields. In mustard, seed and stover yield is markedly governed by sulphur levels (Sharma *et al.*, 2006) ^[42]. Sulphur is the key component of balanced nutrient application for higher yields and superior quality produce of mustard. Sulphur plays a vital role in the synthesis of amino acids (Rathore *et al.*, 2015) ^[34]

Application of macronutrients through basal application and micronutrients (Multiplex) through foliar spray can influence some of the physiological processes which in-turn help minimize the yield reduction due to drought i.e., insufficient soil moisture. Recent research showed that micronutrients, particularly Zn, Fe and N supplied through the foliar spray, has resulted in a significant increase in crop yield. To enhance the productivity of the crop, micronutrients like Fe, Mn, Cu and Zn need to be supplemented along with NPK fertilizers (Kumar *et al.*, 2012) ^[12]. Foliar application of N:P:K improves the ability of the plant for nutrient absorption, assimilation and translocation in mustard (Sarkar *et al.*, 2008) ^[39].

The foliar application of nano plus urea and NPK multiplex sprays and to compare its effect with that of conventionally applied urea under Northern Telangana Zone conditions, so that

farmers in this region can have a viable and economically viable option for maintaining sustainable crop production with improved nitrogen use efficiency in mustard crop.

2. Materials and Methods

The field experiment was conducted during *rabi*, 2025-26 in field block no. A₂ at Regional Agricultural Research Station (RARS), Polasa, Jagtial, Professor Jayashankar Telangana Agricultural University (PJTAU) which was located at 18° 84' 03.38" N latitude and 78° 94' 92.99" E longitude, with an altitude of 243.4 m above mean sea level in the Northern Telangana Agro-climatic Zone. During the experimental period the average maximum and minimum temperatures were 34.0°C and 11.5°C, respectively. The experiment was evaluated under a randomized block design (RBD) and replicated thrice and comprised of nine treatments:- T1: 100% RDF, T2: 100% RDF + 25 kg S ha⁻¹, T3: 100% RDF + 2% urea spray, T4: 100% RDF + nano plus urea spray, T5: 100% RDF + NPK multiplex spray, T6: 100% RDF + 25 kg S ha⁻¹ + 2% urea spray, T7: 100% RDF + 25 kg S ha⁻¹ + nano plus urea spray, T8: 100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray, T9: 75% RDF, T10: 75% RDF + nano plus urea spray and T11: 75% RDF + NPK multiplex spray. The variety used was NRCHB- 101. The soil of experimental site was sandy clay loamy soil having slightly alkaline nature with (pH 7.9), EC (0.39 dS m⁻¹), organic carbon (0.43 g kg⁻¹), low in available nitrogen (210.1 kg ha⁻¹), low in available phosphorus (8.1 kg ha⁻¹), high in available potassium (201.5 kg ha⁻¹), low in available sulphur (4.4 mg kg⁻¹) and the soil is also having sufficient levels of micronutrients such as zinc (0.62 mg kg⁻¹), iron (7.60 mg kg⁻¹), manganese (5.98 mg kg⁻¹) and copper (5.83 mg kg⁻¹). N, P, K and S were applied during sowing in the form of urea, diammonium phosphate, muriate of potash and elemental sulphur, respectively, while urea was applied in two equal splits as basal and topdressing at 30 DAS and 60 DAS. Diammonium phosphate and elemental sulphur was applied only basal. Muriate of potash was applied as basal and top dressing at 30 DAS and 60 DAS respectively. Foliar sprays such as nano plus urea, NPK multiplex (19:19:19), 2% urea spray was applied first at 30 DAS and next at 60 DAS. Recommended dose is 60:40:40 for mustard crop. Data was recorded from five plants selected randomly from each treatment in every replication. Data on growth parameters such as plant height, no of primary branches, no of secondary branches, no of tertiary branches, Dry matter yield and yield attributes such as number of siliques plant⁻¹, no of filled seeds siliqua⁻¹, Test weight, seed yield, stover yield were analyzed statistically using ANOVA.

3. Results and Discussion

3.1 Effect of sulphur and nutrient sprays on growth parameters of mustard

3.1.1 Plant height (cm)

Plant height is an important growth parameter reflecting the vegetative vigour of the crop and is influenced by nutrient availability. The data on plant height of hybrid mustard (NRCHB-101) was analysed statistically at 30 DAS and 60 DAS. The data on plant height of Indian mustard cv. NRCHB-101 revealed that the application of sulphur and nutrient sprays significantly influenced plant height at both 30 DAS and 60 DAS. Compared with T1 (100% RDF) (28.2 and 151.6 cm), T2 (100% RDF + 25 kg S ha⁻¹) (35.4 and 163.1 cm) at 30 and 60 DAS respectively recorded significantly higher plant height due to the beneficial effect of sulphur application, which enhanced chlorophyll synthesis, sulphur-containing amino acid formation, protein synthesis and efficient nutrient utilization, thereby

