

Interactive Effect of Foliar Application of Zinc, Iron, and Nitrogen on Growth and Productivity of Mustard (*Brassica juncea* L.)

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Abstract

Foliar application has become the greatest strategy to enhance the micronutrient content in crops among different bio-fortification techniques and also promotes the growth of the plants even in less favourable climates as the nutrients are supplied to the plants at appropriate growth stages. Also, it prevents the depletion of nutrients in the environment and stimulates nutrient translocation in the edible part of the seed. Indian mustard (*Brassica juncea* L.) belonging to the Brassicaceae family cultivated in Rabi season. The deficiencies of micronutrients such as zinc (Zn), iron (Fe), and nitrogen (N) could significantly threaten public health as well limit the growth of the plant. This experiment aims to determine the impact of foliar applied Zn, Fe, and N and the interactive effect of Zn, Fe, and N on the growth and yield of mustard and also to determine the most efficient economical, treatment of Zn, Fe, and N to enhance oil quality and yield. This experiment was carried out at the Agronomy experimental field, School of Agriculture, Lovely Professional University, Punjab, in Randomized Block Design experimental design with 8 treatments and 3 replications. Therefore, the results of this experiment determined the influence of foliar-applied Zn, Fe, and N on the growth and yield of the mustard in which RDF +1% Urea Foliar Spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45DAS recorded remarkable variations over all other treatments.

Key words

Biofortification, Micronutrients, Sustainability, Foliar application, Mustard

Introduction

Indian mustard (*B. juncea* L.) belonging to the Brassicaceae family is one of the oldest and most important oilseed crops. The Brassicaceae contains about 3500 species and 350 genera and is one of the 10 most economically important plant families. The production of oil along with good quality forage such as stems and leaves, owing to their low fibre and high protein concentration, increases the importance of Indian mustard [1]. Rapeseed and mustard are the main oilseed crops grown in the Rabi season in India [2]. They are sown around mid-November, preferably harvesting begins in April or May after the monsoon rains are over. India is one of the dominant oilseed production countries across the globe with an estimated area, production, and yield of rapeseed-mustard in the world were 36.59 million hectares, 72.37 million tons and 1980 kg ha⁻¹, respectively, during 2018-19. Oilseed production is the second largest after cereals in India. India contributes nearly 23.33% and 26.24% mustard-rapeseed acreage and production respectively during 2018-19. It is one of the predominant crops in Gujarat, Haryana, Rajasthan, Uttar Pradesh, and Madhya Pradesh of India [3].

Mustard is the chief edible oilseed crop of the semi-arid area after groundnut, contributing nearly 26.1% of total oilseed production. According to COO-

IT, the production of mustard stood at 85 lakh tons in the 2020–21 crop year (July–June). According to Punjab director of agriculture, Gurvinder Singh said the area of cultivating mustard-rapeseed had increased steadily from 32,000 hectares in 2019–20 to 44,000 hectares in 2020–21 to 54,000 hectares this season (2021–22).

Micronutrients are as important to plant nutrition as primary and secondary nutrients, though plants don't require as much of them. Lack of any one of the micronutrients in the soil can limit growth, even when all other nutrients are present in adequate amounts. There is need for micronutrients application in order to achieve balanced nutrition. Thus, there is an urgent need for stepping up the use of micronutrients in growing field crops. Every micronutrient has specific role to play in plant physiology and its presence in optimum concentration in plant to complete its life cycle. The Zn and Fe also act as a structural component of several enzymes required for enzyme activation, stimulation of pod setting, seed formation and oil synthesis in the seeds of mustard [2]. The oilseed crop (Indian mustard) is highly sensitive to Zn, Fe, and N, deficiency, thereby resulting in a decreased growth, yield, and productivity of the crop [4, 5]. The introduction of high-yielding cultivars increased cropping intensity, application of micronutrient-free fertilizers, and limited addition of organic manures, leading to Zn, and Fe deficiency in most of the Indian soils.

Currently, 42% of Indian soils are not sufficient in Zn concentration, and this deficiency is expected to rise as more areas of marginal lands are being brought under intensive cultivation without any adequate micronutrient supplementation [6]. The Zn is closely involved in the metabolism of N and protein synthesis, whereas Fe contributes to the formation of chlorophyll and photosynthesis, thereby altering the yield and quality of oilseed crops [3]. In addition, N is a major nutrient that holds a crucial role in cell division, growth, photosynthetic activity, and protein synthesis, which acts as a base in the improvement of yield, and accumulation of nutrients, as well as the quality of oilseed crops, including Indian mustard [7]. Thus, a balanced amount of nutrient application is required for optimum yield and nutrient concentration of crops. Foliar application is the greatest strategy to increase the micronutrient content in crops among different bio-fortification techniques because nutrients are supplied to the leaves at the appropriate growth stages [8]. Recent research showed that micronutrients, particularly Zn, Fe, and N supplied through the foliar spray, has resulted in a significant increase in crop yield [9]. Therefore, the present study was performed to determine the influence of foliar-applied Zn, Fe and N on growth and yield of Indian mustard.

Materials and Methods

Preliminary information

This field experiment was carried out on the experimental field of Lovely Professional University, Phagwara, and Punjab, during the Rabi season 2022–2023, on the agricultural field lies in the Northern plain zone between Latitude 31° N, Longitude 31.25° N 7, and 5° E following all the intercultural practices as followed in PAU, Ludhiana's and norms for nor-

mal growth. The field trials were carried out on a sandy loam nature soil consisting of a total of 24 plots, with a size of 5 x 5 m with a spacing of 30 x 30 cm row apart. The analysis of the soil was carried out before the experiment to determine the initial nature of the soil. The crop was sown on 22nd of November with the variety of GHM-503.

