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Effect of seed priming by nano-urea and nano-zinc on growth and yield of rat-tail radish (*Raphanus sativus* var. *caudatus*)

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Abstract
Nano-fertilizers have the potential to enhance crop productivity by enhancing nutrient use efficiency. The present investigation was conducted during the *rabi* season of 2022-2023 in the experimental farm of DAV University, Jalandhar, to determine the effect of seed priming by Nano-Urea and Nano-Zinc on growth, yield and quality attributes of rat-tail radish. The experiment was laid in a randomized block design (RBD) with three replications comprising twelve treatments *viz*., T_1 (Control), T_2 (NPK *i.e.*, 100% recommended dose), T_3 (Nano-Urea *i.e.*, 100%), T_4 (Nano-Urea *i.e.*, 50%), T_5 (Nano-Zinc *i.e.*, 100%), T_6 (Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%), T_7 (Nano-Urea *i.e.*, 50% + Nano-Zinc *i.e.*, 100%), T_8 (NPK *i.e.*, 100% recommended dose + Nano-Zinc *i.e.*, 100%), T_9 (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100%), T_{10} (NPK *i.e.*, 100% recommended dose +Nano-Urea *i.e.*, 50%), T_{11} (NPK *i.e.*, 100% recommended dose +Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%) and T_{12} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 50% + Nano-Zinc *i.e.*, 100%). The results showed that the seed-priming application of Nano-Urea (50%) along with NPK minimised the days to 50% germination. It was also observed that NPK along with Nano-Urea (100%) and Nano-Zinc (100%) minimised the days to 50% flowering, and increased the number of leaves per plant, leaf length and leaf area. Further, the combination of both Nano-Urea (50%) and Nano-Zinc (100%) along with NPK recorded the highest plant height, number of branches per plant and leaf width. Among, the pod yield of rat-tail radish, the highest pod length and pod diameter were recorded with the combination of NPK along with Nano-Urea (100%). Whereas, the maximum number of pods per plant was recorded under the combination application of both Nano-Urea (100%) and Nano-Zinc (100%) along with NPK. It was also observed that NPK along with Nano-Urea (100%) and Nano-Zinc (100%) recorded the highest pod yield per plant, pod yield per plot and pod yield per hectare. Among the quality attributes, the soluble protein content, carotenoid content, total phenolic content and chlorophyll content. The TSS was recorded maximum when NPK was applied with 100% Nano-Zinc. Ascorbic acid and total flavonoid content were recorded maximum when NPK was applied in combination with the seed-priming of 100% Nano-Urea and 100%Nano-Zinc. The analysis of yield suggested that the maximum gross income, net income and benefit-cost ratio from the treatment T_{11} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%).

Keywords: Nano-fertilizers, seed-priming, nano-urea, nano-zinc, benefit-cost ratio, economics, rat-tail radish

Introduction
Rat-tailed radish (*Raphanus sativus* var. *caudatus*) is a vegetable crop, which is grown for its edible and tender pods. It belongs to the family Brassicaceae (2n = 2x = 18) (Sangthong *et al.*, 2014; Wiersema and Leon, 1999) [1-2]. It is believed to have originated in Southeast Asia and China; and is now being cultivated throughout India and Eastern Asia (Schippers, 2004) [3]. With the increasing global human population, food production is also required to increase (Wallace, 2000) [4]. It is quite challenging to ensure food and nutritional security for the increasing human population. Therefore, to meet the increasing food demand, various researchers are trying to develop an efficient and eco-friendly crop production technology based on innovative technologies.

The nutrient management for crop plants is considered a key to ensuring a good harvest. Crop nutrition requirements vary depending on soil fertility, soil type, agro-climatic conditions, and the genotype. For the optimum production and good quality of rat-tail radish optimum fertilization is essential (Dhanajaya, 2007) [5]. The recommended NPK dosage for rat-tail radish is 25 kg of N (55 kg of Urea) and 12 kg of P_2O_5 (75 kg of Single Superphosphate) per acre (Thind, 2021) [6]. The overuse of chemical-based fertilizers has resulted in several serious environmental issues (Savci, 2012) [7], therefore it is desired to reduce the usage of chemical fertilizers without affecting the yield. To increase food production, it is desirable to use the recent technological advancements in agriculture (Davis *et al.*, 2017) [8]. Nanotechnology is one such modern technology, which has the potential to change the pattern of the utilization of chemical fertilizers and reduce their dosage (Chen and Yada, 2011; Prasad *et al.*, 2014) [9-10]. Nano-fertilizers regulate the release of nutrients and deliver the correct quantity of nutrients required by the crop plants in appropriate proportion and promote productivity while ensuring environmental safety (De Rosa *et al.*, 2010; Manjunatha *et al.*, 2016) [11-12]. The nutrition may be administered as nano-scale particles or emulsions, covered with a thin protective polymer coating, or contained within nanomaterials, such as nanotubes or non-porous materials (De Rosa *et al.*, 2010) [11]. In a conventional nutrient management system, it is quite difficult to control the micronutrient delivery to a specific crop, however, the nano-fertilizers are capable of supplying adequate amounts of such nutrients (Zulfiqar *et al.*, 2019) [13]. Recently, both macro- and micro-nutrients have been available as their nano-formulations in the market. The nano-fertilizers are less expensive and required in smaller quantities than chemical fertilizers (Rameshaiah *et al.*, 2015) [14].