promoting vigorous vegetative growth. Similarly, T3 (100% RDF + 2% urea spray) (32.2 and 155.9 cm), T4 (100% RDF + nano urea spray) (33.8 and 158.3 cm) and T5 (100% RDF + NPK multiplex spray) (29.6 and 153.9 cm) at 30 and 60 DAS respectively recorded significantly higher plant height than T1 due to the beneficial effect of foliar nutrient sprays on nutrient availability and photosynthetic activity were supported by Yadav *et al.* (2020). The highest plant height was recorded in T7 (100% RDF + 25 kg S ha⁻¹ + nano urea spray) (39.2 and 175.5 cm), which was significantly superior to T1 and was statistically

on par with T6 (100% RDF + 25 kg S ha⁻¹ + 2% urea spray) (37.5 and 172.4 cm) at 30 and 60 DAS respectively and T8 (100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray) (36.4 and 167.7 cm). Although T10 (75% RDF + nano urea spray) (27.1 and 146.8 cm) and T11 (75% RDF + NPK multiplex spray) (25.1 and 145.4 cm) at 30 and 60 DAS respectively recorded comparatively lower numerical values than T1, they were statistically on par with T1, indicating that foliar nutrient sprays under (75% RDF +

Table 1: Plant height (cm) of mustard as influenced by application of sulphur and nutrient sprays at different stages of crop growth

	Treatments	30 DAS	60 DAS
T ₁	100%RDF	28.2	151.6
T ₂	100%RDF+25 kg S ha ⁻¹	35.4	163.1
T ₃	100%RDF+2% urea spray	32.2	155.9
T ₄	100%RDF+nano plus urea spray	33.8	158.3
T ₅	100%RDF+NPK multiplex spray	29.6	153.9
T ₆	100%RDF+25kg S ha ⁻¹ +2% urea spray	37.5	172.4
T ₇	100%RDF+25kg S ha ⁻¹ +nano plus urea spray	39.2	175.5
T ₈	100%RDF+25kg S ha ⁻¹ +NPK multiplex spray	36.4	167.7
T ₉	75%RDF	15.4	125.9
T ₁₀	75%RDF+nano plus urea spray	27.1	146.8
T ₁₁	75%RDF+NPK multiplex spray	25.1	145.4
	SEm±	1.76	8.52
	CD (p=0.05)	5.20	25.14
	CV%	9.88	9.46

NPK multiplex spray) (25.1 and 145.4 cm) at 30 and 60 DAS respectively recorded comparatively lower numerical values than T1, they were statistically on par with T1, indicating that foliar nutrient sprays under 75% RDF maintained plant growth comparable to the recommended fertilizer dose, as reported by Singh and Meena (2020) ^[21]. The lowest plant height was recorded in T9 (75% RDF) (15.4 and 125.9 cm) at 30 and 60 DAS respectively which was significantly inferior to T1. This reduction in plant height may be due to inadequate nutrient supply resulting from the application of 75% RDF without sulphur or nutrient sprays, leading to poor vegetative growth. These findings concur with those of Rathore *et al.* (2015) ^[34].

3.1.2. Number of primary branches plant⁻¹

Number of primary branches plant⁻¹ is the major yield attributing character. Sulphur and foliar spray had significantly influenced the primary branches in mustard crop. This was demonstrated in Table. (2)

The data on the number of primary branches of Indian mustard (*Brassica juncea* L.) cv. NRCHB-101 revealed that the application of sulphur and nutrient sprays significantly influenced the number of primary branches at both 30 DAS and 60 DAS. Compared with T1 (100% RDF) (7.9 and 11.2), T2 (100% RDF + 25 kg S ha⁻¹) (8.8 and 16.4) at 30 and 60 DAS, respectively, recorded significantly higher number of primary branches due to the beneficial effect of sulphur on meristematic growth, enhanced nitrogen metabolism and efficient utilization of nutrients, resulting in better development of lateral branches. Among the nutrient spray treatments without sulphur, T4 (100% RDF + nano urea spray) (8.6 and 15.2) recorded higher number of primary branches than T3 (100% RDF + 2% urea spray) (8.4 and 14.1) and T5 (100% RDF + NPK multiplex spray) (8.1 and

