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Effect of Nitrogen and Boron Fertilization on Nutrient Content and Uptake by Mustard Crop in Chitrakoot Area

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Authors' contributions

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

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ABSTRACT

This study assessed the impact of nitrogen (N) and boron (B) fertilization on yield, nutrient composition, and nutrient uptake in Indian mustard (*Brassica juncea*) in Chitrakoot, Madhya Pradesh, India. A field trial featuring 13 treatments combined reduced nitrogen levels, nano-urea applications, and different boron doses, using a randomized block design with three replications. Treatment T12 [½ recommended nitrogen dose (RDN) + two nano-urea sprays + 1.25 kg B ha^{-1}] achieved the highest seed yield (1523.81 kg ha^{-1}), surpassing the control (100% NPK as per RDF) which yielded 958.73 kg ha^{-1}. T_{12} also had the highest nutrient concentrations 2.78% nitrogen,

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0.482% phosphorus, and 0.74% potassium as well as the highest nutrient uptake, with nitrogen at 42.36 kg ha^{-1}, phosphorus at 7.34 kg ha^{-1}, and potassium at 11.28 kg ha^{-1}. These results indicate that combining nano-urea with boron, especially at elevated boron levels, can significantly improve yield and nutrient absorption in mustard, highlighting its potential for sustainable farming in semi-arid areas.

Keywords: Nitrogen; boron; yield; nutrient content; nutrient uptake.

1. INTRODUCTION

Mustard (*Brassica juncea* (L.)) is considered to be one of the most valuable oil-seed crops. It belongs to Brassicaceae (*Cruciferae*) family, with around 338 genera and 3709 species scattered worldwide. Mustard seeds are known by several names in different parts of the world, such as sarson, rai or raya, toria or lahi. While sarson and toria (lahi) are commonly referred to as rapeseed, rai, raya, or laha. Afghanistan and neighbouring countries (Central Asia) were the principal sites of origin, whereas central and western China, eastern India, and Asia were subsidiary centres of origin for Brassica [1].

The oil is utilized for human consumption throughout northern India for cooking and frying purposes. The whole seed is used as condiment in the preparation of pickles and for flavouring curries and vegetables. The mustard oil is also used in preparing vegetable ghee, hair oil, medicines, soaps, lubricating oil and in tanning industries. The oil content in mustard seeds varies from 37-49 per cent. The seeds are highly nutritive containing 38-57% erucic acid, 5- 13% linolic acid and 27% oleic acid [2].

India ranks third in terms of area and production of rapeseed-mustard after Canada and China. Globally, the area and production of rapeseed-mustard is 36.81 million hectares and 72.61 million tonnes, respectively [3]. Rapeseed mustard is the second most consumed edible oilseed crop in India, after soybean. India has 6.23 million hectares area under rapeseed mustard and 9.34 million tonnes production with average productivity of 1499 kg ha^{-1}, which is about three-fourth of the world's average productivity (1960 kg ha^{-1}) (DAC & FW, 2020). In the Madhya Pradesh, it is grown on an area 1038.15 thousand hectares with a production of 1.69 million tonnes (Anonymous 2021-22).

Nitrogen is central to plant growth due to its presence in nucleic acids, enzymes, chlorophyll proteins and hormones [4]. Nitrogen is the most limiting nutrient for crop production worldwide, primarily due to soils' restricted capacity to provide sufficient available nitrogen. Consequently, humans have consistently supplemented soil nitrogen with inorganic fertilizers to boost crop yields [5].

In order to improve N use efficiency, several slow/controlled release fertilizers like neem-coated urea, tar-coated urea, nano fertilizers have been studied extensively to enhance Nitrogen use efficiency. These formulations aim to extend the release of nitrogen over a prolonged period, thereby reducing nutrient loss through leaching or volatilization and ensuring a more efficient uptake by the plants. Nanotechnology involves manipulating materials at the atomic, molecular and macromolecular scales, which operate at 100 nm, their properties significantly differed from at a large scale [6,7]. Nanofertilizers are designed to control the release of nutrients [8] from the fertilizer granules, thereby improving nutrient use efficiency while minimizing losses to the environment [9] and supply with a range of nutrients in desirable proportions. These fertilizers utilize nanomaterials to enhance nutrient delivery to plants, potentially increasing efficiency and reducing environmental impact compared to traditional fertilizers. The use of nano fertilizers has the potential to increase in nutrient use efficiency, reduces soil toxicity, minimizes the potential negative effects associated with over dosage and reduces the frequency of the application [10].