The experiment was followed the Randomized Block Design with 8 treatments, and 3 replications via. T₁ - Control (recommended NPK only), T₂ - RDF+1% urea foliar spray at 45DAS, T₃ - RDF + 0.5% FeSO₄.7H₂O foliar spray at 45 DAS, T₄ - RDF + 0.5% ZnSO₄.7H₂O foliar spray at 45 DAS, T₅ - RDF + 0.5 % FeSO₄.7H₂O + 0.5% ZnSO₄.7H₂O foliar spray at 45 DAS, T₆ - RDF + 1% urea foliar spray + 0.5% FeSO₄.7H₂O at 45 DAS, T₇ - RDF + 1% urea foliar spray + 0.5% ZnSO₄.7H₂O at 45 DAS, T₈ - RDF +1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45DAS. The soil was fertilized with urea, and SSP as basal application. The crop was supplied with urea, FeSO₄, and ZnSO₄ at 45 DAS as foliar using a knapsack sprayer. Crop protection measures have been implemented depending on the necessity of foliar using a knapsack. The different morphological and physiological observations such as plant height, leaf area, number of leaves per plant, number of branches and plant dry weight were measured following standard protocol. The morphological attributes and the average value were recorded from the five random plants chosen from each plot, to determine the result of the data relation to the treatment.

Chlorophyll index: The chlorophyll index was determined by assessing the level of greenness in a mature leaf using a Soil Plant Analysis Development (SPAD) meter. The chlorophyll content is determined by calculating the average of three measurements obtained from a single leaf using a SPAD meter [10].

Crop growth rate: Crop growth rate (CGR) refers to the increase in dry matter production per unit of land over a specific period of time. The calculation can be determined by the formula provided by Watson [7] in the year 1952.

Relative growth rate: The relative growth rate (gg⁻¹day⁻¹) refers to the overall increment in the plant's dry weight seen between two specific time intervals. The term was introduced by Williams [11] in the year 1946.

Yield attributes: The yield attributes such as number of siliqua, average length of siliqua, average number of seed per siliqua, test weight, seed weight, stover yield and harvest index are observed at the harvest stage following standard protocols.

Quality attributes

Oil content (%): Mustard seeds were subjected to a drying process in a hot air oven at a temperature of 70 °C. This procedure effectively eliminated all moisture content from the seeds. Subsequently, the dried seeds were ground using a pestle and mortar, resulting in a powdered form. The extraction of oil from the powdered mustard seeds was performed using the Soxhlet method of oil extraction, as outlined in the AOAC [12] guidelines. The extraction process was carried out using the socoplus apparatus. The quantity of oil obtained was determined using the following formula:

$$\text{Oil content (\%)} = \frac{\text{Weight of oil flask + ether extract} - \text{weight of flask oil}}{\text{Substances taken}} \times 100$$

Oil recovery (kg ha⁻¹): Oil yield is computed by multiplying the seed yield with the concentration of oil. The following formula is used to compute oil recovery:

$$\text{Oil recovery kg ha}^{-1} = \frac{\text{Seed yield (kg / ha)} \times \text{oil content (\%)}}{100}$$

Protein content (%): The seed powder obtained from desiccated seeds was utilised to determine the nitrogen percentage in powdered seeds using Kjeldahl's method. Subsequently, the protein content of the seeds was calculated by multiplying the nitrogen percentage by 6.25.

Protein recovery (kg ha⁻¹): Protein recovery is the yield of protein. It was calculated by multiplying protein content extracted in percent by the seed yield (kg ha⁻¹) and divided by 100 which gave the protein recovery in kg ha⁻¹.

Statistical analysis

The study employed the SPSS 22 programme to analyse data using the generalised linear model within the framework of univariate approaches. This model was utilised to examine the variations in means resulting from two components. In order to determine the optimal treatment, a mean separation technique was employed, utilising a significance level of $p < 0.05$ and the Duncan multiple range test. The Fisher's least significant difference test was employed as a post-hoc analysis to assess the presence of a significant difference between the means. The computations were derived from the least significant difference with a significance threshold of 5%.

Results

Interactive effect of Zn, Fe, and N on growth attributes of mustard

Plant height is the main growth and yield contributing character. Plant height in the case of mustard varied significantly by the different fertilizer and their amount. There was a significant variation recorded in the case of all the treatments. The discrimination between the plots from germination to 60 DAS due to different treatments shown in figure 1, figure 2, and figure 3. Highest plant height (147.56 cm) was recorded in treatment RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS, although, treatment RDF + 1% urea foliar spray + 0.5% FeSO₄·7H₂O at 45 DAS also showed the same effect on plant height. The second highest plant height (137.60cm) was recorded in treatment RDF + 0.5% FeSO₄·7H₂O foliar spray at 45 DAS. There was non-significant variation observed in treatment RDF + 0.5% FeSO₄·7H₂O foliar spray at 45 DAS, RDF + 0.5% FeSO₄·7H₂O + 0.5% ZnSO₄·7H₂O foliar spray at 45 DAS, RDF + 1% urea foliar spray + 0.5% ZnSO₄·7H₂O at 45 DAS, the lowest plant height (125.2 cm) was recorded in control. The leaf area is also an important index in plants. Leaves supply all the required food for the plant in the process of photosynthesis. The leaf area indicates the health and plant potential to produce improved yield and quality.