Seed priming is the method of pre-treating seeds before planting using traditional methods like pre-soaking and/or coating. It may result in a physiological change in the seed that permits it to germinate more rapidly (Bruce *et al.*, 2007) [15]. Priming is also performed to enhance crop activity by stimulating the resistance of plants against various types of abiotic and biotic stresses (Arnott *et al.*, 2021) [16]. Similar to the conventional methods of seed priming, nano-priming may also be applied to seeds (using nanomaterials like nano-fertilizers). New studies showed that seed nano-priming can activate different genes during germination, especially those related to plant stress resistance (Mahakham, 2017; An *et al.*, 2020; Ye *et al.*, 2020) [17-18-19]. Seed nano-priming also can be utilized for seed protection, as many nanoparticles have antimicrobial properties and can load antimicrobial agents (Abbasi *et al.*, 2021) [20]. In addition, nano-priming may be used to aim for bio-fortification of seeds to promote an increase in food quality and production (Pirzada *et al.*, 2022; Roche *et al.*, 2020; Sharifi *et al.*, 2016) [21-22-23]. The treatment with zinc nanoparticles improved both the yield and quality of common bean (Aziz *et al.*, 2019) [24]. Seed priming by nano-Zn increases the availability of the nutrient to growing seedlings and also promotes seedling growth (Esper Neto *et al.*, 2020) [25]. The use of nano-fertilizers as seed-priming agents will further reduce their dosage, will be more economical and capable of providing initial growth advantage to the seedling emerging from primed seeds. Keeping this view the work was done to study the effect of seed priming by nano-urea and nano-zinc on growth and yield of rat-tail radish.

Materials and Methods

The field experiment was carried out during the *rabi* season of the year 2022-23 at the experimental farm of the Faculty of Agricultural Sciences, DAV University, Sarmastpur, Jalandhar (Punjab). Geographically, the experimental site is situated at 75°37´15´´ East latitude and 31°25´23´´ North longitude, with an average altitude of 230 meters (754.5 feet) from the sea level.

Plant material

Plant material, *i.e.*, rat-tail radish (*Hybrid singra*).

Nano-fertilizers and fertilizers

Nano-fertilizers *i.e.*, Nano-Urea (IFFCO) and Nano-Zinc (Geolife), Commercial fertilizers *i.e.*, NPK (IFFCO).

Experimental design

The experiment was laid out in a randomized block design with three replications comprising twelve treatments represented in (Table 1).

Field preparation

The experimental field was prepared using a disc plough that prepared it to a fine tilth, followed by light ploughing, harrowing, and planking using the cultivator. The recommended dose for rat tail radish is 25 kg of N and 12 kg of P_2O_5, per hectare in the form of urea and Single Super Phosphate (SSP) was applied after appropriate plot delineation. The light irrigation was given immediately after the sowing of seeds.

Table 1: Treatment details

Treatment	Details of the treatment
T_1	Control
T_2	NPK (100% recommended dose)
T_3	Nano-Urea (100%)
T_4	Nano-Urea (50%)
T_5	Nano-Zinc (100%)
T_6	Nano-Urea (100%) + Nano-Zinc (100%)
T_7	Nano-Urea (50%) + Nano-Zinc (100%)
T_8	NPK + Nano-Zinc (100%)
T_9	NPK + Nano-Urea (100%)
T_{10}	NPK+ Nano-Urea (50%)
T_{11}	NPK + Nano-Urea (100%) + Nano-Zinc (100%)
T_{12}	NPK+ Nano-Urea (50%) + Nano-Zinc (100%)

Seed priming and sowing

The application of fertilizers was manually done to the individual plots as per the treatments. Nano-Urea and Nano-Zinc were used as seed priming agents at a concentration of 2.5 g/liters (100%) for Nano-Zinc, 30 ml/liters (100%) and 15 ml/liters (50%) for Nano-Urea. The treated seeds were sown directly on the ridges at a depth of 2 cm and with a spacing of 60 × 10 cm (row to row × plant to plant).

Collection of experimental data

Growth parameters: From the first week after sowing, the morphological observations were taken at different stages. Five plants were chosen at random from each plot and tagged. All observations *viz.* days to 50% germination, days to 50% flowering, plant height, number of leaves per plant, number of branches per plant leaf length, leaf width and leaf area were recorded from these plants.

Yield parameters

Upon harvesting, the yield measurements were recorded for each treatment. On the basis of net plot size, various observations were recorded *viz.* pod length, pod diameter, number of pods per plant, pod yield per plant, pod yield per plot and pod yield per hectare.

Quality parameters
Different quality parameters (*viz.*TSS, ascorbic acid, chlorophyll content, carotenoid content, flavonoid content, phenolic content and protein content) were measured.

Total soluble solids
The total soluble solids (TSS) of the pods were determined using a digital hand Refractometer (Erma Hand Refractometer 0-32 °Brix). Juice of the selected samples was extracted. With the help of the dropper, a drop of juice was placed on Refractometer and TSS was recorded.