12.7) at both stages. The higher response under nano urea spray may be attributed to its gradual nutrient release and higher nutrient use efficiency, whereas foliar urea and NPK multiplex improved branching by supplying readily available nutrients during the active vegetative phase. Similar observations were reported by Parth *et al.* (2024) and Kaur *et al.* (2019) ^[10]. The highest number of primary branches was recorded in T7 (100% RDF + 25 kg S ha⁻¹ + nano urea spray) (9.7 and 20.7), which was significantly superior to T1 and was statistically on par with T6 (100% RDF + 25 kg S ha⁻¹ + 2% urea spray) (9.5 and 18.9) and T8 (100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray) (9.2 and 17.7) at both 30 and 60 DAS. The superior performance of these treatments may be attributed to the combined effect of soil-applied sulphur and foliar nutrient application, which maintained a continuous supply of nutrients, enhanced photosynthate production, increased translocation of assimilates and promoted the differentiation of axillary buds into productive branches. Although T10 (75% RDF + nano urea spray) (7.7 and 10.1) and T11 (75% RDF + NPK multiplex spray) (7.6 and 9.5) recorded comparatively lower values than T1, they were statistically on par with T1, indicating that foliar nutrient application under 75% RDF partially compensated for the reduced basal fertilizer dose by improving nutrient use efficiency and sustaining vegetative growth. Similar observations were reported by Uddin *et al.* (2024) ^[47]. The lowest number of primary branches was recorded in T9 (75% RDF) (6.5 and 8.9) at 30 and 60 DAS respectively, which was inferior to T1. The reduced branching under this treatment may be due to inadequate significantly nutrient availability throughout the crop growth period, leading to poor vegetative development and restricted emergence of lateral branches. These findings are in agreement with Kapur *et al.* (2010) ^[8].

Table 2: Number of primary branches plant⁻¹ of mustard as influenced by application of sulphur and nutrient sprays at different stages of crop growth

	Treatments	30 DAS	60 DAS
T ₁	100%RDF	7.9	11.2
T ₂	100%RDF+25 kg S ha ⁻¹	8.8	16.4
T ₃	100%RDF+2% urea spray	8.4	14.1
T ₄	100%RDF+nano plus urea spray	8.6	15.2
T ₅	100%RDF+NPK multiplex spray	8.1	12.7
T ₆	100%RDF+25kg S ha ⁻¹ +2% urea spray	9.5	18.9
T ₇	100%RDF+25kg S ha ⁻¹ +nano plus urea spray	9.7	20.7
T ₈	100%RDF+25kg S ha ⁻¹ +NPK multiplex spray	9.2	17.7
T ₉	75%RDF	6.5	8.9
T ₁₀	75%RDF+nano plus urea spray	7.7	10.1
T ₁₁	75%RDF+NPK multiplex spray	7.6	9.5
	SEm±	0.48	0.80
	CD (p=0.05)	1.42	2.47
	CV%	9.96	9.75

3.1.3 No of secondary branches⁻¹

Number of secondary branches plant⁻¹ plant play a vital role in increasing seed yield of mustard. The data on the number of secondary branches as influenced by sulphur and nutrient sprays. This was represented in table (3).

A scrutiny of data revealed that the number of secondary branches ranged from 3.19 to 6.25 at 30 DAS and 5.3 to 15.4 at 60 DAS. The highest number of secondary branches at 60 DAS was recorded in T₇ (100% RDF + 25 kg S ha⁻¹ + nano urea spray) (15.4 branches plant⁻¹), which was statistically on par with T₆ (13.6 branches plant⁻¹) and T₈ (12.3 branches plant⁻¹). At 30 DAS, however, T₆ recorded the highest value (6.25 branches plant⁻¹), followed closely by T₇ (6.15 branches plant⁻¹) and T₈ (5.77 branches plant⁻¹). The superior performance of these treatments may be attributed to the combined application of sulphur and foliar nutrient sprays, which ensured balanced nutrient supply, enhanced photosynthetic activity and promoted greater branching. Similar findings were reported by Parth *et al.* (2024) and Bhakher *et al.* (2023) [2]. Application of sulphur alone (T₂) also markedly improved the number of secondary branches over T₁ (100% RDF), recording 5.33 and 11.7 branches plant⁻¹ at 30 and 60 DAS, respectively, compared with 4.20 and 8.7 branches plant⁻¹ in T₁. Likewise, foliar nutrient application along with 100% RDF increased branching, with T₄ (5.24 and 10.6) performing better than T₃ (5.06 and 10.1) and T₅ (4.58 and 9.6) at both stages. This improvement may be due to increased nutrient availability and better translocation of assimilates to developing branches. Similar observations were reported by Pandav *et al.* (2022) [27]. Reduction of the fertilizer dose to 75% RDF adversely affected branch development. The lowest number of secondary branches was recorded in T₉ (75% RDF) with 3.19 and 5.3 branches plant⁻¹ at 30 and 60 DAS, respectively. Although the addition of nano urea (T₁₀) and NPK multiplex spray (T₁₁) under 75% RDF improved the values to 4.19 and 7.6 and 4.24 and 7.3 branches plant⁻¹, respectively, they remained lower than the treatments receiving 100% RDF. These findings indicate that foliar nutrient sprays partially compensated for the reduced fertilizer dose but could not match the performance of integrated sulphur and nutrient spray treatments. Similar results were reported by Saha *et al.* (2023) [37] and Rathore *et al.* (2015) [34].

3.1.4 No of tertiary branches⁻¹

The number of tertiary branches is an important growth attribute in Indian mustard as it contributes to canopy development, increases the number of flowering sites and enhances the potential for silique formation. The development of tertiary branches largely depends on the availability of essential nutrients during the vegetative stage. Adequate sulphur nutrition along with balanced foliar nutrient application promotes

vigorous plant growth, stimulates axillary bud development and encourages the formation of tertiary branches by improving photosynthetic efficiency, protein synthesis and nutrient uptake. The effect of different sulphur and nutrient spray treatments on the number of tertiary branches of Indian mustard. This was shown in in Table(4).