Widespread B deficiencies in soils have been reported from different parts of the world [11]. Deficiency of B has been now emerged in Indian soils and crops, next to zinc primarily due to intensive cultivation using high yielding crop varieties that warrants for precise estimation of the B in soils. Studies on B in soils and plant are mostly confined to acid soils, neutral to alkaline and non-calcareous soils were well-supplied with B. However, in the post-Green revolution period, inadequacy or sufficiency of different nutrients, including B, in the soil depended mainly on its annual withdrawals under exhaustive cropping systems and replenishment through fertilizers, manures, crop residues and irrigation water [12]. Continuous neglect of B replenishment over the years led to emergence of B deficiency across the soils and crops in India and with spread deficiencies are now noticed in the areas that were generally considered rich in B. Resent estimates suggested B deficiency in one-third of over 40 thousand soil samples analysed [13].

Recent advances in B research have greatly improved an understanding for B uptake and transport processes [14], and roles of B in cell wall formation [15], cellular membrane functions [16], and anti-oxidative defense systems. Reproductive growth, especially flowering, fruit and seed set is more sensitive to boron (B) deficiency than vegetative growth. Thus, B fertilization is necessary for improvement of crop yield as well as nutritional quality. Mustard as a Brassica crop is very responsive to B application. There are numerous reports on the positive response of mustard to B fertilization [17,18].

2. METHOD AND MATERIALS

2.1 Experimental Sites

This experiment took place at the Rajaula Agriculture Farm, located within Mahatma Gandhi Chitrakoot Gramoday Vishwavidyalaya in Chitrakoot, Satna, Madhya Pradesh. The farm is situated in a semi-arid, sub-tropical region, positioned at 25.148° North latitude and 80.855° East longitude, with an elevation ranging from 190 to 210 meters above sea level.

2.2 Edaphic Condition

The chemical properties of the experimental soil are summarized as follows: The soil pH was measured to be 7.4 using a glass electrode and pH meter, following the method described by Jackson [19]. Electrical conductivity (EC), determined using a conductivity bridge with a soil-water suspension ratio of 1:2.5, was found to be 0.34 dS/m [19]. Organic carbon content was relatively low at 0.31%, as measured by the Wet Oxidation Method [20]. The total nitrogen content of the soil was 97.68 kg ha^{-1}, assessed using the Kjeldahl Method [21]. Available phosphorus was measured at 16.25 kg ha^{-1} using the colorimetric method [22], while available potash was relatively high at 292.90 kg ha^{-1}, determined by flame photometry following ammonium acetate extraction [23]. The soil also had an available boron content of 0.38 mg kg^{-1}, as determined by the Azomethine-H method [24].

2.3 Crop Husbandry

Field preparation involved tractor-driven ploughing with a disc plough, followed by cross-harrowing and levelling. After the land was prepared, the experiment was set up according to the treatment plan across 39 plots. Each plot measured 5.0 x 4.0 meters (gross plot) with a net plot size of 4.5 x 3.5 meters. Farmyard manure (FYM) was applied as a basal dose at a rate of 10 q ha^{-1}. Fertilizers, weighed according to treatment recommendations, were evenly applied and mixed into the soil of each plot. The designated doses of Nitrogen, Phosphorus, and Potassium (60:40:40 kg ha^{-1}) were supplied through Urea, DAP, and MOP, respectively, while boron was provided through borax at varying doses (0, 0.5, 1.0, 1.25 kg B ha^{-1}). Seeds were sown in rows created by narrow furrows, using a pointed wooden stick to achieve precise row spacing. The experiment was conducted without irrigation throughout the crop cycle. The crop reached physiological maturity on February 14, 2023, marked by yellowing leaves and more than 70% of the capsules fully matured. Harvesting occurred at this stage to minimize shattering losses

2.4 Detail of Treatments and Design

The 13 treatments combination of nutrient management practices. Experiment was laid out in Randomized Block Design with three replications.

