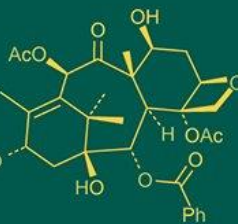
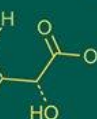
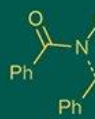
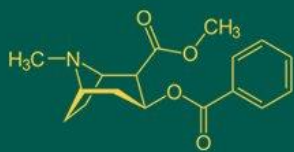


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P Harshith

PG Scholar, Department of
Soil Science and Agricultural
Chemistry, Agricultural
College, Polasa, Jagtial,
PJTAU, Rajendranagar,
Hyderabad, Telangana, India

R Saikumar

Coordinator, Department of
Soil science and Agricultural
Chemistry, TRVK,
Vemulawada, PJTAU,
Hyderabad, Telangana, India

N Sainath

Scientist, Department of Soil
Science and Agricultural
Chemistry AICRP on LTFE,
Regional Agricultural
Research Station, Jagtial,
PJTAU, Hyderabad,
Telangana, India

Dr. O Sampath

Coordinator, Department of
Agronomy, TRVK, Peddapalli,
PJTAU, Hyderabad,
Telangana, India

Corresponding Author:**P Harshith**

PG Scholar, Department of
Soil Science and Agricultural
Chemistry, Agricultural
College, Polasa, Jagtial,
PJTAU, Rajendranagar,
Hyderabad, Telangana, India

Effect of nano zinc and seaweed extract on growth, yield attributes and yield of mustard (*Brassica juncea* L.) under northern Telangana conditions

P Harshith, R Saikumar, N Sainath and O Sampath

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Abstract

A field experiment was conducted during the *rabi* 2025-26 season at the College Farm, Agricultural College, Jagtial, PJTAU, Telangana, to evaluate the effect of nano zinc and seaweed extract on the growth, yield attributes and yield of mustard (*Brassica juncea* L.) under the Northern Telangana Zone. The experiment was laid out in a Randomized Block Design with seven treatments and three replications. Among the treatments, 100% RDF + Nano Zn + Seaweed extract (T₅) recorded the highest plant height (162.0 cm), SPAD chlorophyll value (38.9), dry matter production (1920 kg ha⁻¹), number of siliqua plant⁻¹ (325), filled seeds siliqua⁻¹ (21.8), seed yield (1766 kg ha⁻¹), stover yield (3323 kg ha⁻¹) and harvest index (34.7%). The superior performance was attributed to improved nutrient availability, enhanced photosynthetic efficiency and the synergistic action of nano zinc and seaweed extract. The study demonstrated that integrating 100% RDF with Nano Zn and Seaweed extract is an effective nutrient management strategy for improving mustard productivity under Northern Telangana conditions.

Keywords: Mustard (*Brassica juncea* L.), nano zinc, seaweed extract, recommended dose of fertilizers (RDF), yield attributes, seed yield

1. Introduction

Mustard (*Brassica juncea* L.) is one of the most important edible oilseed crops of India and contributes substantially to the country's vegetable oil economy. The crop contains 38-45% oil and 20-25% protein, making it an important source of edible oil, animal feed and industrial raw material. However, its productivity remains below the global average due to nutrient deficiencies, imbalanced fertilizer use and declining soil fertility. Efficient nutrient management is therefore essential for sustaining mustard production and improving nutrient use efficiency. Mustard is the main oilseed crop grown in the *rabi* season in India (Kumar *et al.*, 2014)^[1].

Mustard is often referred to as the "Golden crop" due to its economic and nutritional value. It is a cool-season, annual crop that follows the C3 photosynthetic pathway, making it moderately efficient in water and nutrient use. It serves as a vital source of edible oil, animal feed (oil cake) and an industrial raw material for condiments, biodiesel and various processed products (Dhaliwal *et al.*, 2022)^[4].

In India, mustard is cultivated on 9.18 million hectares, producing 13.26 million tonnes with an average productivity of 1,444 kg ha⁻¹ (Indiastat, 2024). It is considered as a promising *rabi* crop owing to its wide adaptability and ability to utilize residual soil moisture effectively.

In Telangana, mustard is cultivated over an area of about 4000 ha, producing 0.776 mt with an average productivity of 1940 kg ha⁻¹.

Among the essential plant nutrients, zinc (Zn) is the most important micronutrient after nitrogen, phosphorus and potassium and nearly 36-48% of Indian soils are deficient in available zinc (Arunachalam *et al.*, 2013; Arvind *et al.*, 2019)^[2, 3]. Zinc plays a vital role in chlorophyll synthesis, auxin production, enzyme activation, protein synthesis, pollen development and seed formation. Deficiency of zinc adversely affects photosynthesis, growth, nutrient uptake and ultimately reduces yield and seed quality in mustard.