Ascorbic acid (mg/g FW)
Ascorbic acid was determined using the 2, 6 dichlorophenol-indophenol titration method (Rekha *et al*., 2012) [26]. The results were expressed as mg/g of fresh weight of the sample and were calculated using the formula.

$$\text{Ascorbic acid content (mg/g FW)} = \frac{\textit{Titrate valve} \times \textit{dye factor} \times \textit{volume made up}}{\textit{Aliquot of extract taken} \times \textit{weight of sample}} \times 100$$

Protein content
The protein content was estimated as described by Sharma *et al.*, (2011) [27]. The total protein content was determined from the above supernatant (protein extract) using the method given by Bradford (1976) [93], using bovine serum albumin (BSA) as a standard. The standard curve was plotted between different known concentrations of BSA and absorbance was recorded at 595 nm.

Total flavonoid content
Total flavonoid content was determined by using the method given by Ardekani *et al.*, (2011) [28]. This reaction was mixed well and kept in a dark room for 1 hour and then the absorbance was recorded at 510 nm. Catechin was used as a standard and the total flavonoid content was calculated using a standard curve of Catechin.

Total phenolic content
Total phenolic content was analyzed by using Singleton's method (Singleton *et al*., 1999) [29]. This reaction mixture was incubated at room temperature for approximately 1 hour and the absorbance was measured at 650 nm.

Pigment composition
During the investigation, different plant pigments like chlorophyll (total chlorophyll, chlorophyll a and chlorophyll b) and carotenoids were quantified as given below:
Chlorophyll content
The chlorophyll content of leaves was determined after sowing at 45 days. A hundred mg of fresh leaves were homogenized using 5 ml of 80% acetone (v/v) and centrifuged at 10,000 rpm for 10 minutes and the volume of supernatant was made to 10 ml with 80% acetone. The supernatant was separated carefully, and the absorbance was recorded at 645 and 663 nm. The results were expressed in mg/g fresh weight of leaves and were calculated using the method given by Arnon (1949) as per the following formulae:

Total Chlorophyll (mg/g FW) = 20.2(A645) + 8.02(A663)
Chlorophyll a (mg/g FW) = 12.7(A663) + 2.69(A645)
Chlorophyll b (mg/g FW = 22.9(A645) − 4.68(A663)

Carotenoid content
The carotenoid content of leaves was determined after sowing at 45 days. Hundred mg fresh leaves were homogenized with 5ml of 80% acetone (v/v) and centrifuged at 10000 rpm for 10 minutes and the volume of the supernatant was made to 10 ml with 80% acetone. The supernatant was taken carefully, and absorbance was recorded at 480 and 510 nm (Kapoor *et al.*, 2014) [30]. The results were expressed in mg/g fresh weight of leaves and were calculated using the formula:

Carotenoids (mg/g FW) = 7.6(A480) −1.49(A510)

Statistical analysis
The data collected was subjected to Analysis of Variance (ANOVA) in RBD with Fisher's test to find the critical difference (CD) among different treatment means using OPSTAT to check the significant differences among treatments at $p \leq 0.05$.

Yield economics: The cost of cultivation of different treatments was calculated by considering all the expenses incurred in the cultivation of experimental crop and added with common costs due to various operations and inputs used. Accordingly, the cost of cultivation was calculated for all the treatments (Zangeneh *et al*., 2010) [31]. Gross returns were calculated by multiplying total pod yield, separately for the various treatments with their existing market price (Verma *et al.*, 2011) [32]. Net return was calculated by deducting the cost of cultivation from the gross return of the individual treatments (Umesh *et al*., 2014) [34]. The benefit-cost ratio was calculated by dividing the net return by the cost of cultivation of the individual treatments (Mohammadi *et al.*, 2008) [33], as under:

$$\text{Benefit-cost ratio} = \frac{\textit{Net return}}{\textit{Cost of cultivation}}$$

Results
The results for various growth, yield, and quality attributes are briefly detailed in the appropriate sections below.

Growth attributes
The effect of seed priming by Nano-Urea and Nano-Zinc fertilizers on various growth parameters *viz.*, days to 50% germination, days to 50% flowering, plant height, number of leaves per plant, number of branches per plant, leaf length, leaf width and leaf area are presented in (Table 2). All the observations except days to 50% germination and days to 50% flowering were recorded after 90 days.

Days to 50% germination
The plants were observed daily until the 50% germination was achieved (Table 2). The minimum days to 50% germination (5.00 days for both) were observed in the treatments T_2 and T_{10}, which however, were statistically at par (not significantly different at $p \leq 0.05$) with the treatments T_4, T_{11} and T_{12} *i.e.*, 5.33 days for all three. Whereas, the maximum days to 50% germination (10.33 days) was observed in the treatment T_8, which was significantly higher than all other treatments.

Days to 50% flowering
An observation was made daily until the 50% flowering was achieved (Table 2). The minimum days to 50% flowering were observed in the treatments T_2 and T_{11}(55.00 days for both) which however, was statistically at par (not significantly different at

$p \leq 0.05$) with the treatments T_1 and T_{12}(56.00 days for both) and the treatment T_{10} (56.33). Whereas, the maximum days to 50% flowering were observed in three different treatments T_5, T_8 and T_9 *i.e.*, 59.66 days for all three treatments, which were significantly higher than all the treatments.