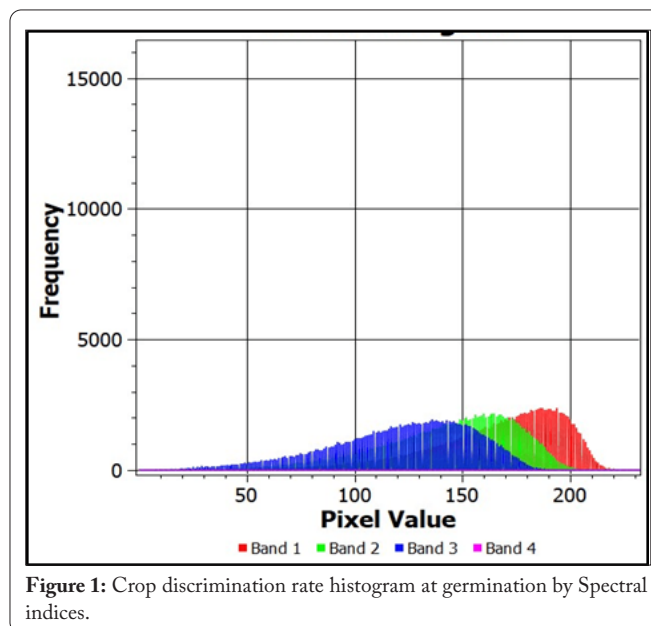


Figure 1: Crop discrimination rate histogram at germination by Spectral indices.

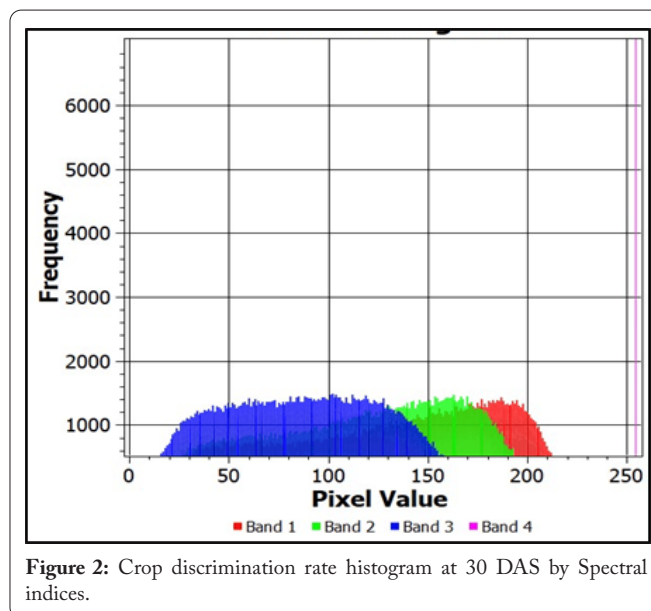
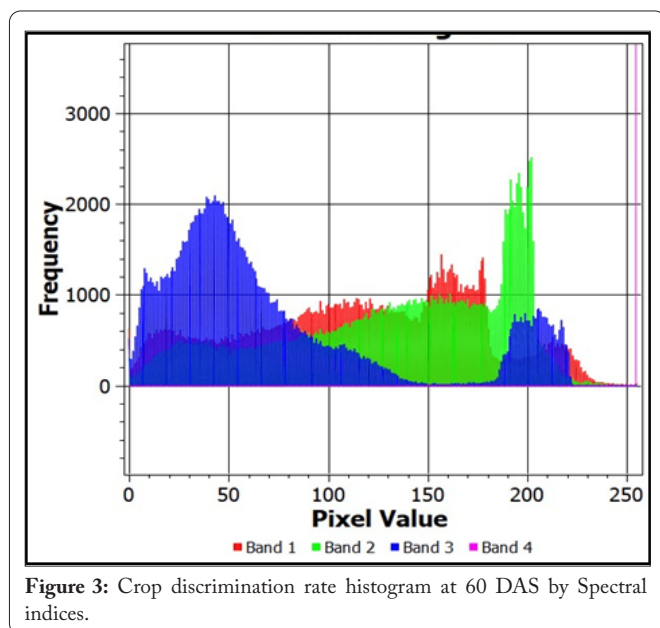


Figure 2: Crop discrimination rate histogram at 30 DAS by Spectral indices.

The impact on the leaf area of different treatments is significant in the case of mustard. RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS recorded the best leaf area with 641 cm² followed by RDF + 1% urea foliar spray + 0.5% FeSO₄·7H₂O at 45 DAS also RDF + 1% urea foliar spray + 0.5% ZnSO₄·7H₂O at 45 DAS has the similar leaf area. Control (recommended NPK only) has the minimum leaf area. The number of leaves has a great impact on the growth of the plant. It plays an important mechanism in providing food to plants in the process of photosynthesis for their growth. The highest number of leaves (77.66) is observed with the application RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS. RDF + 1% urea foliar spray + 0.5% ZnSO₄·7H₂O at 45 DAS (74.66) has the second highest number of leaves and RDF + 0.5% FeSO₄·7H₂O foliar spray at 45 DAS recorded the minimum number of leaves. In case of mustard the impact of different treatments was observed significantly on numbers of leaves.