The number of tertiary branches of Indian mustard (*Brassica juncea* L.) cv. NRCHB-101 was significantly influenced by the application of sulphur and nutrient sprays at both 30 DAS and 60 DAS. The values ranged from 1.4 to 4.7 branches plant⁻¹ at 30 DAS and 3.3 to 6.5 branches plant⁻¹ at 60 DAS, indicating that integrated nutrient management promoted better branch development than the application of RDF alone. The combined application of 100% RDF, 25 kg S ha⁻¹ and foliar nutrient sprays produced a greater number of tertiary branches than the individual application of sulphur or foliar nutrients. Among all the treatments, T₇ (100% RDF + 25 kg S ha⁻¹ + nano urea spray) recorded the highest number of tertiary branches (4.7 and 6.5 branches plant⁻¹) at 30 and 60 DAS respectively, and was statistically on par with T₆ (4.6 and 6.3 branches plant⁻¹) and T₈ (4.5 and 6.2 branches plant⁻¹). The superior performance of these treatments may be attributed to improved nutrient availability, efficient utilization of nitrogen and sulphur, and enhanced crop vigour, which favoured the production of more tertiary branches. Similar improvements in growth with sulphur and foliar nutrient application were reported by Navya *et al.* (2021) [25], Kour *et al.* (2017) [11] and Pandav *et al.* (2022) [27]. Application of 25 kg S ha⁻¹ alone (T₂) also increased the number of tertiary branches (4.2 and 5.4 branches plant⁻¹) compared with T₁ (100% RDF) (2.9 and 4.4 branches plant⁻¹) at 30 and 60 DAS respectively. Likewise, among the foliar nutrient treatments under 100% RDF, T₄ (3.8 and 5.3 branches plant⁻¹) at 30 and 60 DAS respectively performed better than T₃ (3.7 and 4.8 branches plant⁻¹) and T₅ (3.2 and 4.7 branches plant⁻¹) at 30 and 60 DAS respectively. The improvement may be due to enhanced nutrient absorption and increased photosynthetic activity resulting from foliar nutrition. Similar observations were reported by Rajput *et al.* (2018) [30] and Kumar *et al.* (2021) [13]. The lowest number of tertiary branches was recorded in T₉ (75% RDF) with 1.4 and 3.3 branches plant⁻¹ at 30 and 60 DAS, respectively. Although the application of nano urea (T₁₀) and NPK multiplex spray (T₁₁) under 75% RDF increased the values to 2.8 and 4.3, 2.5 and 4.2 branches plant⁻¹ at 30 and 60 DAS respectively. They remained lower than the treatments receiving 100% RDF with sulphur. This indicates that reducing the basal fertilizer dose adversely affected branch production, while foliar nutrient sprays could only partially compensate for the reduced nutrient supply. Similar findings on improved growth under integrated nutrient management were reported by (Alam *et al.*, 2014) [1].

Table 3: Number of secondary branches plant⁻¹ of mustard as influenced by application of application of sulphur and nutrient sprays at different stages of crop growth

	Treatments	30 DAS	60 DAS
T ₁	100%RDF	4.2	8.7
T ₂	100%RDF+25 kg S ha ⁻¹	5.3	11.7
T ₃	100%RDF+2% urea spray	5.0	10.1
T ₄	100%RDF+nano plus urea spray	5.2	10.6
T ₅	100%RDF+NPK multiplex spray	4.6	9.6
T ₆	100%RDF+25kg S ha ⁻¹ +2% urea spray	6.1	13.6
T ₇	100%RDF+25kg S ha ⁻¹ +nano plus urea spray	6.2	15.4
T ₈	100%RDF+25kg S ha ⁻¹ +NPK multiplex spray	5.8	12.3
T ₉	75%RDF	3.1	5.3
T ₁₀	75%RDF+nano plus urea spray	4.1	7.6
T ₁₁	75%RDF+NPK multiplex spray	4.2	7.3
	SEm±	0.28	0.56
	CD (p=0.05)	0.82	1.66
	CV%	9.74	9.57

Table 4: Number of tertiary branches plant⁻¹ of mustard as influenced by application of sulphur and nutrient sprays at different stages of crop growth

	Treatments	30 DAS	60 DAS
T ₁	100%RDF	2.9	4.4
T ₂	100%RDF+25 kg S ha ⁻¹	4.2	5.4
T ₃	100%RDF+2% urea spray	3.7	4.8
T ₄	100%RDF+nano plus urea spray	3.8	5.3
T ₅	100%RDF+NPK multiplex spray	3.2	4.7
T ₆	100%RDF+25kg S ha ⁻¹ +2% urea spray	4.6	6.3
T ₇	100%RDF+25kg S ha ⁻¹ +nano plus urea spray	4.7	6.5
T ₈	100%RDF+25kg S ha ⁻¹ +NPK multiplex spray	4.5	6.2
T ₉	75%RDF	1.4	3.3
T ₁₀	75%RDF+nano plus urea spray	2.8	4.3
T ₁₁	75%RDF+NPK multiplex spray	2.5	4.2
	SEm±	0.23	0.31
	CD (p=0.05)	0.67	0.91
	CV%	11.34	10.59

5. Dry matter yield

Dry matter yield is an important indicator of crop growth as it reflects the cumulative effect of photosynthesis, nutrient uptake and biomass accumulation. The results revealed that the application of sulphur and nutrient sprays exerted a significant influence on dry matter yield as mentioned in table (5).