Plant height (cm): Significant differences in the plant height at 90 DAS was observed among the different treatments (Table 2). The maximum plant height (119.40 cm) was observed in treatment T_{12}, which was significantly higher than all the treatments. Whereas, the minimum plant height (71.48 cm) was observed in treatment T_6, which was significantly lower than all the treatments.

Number of leaves per plant: Significant differences in the number of leaves per plant at 90 DAS was observed among the different treatments (Table 2). It was observed that the maximum number of leaves (72.40) in treatment T_{11}, was significantly higher than all the treatments. Whereas, the minimum number of leaves (25.47) was found in treatment T_6, which was significantly lower than all the treatments.

Number of branches per plant

Significant differences in the number of branches per plant at 90 DAS were observed among the different treatments (Table 2). It was observed that the maximum number of branches (17.33) in the treatment T_{12}, which was however, statistically at par with the treatment T_{10} (16.33), T_{11} (15.66) and the treatments T_9 and T_8*i.e.*, 14.16 (for both T_8 and T_9). Whereas, the minimum number of branches (5.83) was found in treatment T_6, which was however, statistically at par with the treatments T_3 (7.00), T_5 (8.00), T_7 (8.33), T_4 (10.50) and the treatment T_1 (8.50).

Leaf length (cm)

Significant differences in the leaf length at 90 DAS was observed among the different treatments (Table 2). It was observed that the maximum leaf length (17.25 cm) in the treatment T_{11}, which was however, statistically at par with the treatment T_9*i.e.*, 17.41 cm, T_{12}*i.e.*, 16.19 cm, and the treatment T_3 *i.e.*, 16.18 cm. Whereas, the minimum leaf length (14.04 cm) was observed in treatment T_6, and the treatment which was however, statistically at par with the treatment T_1 (14.10 cm), T_2*i.e.*, 14.50 cm and the treatment T_8*i.e.*, 14.88 cm.

Leaf width (cm): Significant differences in the leaf width at 90 DAS was observed among the different treatments (Table 2). It was observed that the maximum leaf width (7.40 cm) in the treatment T_{12}, which was however, statistically at par with the treatment T_9 (7.29 cm), and the treatment T_{11} (7.09 cm). Whereas, the minimum leaf width (5.22 cm) was observed in treatment T_1, was statistically at par with treatment T_6 (5.66 cm), treatment T_3(5.33 cm), the treatment T_7(5.69 cm).

Leaf area (cm^2)

Significant differences in leaf area at 90 DAS was observed among the different treatments (Table 2). The maximum leaf area (126.91 cm^2) was observed in treatment T_9, which was significantly higher than all the treatments. Whereas, the minimum leaf area (73.60 cm^2), was observed in treatment T_1, which was significantly minimum than all the treatments.

Table 2: Effect of nano-urea and nano-zinc on growth attributes of rat-tail radish *viz*., days to 50% germination, days to 50% flowering, plant height and number of leaves per plant

Treatments	Days to 50% germination	Days to 50% flowering	Plant height (cm)	No. of leaves per plant
T_1	6.00	56.00	83.29	34.40
T_2	5.00	55.00	104.29	67.34
T_3	6.00	57.33	92.20	31.53
T_4	5.33	56.66	82.40	29.25
T_5	6.33	59.66	72.38	25.47
T_6	6.33	56.66	71.48	43.32
T_7	6.00	56.66	101.63	28.62
T_8	10.33	59.66	83.78	32.72
T_9	9.33	59.66	87.47	36.50
T_{10}	5.00	56.33	87.71	51.51
T_{11}	5.33	55.00	112.45	72.40
T_{12}	5.33	56.00	119.40	54.37
SE (m) ±	0.93	1.49	0.46	0.38
CD @ 5% ($p \leq 0.05$)	0.31	0.50	0.16	0.13

Table 3: Effect of Nano-Urea and Nano-Zinc on growth attributes of rat tail radish *viz*., number of branches per plant, leaf length, leaf width and leaf area

Treatments	No. of branches per plant	Leaf length (cm)	Leaf width (cm)	Leaf area(cm^2)
T_1	8.50	14.10	5.22	73.60
T_2	11.83	14.50	5.69	82.50
T_3	7.00	16.18	5.33	86.23
T_4	10.5	15.13	6.05	91.53
T_5	8.00	15.32	6.46	98.96
T_6	5.83	14.04	5.66	79.46
T_7	8.33	16.4	5.58	91.51
T_8	14.16	14.88	5.99	89.13
T_9	14.16	17.41	7.29	126.91
T_{10}	16.33	16.20	6.50	105.30
T_{11}	15.66	17.25	7.09	122.30
T_{12}	17.33	16.19	7.40	119.80
SE (m) ±	5.06	1.07	0.69	0.73
CD @ 5% ($p \leq 0.05$)	1.71	0.36	0.23	0.24

Yield attributes

The effect of seed priming by Nano-Urea and Nano-Zinc fertilizers on various yield parameters of rat tail radish were recorded during harvesting *viz.*, pod length, pod diameter, number of pods per plant, pod yield per plant, pod yield per plot and pod yield per hectare are presented in (table 4). Except pod length and pod diameter, all the characters were calculated by pooling the data of all three pickings.