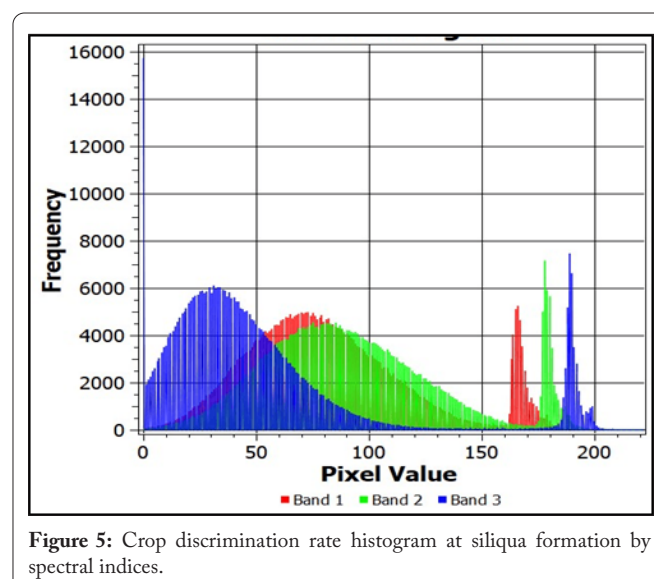
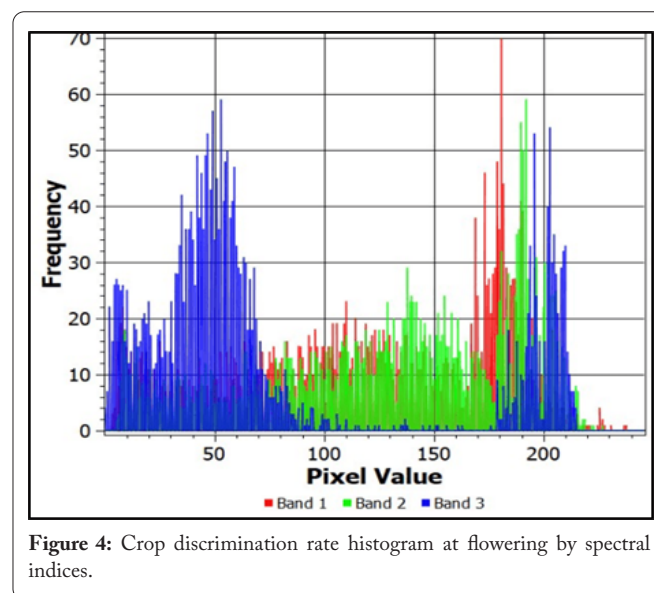
The chlorophyll index indicates the health of the plants. In the case of mustard crops, chlorophyll plays a major role in the growth of the crop takes the role in process of photosynthesis providing the required food for the plant. RDF + 1% urea foliar Spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS recorded the best chlorophyll index with 54.2, RDF + 0.5% FeSO₄·7H₂O foliar spray at 45 DAS (51.63) observed the second-best chlorophyll index. Control (recommended NPK only) was recorded the minimum chlorophyll index of 48.3. With different treatments, the effect on chlorophyll index was observed significant in the case of mustard. Dry weight helps evaluate the plants' potential with different treatments applied and evaluate the yield or quality of the crop. The dry weight was recorded significantly with different treatments. RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS was recorded the highest (83.33 g), however RDF + 1% urea foliar spray + 0.5% FeSO₄·7H₂O at 45 DAS and RDF + 1% urea foliar spray + 0.5% ZnSO₄·7H₂O at 45 DAS had same effect. The second highest (77.86 g) was recorded in control (recommended NPK only). RDF + 0.5% ZnSO₄·7H₂O foliar spray at 45 DAS, (76.466 g) was recorded minimum dry weight. The CGR (g day⁻¹ m⁻²) is an important parameter in agriculture research. It provides valuable observation into crop productivity, developments, and responded to environmental factors.

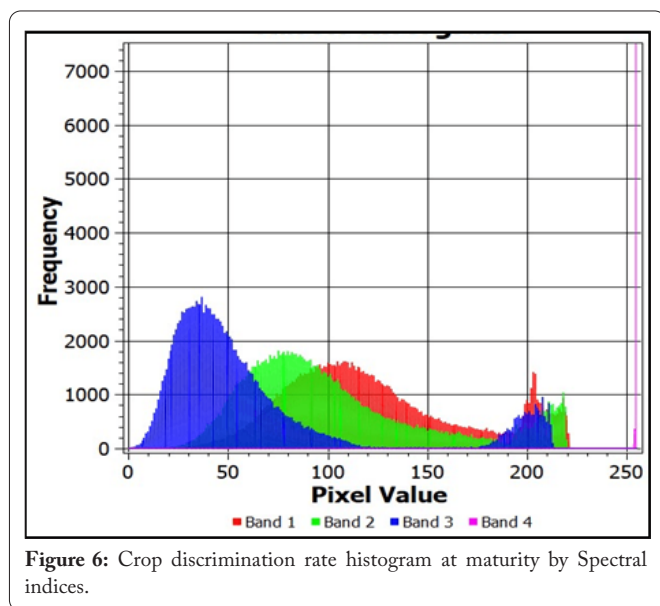
In this experiment RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS recorded the maximum CGR (1.35 g day⁻¹ m⁻²). Control (recommended NPK only) observed the second-highest CGR. The minimum CGR was recorded on RDF + 0.5% ZnSO₄·7H₂O foliar spray at 45 DAS (1.24 g day⁻¹ m⁻²). The RGR (g g⁻¹ day⁻¹) measures the growth potential of the plant. It compares the growth rate of the plant with different treatments and insight into the plant's growing efficiency in adapting to the environment. RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS recorded the best RGR (0.0870 g g⁻¹ day⁻¹) followed by RDF + 1% urea foliar spray + 0.5% ZnSO₄·7H₂O at 45 DAS (0.076 g g⁻¹ day⁻¹). The lowest RGR was recorded on RDF +

1% urea foliar spray + 0.5% FeSO₄·7H₂O at 45 DAS (0.0633 g g⁻¹ day⁻¹).