The analysis of variance of dry matter yield at 30 DAS and 60 DAS respectively revealed that the application of 100% RDF along with sulphur (T₂) recorded higher dry matter yield (392.50 and 932 kg ha⁻¹) at 30 DAS and 60 DAS respectively than 100% RDF alone (T₁) (372.48 and 823.15 kg ha⁻¹), indicating the photosynthetic efficiency, which ultimately resulted in greater biomass accumulation. Rajput *et al.* (2018) [30] also observed increased dry matter production in mustard with sulphur application. The addition of foliar nutrient sprays with 100% RDF, namely 2% urea spray (T₃), nano urea spray (T₄) and NPK multiplex spray (T₅), further improved dry matter production over T₁, recording 432.76 and 1104.33 kg ha⁻¹, 453.14 and 1243.22 kg ha⁻¹, 418.91 and 991.34 kg ha⁻¹ at 30 DAS and 60 DAS respectively. The improvement may be attributed to continuous nutrient availability through foliar feeding, which enhanced photosynthetic activity and assimilate production. Pandav *et al.* (2022) [27] also noticed increased dry matter production in mustard with nano urea application. The combined application of sulphur and nutrient sprays proved more effective than either practice alone. Among all the

treatments, T₇ (100% RDF + 25 kg S ha⁻¹ + nano urea spray) recorded highest dry matter yield (548.17 and 1502 kg ha⁻¹) and remained statistically on par with T₆ (100% RDF + 25 kg S ha⁻¹ + 2% urea spray) (506.14 and 1446.55 kg ha⁻¹) and T₈ (100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray) (485.62 and 1389.81 kg ha⁻¹) at 30 DAS and 60 DAS respectively. The higher biomass production under these treatments may be due to the synergistic effect of soil-applied sulphur and foliar nutrient sprays, which improved nutrient assimilation, chlorophyll formation and translocation of photosynthates. These findings are in close agreement with Pachauri *et al.* (2012) [26]. Under 75% RDF, the application of nano urea spray (T₁₀) and NPK multiplex spray (T₁₁) recorded 347.16 and 734.31 kg ha⁻¹, 328.23 and 70.34 kg ha⁻¹ at 30 DAS and 60 DAS respectively. Although these values were numerically lower than T₁ (372.48 and 823 kg ha⁻¹), both T₁₀ and T₁₁ were statistically on par with T₁, indicating that foliar nutrient sprays were able to partially compensate for the reduced fertilizer dose and maintain dry matter production comparable to the recommended fertilizer dose. In contrast, T₉ (75% RDF) recorded the lowest dry matter yield (295.19 and 605 kg ha⁻¹) at 30 DAS and 60 DAS respectively and was significantly inferior to T₁, suggesting that reduction in fertilizer dose without sulphur or nutrient sprays restricted nutrient availability, photosynthetic activity and biomass accumulation.

Table 5: Dry matter yield (kg/ha) ⁻¹ of mustard as influenced by application of sulphur and nutrient sprays at different stages of crop growth

	Treatments	30 DAS	60 DAS
T ₁	100%RDF	372.48	823.15
T ₂	100%RDF+25 kg S ha ⁻¹	392.50	933.28
T ₃	100%RDF+2% urea spray	432.76	1104.33
T ₄	100%RDF+nano plus urea spray	453.14	1243.32
T ₅	100%RDF+NPK multiplex spray	418.91	991.34
T ₆	100%RDF+25kg S ha ⁻¹ +2% urea spray	506.14	1446.55
T ₇	100%RDF+25kg S ha ⁻¹ +nano plus urea spray	548.17	1502.79
T ₈	100%RDF+25kg S ha ⁻¹ +NPK multiplex spray	485.62	1389.81
T ₉	75%RDF	295.19	605.13
T ₁₀	75%RDF+nano plus urea spray	347.16	734.31
T ₁₁	75%RDF+NPK multiplex spray	328.23	701.34
	SEm±	31.71	54.92
	CD (p=0.05)	93.54	162.00
	CV%	13.29	9.12

Table 6: Yield attributes in mustard as influenced by application of sulphur and nutrient sprays at harvest stage