Pod Length (cm)

The effect of Nano-Urea and Nano-Zinc fertilizers on pod length is presented in (Table 4). The maximum pod length (29.34 cm) was observed in treatment T_9, which was however, statistically at par with the treatment T_{11} (26.84 cm), T_3 (25.86 cm) and treatment T_4 (26.15 cm). Whereas, the minimum pod length (20.87 cm) was observed in T_{12}, which was however, significantly at par with the treatment T_6 (22.45 cm), T_7(23.86 cm), T_5 (23.74 cm), and the treatment T_2(23.41 cm).

Pod Diameter (mm)

The effect of Nano-Urea and Nano-Zinc fertilizers on pod diameter is presented in (Table 4). The maximum pod diameter (3.75 mm) was observed in treatment T_9, which was however, statistically at par with the treatment T_2 (3.63 mm), T_{10}(3.44 mm) and treatment T_3 (3.42 mm). Whereas, the minimum pod diameter (2.84 mm) was observed in treatment T_8, which was however, statistically at par with the treatment T_5(3.13 mm), T_6 (3.22 mm), T_7 (3.19 mm), T_{12}(3.05 mm), and the treatment T_1 (3.04 mm).

Number of pods per plant

The effect of Nano-Urea and Nano-Zinc fertilizers on number of pods per plant is presented in (Table 4). The maximum number of pods per plant (170.51) was observed in the treatment in T_{12}, which was significantly higher than all the treatments. Whereas, the minimum number of pods per plant (74.52) was observed in treatment T_6, which was significantly lower than all the treatments.

Pod yield per plant (kg)

The effect of Nano-Urea and Nano-Zinc fertilizers on pod yield per plant is presented in (Table 4). The maximum pod yield per plant (1.53 kg) was observed in treatment T_{11}, which was, however, statistically at par with treatment T_3 (1.14 kg). Whereas, the minimum pod yield per plant (0.27 kg) was observed in treatment T_6, which was however, statistically at par with the treatment T_1(0.69 kg), T_2(0.70 kg), T_4 (0.63 kg), T_5(0.49 kg), T_7(0.53 kg), T_8(0.64 kg), T_9(0.77 kg), T_{10} (0.66 kg) and the treatment T_{12} (0.88 kg).

Pod yield per plot (kg)

The effect of Nano-Urea and Nano-Zinc fertilizers on pod yield per plot is presented in (Table 4). The maximum pod yield per plot (4.32 kg) was observed in treatment T_{11}, which was however, statistically at par with treatment T_{12}(3.28 kg), T_{10}(3.09 kg) and treatment T_3 (4.04 kg). Whereas, the minimum pod yield per plot (1.52 kg) was observed in treatment T_5, which was however, statistically at par with treatments T_1 (2.07 kg), T_2 (1.91 kg), T_4 (1.75 kg), T_6 (2.59 kg), T_7 (1.72 kg), T_8 (1.92 kg), T_9 (2.08 kg).

Pod yield per hectare (q/ha): The effect of Nano-Urea and Nano-Zinc fertilizers on pod yield per hectare is presented in (Table 4). The maximum pod yield per hectare (72.40 q/ha) was observed in treatment T_{11}, which was significantly higher than all the treatments. Whereas, the minimum pod yield per hectare (25.47 q/ha) was observed in treatment T_5, which was significantly lower than all the treatments.

Table 4: Effect of Nano-Urea and Nano-Zinc on yield attributes of rat tail radish

Treatments	Pod Length (cm)	Pod Diameter (mm)	No. of pods per plant	Pod Yield per plant (kg)	Pod yield per plot(kg)
T_1	24.47	3.04	100.37	0.69	2.07
T_2	23.41	3.63	148.29	0.70	1.91
T_3	25.86	3.42	166.61	1.14	4.04
T_4	26.15	3.33	114.32	0.63	1.75
T_5	23.74	3.13	192.51	0.49	1.52
T_6	22.45	3.22	74.52	0.27	2.59
T_7	23.86	3.19	110.25	0.53	1.72
T_8	25.11	2.84	90.69	0.64	1.92
T_9	29.34	3.75	148.40	0.77	2.08
T_{10}	25.17	3.44	129.79	0.66	3.09
T_{11}	26.84	3.27	168.34	1.53	4.33
T_{12}	20.87	3.05	170.51	0.88	3.28
SE (m) ±	3.55	0.40	2.10	0.63	1.36
CD @ 5% ($p \leq 0.05$)	1.20	0.13	0.71	0.21	0.46

Quality attributes

The effect of seed priming by Nano-Urea and Nano-Zinc fertilizers on various quality parameters of rat tail radish *viz.*, TSS, ascorbic acid, carotenoids, total chlorophyll, chlorophyll a, chlorophyll b, proteins, flavonoids and phenolics are presented in (Table 5).