In recent years, nano-fertilizers have emerged as an innovative approach to improve fertilizer use efficiency while minimizing nutrient losses and environmental pollution. Due to their small particle size, large surface area and controlled nutrient release, nano-fertilizers enhance nutrient absorption, translocation and utilization by plants. Foliar application of nano zinc has been reported to improve chlorophyll synthesis, photosynthetic efficiency, nutrient uptake and productivity in mustard (Sharma *et al.*, 2022; Sharma *et al.*, 2024)^[17, 18].

Seaweed extracts are natural biostimulants containing auxins, cytokinins, gibberellins, amino acids, vitamins and micronutrients, which promote root growth, nutrient uptake, photosynthesis and stress tolerance. Several studies have demonstrated that foliar application of seaweed extract enhances vegetative growth, chlorophyll content, yield attributes and crop productivity in field crops (Layek *et al.*, 2015; Gandhi *et al.*, 2024; Naz *et al.*, 2023)^[12, 6, 13]. Furthermore, the combined application of nano-fertilizers and seaweed-based biostimulants has been shown to produce synergistic effects by improving nutrient use efficiency and overall crop performance.

Although the individual benefits of nano zinc and seaweed extract have been reported, information on their combined application under the Northern Telangana Zone is limited. Therefore, the present investigation was undertaken to evaluate the “effect of nano zinc and seaweed extract in combination with the recommended dose of fertilizers, on the growth, yield attributes and yield of mustard under the agro-climatic conditions of Northern Telangana”.

2. Methodology

The present study was conducted at the College Farm, Agricultural College, Jagtial, Professor Jayashankar Telangana Agricultural University (PJTUAU), Telangana, India, during the *rabi* season of 2025-26 to investigate the influence of nano zinc and seaweed extract on the growth and yield of mustard under the Northern Telangana Zone. The experimental farm is located at 18°50'58" N latitude and 78°56'97" E longitude, with an elevation of 243.4 m above mean sea level. The field trial was established in a Randomized Block Design (RBD) comprising seven treatments replicated three times. The treatment details were T₁: Absolute control, T₂: 100% RDF (60:40:40:25 kg N: P₂O₅: K₂O: S ha⁻¹), T₃: 100% RDF + Nano Zn, T₄: 100% RDF + Seaweed extract, T₅: 100% RDF + Nano Zn + Seaweed extract, T₆: 75% RDF + Seaweed extract and T₇: 75% RDF + Nano Zn + Seaweed extract.

The soil of the experimental field was sandy clay loam in texture, having a pH of 7.68, electrical conductivity (EC) of 0.32 dS m⁻¹ and organic carbon content of 0.55%. Initial soil analysis revealed low available nitrogen (116 kg ha⁻¹), low available sulphur (10.4 kg ha⁻¹) and available zinc (0.39 mg kg⁻¹), whereas available phosphorus (35 kg ha⁻¹) and available potassium (275 kg ha⁻¹) were in the higher range. The mustard cultivar Sitara Sringar was grown at a spacing of 45 × 15 cm. The experiment was conducted with a gross plot size of 5.4 × 4.5 m and a net plot size of 3.6 × 3.9 m.

The recommended fertilizer schedule of 60:40:40:25 kg N: P₂O₅: K₂O: S ha⁻¹ was followed throughout the experiment. Nitrogen was supplied through urea (46% N), phosphorus and sulphur through single superphosphate (16% P₂O₅ and 12% S) and potassium through muriate of potash (60% K₂O). The complete quantity of phosphorus, potassium and

sulphur, together with 50% of the recommended nitrogen, was incorporated into the soil at sowing, while the remaining nitrogen was top-dressed during the flowering stage (55-60 DAS).

IFFCO Nano Zinc, containing 1.0% zinc, was sprayed as a foliar application at the rate of 1.0 mL L⁻¹ of water during the pre-flowering stage. Likewise, IFFCO Sagarika, a liquid seaweed extract containing 28% (w/v) seaweed extract, was applied as a foliar spray at 2.0 mL L⁻¹ of water at the same growth stage according to the respective treatment schedule.

All recommended agronomic practices were followed uniformly in every treatment throughout the crop season. Land preparation involved ploughing followed by rotavation to obtain a fine tilth. Gap filling was carried out 7 days after sowing, whereas thinning was completed on the 22nd day after sowing. Weed control was achieved by applying pendimethalin (4 mL L⁻¹) as a pre-emergence herbicide followed by one manual weeding at 14 DAS. Irrigation and plant protection measures were provided as and when required to ensure normal crop growth.