2.5 Nutrient Content and Uptake

Nitrogen content (per cent) and uptake (kg ha^{-1}): The nitrogen content in grain was determined by micro- kjeldahl's method [19]. The total nitrogen uptake was calculated by multiplying nitrogen content to the total dry weight to grain yield.

$$\text{N} - \text{uptake by grain (kg ha}^{-1}) = \frac{\text{N content in grain (\%)}\times\text{grain yield (kg ha}^{-1})}{100}$$

Phosphorous content (per cent) and uptake (kg ha^{-1}): The phosphorous content was analyzed in grain separately to work out their uptake. Plant samples were dried in drier at 70± 5^{0}C for 72 hours and followed wet digestion, vanado-molybdo phosphoric acid yellow colour method [19]. The total phosphorous uptake was calculated as below.

Table 1. Treatment combination

Symbol	Treatment Combinations	Details of Treatment
T_0		100% NPK as per RDF
T_1	N_0B_0	½ of RDN + (2 water spray + 0.0 kg B)
T_2	N_1B_0	½ of RDN + (I^{st} nano-urea spray + 2^{nd} water spray + 0.0 kg B)
T_3	N_2B_0	½ of RDN + (I^{st} nano-urea spray + 2^{nd} nano-urea spray + 0.0 kg B)
T_4	N_0B_1	½ of RDN + (2 water spray + 0.5 kg B)
T_5	N_1B_1	½ of RDN + (I^{st} nano-urea spray + 2^{nd} water spray + 0.5 kg B)
T_6	N_2B_1	½ of RDN + (I^{st} nano-urea spray + 2^{nd} nano-urea spray + 0.5 kg B)
T_7	N_0B_2	½ of RDN + (2 water spray + 1.0 kg B)
T_8	N_1B_2	½ of RDN + (I^{st} nano-urea spray + 2^{nd} water spray + 1.0 kg B)
T_9	N_2B_2	½ of RDN + (I^{st} nano-urea spray + 2^{nd} nano-urea spray + 1.0 kg B)
T_{10}	N_0B_3	½ of RDN + (2 water spray + 1.25 kg B)
T_{11}	N_1B_3	½ of RDN + (I^{st} nano-urea spray + 2^{nd} water spray + 1.25 kg B)
T_{12}	N_2B_3	½ of RDN + (I^{st} nano-urea spray + 2^{nd} nano-urea spray + 1.25 kg B)

$$\text{P} - \text{uptake by grain (kg ha}^{-1}) = \frac{\text{P content in grain (\%)} \times \text{grain yield (kg ha}^{-1})}{100}$$

Potassium content (per cent) and uptake (kg ha^{-1}): Potassium content was analyzed by flame photometer and total potassium uptake by grain was worked out separately. The total potassium uptake was obtained by using following formula:

$$\text{K} - \text{uptake by grain (kg ha}^{-1}) = \frac{\text{K content in grain (\%)} \times \text{grain yield (kg ha}^{-1})}{100}$$

2.6 Statistical Analysis

The growth parameters and yields were recorded and analyzed as per Gomez [25] the tested at 5% level of significance to interpret the significant differences.

3. RESULTS AND DISCUSSION

3.1 Seed Yield

The findings showed that mustard's total seed yield varied from 958.73 to 1523.81 kg ha^{-1} across the treatments, with all treatments showing significantly higher yields than T_0 (100% NPK based on RDF). The highest total seed yield (1523.81 kg ha^{-1}) was observed with the T_{12} treatment combination, which applied half the recommended dose of nitrogen (RDN) along with the first and second nano-urea sprays and 1.25 kg of boron. This was closely followed by the T_9 treatment, which involved half the RDN, the first and second nano-urea sprays, and 1.0 kg of boron, resulting in a yield of 1485.71 kg ha^{-1}. In contrast, the lowest yield (958.73 kg ha^{-1}) was recorded under T_0 (100% NPK as per RDF). The yield increased significantly when boron was used in combination with 50% nitrogen or urea spray. The lowest recorded yield in this set of treatments was 1066.66 kg ha^{-1} for 0 kg B ha^{-1} + 50% RDN + N0 spray, while the highest was 1523.80 kg ha^{-1} for 1.25 kg B ha^{-1} + 50% RDN + N2 spray. Similar findings have been reported in studies by Kumar et al*.* [26], Sinha et al*.* [27], and Kumar et al*.* [28].

