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Augmenting conventional and Nano fertilizers for growth and production efficiency of Indian mustard (*Brassica juncea* L.)

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Abstract

A field experiment entitled “Augmenting Conventional and Nano Fertilizers for Growth and Production Efficiency of Indian Mustard (*Brassica juncea* L.)” was conducted during the rabi seasons of 2023–24 and 2024–25 at the Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, to evaluate graded nitrogen and phosphorus (NP) levels and foliar application of nano fertilizers. The experiment was laid out in a factorial randomized block design with three NP levels (100, 75 and 50% of the recommended dose; 120:40:20:20 kg N, P₂O₅, K₂O, S ha⁻¹) and four nano-fertilizer treatments comprising two sprays of nano urea, two sprays of nano DAP, one spray each of nano urea and nano DAP, and two sprays each of nano urea and nano DAP. Application of 100% recommended NP significantly improved plant height (205.4 and 207.2 cm), SPAD value (43.2 and 43.4), leaf area index (4.52 and 4.55), root shoot ratio (0.26 and 0.27), seeds siliquea⁻¹ (13.6 and 14.9), test weight (4.9 and 5.2 g) and production efficiency (17.7 and 17.8 kg ha⁻¹ day⁻¹) over the 50% nitrogen phosphorus dose. Among nano-fertilizer treatments, two sprays each of nano urea and nano DAP recorded the highest values for these parameters. Production efficiency was significantly influenced by the interaction of NP levels and nano-fertilizers, with the highest value recorded under 75% recommended NP + two sprays each of nano urea and nano DAP (18.8 and 19.2 kg ha⁻¹ day⁻¹). The synergistic effect of nano-fertilizers with conventional NP fertilizers promoted efficient nutrient absorption and sustained nutrient availability, leading to enhanced physiological performance, quality and production efficiency of Indian mustard. Study suggest that the production efficiency of Indian mustard can be maintained with the application of 75% of recommended dose of nitrogen and phosphorus along with two sprays of nano urea and nano DAP.

Keywords: *Brassica juncea* L., Nano urea, Nano DAP, Nitrogen, Phosphorus

Introduction

Indian mustard (*Brassica juncea* L.), a member of the family Brassicaceae, is one of the most important rabi oilseed crops cultivated in South Asia. It is a cool-season C₃ crop with optimum growth under temperatures of 15–20 °C and is valued for its wide adaptability, high yield potential and significant contribution to edible oil security (Shekhawat *et al.*, 2012) ^[1]. Mustard seed contains 38–42% oil and 20–25% protein, making it an important source of edible oil, protein-rich meal and industrial raw material (Shekhawat *et al.*, 2012) ^[1]. India is the third-largest producer of rapeseed–mustard after Canada and China. During 2024–25, rapeseed–mustard occupied about 9.8 million ha with an estimated production of

13.7–13.8 million tonnes, while productivity remained around 1443 kg ha⁻¹, highlighting substantial opportunities for further yield improvement through efficient crop management (MoA&FW, 2025; ICAR-IIMR, 2025).

Among the essential nutrients, nitrogen (N) and phosphorus (P) are the primary determinants of mustard productivity. Nitrogen regulates chlorophyll synthesis, photosynthetic activity, vegetative growth and protein formation, whereas phosphorus plays a central role in root development, energy transfer (ATP), nucleic acid synthesis and assimilate translocation, thereby improving flowering, seed development and yield (Marschner, 2012; Havlin *et al.*, 2014; Taiz).

Owing to their mobility within plants, both nutrients are absorbed during early growth and subsequently remobilized to developing siliquae and seeds, emphasizing the importance of balanced nitrogen and phosphorus management for achieving higher productivity and nutrient use efficiency (Taiz).

Conventional fertilizers are widely used for mustard cultivation, although their nutrient recovery efficiency is still quite low. Because fixation processes take place right after fertilizer application, phosphorus recovery seldom surpasses 20–25%, while crops typically only absorb 30–50% of supplied nitrogen. Conventional fertilizers are prone to losses leading to lesser amount of nutrients available for crop plants, raising production costs and polluting the environment. Thus, increasing the effectiveness of fertilizer use has emerged as a key goal of sustainable nutrient management (Mirbakhsh, 2023) [2]. Recently, nanotechnology has shown promise as a means of increasing nutrient use efficiency. Nutrient particles with more surface area, higher reactivity and better penetration through stomata and cuticular pores make up nano-fertilizers, which are typically smaller than 100 nm. These qualities minimize nutrient losses to the environment while promoting quick nutrient absorption and translocation inside plant tissues. As a result, nano-fertilizers have gained a lot of interest as effective nutrient management methods that can improve crop growth, productivity, and nutrient usage efficiency with relatively smaller fertilizer inputs (Babu *et al.*, 2022) [3].