	Treatments	Number of siliqua plant ⁻¹	Number of seeds siliqua ⁻¹	Test weight(g)
T ₁	100%RDF	148.20	12.29	5.89
T ₂	100%RDF+25 kg S ha ⁻¹	164.67	16.79	5.95
T ₃	100%RDF+2% urea spray	155.70	14.29	5.93
T ₄	100%RDF+nano plus urea spray	160.48	15.60	5.94
T ₅	100%RDF+NPK multiplex spray	152.59	13.79	5.91
T ₆	100%RDF+25kg S ha ⁻¹ +2% urea spray	193.11	19.90	5.98
T ₇	100%RDF+25kg S ha ⁻¹ +nano plus urea spray	197.70	20.69	5.99
T ₈	100%RDF+25kg S ha ⁻¹ +NPK multiplex spray	190.76	18.27	5.97
T ₉	75%RDF	93.27	7.83	4.90
T ₁₀	75%RDF+nano plus urea spray	144.98	12.04	5.88
T ₁₁	75%RDF+NPK multiplex spray	144.71	11.95	5.87
	SEm±	8.33	0.79	0.29
	CD (p=0.05)	24.57	2.33	NS
	CV%	9.09	9.23	8.48

**Fig 1:** Showing seed and stover yield across observations

3.2 Effect of sulphur and nutrient sprays on yield attributes of mustard

3.2.1. Number of siliqua plant⁻¹

The number of siliqua per plant is an important yield-attributing character that directly influences seed yield in mustard. The experimental data revealed that the application of sulphur and nutrient sprays significantly influenced the number of siliqua per plant. The data pertaining to no of siliqua plant⁻¹ mentioned in table (6)

A keen inspection of data unveiled that application of sulphur and nutrient sprays significantly influenced the treatments in the

study. At T₂ (100% RDF + 25 kg S ha⁻¹) recorded 164.6 siliqua plant⁻¹, which was higher than the application of RDF alone. The increase may be attributed to sulphur-induced improvement in chlorophyll synthesis, protein formation and enzyme activation, resulting in better vegetative growth, increased flowering and higher pod setting. Ramya *et al.* (2022) [31] also observed that sulphur application significantly increased the number of siliqua per plant in mustard. Application of foliar nutrients along with RDF also improved siliqua production. T₃ (100% RDF + 2% urea spray) recorded 155.7 siliqua plant⁻¹, T₄ (100% RDF + nano urea spray) recorded 160.4 siliqua

plant⁻¹, and T5 (100% RDF + NPK multiplex spray) recorded 152.5 siliquae plant⁻¹. The improvement under these treatments may be due to rapid absorption of nutrients through foliage during the critical reproductive stage, which enhanced photosynthetic activity, reduced flower shedding and promoted better pod development. Similar observations were made by Laishram *et al.* (2023) [19]. The combined application of sulphur and foliar nutrient sprays produced the best response. T6 (100% RDF + 25 kg S ha⁻¹ + 2% urea spray) recorded 193.1 siliquae plant⁻¹, while T7 (100% RDF + 25 kg S ha⁻¹ + nano urea spray) recorded the highest number of siliquae plant⁻¹ (197.7) and remained statistically on par with T8 (100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray), which recorded 190.7 siliquae plant⁻¹. The superior performance of these treatments may be attributed to the synergistic effect of sulphur and foliar nutrient sprays. Sulphur improved chlorophyll synthesis, sulphur-containing amino acid synthesis, protein metabolism and enzyme activity, whereas foliar nutrients ensured timely nutrient availability during flowering and pod formation. This enhanced pollen viability, fertilization, flower retention and efficient translocation of photosynthates to developing reproductive organs, resulting in maximum silique formation. These findings are in close agreement with Sinha *et al.* (2022) [45]. Under reduced fertilizer application, T10 (75% RDF + nano urea spray) and T11 (75% RDF + NPK multiplex spray) recorded 144.9 and 144.7 siliquae plant⁻¹, respectively. Although these values were lower than those obtained under 100% RDF combined with sulphur and foliar nutrition, they were markedly higher than T9 (75% RDF), which recorded only 93.2 siliquae plant⁻¹. The improvement in T10 and T11 indicates that foliar nutrient sprays partially compensated for the reduced fertilizer dose by improving nutrient absorption, photosynthetic efficiency and reproductive development. Similar beneficial effects of balanced nutrient management on silique formation were also observed by Kumar *et al.* (2025) [18]. The lowest number of siliquae plant⁻¹ was recorded in T9 (75% RDF). The reduced availability of nutrients under this treatment might have restricted chlorophyll formation, photosynthesis, flowering and assimilate translocation, leading to poor pod setting and fewer siliquae per plant⁻¹.