3.2 Nutrient Content

The highest nitrogen content (2.78%) was observed in treatment T_{12}, which used half of the recommended dose of nitrogen (RDN) along with two nano-urea sprays and 1.25 kg of boron (B). The lowest nitrogen content (2.51%) was observed in T_1, which used half of the RDN and two water sprays without boron. The highest phosphorus content (0.482%) was also observed in T_{12}, which combined half RDN, two nano-urea sprays, and 1.25 kg boron. The lowest phosphorus content (0.455%) was found in T_0 (100% NPK as per RDF), which lacked any boron or spray treatment. Potassium content peaked at 0.74% in T_{12}, indicating the positive impact of combining nano-urea sprays with boron. Like nitrogen and phosphorus, potassium content was higher in treatments that included nano-urea sprays compared to water spray-only treatments. The lowest potassium content (0.55%) was observed in T_0, which received only the standard NPK dose. Treatments that combined half the RDN, nano-urea sprays, and boron (especially at higher rates) produced the highest N, P, and K content, with T_{12} (½ RDN + two nano-urea sprays + 1.25 kg B) showing the greatest enhancement across all nutrients. Similar findings were reported by Dhaliwal et al*.* [29], Sharma et al*.* (2022) and Kumar et al*.* [28].

Table 2. Effect of different treatment combination on number of total seed yield (kg ha^{-1})

Treatment	Treatment Combination	Total seed yield (kg ha^{-1})
T_0	100% NPK as per RDF	958.73
T_1	½ of RDN + (2 water spray + 0.0 kg B)	1009.52
T_2	½ of RDN + (Ist nano-urea spray + 2nd water spray + 0.0 kg B)	1066.67
T_3	½ of RDN + (Ist nano-urea spray + 2nd nano-urea spray + 0.0 kg B)	1155.55
T_4	½ of RDN + (2 water spray + 0.5 kg B)	1117.46
T_5	½ of RDN + (Ist nano-urea spray + 2nd water spray + 0.5 kg B)	1212.70
T_6	½ of RDN + (Ist nano-urea spray + 2nd nano-urea spray + 0.5 kg B)	1346.03
T_7	½ of RDN + (2 water spray + 1.0 kg B)	1295.24
T_8	½ of RDN + (Ist nano-urea spray + 2nd water spray + 1.0 kg B)	1422.22
T_9	½ of RDN + (Ist nano-urea spray + 2nd nano-urea spray + 1.0 kg B)	1485.71
T_{10}	½ of RDN + (2 water spray + 1.25 kg B)	1384.13
T_{11}	½ of RDN + (Ist nano-urea spray + 2nd water spray + 1.25 kg B)	1453.97
T_{12}	½ of RDN + (Ist nano-urea spray + 2nd nano-urea spray + 1.25 kg B)	1523.81
SEm ±		**3.64**
C.D. (P=0.05)		**10.75**

Table 3. Effect of different treatment combination on nutrient content in mustard seed

Treatment	Treatment Combination	N content (%)	P content (%)	K content (%)
T_0	100% NPK as per RDF	2.60	0.455	0.55
T_1	½ of RDN + (2 water spray + 0.0 kg B)	2.51	0.458	0.58
T_2	½ of RDN + (I^{st} nano-urea spray + 2^{nd} water spray + 0.0 kg B)	2.62	0.464	0.65
T_3	½ of RDN + (I^{st} nano-urea spray + 2^{nd} nano-urea spray + 0.0 kg B)	2.71	0.472	0.70
T_4	½ of RDN + (2 water spray + 0.5 kg B)	2.52	0.459	0.60
T_5	½ of RDN + (I^{st} nano-urea spray + 2^{nd} water spray + 0.5 kg B)	2.65	0.465	0.67
T_6	½ of RDN + (I^{st} nano-urea spray + 2^{nd} nano-urea spray + 0.5 kg B)	2.74	0.476	0.71
T_7	½ of RDN + (2 water spray + 1.0 kg B)	2.55	0.461	0.62
T_8	½ of RDN + (I^{st} nano-urea spray + 2^{nd} water spray + 1.0 kg B)	2.67	0.467	0.68
T_9	½ of RDN + (I^{st} nano-urea spray + 2^{nd} nano-urea spray + 1.0 kg B)	2.76	0.479	0.73
T_{10}	½ of RDN + (2 water spray + 1.25 kg B)	2.58	0.462	0.64
T_{11}	½ of RDN + (I^{st} nano-urea spray + 2^{nd} water spray + 1.25 kg B)	2.69	0.470	0.69
T_{12}	½ of RDN + (I^{st} nano-urea spray + 2^{nd} nano-urea spray + 1.25 kg B)	2.78	0.482	0.74
SEm ±		**0.002**	**0.001**	**0.001**
C.D. (P=0.05)		**0.005**	**0.003**	**0.004**