Foliar sprays of Nano Urea and Nano DAP offer a very effective and sustained method of managing nutrients. This nutrient management strategy speeds up nutrient absorption throughout crucial crop growth phases, and can reduce conventional nitrogen fertilizer requirements by 25% without sacrificing seed production (Meena *et al.*, 2024) [4, 5]. Use of these cutting-edge nano-fertilizers greatly reduce cost involved of fertilizer production, transportation and also reduce environmental pollution while increasing total crop productivity and nutrient use efficiency.

Considering the increasing need of improving nutrient use efficiency and sustaining soil health, application of nano fertilizers foliar spray and conventional nutrient management practices appear to be a viable strategy for enhancing mustard productivity. Therefore, the present study was undertaken to evaluate the effect of nano fertilizers and varying levels of nitrogen and phosphorus on growth, production efficiency and quality parameters of Indian mustard under the *Tarai* region of Uttarakhand.

Materials and Methods

A field experiment was conducted during rabi season of 2023-24 and 2024-25 at the Norman E. Borlaug Crop Research Centre of

G.B. Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar, Uttarakhand, representing the *Tarai* region of Uttarakhand. Pantnagar is located at the foothills of Himalayas at 29 ° N latitude, 79.29 ° E longitude and an altitude of 243.83 m above mean sea level with sub-humid, sub-tropical climate and characterized by the cold winters and hot humid summers. The average annual rainfall of 1444 mm is received in the region. The soil of the experimental site was neutral in reaction with a pH of 7.1, medium in organic carbon content 0.74%, low in available nitrogen 224 kg/ha, medium in available phosphorus 23.8 kg/ha and available potassium 216 kg/ha.

The experiment was laid out in factorial randomized block design (FRBD) with twelve treatments that replicated thrice. The twelve treatments comprised three nitrogen and phosphorus levels viz., recommended dose of 100%, 75% and 50 % and four nano fertilizers spray- two sprays of nano urea, two sprays of nano DAP, one spray of nano urea+ nano DAP and two sprays of nano urea +nano DAP. The recommended dose of fertilizer (RDF) used for NPKS in Indian mustard was 120:40:20:20 kg/ha. The nano fertilizers- nano urea and nano DAP were obtained from IFFCO and applied at the rate of 4 ml/litre. *Plant* height, SPAD, LAI, root: shoot ratio was measured from five randomly selected plants which were tagged initially in each plot to ensure accurate representation.

For calculating **root:** Shoot ratio on the dry matter basis, following formula was used (Naidu *et al.*, 1982) [6].

$$\text{Root: Shoot ratio} = \frac{\text{Dry weight of root}}{\text{Dry weight of shoot}}$$

Oil content (%) and protein content (%) was estimated using a Fourier Transform Near-Infrared (FT-NIR) spectrometer NIRFLEX 500, a rapid and non-destructive analytical technique based on the absorption of near-infrared radiation by chemical bonds in the seed, enabling accurate quantification of oil content. Production efficiency ($\text{kg ha}^{-1}\text{day}^{-1}$) was calculated by using the following formula: -

$$\text{Production efficiency (kg ha}^{-1}\text{day}^{-1}) = \frac{\text{Seed yield (kg/ha)}}{\text{Crop duration (days)}}$$

All the recorded data were statistically analysed to draw a valid conclusion.

Results and Discussion

The growth parameters and yield attributes of Indian mustard were significantly influenced by varied dose of nitrogen, phosphorus and nano fertilizer as foliar spray.

Table 1: Effect of nitrogen and phosphorus levels with the different nano fertilizers foliar spray on the plants height (cm) at harvest, number of leaves, SPAD, LAI and root: shoot ratio