TSS (°Brix)

The maximum TSS (5.56°B) was recorded in the treatment T_5 (Nano-Zinc *i.e.*, 100%), which was significantly higher than all other treatments (Table 5). Whereas, the minimum TSS (4.18°B) was observed in treatment T_4, which was however, statistically at par with the treatment T_1 (4.61°B), T_2 (4.31°B), T_6 (4.38°B), T_7 (4.45°B), the treatments T_8 and T_3 (4.43°B) for both T8 and T_3.

Ascorbic acid (mg/g FW)

The maximum ascorbic acid (18.08 mg/g FW) was recorded in the treatment T_{11}, which was however, statistically at par with the treatment T_5 (17.80 mg/g FW) and the treatment T_9 (17.28 mg/g FW) (Table 5). Whereas, the minimum ascorbic acid (12.14 mg/g FW) was observed in the treatment T_1, which was however, statistically at par with treatment T_4(13.14 mg/g FW) and treatment T_8 (13.95 mg/g FW).

Protein content (µg/g FW)

The maximum protein content (1.91 µg/g FW) was observed in the treatment T_{12} (Table 5), which was however, statistically at par with the treatment T_{10} (1.84 µg/g FW) and the treatment T_{11} (1.80 µg/g FW). Whereas, the minimum protein content was observed (1.06 µg/g FW) in the treatment T_1, which was, however, statistically at par with the treatment T_2(1.10 µg/g FW).

Total phenolic content (mg Gallic acid eq./g FW)

The maximum total phenolic content (1.21 mg Gallic acid eq./g FW) was observed in treatment T_{12} (Table 5), which was significantly higher than all the treatments. Whereas, the minimum total phenolic content was observed (0.07 mg Gallic acid eq./g FW) in the treatment T_1, which was however, statistically at par with the treatment T_9 (0.13 mg Gallic acid eq./g FW).

Total flavonoid content (mg/g Catechin eq./g FW)

The maximum total flavonoid content (0.86 mg/g Catechin eq./g FW) was observed in treatment T_{11} which was however, statistically at par with treatment T_{12} (0.73 mg/g Catechin eq./g FW) (Table 5). Whereas, the minimum total flavonoid content was observed (0.14 mg/g Catechin eq./g FW**)** in the treatment T_1, which was however, statistically at par with the treatment T_2 (0.15 mg/g Catechin eq./g FW), T_3 (0.18 mg/g Catechin eq./g FW), T_4 (0.31 mg/g Catechin eq./g FW), T_6 (0.21 mg/g Catechin eq./g FW), T_7 (0.27 mg/g Catechin eq./g FW) and the treatment T_9 (0.20 mg/g Catechin eq./g FW).

Carotenoids (mg/g FW)

Maximum carotenoid content at 90 DAS was observed (0.52 mg/g FW) in the treatment T_{12}, which was significantly higher than all the treatments (Table 5). Whereas, the minimum carotenoid content was observed (0.17 mg/g FW) in the treatment T_1, which was statistically at par with treatment T_2 (0.24 mg/g FW), the treatment, treatment T_4 (0.19 mg/g FW), T_7 (0.24 mg/g FW), T_8 (0.18 mg/g FW), the treatment T_3, T_5 and the treatment T_{10} (0.22 mg/g FW) for all three treatments T_3, T_5 and T_{10}.

Table 5: Effect of nano-urea and nano-zinc on quality attributes of rat-tail radish *viz.* TSS, Ascorbic acid, protein content, Carotenoids, Total Flavonoid content, total Phenolic content, chlorophyll a, chlorophyll b and total chlorophyll

Treatments	TSS (°Brix)	Ascorbic acid (mg/100g)	Protein content (µg/g)	Carotenoids (mg/g FW)	Total Flavonoid content (mg/g FW of Catechin eq.)	Chlorophyll a (mg/g FW)	Chlorophyll b (mg/g FW)	Total Chlorophyll (mg/g FW)
T_1	4.61	12.14	1.06	0.17	0.14	3.91	1.02	4.93
T_2	4.31	14.14	1.10	0.24	0.15	7.87	1.80	9.67
T_3	4.43	15.30	1.20	0.22	0.18	5.63	0.91	6.54
T_4	4.18	13.14	1.40	0.19	0.31	5.56	1.32	6.88
T_5	5.66	17.80	1.77	0.22	0.39	5.43	0.52	5.95
T_6	4.38	15.70	1.21	0.37	0.21	4.94	0.6	5.59
T_7	4.45	15.22	1.40	0.24	0.27	6.16	0.78	6.94
T_8	4.43	13.95	1.65	0.18	0.42	7.30	2.13	9.43
T_9	4.76	17.28	1.55	0.32	0.20	7.27	1.74	9.01
T_{10}	4.85	14.31	1.84	0.22	0.42	5.06	1.76	6.82
T_{11}	5.05	18.08	1.80	0.30	0.86	7.79	2.50	10.29
T_{12}	5.03	15.60	1.91	0.52	0.73	8.38	3.61	11.99
SE (m) ±	0.43	1.89	0.11	0.07	0.213	2.68	1.44	4.12
CD @ 5% ($p \le 0.05$)	0.14	0.64	0.04	0.02	0.072	0.90	0.48	1.38