3.2.2. Number of silique plant⁻¹

The number of seeds per silique⁻¹ is an important yield-attributing character that directly influences seed yield in mustard. It is greatly affected by nutrient availability during flowering and seed development. Sulphur plays a vital role in pollen viability, fertilization, protein synthesis and seed formation, while foliar nutrient sprays improve nutrient uptake and assimilate translocation, thereby enhancing seed filling. The application of sulphur and nutrient sprays significantly increased the number of filled seeds per silique as depicted in table (6). The analysis of variance of no of seeds per silique⁻¹ revealed that the comparison with T1 (100% RDF) (12.29), T2 (100% RDF + 25 kg S ha⁻¹) (16.79) recorded significantly higher values due to improved pollen fertility, fertilization and seed development. Likewise, T3 (100% RDF + 2% urea spray) (14.29), T4 (100% RDF + nano urea spray) (15.60) and T5 (100% RDF + NPK multiplex spray) (13.79) also recorded significantly higher values owing to improved nutrient availability and efficient translocation of assimilates to developing seeds. Similar results were observed by Rana *et al.* (2005) [32]. The highest number of filled seeds per silique was recorded in T7 (100% RDF + 25 kg S ha⁻¹ + nano urea spray) (20.69), which was significantly superior to T1 and statistically on par with T6 (100% RDF + 25

kg S ha⁻¹ + 2% urea spray) (19.90) and T8 (18.27). The superior performance may be attributed to the synergistic effect of sulphur and foliar nutrient sprays, which enhanced nutrient uptake, enzyme activity, photosynthesis and seed filling. Although T10 (75% RDF + nano urea spray) (12.04) and T11 (75% RDF + NPK multiplex spray) (11.95) recorded slightly lower values than T1, they were statistically on par with T1, indicating that foliar nutrient sprays under 75% RDF compensated for the reduced fertilizer dose. The lowest value was recorded in T9 (75% RDF) (7.83) due to inadequate nutrient supply, resulting in poor fertilization and seed development. These findings are in agreement with Piri and Sharma (2006) [29]

3.2.3. Test weight (g)

Test weight is an important seed quality parameter that reflects the extent of seed development and grain filling. It is influenced by nutrient availability during seed filling, although it is largely governed by the genetic potential of the variety. The analysis of data disclosed that application of sulphur and foliar spray effected test weight. This was presented in table (6).

The application of sulphur and nutrient sprays did not significantly influence test weight. Compared with T1 (100% RDF), all the treatments except T9 recorded superior values. Among them, T7 recorded the highest value and was statistically on par with T6 and T8, whereas T10 and T11, despite recording comparatively lower numerical values, were statistically on par with T1, indicating that foliar nutrient sprays under 75% RDF maintained the respective parameter at a level comparable to the recommended fertilizer dose. compared with T1 (100% RDF) (5.89 g), T2 (5.95 g), T3 (100% RDF + 2% urea spray) (5.93 g), T4 (100% RDF + nano urea spray) (5.94 g) and T5 (100% RDF + NPK multiplex spray) (5.91 g) recorded slight numerical improvements due to better nutrient uptake and enhanced protein and oil synthesis during seed development. Similar findings were reported by Rao *et al.* (2006) [33]. The lowest test weight was recorded in T9 (75% RDF) (4.90 g) due to inadequate nutrient availability during grain filling. Similar observations were reported by Meena *et al.* (2020) [21] and Satyanarayana *et al.* (2021) [40].

3.2.4. Seed yield (kg ha⁻¹)

Seed yield is the ultimate economic output of mustard and represents the cumulative effect of various physiological, biochemical and metabolic processes occurring throughout the crop growth period. It is the result of the integrated performance of growth and yield-attributing characters. Balanced nutrient management enhances the source-sink relationship by improving vegetative growth, photosynthetic efficiency and dry matter accumulation, thereby increasing the production and translocation of photosynthates from source tissues to developing seeds. Sulphur plays a vital role in chlorophyll synthesis, protein formation, enzyme activation and the synthesis of sulphur-containing amino acids, while foliar nutrient sprays improve nutrient availability during critical growth stages and enhance nutrient use efficiency. The data revealed that the application of sulphur and nutrient sprays significantly influenced seed yield was showed in Table (7).

Statistical analysis of data revealed that there was a significant difference in seed yield among treatments. Compared with T1 (100% RDF) (893.32 kg ha⁻¹), T2 (100% RDF + 25 kg S ha⁻¹) (1066.43 kg ha⁻¹) recorded a significantly higher seed yield due to improved chlorophyll synthesis, protein formation and nutrient uptake following sulphur application, resulting in better flowering and seed development. Similarly, T3 (100% RDF +