Treatment	Plant height (cm)		SPAD		LAI		Root Shoot ratio
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24
Nitrogen and phosphorus levels							
100 % N and P	205.4	207.2	43.2	43.4	4.52	4.55	0.26
75 % N and P	203.0	205.3	42.9	43.1	4.50	4.51	0.25
50 % N and P	196.3	198.9	39.1	39.7	4.21	4.23	0.21
Sem±	1.0	1.0	0.6	0.5	0.06	0.03	0.01
CD (P=0.05)	2.9	2.8	1.8	1.6	0.17	0.08	0.02
Nano fertilizers foliar sprays							
2 Nano urea	198.7	200.2	40.3	40.9	4.28	4.31	0.22
2 Nano-DAP	202.4	204.9	41.9	42.3	4.42	4.44	0.25
1 Nano urea+1 Nano-DAP	202.1	204.2	41.4	41.6	4.38	4.38	0.23
2 Nano urea+2 Nano-DAP	203.2	205.9	43.3	43.5	4.56	4.60	0.26
Sem±	1.1	1.1	0.7	0.6	0.07	0.03	0.01
CD (P=0.05)	3.3	3.3	2.1	1.8	0.19	0.10	0.02
Interaction CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS

Table 2: Effect of nitrogen and phosphorus levels and the different nano fertilizers on the test weight (g), Seed per siliqua, oil content (%), protein content (%) and production efficiency (kg/ha/day)

Treatment	Test weight (g)		Seeds per siliqua		Protein content (%)		Production efficiency (kg/ha/day)
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24
Nitrogen and phosphorus levels							
100 % N and P	4.9	5.2	13.6	14.9	20.7	21.1	17.7
75 % N and P	4.8	5.1	13.2	14.4	20.3	20.8	16.8
50 % N and P	4.6	4.6	10.0	12.3	19.5	19.8	10.5
Sem±	0.08	0.13	0.4	0.2	0.4	0.4	0.3
CD (P=0.05)	0.2	0.4	1.1	0.7	NS	NS	1.0
Nano fertilizers foliar sprays							
2 Nano urea	4.7	4.7	10.7	13.3	19.8	20.1	13.6
2 Nano-DAP	4.7	5.0	12.0	13.9	20.3	20.7	14.9
1 Nano urea+1 Nano-DAP	4.8	4.9	12.4	13.3	20.1	20.5	14.7
2 Nano urea+2 Nano-DAP	5.0	5.3	13.9	14.9	20.5	21.0	16.8
Sem±	0.09	0.14	0.4	0.3	0.4	0.5	0.3
CD (P=0.05)	NS	NS	1.2	0.8	NS	NS	1.0
Interaction CD(P=0.05)	NS	NS	NS	NS	NS	NS	2.0

Table 3: Interaction effect between nitrogen & phosphorus and nano-fertilizers on the production efficiency (kg/ha/day) of Indian mustard

Treatments	Nano-Fertilizers									
	2023-24					2024-25				
	2 sprays of nano-urea	2 sprays of nano-DAP	1 spray of nano-urea & 1 spray of nano-DAP	2 sprays of nano-urea & 2 sprays of nano-DAP	Mean	2 sprays of nano-urea	2 sprays of nano-DAP	1 spray of nano-urea & 1 spray of nano-DAP	2 sprays of nano-urea & 2 sprays of nano-DAP	Mean
100% RD-NP	17.3	17.7	17.6	18.1	17.7	17.5	17.7	17.5	18.7	17.8
75% RD-NP	14.8	16.9	16.8	18.8	16.8	15.4	17.0	16.9	19.2	17.1
50% RD-NP	8.6	10.2	9.8	13.6	10.5	9.2	10.4	10.2	13.9	10.9
Mean	13.6	14.9	14.7	16.8		14.0	15.0	14.9	17.3	
SEm±	0.6					0.5				
CD (P=0.05)	1.8					1.5				

Plant height (cm)

Plant height was significantly influenced by nitrogen and phosphorus levels as well as nanofertilizer application, whereas their interaction remained non-significant (Table 1). Application of 100% NP recorded the tallest plants (205.4 and 207.2 cm during 2023–24 and 2024–25, respectively), which remained statistically on a par with 75% NP but significantly higher than 50% NP. Among the nano-fertilizer treatments, two foliar sprays each of nano urea and nano DAP produced the highest plant height (203.2 and 205.9 cm) during both the year of study. The increase in plant height could be attributed to enhanced nutrient availability, improved chlorophyll synthesis, higher photosynthetic activity and efficient nutrient use, resulting in

greater cell division, cell elongation and dry matter accumulation. Tarafdar *et al.* (2020)^[7] also observed the response to enhanced nutrient availability and utilization with the nano fertilizer application. Likewise, Chaudhary *et al.* (2023)^[8] reported that balanced nutrient supply through nano-fertilizers improved vegetative growth and plant vigor in crops.