Growth parameters including plant height, SPAD chlorophyll meter readings and dry matter accumulation were recorded at the branching and flowering stages. At harvest, observations on number of siliqua plant, number of filled seeds siliqua⁻¹ and 1000-seed weight (test weight) were documented. Seed yield, stover yield and harvest index were estimated from the produce harvested from the net plot area.

The recorded observations were statistically evaluated by analysis of variance (ANOVA) appropriate for the Randomized Block Design. Treatment differences were tested using the F-test and whenever significant differences were observed, the critical difference (CD) was calculated at the 5% probability level.

3. Results and Discussion

3.1 Effect of nano zinc and seaweed extract on growth parameters

The effect of nano zinc and seaweed extract on plant height of mustard at different growth stages is presented in Table 1. The analysis revealed that plant height differed significantly among the treatments at both the branching and flowering stages.

At the branching stage, plant height ranged from 12.13 to 22.27 cm. The highest plant height (22.27 cm) was recorded with 100% RDF + Nano Zn (T₃), which was statistically on par with 100% RDF (T₂; 21.87 cm), 100% RDF + Seaweed extract (T₄; 21.07 cm) and 100% RDF + Nano Zn + Seaweed extract (T₅; 21.00 cm). This was followed by 75% RDF + Nano Zn + Seaweed extract (T₇; 19.07 cm) and 75% RDF + Seaweed extract (T₆; 18.43 cm), whereas the lowest plant height (12.13 cm) was observed under the Absolute Control (T₁).

At the flowering stage, plant height varied significantly from 106.0 to 162.0 cm. The maximum plant height (162.0 cm) was recorded with 100% RDF + Nano Zn + Seaweed extract (T₅), followed by 100% RDF + Seaweed extract (T₄) (152.0 cm), 100% RDF + Nano Zn (T₃) (142.0 cm), 75% RDF + Nano Zn + Seaweed extract (T₇) (132.0 cm), 100% RDF (T₂) (130.0 cm) and 75% RDF + Seaweed extract (T₆) (129.0 cm), whereas the lowest plant height (106.0 cm) was recorded under the Absolute Control (T₁). The superior plant height observed with 100% RDF + Nano Zn + Seaweed extract may be attributed to the combined effect of balanced

nutrient supply, improved zinc availability through nano zinc and the biostimulant action of seaweed extract, which enhanced cell division, cell elongation and photosynthetic efficiency.

The present findings are consistent with those of Sharma *et al.*, (2023)^[16], Verma *et al.*, (2022)^[20], Ekta *et al.*, (2024)^[5], Sharma *et al.*, (2022)^[17], Gandhi *et al.*, (2024)^[6], Naz *et al.*, (2023)^[13], Yusuf *et al.*, (2021)^[21] and Hassanein *et al.*, (2021)^[7].

The effect of nano zinc and seaweed extract on SPAD chlorophyll meter readings at branching and flowering stages is presented in Table 1. At the branching stage, SPAD values ranged from 29.2 to 36.8 and the treatment differences were non-significant. However, the highest SPAD value (36.8) was recorded with 100% RDF + Nano Zn + Seaweed extract (T₅), while the lowest (29.2) was observed under the Absolute Control (T₁).

At the flowering stage, SPAD values differed significantly among the treatments, ranging from 30.4 to 38.9. The highest SPAD reading (38.9) was recorded with 100% RDF + Nano Zn + Seaweed extract (T₅), which was on par with 100% RDF + Seaweed extract (T₄) (38.1) and 100% RDF + Nano Zn (T₃) (36.3), whereas the lowest value (30.4) was recorded under the Absolute Control (T₁). The higher SPAD values under the combined application of nano zinc and seaweed extract may be attributed to enhanced chlorophyll synthesis, improved nutrient uptake and increased photosynthetic efficiency.

The present findings are in agreement with Nikzad *et al.*, (2025)^[14], Sharma *et al.*, (2023)^[16], Verma *et al.*, (2022)^[20], Ekta *et al.*, (2024)^[5], Gandhi *et al.*, (2024)^[6], Naz *et al.*, (2023)^[13] and Hassanein *et al.*, (2021)^[7].

The effect of nano zinc and seaweed extract on dry matter production of mustard at different growth stages is presented in Table 1. At the branching stage, dry matter production ranged from 295 to 394 kg ha⁻¹ and the treatment differences were non-significant. The highest dry matter production (394 kg ha⁻¹) was recorded with 100% RDF + Nano Zn (T₃), while the lowest (295 kg ha⁻¹) was observed under the Absolute Control (T₁).