2% urea spray) (996.16 kg ha⁻¹), T4 (100% RDF + nano urea spray) (1003.18 kg ha⁻¹) and T5 (100% RDF + NPK multiplex spray) (992.37 kg ha⁻¹) also recorded significantly higher seed yield than T1 owing to improved nutrient availability, photosynthetic efficiency and assimilate translocation through foliar nutrient application. Similar findings were reported by Mishra *et al.* (2010) [23], Kumar *et al.* (2013) [14] and Singh *et al.* (2021) [44]. The highest seed yield was recorded in T7 (100% RDF + 25 kg S ha⁻¹ + nano urea spray) (1295.32 kg ha⁻¹), which was significantly superior to T1 and statistically on par with T6 (100% RDF + 25 kg S ha⁻¹ + 2% urea spray) (1231.11 kg ha⁻¹) and T8 (100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray) (1250.91 kg ha⁻¹). The higher seed yield may be attributed to the synergistic effect of sulphur and foliar nutrient sprays, which enhanced nutrient uptake, photosynthesis, dry matter production, siliqua formation and seed filling. These findings are in agreement with Katiyar *et al.* (2014) [9], Sienkiewicz-Cholewa and Kieloch (2015) [43] and Ravikumar *et al.* (2021) [35]. Although T10 (75% RDF + nano urea spray) (875.22 kg ha⁻¹) and T11 (75% RDF + NPK multiplex spray) (856.37 kg ha⁻¹) recorded slightly lower values than T1, both treatments were statistically on par with T1, indicating that foliar nutrient sprays partially compensated for the reduced fertilizer dose. The lowest seed yield was recorded in T9 (75% RDF) (683.74 kg ha⁻¹), which was significantly inferior to T1 due to inadequate nutrient availability and poor growth. Similar observations were reported by Nadaf and Chandranath (2019) [24] and Sharma and Bansal (1998) [41].

3.2.5. Stover yield (kg ha⁻¹)

Stover yield is an important indicator of vegetative growth and biomass production in mustard and reflects the crop's ability to efficiently utilize available nutrients throughout its growth period. It is the cumulative result of plant height, branching pattern, leaf area development and dry matter accumulation, all of which contribute to total above-ground biomass. The data revealed that the application of sulphur and nutrient sprays significantly influenced seed yield was showed in Table (7). Observation of the data revealed that stover yield of mustard increased significantly. Compared with T1 (100% RDF) (1855.89 kg ha⁻¹), T2 (100% RDF + 25 kg S ha⁻¹) (1965.72 kg ha⁻¹) recorded a significantly higher stover yield due to the role of sulphur in promoting cell division, cell elongation and structural development of plant tissues, resulting in vigorous vegetative growth and greater biomass accumulation. Similar observations were reported by Chaurasiya *et al.* (2019) [3] and Wasmatkar *et al.* (2005) [49]. Likewise, T3 (100% RDF + 2% urea spray) (1902.98 kg ha⁻¹), T4 (100% RDF + nano urea spray) (1931.94 kg ha⁻¹) and T5 (100% RDF + NPK multiplex spray) (1894.23 kg ha⁻¹) also recorded significantly higher stover yield than T1. This increase may be attributed to the timely foliar supply of nutrients during active crop growth, which prolonged leaf functionality, delayed senescence, promoted continuous vegetative growth and increased stem and leaf biomass. These findings are in agreement with Sankar *et al.* (2018) [38], Sharma *et al.* (2023) [43] and Verma *et al.* (2022) [48]. The highest stover yield was recorded in T7 (100% RDF + 25 kg S ha⁻¹ + nano urea spray) (2049.34 kg ha⁻¹), which was significantly superior to T1 and statistically on par with T6 (100% RDF + 25 kg S ha⁻¹ + 2% urea spray) (1993.85 kg ha⁻¹) and T8 (100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray) (1982.15 kg ha⁻¹). The superior performance of these treatments may be attributed to the combined application of sulphur and foliar nutrients, which maintained a balanced nutrient supply

throughout the crop growth period, encouraged vigorous canopy development, increased branching and stem growth, and enhanced the accumulation of structural carbohydrates producing greater vegetative biomass. These results corroborate the findings of Dhaliwal *et al.* (2021) [5]. Although T10 (75% RDF + nano urea spray) (1829.87 kg ha⁻¹) and T11 (75% RDF + NPK multiplex spray) (1799.78 kg ha⁻¹) recorded slightly lower numerical values than T1, both treatments were statistically on par with T1, indicating that foliar nutrient application under 75% RDF helped sustain vegetative growth despite the reduction in basal fertilizer application. The lowest stover yield was recorded in T9 (75% RDF) (1193.84 kg ha⁻¹), which was significantly inferior to T1 because the lower fertilizer dose without sulphur or foliar nutrients restricted vegetative development, reduced stem thickness and branching, and ultimately decreased biomass production.

4. Conclusion

From the results obtained in current research work, it could be concluded that 100% RDF alone under T1 was not adequate for basic crop production, but supplementation with 25 kg S ha⁻¹ and foliar nutrition, particularly under T7 (100% RDF + 25 kg S ha⁻¹ + 2% urea spray), improved crop growth, biomass production, reproductive development, seed and stover yield, oil productivity, nutrient uptake, soil biological activity and economic returns. As RDF supplemented with sulphur and foliar sprays gives best results as compared with 100% RDF and 75% RDF. T7 is on par with T6 (100% RDF + 25 kg S ha⁻¹ + 2% urea spray), and T8 (100% RDF + 25 kg S ha⁻¹ + NPK multiplex spray) but numerical superiority of T7 over T6 and T8 may be attributed to the more efficient complementary effect of nano plus urea foliar nutrition in combination with 100% RDF and basal sulphur application.

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