Interactive effect of Zn, Fe, and N on yield attributes of mustard

There was clear variation recorded at flowering and siliqua formation stages. The discrimination between the plots from flowering to maturity due to different treatments shown in figure 4, figure 5, and figure 6. Siliqua per plant can determine the productivity of the seed yield. The plant with more siliqua has more seed yield. The highest siliqua was 278 recorded in application of RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS, followed by RDF + 1% urea foliar spray + 0.5% FeSO₄·7H₂O at 45 DAS (263.33). The minimum siliqua per plant (247) was observed in control (recommended NPK only) with. The different treatments observed significant siliqua per plant. Seed per siliqua is the number of grains present in one pod. The amount of yield increased with a greater number of seeds per siliqua is more. RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS gives





the highest seed per siliqua (21.33), although RDF + 1% urea foliar spray + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ at 45 DAS, RDF + 1% urea foliar spray + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ at 45 DAS also observed the similar effect. The second highest seed per siliqua (17) was observed in the application of RDF + 0.5 % $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray at 45 DAS.

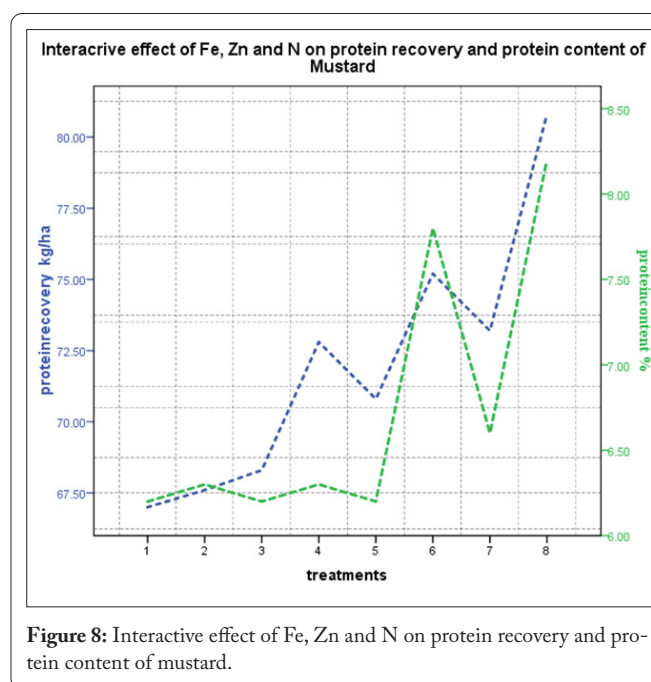
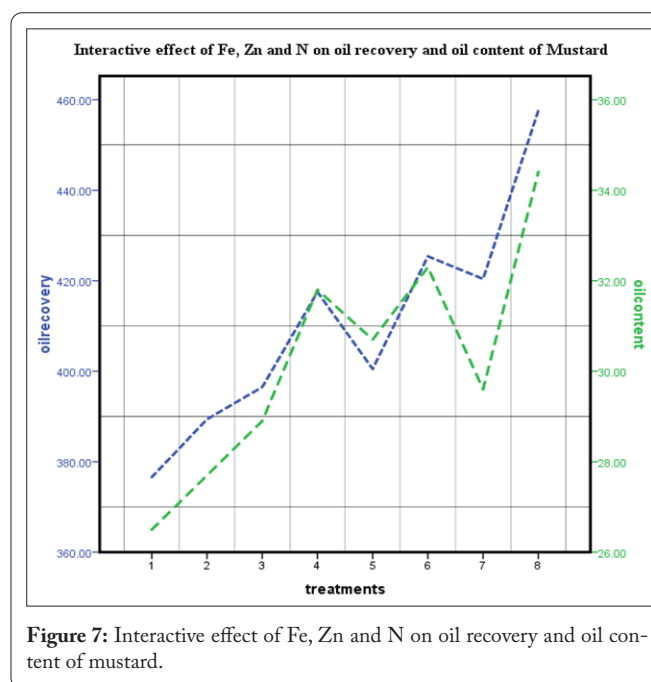
The lowest impact (14.66) was recorded in RDF + 1% urea foliar spray at 45 DAS. Siliqua is one of the major components in the yield of oil crops. Its length and size denote the quantity of the yield. The more the length and size of the siliqua has more yield. With different fertilizers and their quantity applied to the mustard crop, the length of the siliqua has been recorded as significant. The highest length of siliqua was observed in RDF +1% urea foliar spray 45 DAS + 0.5% ZnSO_4 + 0.5% FeSO_4 at 45 DAS 5.72cm. The second highest length of siliqua 5.51 cm was recorded in RDF + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray 45 DAS. Control (recommended NPK only) was recorded the lowest length of siliqua (5.18 cm). Seed yield is the most important product in the crop. The seed yield was determined the success of cultivating a crop. The best seed yield of 2869 kg ha^{-1} was recorded in RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO_4 + 0.5% FeSO_4 at 45 DAS. RDF + 0.5% ZnSO_4 at 45 DAS observed the second-best seed yield of 2465 kg ha^{-1} RDF + 1% urea foliar spray at 45 DAS observed the minimum effect on seed yield with 1998 kg ha^{-1} .