Chlorophyll a (mg/g FW)

The maximum chlorophyll a content at 90 DAS was observed (8.38 mg/g FW) in the treatment T_{12}, which was however, statistically at par with treatments T_2 (7.87 mg/g FW), T_{11} (7.79 mg/g FW), T_9 (7.27 mg/g FW), T_8 (0.81 mg/g FW), and T_7 (6.16 mg/g FW) (Table 5).Whereas, the minimum chlorophyll a content was observed (3.91 mg/g FW) in treatment T_1, which was however, statistically at par with treatments T_3 (5.63 mg/g FW), T_4 (5.56 mg/g FW), T_6 (4.94 mg/g FW), T_{10} (5.06 mg/g FW) and treatment T_5 (Nano5.43 mg/g FW).

Chlorophyll b (mg/g FW)

The maximum chlorophyll b content at 90 DAS was observed (3.61 mg/g FW) in the T_{12}, which was statistically at par with the treatment T_{11} (2.50 mg/g FW) (Table 5). Whereas, the minimum chlorophyll b content was observed (0.52 mg/g FW) in treatment T_5, which was however, statistically at par with the treatments T_1 (1.02 mg/g FW), T_2 (1.80 mg/g FW), T_3 (0.91 mg/g FW), T_4 (1.32 mg/g FW), T_6 (0.60 mg/g FW), T_7 (0.78 mg/g FW), T_9 (1.74 mg/g FW) and T_{10} (1.76 mg/g FW).

Total Chlorophyll (mg/g FW)

The maximum total chlorophyll content at 90 DAS was observed (11.99 mg/g FW) in the T_{12}, which was however, statistically at par with the treatment T_{11} (10.29 mg/g FW), T_2 (9.67 mg/g FW), T_8 (9.43 mg/g FW) and T_9 (9.01 mg/g FW) (Table 5). Whereas, the minimum total chlorophyll content was observed (4.93 mg/g FW) in the treatment T_1, which was however, statistically at par with the treatment T_3 (6.45 mg/g FW), T_5 (5.95 mg/g FW), T_4 (6.88 mg/g FW), T_6 (5.59 mg/g FW), T_7 (6.94 mg/g FW) and T_{10} (6.82 mg/g FW).

Economics: The data obtained on the economics of rat-tail radish as influenced by the application of Nano-Urea and Nano-Zinc fertilizers are represented in (Table 7). The gross income (Rs. 289600 ha^{-1}), net income (Rs. 227258 ha^{-1}), and benefit-cost ratio (B:C ratio) (Rs. 3.64 ha^{-1}) were observed maximum in treatment T_{11} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%), followed by the treatment T_{12} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 50% + Nano-Zinc *i.e.*, 100%) with (B:C ratio) (Rs 3.43 ha^{-1}) and T_2 (NPK *i.e.*, 100% recommended dose) with B:C ratio (Rs 2.53 ha^{-1}). Whereas, the minimum gross income (Rs. 101880 ha^{-1}), net income (Rs. 45330 ha^{-1}), and benefit-cost ratio (B.C. ratio) (Rs. 0.80 ha^{-1}) were observed in treatment T_1 (Control), followed by the treatment T_7 (Nano-Urea 50% + Nano-Zinc) with B:C ratio (Rs. 0.99 ha^{-1}) and T_4 (Nano-Urea *i.e.*, 50%) with B:C ratio (Rs 1.06 ha^{-1}).

Table 6: Effect of Nano-Urea and Nano-Zinc on the economics of rat-tail radish

Treatments	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B.C. ratio
T_1	56550	101880	45330	0.80
T_2	60756	217480	155934	2.53
T_3	57123	126120	68997	1.20
T_4	56714	117000	60286	1.06
T_5	56842	137600	80758	1.42
T_6	57421	173280	115859	2.01
T_7	57323	114480	57157	0.99
T_8	61546	130880	69334	1.12
T_9	61622	146000	84378	1.36
T_{10}	61876	206040	144164	2.32
T_{11}	62342	289600	227258	3.64
T_{12}	61546	269360	208604	3.43

Discussion

Nano-fertilizers are the nano-materials, which are either nutrients themselves (micro- or macro- nutrients) or are acting as the carriers/additives for the nutrients (Kah *et al.*, 2018) [35]. Nano-fertilizers (micro- and/or macro-nutrient fertilisers in their nano-particle formulations) have facilitated the development of slow/controlled release fertilizers, which improve the fertilizer use efficiency and reduce the losses of nutrients in the environment (Liu and Lal, 2015; Naderi and Abedi, 2012) [36-37]. Therefore, they can improve crop yield and quality. Also, they are cost-effective, because they are used in lesser doses and therefore, also contribute towards agricultural sustainability. The application of nano-fertilizers improves the ability of the plants to absorb nutrients (Mousavi and Rezai 2011; Srilatha 2011; Ditta 2012) [38-39-40] and it also delivers the correct dose of nutrients in the right proportion, thereby increasing the crop productivity (De Rosa *et al.*, 2010) [11]. There are different methods for the application of nano-fertilizers, which include soil application, foliar spray, seed priming, root-dip treatment of the seedling and fertigation *etc* (Shang *et al.*, 2019) [41]. Out of these, the seed 'nano-priming' is an important method to improve seed germination and plant establishment (Pereira *et al.*, 2021) [42], as it provides the initial growth advantage to the crop plants. Moreover, the seed priming needs a lesser dose of the nano-fertilizers, making their priming treatment more economical in comparison to the various other types of nano-fertilizer application methods.