At the flowering stage, dry matter production varied significantly from 944 to 1920 kg ha⁻¹. The highest dry matter production (1920 kg ha⁻¹) was recorded with 100% RDF + Nano Zn + Seaweed extract (T₅), followed by 100% RDF + Seaweed extract (T₄) (1833 kg ha⁻¹) and 100% RDF + Nano Zn (T₃) (1722 kg ha⁻¹), whereas the lowest value (944 kg ha⁻¹) was recorded under the Absolute Control (T₁). The higher dry matter accumulation under 100% RDF + Nano Zn + Seaweed extract may be attributed to improved nutrient use efficiency, enhanced photosynthetic activity and the growth-promoting effect of seaweed extract. The present findings are in accordance with Nikzad *et al.*, (2025)^[14], Sharma *et al.*, (2023)^[16], Ekta *et al.*, (2024)^[5], Verma *et al.*, (2022)^[20], Kumar *et al.*, (2022)^[10], Gandhi *et al.*, (2024)^[6],

Huda *et al.*, (2023)^[8], Yusuf *et al.*, (2021)^[21], Layek *et al.*, (2015)^[12] and Hassanein *et al.*, (2021)^[7].

3.2 Effect of nano zinc and seaweed extract on yield attributes and yield

3.2.1 Yield attributing characteristics

Data pertaining to yield attributes as influenced by nano zinc and seaweed extract are presented in Table 2. Among all the treatments, the highest number of siliqua plant-1 (325) and filled seeds siliqua-1 (21.8) were recorded with T₅ (100% RDF + Nano Zn + Seaweed extract), which was significantly superior to all other treatments. It was followed by T₄ (100% RDF + Seaweed extract) with 278 siliqua plant-1 and 20.0 filled seeds siliqua-1, whereas the lowest values (152 siliqua plant-1 and 9.5 filled seeds siliqua-1) were recorded under T₁ (Absolute Control). The test weight ranged from 4.71 to 5.08 g and did not differ significantly among the treatments.

The improvement in yield attributes under 100% RDF + Nano Zn + Seaweed extract may be attributed to the combined effect of balanced nutrient supply, enhanced zinc availability and the biostimulant action of seaweed extract, which promoted flowering, siliqua formation, seed development and assimilate translocation. The present findings are in agreement with Sharma *et al.*, (2022)^[17], Sharma *et al.*, (2024)^[18], Senthil Kumar *et al.*, (2025)^[15] and Singh *et al.*, (2023)^[19].

3.2.2 Yield

The seed yield (kg ha⁻¹), stover yield (kg ha⁻¹) and harvest index (%) of mustard as influenced by nano zinc and seaweed extract are presented in Table. 2 and Fig. 1 The highest seed yield (1766 kg ha⁻¹), stover yield (3323 kg ha⁻¹) and harvest index (34.7%) were recorded with 100% RDF + Nano Zn + Seaweed extract (T₅). The treatment was significantly superior for seed and stover yield over the remaining treatments, while harvest index did not differ significantly among the treatments. Among the individual applications, 100% RDF + Seaweed extract (T₄) recorded higher seed yield (1650 kg ha⁻¹) and stover yield (3195 kg ha⁻¹) than 100% RDF + Nano Zn (T₃), whereas the Absolute Control (T₁) recorded the lowest seed yield (751 kg ha⁻¹) and stover yield (1596 kg ha⁻¹).

The increased seed and stover yields under 100% RDF + Nano Zn + Seaweed extract may be attributed to the synergistic effect of balanced nutrient supply, improved nutrient uptake and photosynthetic efficiency through nano zinc, together with the growth-promoting action of seaweed extract, which enhanced dry matter accumulation, assimilate translocation and yield attributes. The present findings are in conformity with Sharma *et al.*, (2024)^[18], Sharma *et al.*, (2022)^[17], Verma *et al.*, (2022)^[20], Sharma *et al.*, (2023)^[16], Senthil Kumar *et al.*, (2025)^[15], Abd *et al.*, (2024)^[1], Gandhi *et al.*, (2024)^[6], Naz *et al.*, (2023)^[13] and Layek *et al.*, (2015)^[12].