The highest stover yield (5615.93 kg ha^{-1}) was recorded in RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO_4 + 0.5% FeSO_4 at 45 DAS which was followed by RDF + 1% urea foliar spray + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ at 45 DAS with 5340 kg ha^{-1} stover yield. The lowest stover yield of 4655.8 kg ha^{-1} was recorded in RDF + 0.5 % $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray at 45 DAS. The different treatments were observed significant among themselves. The harvest index (%) of a plant reflects the potential yield of the crop and its economic value. It also measures how efficiently a plant allocates its resource to the plant parts harvested for human consumption. RDF + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray at 45 DAS (35.16%) observed the highest harvest index. The second highest (31.57%) was ob-

served in control (recommended NPK only) and the lowest was observed in RDF + 1% urea foliar spray at 45 DAS (29.29%).

Interactive effect of Zn, Fe, and N on quality attributes of mustard

It was concluded from the figure 7 that the highest oil content (34.40%) was recorded in the interaction of RDF + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray + 1% urea foliar spray 45 DAS. While the lowest concentration of oil (26.5%) was recorded in 100% RDF. Highest oil recovery (457.6 kg ha^{-1}) was recorded in the interaction between RDF + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray + 1% urea foliar spray 45 DAS. While the lowest oil recovery (376.6 kg ha^{-1}) was observed in the control. Perusal of trend of data from the figure 8 specified that the



interaction effects of Fe, Zn and N fertilizer levels recorded a maximum concentration of protein (8.2%) in the interaction of RDF + 0.5% FeSO₄·7H₂O Foliar Spray + 0.5% ZnSO₄·7H₂O foliar spray + 1% urea foliar spray 45 DAS. While the least amount of concentration of protein (6.7%) was recorded in the interaction 100 % RDF level. Scrutiny of data trend from figure 8 portrayed that the interaction effects of Fe, Zn and N fertilizer level recorded maximum protein recovery (80.83 kg ha⁻¹) in the RDF + 0.5% FeSO₄·7H₂O foliar spray + 0.5% ZnSO₄·7H₂O foliar spray + 1% urea foliar spray 45 DAS. While the minimum amount of protein recovery (67 kg ha⁻¹) was recorded in the interaction 100% RDF level.

Correlation of quality parameters of mustard with seed yield

There was a positive correlation exist between quality parameters and seed yield. ** shown that correlation is statistically significant among themselves. There was a linear trend observed if seed yield increased than quality parameters viz. oil recovery, oil content, protein recovery and protein content also increased as shown in table 1.

Discussion

Impact on growth parameter on the application of urea, ZnSO₄, and FeSO₄ on mustard

The maximum plant height (147.566 cm), leaf area (641 cm²), number of leaves (77.66), chlorophyll index (54.2), and dry weight (83.33 g ha⁻¹) were observed in the application of RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO₄ + 0.5% FeSO₄ at 45 DAS as compared to control (recommended NPK). This may be due to the right balance of macro and micronutrients for the optimum growth of the mustard. N being the constituent of amino acids, proteins, chlorophyll, and protoplast would directly influence the growth and yield attributing characteristics through better utilization of photosynthates. Also, the increase in N supply increases the amount of protein formed and therefore the amount of protoplasm (Table 2).

This increase in turn results in greater cell size, more cell division, and larger leaf area. It ultimately provides a larger frame, resulting in improved plant height and number of capsules. It is also reported an increase in growth and yield attributes of rapeseed mustard due to N application [13]. Zinc and iron application increased root cell membrane integrity, plant enzyme systems, protein synthesis, and auxins which increase photosynthetic assimilates and seed set, and finally increased grain yield [14]. The minimum plant height (125.2 cm), leaf area (519.93 cm²), chlorophyll index (48.3), and dry weight (76.46 kg ha⁻¹) was observed in control (recommended NPK)

Table 1: Correlation of quality parameters of mustard with seed yield.

| Correlations | | | | | | |
|------------------|---------------------|--------------|-------------|------------------|-----------------|------------|
| | | Oil recovery | Oil content | Protein recovery | Protein content | Seed yield |
| Oil recovery | Pearson Correlation | 1 | 0.930* | 0.986** | 0.847** | 0.755* |
| Oil content | Pearson Correlation | 0.930** | 1 | 0.932** | 0.773* | 0.681 |
| Protein recovery | Pearson Correlation | 0.986** | 0.932** | 1 | 0.884** | 0.716* |
| Protein content | Pearson Correlation | 0.847** | 0.773* | 0.884** | 1 | 0.591 |
| Seed yield | Pearson Correlation | 0.755* | 0.681 | 0.716* | 0.591 | 1 |

** . Correlation is significant at the 0.01 level (2-tailed); * . Correlation is significant at the 0.05 level (2-tailed)

Table 2: Interactive effect of Fe, Zn, and N on growth parameter of mustard crop.