SPAD Value

Nitrogen and phosphorus levels and nano-fertilizer application significantly influenced SPAD values (Table 1). Among the fertility levels, application of 100% NP recorded the highest SPAD values (43.2 and 43.4 during 2023–24 and 2024–25, respectively), which remained statistically at par with 75% NP

(42.9 and 43.1), whereas the lowest values were recorded under 50% NP (39.1 and 39.7). Among the nano-fertilizer treatments, two foliar sprays each of nano urea and nano DAP recorded the maximum SPAD values (43.3 and 43.5). The higher SPAD values under these treatments could be attributed to improved nitrogen availability, enhanced chlorophyll biosynthesis and greater photosynthetic efficiency, resulting from synchronized nutrient supply and improved nutrient use efficiency. Delfine *et al.* (2005)^[9], also observed increased chlorophyll content with improved nitrogen nutrition, similarly Harode *et al.* (2024)^[10] also reported enhanced SPAD values following nano-fertilizer application due to improved nutrient use efficiency. Increase chlorophyll content with the balanced nutrient management practices also reported by Nanda *et al.*, (2025).

Leaf area index (LAI)

Leaf area index was significantly influenced by nitrogen and phosphorus levels and nanofertilizer application, whereas their interaction remained non-significant during both the years of experimentation (Table 1). The highest LAI was recorded under 100% N and P (4.52 and 4.55), which was statistically at par with 75% N and P (4.50 and 4.51). Among nano-fertilizer treatments, two sprays each of nano urea and nano-DAP produced the highest LAI (4.56 and 4.60), which was statistically comparable with two sprays of nano-DAP (4.42 and 4.44) and one spray each of nano urea and nano-DAP (4.38 and 4.38). The interaction effect was found to be non-significant during both years.. The higher LAI may be attributed to enhanced leaf expansion and canopy development resulting from improved nutrient availability and photosynthetic activity. Prasad *et al.* (2021)^[11] also found the role of nano fertilizers in improving vegetative growth and leaf development and Harode *et al.* (2024)^[10] and Meena *et al.* (2022)^[12] also reported greater canopy development under balanced nutrient management with nano fertilizer application.

Root: shoot ratio

Root:shoot ratio was significantly influenced by nitrogen and phosphorus levels and nanofertilizer application, whereas their interaction remained non-significant (Table 1) during both the years. Application of 100% NP recorded the highest root: shoot ratio (0.26 and 0.27 during 2023–24 and 2024–25, respectively), which remained statistically at par with 75% NP (0.25 and 0.26) but significantly exceeded 50% NP (0.21 and 0.22). Among the nano-fertilizer treatments, two foliar sprays each of nano urea and nano DAP recorded the maximum root: shoot ratio (0.26 and 0.27). The higher root: shoot ratio under these treatments indicates improved root growth and biomass partitioning due to enhanced nutrient uptake and utilization. Raliya *et al.* (2018)^[13], observed enhanced root development and nutrient uptake with nano-fertilizer application, similarly Singh *et al.* (2026)^[14] also found improved root weight with the nano fertilizer application and Kah *et al.* (2018)^[15] recorded the potential of nano fertilizers to improve plant growth and nutrient use efficiency.

Test weight

Test weight was significantly influenced by nitrogen and phosphorus levels, whereas nanofertilizer application and their interaction had no significant effect (Table 2) during both the years of study. Application of 100% NP recorded the highest test weight (4.9 and 5.2 g during 2023–24 and 2024–25, respectively), which remained statistically at par with 75% NP (4.8 and 5.1 g) but significantly exceeded 50% NP (4.6 and 4.6 g). Although the effect of nano-fertilizers was non-significant, two foliar sprays

each of nano urea and nano DAP recorded the highest numerical values (5.0 and 5.3 g). The improvement in test weight under adequate NP nutrition may be attributed to enhanced assimilate production and efficient translocation to developing seeds during grain filling. Similarly, Harode *et al.* (2024)^[10] found non-significant values of test weight (g) whereas Malhi and Gill (2007)^[16], recorded improved seed weight with balanced nitrogen and phosphorus nutrition, while Ahmad *et al.* (2023) and Acharya *et al.* (2024)^[17] also reported that nano-fertilizers enhanced nutrient use efficiency and seed development.