Table 4. Effect of different treatment combination on nutrient uptake by mustard seed

Treatment	Treatment Combination	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
T_0	100% NPK as per RDF	24.93	4.36	5.27
T_1	½ of RDN + (2 water spray + 0.0 kg B)	25.34	4.62	5.86
T_2	½ of RDN + (Ist nano-urea spray + 2nd water spray + 0.0 kg B)	27.95	4.95	6.93
T_3	½ of RDN + (Ist nano-urea spray + 2nd nano-urea spray + 0.0 kg B)	31.32	5.45	8.09
T_4	½ of RDN + (2 water spray + 0.5 kg B)	28.16	5.13	6.70
T_5	½ of RDN + (Ist nano-urea spray + 2nd water spray + 0.5 kg B)	32.14	5.64	8.13
T_6	½ of RDN + (Ist nano-urea spray + 2nd nano-urea spray + 0.5 kg B)	36.88	6.41	9.56
T_7	½ of RDN + (2 water spray + 1.0 kg B)	33.03	5.97	8.03
T_8	½ of RDN + (Ist nano-urea spray + 2nd water spray + 1.0 kg B)	37.97	6.64	9.67
T_9	½ of RDN + (Ist nano-urea spray + 2nd nano-urea spray + 1.0 kg B)	41.01	7.12	10.85
T_{10}	½ of RDN + (2 water spray + 1.25 kg B)	35.71	6.39	8.86
T_{11}	½ of RDN + (Ist nano-urea spray + 2nd water spray + 1.25 kg B)	39.11	6.83	10.03
T_{12}	½ of RDN + (Ist nano-urea spray + 2nd nano-urea spray + 1.25 kg B)	42.36	7.34	11.28
SEm ±		**0.12**	**0.020**	**0.039**
C.D. (P=0.05)		**0.35**	**0.060**	**0.114**

3.3 Nutrient Uptake (kg ha^{-1})

The highest N uptake (42.36 kg ha^{-1}) was recorded in treatment T_{12} (½ RDN + two nano-urea sprays + 1.25 kg B). The lowest N uptake (24.93 kg ha^{-1}) was seen in T0 (100% NPK as per RDF), indicating that reduced N application supplemented with nano-urea sprays can enhance N uptake. Treatment T_{12} also had the highest P uptake (7.34 kg ha^{-1}), demonstrating the positive impact of nano-urea and boron application on P absorption. The lowest P uptake (4.36 kg ha^{-1}) was observed in T_0, which lacked additional sprays or boron supplementation. Potassium uptake was highest (11.28 kg ha^{-1}) in T_{12}, confirming that the combination of nano-urea sprays and 1.25 kg boron significantly boosts K absorption. The lowest K uptake (5.27 kg ha^{-1}) was seen in T_0, indicating the baseline uptake without additional boron or spray interventions. Treatment T_{12}, with half RDN, two nano-urea sprays, and 1.25 kg boron, resulted in the highest N, P, and K uptake. This indicates that combining nano-urea sprays and boron application, especially at higher boron levels, significantly enhances nutrient uptake compared to conventional NPK treatment. Similar findings were reported by Rana et al*.* [30], Hossain et al*.* [31] and Singh et al*.* [32].

4. CONCLUSION

The optimized treatment not only boosted yield but also enhanced nutrient content in the seeds, showing the highest percentages of nitrogen (2.78%), phosphorus (0.482%), and potassium (0.74%). Nutrient uptake in this treatment was similarly robust, with 42.36 kg ha^{-1} for nitrogen, 7.34 kg ha^{-1} for phosphorus, and 11.28 kg ha^{-1} for potassium. These findings underscore the effectiveness of integrating nano-urea and boron in mustard cultivation to enhance productivity and nutrient efficiency, suggesting that such tailored fertilization practices can support sustainable agricultural practices, especially in semi-arid regions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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