| Treatments | Plant height (cm) | Leaf area (cm ²) | No. of leaves | Chlorophyll index (SPAD) | Dry weight (g ha ⁻¹) | CGR (g day ⁻¹ m ⁻²) | RGR (g g ⁻¹ day ⁻¹) |
|---|---------------------------|------------------------------|-------------------------|-----------------------------|----------------------------------|--|--|
| Control (recommended NPK only) | 48.30d ± 0.82 | 519.9 ^f ± 2.5 | 71 ^c ± 1.15 | 48.30 ^d ± 0.82 | 77.87 ^b ± 1.90 | 1.275 ^b ± 0.023 | 0.064 ^c ± 0.003 |
| RDF + 1% urea foliar spray at 45 DAS | 49.73 ^d ± 1.33 | 522.6 ^f ± 1.6 | 73 ^{bc} ± 1.03 | 49.73 ^{bcd} ± 1.33 | 77.20 ^b ± 1.06 | 1.262 ^b ± 0.015 | 0.066 ^c ± 0.001 |
| RDF + 0.5% FeSO ₄ ·7H ₂ O foliar spray at 45 DAS | 51.63 ^b ± 1.11 | 542.8 ^d ± 2.5 | 69 ^d ± 1.15 | 51.63 ^{bc} ± 1.11 | 76.57 ^b ± 2.10 | 1.250 ^b ± 0.029 | 0.065 ^c ± 0.001 |
| RDF + 0.5% ZnSO ₄ ·7H ₂ O foliar spray at 45 DAS | 50.47 ^c ± 1.43 | 577.8 ^c ± 2.1 | 74 ^b ± 1.26 | 50.47 ^{bcd} ± 1.43 | 76.47 ^b ± 1.37 | 1.249 ^b ± 0.024 | 0.069 ^c ± 0.001 |
| RDF + 0.5 % FeSO ₄ ·7H ₂ O + 0.5% ZnSO ₄ ·7H ₂ O foliar spray at 45 DAS | 50.60 ^b ± 0.86 | 536.5 ^e ± 1.5 | 71 ^c ± 0.75 | 50.60 ^{bcd} ± 0.86 | 76.70 ^b ± 1.21 | 1.252 ^b ± 0.017 | 0.064 ^c ± 0.000 |
| RDF + 1% urea foliar spray + 0.5% FeSO ₄ ·7H ₂ O at 45 DAS | 52.30 ^a ± 0.54 | 592.7 ^b ± 4.2 | 74 ^b ± 1.80 | 52.30 ^b ± 0.54 | 81.83 ^a ± 1.61 | 1.334 ^a ± 0.022 | 0.064 ^c ± 0.000 |
| RDF + 1% urea foliar spray + 0.5% ZnSO ₄ ·7H ₂ O at 45 DAS | 49.27 ^b ± 0.42 | 577.0 ^c ± 2.6 | 74 ^b ± 1.10 | 49.27 ^{cd} ± 0.42 | 81.97 ^a ± 1.31 | 1.335 ^a ± 0.017 | 0.076 ^b ± 0.003 |
| RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO ₄ + 0.5% FeSO ₄ at 45 DAS | 54.30 ^a ± 1.76 | 641.0 ^a ± 3.7 | 77 ^a ± 0.61 | 54.20 ^a ± 1.76 | 83.33 ^a ± 1.53 | 1.352 ^a ± 0.20 | 0.087 ^a ± 0.004 |

and the minimum number of leaves (68.66) in RDF + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray at 45 DAS due to the fact that lack of the required nutrients in an optimum amount decrease the growth of the crops.

Impact of urea, ZnSO_4 , and FeSO_4 on yield parameters of mustard

The maximum number of siliqua (21.33), length of siliqua, stover yield ($5615.93 \text{ kg ha}^{-1}$), and seed yield (2867 kg ha^{-1}) with the application of RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO_4 + 0.5% FeSO_4 at 45 DAS was recorded (Table 3). The improvement in yields with the foliar application of micronutrients (Zn and Fe) and urea may be due to the fact that the erogenous supply of N fertilizer resulted in increased photosynthetic rate, synthesis of metabolites, assimilates and its translocation to grains thereby enhancing the growth, performance, and value of oilseed crops. These results are in accordance with the findings of [15, 16]. The minimum seed yield and number of siliqua recorded in RDF + 1% urea foliar spray at 45 DAS might be due to the lack of micronutrients i.e., Fe and Zn, which Zn and Fe application increased root cell membrane integrity, plant enzyme systems, protein synthesis, auxins which increase photosynthetic assimilates and seed setting and finally increased grain yield [12]. The minimum length of siliqua (5.18 cm) in control (recommended NPK) and the less stover yield ($4655.8 \text{ kg ha}^{-1}$) in RDF + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray at 45 DAS might be due to lack of optimum micronutrients and macronutrients that the combined application of micronutrients (Zn and Fe) with nitrogen followed by foliar sprays of micronutrients produced the highest grain and stover yield. Similar results have also been reported on the higher straw production on the combined application of micronutrients (Zn + Fe) in mustard crops [17, 18].

Impact of Fe, Zn, and N on quality parameters of mustard

Oil content and oil recovery increased with the application RDF + 1% urea foliar spray 45 DAS + 0.5% ZnSO_4 + 0.5% FeSO_4 at 45 DAS that could be attributed to the fact that RDF provides essential macro and micronutrients that are necessary for the overall growth and development of the mustard plants. Urea, which is a source of N, helps in promoting vegetative growth and increasing biomass. The Zn and Fe are essential micronutrients that play crucial roles in various physiological and biochemical processes, including photosynthesis and enzyme activation. Foliar application of urea, which is a N source, helps provide an additional and readily available nutrient supply directly to the leaves.