Seeds per siliqua

Seeds per siliqua were significantly influenced by nitrogen and phosphorus levels as well as nano-fertilizer application, whereas their interaction remained non-significant during both the years (Table 2). Application of 100% NP recorded the highest number of seeds per siliqua (13.6 and 14.9 during 2023–24 and 2024–25, respectively), which remained statistically at par with 75% NP (13.2 and 14.4) but significantly exceeded 50% NP (10.0 and 12.3). Among the nano-fertilizer treatments, two foliar sprays each of nano urea and nano DAP recorded the maximum number of seeds per siliqua (13.9 and 14.9). The higher seed set may be attributed to improved nutrient availability during the reproductive phase, resulting in better fertilization and assimilate translocation towards developing siliquae. Similar findings were reported by Singh *et al.* (2026)^[14], who observed improved reproductive growth and yield attributes with nano-fertilizer application, while Chaudhary *et al.* (2023)^[8] also reported enhanced seed development due to improved nutrient use efficiency and balanced nutrient supply. Rathour *et al.*, (2024)^[18] also reported increased yield attributes with the application of nano urea.

Protein content (%)

Protein content was not significantly influenced by nitrogen and phosphorus levels, nanofertilizer application or their interaction during both the years of study (Table 2). However, numerically the highest protein content was recorded under 100% NP (20.7 and 21.1% during 2023–24 and 2024–25, respectively), while among the nano-fertilizer treatments, two foliar sprays each of nano urea and nano DAP recorded the highest values (20.5 and 21.0%). The slight increase in protein content under higher NP levels may be attributed to enhanced nitrogen assimilation and amino acid synthesis, which favoured protein accumulation in seeds. Johnson *et al.* (2003)^[19], observed increased seed protein content with higher nitrogen fertilization, while Raliya *et al.* (2018)^[13] also observed the role of nanofertilizers in improving nutrient uptake and nitrogen use efficiency, thereby supporting protein accumulation.

Production efficiency

Production efficiency was significantly influenced by nitrogen and phosphorus levels, nanofertilizer application and their interaction (Tables 2 and 3). Among fertility levels, 100% N and P recorded the highest production efficiency (17.7 and 17.8 kg ha⁻¹ day⁻¹), which was statistically comparable with 75% N and P (16.8 and 17.1 kg ha⁻¹ day⁻¹) but significantly superior to 50% N and P (10.5 and 10.9 kg ha⁻¹ day⁻¹). Among nano-fertilizer treatments, two sprays each of nano urea and nano-DAP resulted in the maximum production efficiency (16.8 and 17.3 kg ha⁻¹ day⁻¹) remained statistically similar with two sprays of nano-DAP (14.9 and 15.0 kg ha⁻¹ day⁻¹) and one spray each of nano urea and nano-DAP (14.7 and 14.9 kg ha⁻¹ day⁻¹). A significant interaction between nitrogen and phosphorus levels

and nano-fertilizer application was observed for production efficiency during both years (Table 3). The highest production efficiency was recorded with 100% N and P + two sprays each of nano urea and nano-DAP (18.1 and 18.7 kg/ha/day during 2023–24 and 2024–25, respectively), which remained statistically on a par with 75% N and P + two sprays each of nano urea and nano-DAP (18.8 and 19.2 kg/ha/day). The lowest production efficiency was recorded under $\sim$ 50% N and P + two sprays of nano urea (8.6 and 9.2 kg/ha/day). The higher production efficiency under these treatments may be attributed to enhanced nutrient use efficiency and greater assimilate partitioning, resulting in higher seed yield within the crop duration. Nanofertilizers improving nutrient use efficiency and crop productivity was reported by Dimkpa *et al.* (2020) ^[20]. The beneficial effect of balanced nutrient management on improving crop productivity and quality has also been demonstrated by Pyne *et al.*, (2024) ^[21]. Pramanick *et al.* (2023) ^[22] also revealed the importance of balance nutrient management resulted increased seed yield and ultimately production efficiency

Conclusion

From the results, it can be concluded that, 100% NP and two foliar sprays each of Nano urea-Nano DAP recorded the higher plant height, leaf area index, SPAD values, root shoot ratio, test weight (g), seeds per silique and protein content (%) and production efficiency (kg/ha/day), but was on par with the treatment 75% NP fertilizer and two foliar sprays each of nano urea and nano-DAP during both the year of experimentation. Since both treatment combinations recorded higher growth and yield of Indian mustard. The adoption of a reduced dose of nitrogen; 75% N and two foliar sprays of nano-urea and nano-DAP at 25 DAS and 45 DAS is an economically and sustainably viable choice for boosting growth when applying a foliar application of nano-urea and nano DAP. The results showed the potential of nano fertilizers as an important component of sustainable nutrient management strategies for enhancing mustard productivity under Tarai region conditions.

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