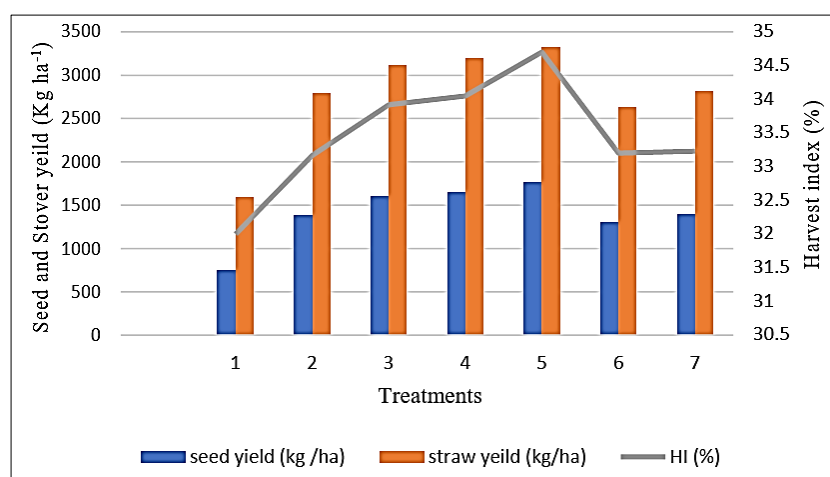
Table 1: Effect of nano zinc and seaweed extract on at different growth parameters of mustard.

Treatments	Plant height (cm)		SPAD chlorophyll meter reading		Dry matter production (kg ha ⁻¹)	
	Branching	Flowering	Branching	Flowering	Branching	Flowering
T ₁ -Absolute Control	12.13	106	29.2	30.4	295	944
T ₂ -100% RDF (60: 40: 40: 25 kg N, P2O5, K2O and S ha ⁻¹)	21.87	130	30.1	32.3	392	1658
T ₃ -100% RDF + Nano Zn	22.27	142	35.9	36.3	394	1722
T ₄ -100% RDF + Seaweed extract	21.07	152	36.2	38.1	386	1833

T ₅ -100% RDF + Nano Zn + Seaweed extract	21.00	162	36.8	38.9	377	1920
T ₆ -75% RDF + Seaweed extract	18.43	129	29.8	31.8	352	1592
T ₇ -75% RDF + Nano Zn + Seaweed extract	19.07	132	33.8	33.9	354	1717
SEm±	1.11	7.07	1.98	1.34	12.99	64.31
CD (p=0.05)	3.42	21.77	NS	4.11	40.01	198.15
CV (%)	9.89	8.99	10.35	6.69	6.18	6.85

Table 2: Effect of nano zinc and seaweed extract on yield attributes and yield of mustard.

Treatments	No. of siliqua plant-1	No. of filled seeds siliqua-1	Seed yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)	Test weight (1000 seed weight) (g)	Harvest index (%)
T ₁ -Absolute Control	152	9.5	751	1596	4.71	32.00
T ₂ -100% RDF (60: 40: 40: 25 kg N, P ₂ O ₅ , K ₂ O and S ha ⁻¹)	220	14.8	1385	2790	4.88	33.17
T ₃ -100% RDF + Nano Zn	252	18.9	1602	3122	4.95	33.92
T ₄ -100% RDF + Seaweed extract	278	20.0	1650	3195	4.98	34.05
T ₅ -100% RDF + Nano Zn + Seaweed extract	325	21.8	1766	3323	5.08	34.70
T ₆ -75% RDF + Seaweed extract	201	13.9	1305	2626	4.81	33.20
T ₇ -75% RDF + Nano Zn + Seaweed extract	230	17.1	1399	2810	4.90	33.23
SEm±	9.9	0.7	60.79	142.07	0.19	1.39
CD (p=0.05)	30.5	2.1	187.30	437.75	NS	NS
CV (%)	7.2	7.1	7.47	8.85	6.78	7.19

**Fig 1:** Effect of nano zinc and seaweed extract on seed, stover yield and harvest index.

4. Conclusion

Considering the objectives of the study and the results obtained after one season of experimentation, it was concluded that the application of 100% RDF + Nano Zn + Seaweed extract recorded the highest growth parameters, yield attributes, seed yield and stover yield of mustard under the Northern Telangana Zone. Therefore, the integrated use of 100% RDF with Nano Zn and Seaweed extract can be recommended for improving mustard productivity under these agro-climatic conditions.

5. Future Scope

Further investigations are required to evaluate the long-term effects of nano zinc and seaweed extract on soil health, nutrient dynamics and soil microbial activity under different agro-climatic conditions. Multi-location and multi-season field trials are needed to validate their effectiveness and optimize application rates for sustainable mustard production. In addition, studies on their economic feasibility, nutrient use efficiency and interaction with other nano-fertilizers and biostimulants would facilitate their wider adoption in oilseed cropping systems.

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Authors contribution

All the authors have contributed equally.

Research content

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