This can enhance photosynthetic activity and plant metabolic processes. Increased photosynthesis can lead to higher carbohydrate production, which is ultimately used for oil synthesis. The addition of ZnSO_4 and FeSO_4 supplies essential micronutrients that can positively influence oil synthesis and accumulation. The Zn is involved in the synthesis of growth regulators and enzymes related to oil metabolism, while Fe plays a role in chlorophyll synthesis and energy transfer processes. The Zn and Fe are cofactors for many enzymes involved in various biochemical reactions, including those related to lipid (oil) metabolism. These enzymes are essential for the synthesis and accumulation of oil in mustard seeds. This result is in similar with the findings of Kumar et al. [2].

Protein content and protein recovery increased with the application of RDF along with urea foliar spray, ZnSO_4 and FeSO_4 at a specific stage of growth in mustard plants can lead to an increase in protein content and protein yield for several reasons: Firstly urea, a N-rich fertilizer, is a key component of the applied treatment. The N is a fundamental building block

Table 3: Effect of Fe, Zn, and urea on yield parameter of mustard crop.

| Treatments | No. of siliqua per plant | Length of siliqua (cm) | No. of seeds per siliqua | Seed yield (kg ha^{-1}) | Stover yield (kg ha^{-1}) | Harvest index (%) |
|---|----------------------------|---------------------------|-----------------------------|------------------------------------|--------------------------------------|----------------------------|
| Control (recommended NPK only) | 247.00 ^c ± 2.65 | 5.18 ^c ± 0.17 | 15.00 ^d ± 1.00 | 2178.50 ^c ± 98.45 | 4718.93 ^d ± 73.45 | 31.57 ^b ± 0.523 |
| RDF + 1% urea foliar spray at 45 DAS | 253.33 ^d ± 3.51 | 5.38 ^b ± 0.11 | 14.67 ^d ± 0.58 | 1998.00 ^c ± 88.02 | 4821.87 ^d ± 69.82 | 29.29 ^c ± 0.700 |
| RDF + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray at 45 DAS | 51.63 ^d ± 3.06 | 5.25 ^{bc} ± 0.05 | 15.57 ^{bcd} ± 0.51 | 2746.53 ^a ± 108.39 | 5062.57 ^c ± 151.57 | 35.16 ^a ± 0.442 |
| RDF + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray at 45 DAS | 50.47 ^{cd} ± 3.06 | 5.46 ^{ab} ± 0.04 | 16.43 ^{bc} ± 0.45 | 2465.00 ^b ± 120.02 | 4751.87 ^d ± 122.21 | 34.15 ^a ± 1.046 |
| RDF + 0.5 % $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ foliar spray at 45 DAS | 50.60 ^e ± 2.00 | 5.51 ^{ab} ± 0.10 | 17.00 ^b ± 0.50 | 2450.07 ^b ± 141.28 | 4655.80 ^d ± 125.94 | 34.47 ^a ± 1.546 |
| RDF + 1% urea foliar spray + 0.5% $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ at 45 DAS | 52.30 ^b ± 3.06 | 5.68 ^a ± 0.19 | 21.33 ^a ± 0.74 | 2733.80 ^a ± 87.20 | 5340.00 ^b ± 91.77 | 33.85 ^a ± 0.661 |
| RDF + 1% urea foliar spray + 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ at 45 DAS | 49.27 ^{bc} ± 1.53 | 5.48 ^{ab} ± 0.13 | 20.30 ^b ± 0.98 | 2804 ^a ± 103.33 | 5234.57 ^{bc} ± 111.05 | 34.88 ^a ± 1.074 |
| RDF +1% urea foliar spray 45 DAS + 0.5% ZnSO_4 + 0.5% FeSO_4 at 45 DAS | 54.30 ^a ± 2.65 | 5.72 ^a ± 0.25 | 21.33 ^a ± 1.22 | 2867.83 ^a ± 91.81 | 5615.93 ^a ± 103.74 | 33.80 ^a ± 0.588 |

of proteins. Adequate N availability can stimulate the synthesis of amino acids, the basic units of proteins, which ultimately leads to increased protein content in plants. Foliar spraying of urea provides a direct and easily absorbable N source to the leaves. This enhances the availability of N for protein synthesis, particularly during the critical growth phase. The addition of $ZnSO_4$ and $FeSO_4$ contributes to the overall health and metabolic processes of the plant. Micronutrients, such as Zn and Fe, play roles in enzyme activation and metabolic pathways that are involved in amino acid synthesis and protein formation. Micronutrients like Zn and Fe act as cofactors for enzymes that are directly or indirectly involved in protein synthesis. These enzymes facilitate the conversion of amino acids into proteins, ensuring optimal protein production. Micronutrients like Zn and Fe are involved in various metabolic pathways, some of which intersect with the processes of amino acid and protein synthesis. These pathways are essential for producing the necessary building blocks for protein molecules. This result is in corroboration with the findings of Dhaliwal et al. [17].

Conclusion

The deficiencies of micronutrients have reduced the growth and yield of various oil crops in Indian soil. The foliar application of micronutrients Fe and Zn with macronutrient N enhances the growth and the potential to produce more yield. In the case of mustard, the foliar application of Fe, Zn along with urea observed significant results. In this experiment treatment RDF + 1% urea foliar spray 45 DAS + 0.5% $ZnSO_4$ + 0.5% $FeSO_4$ at 45 DAS (2867.83 kg ha⁻¹) observed the maximum yield as well as the best growth on all the treatments. Thus, the treatment combination of Fe and Zn with urea was observed as the most efficient treatment. However, this treatment will influence the growth and productivity of the crop which can enhance the economic growth of the farmers.

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Conflict of Interest

The authors declared that they have no conflict of interest with respect to this work.

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