Seed priming is a pre-sowing treatment of seeds that involves their partial hydration to improve germination, early seedling growth (Rehman *et al.*, 2011; Singh *et al.*, 2015) [43-44] and overall seedling vigour (Soleimanzadeh, 2013) [45]. Priming using nano-particles (nano-priming) has been shown to be more promising than standard priming procedures for achieving feasible agricultural yields (Abbasi *et al.*, 2012) [20]. This process activates metabolic processes within the seed, without allowing complete germination. In a study, it was observed that chickpea seeds primed with 1.0mM Zn (Ullah *et al.*, 2019) [46] and rice seeds primed with 0.1% and 0.5% Zn (Abbas *et al.*, 2014; Pavithra *et al.*, 2017) [47-48] had improved seed germination and early seedling growth.

Growth attributes: Nanofertilizers improve the ability of the plants to absorb nutrients and thus, the plant growth too (Mousavi and Rezai 2011; Srilatha 2011; Ditta 2012) [38-39-40]. Some nanofertilizers like Nano-Urea were initially reported to increase the germination percentage and reduce the time of germination (Zheng *et al.*, 2005) [49]. In the present work, minimum days to 50% germination was observed in the treatment T10 (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 50%) and T_2 (NPK *i.e.*, 100% recommended dose) and it was observed that seed priming with nutrients like nitrogen and zinc improves germination. Various other workers also found a similar increase in germination rates in various crops like chickpea (Ullah *et al.*, 2019) [46], and rice (Abbas *et al.*, 2014) [47] seed on priming with zinc; and corn (Esper Neto *et al.*, 2020) [25] with nano-scale zinc oxide. Rice seed priming with a combination of nitrogen and zinc also increased the rate of germination (Tuiwong *et al.*, 2022) [50].

In the present work, minimum days to 50% flowering was observed in the treatment T11 (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%) and T_2 (NPK *i.e.*, 100% recommended dose). Therefore, no conclusive evidence of the effect of seed priming with nano-zinc and nano-urea was observed in rat-tail radish on flowering induction. However, some other workers have reported the role of nano-zinc in inducing an early flowering in different crops. In an experiment to understand the effect of nano zinc oxide (ZnO) particles (20-30 µgml/ml) on flowering in onion, the early flowering was noticed (Laware *et al.*, 2014) [51]. In another study, it was observed that the foliar applications of ZnO-NPs promote flowering in tomato (Ali *et al.*, 2015) [52]. Further, the seeds treatment with high concentration of ZnO-NPs (1000 ppm) resulted in an earlier flowering in peanut (Prasad *et al.*, 2012) [53]. On the contrary, the application of NPK (100% of the recommended dose) in okra helped in attaining early flowering as compared to all the other treatments.

Increased concentration of nano urea spray (0.4%) had significant impact on the growth parameters (Subramani *et al.*, 2023) [54]. The application of nitrogen is generally considered to be associated with an increase in cell growth (Bahmanyar and Mashaee, 2010) [55]. In the present work, the plant height was found maximum in treatment T12 (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 50% + Nano Zinc *i.e.*, 100%). The superiority of high concentrations of nano-fertilizers in increasing plant height may be due to their high permeability, which plays an important role in promoting plant growth (Alqader *et al*, 2020; Midde *et al.*, 2022) [56-57]. Further, nitrogen has a positive role in increasing the activity of meristematic tissues *i.e.*, cell division (Alqader *et al.*, 2020) [56]. The Nano-ZnO at 20 ppm was helpful in enhancing plant height in mung (Mahajan *et al.*, 2011) [58]. Further, it was also observed that the nano zinc-oxide at 2000 ppm concentration enhanced growth and development in groundnut (Prasad *et al.*, 2012) [53]. In another experiment in potato, the application of nano-urea and nano-zinc enhanced plant height (Chauhan *et al.*, 2023) [59].

The maximum number of leaves per plant can increase when sufficient supply of nitrogen for the plants (Lawlor, 2002) [60]. In the present study, the maximum number of leaves per plant was observed in the treatment T11 (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%). The application of Nano-Zinc at the concentration of 50ppm increased the number of leaves per plant in broad bean (Ghidan *et al.*, 2020) [61]. Further, in the present work, the number of branches per plant was found maximum in the treatment T_{12} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 50%+ Nano-Zinc *i.e.*, 100%). Application of zinc also improves different growth attributes due several direct and indirect effects (Vairavan *et al.*, 1997) [62]. Nano zinc also showed significant advantages in terms of increase in number of branches. Application of nano nutrients, especially zinc has clear positive effects on branching in pea and other pulse crops (Sathyan, 2022) [63]. In tomato, the foliar application of nano-Zn at 4ml/l enhanced the number of branches per plant (Mishra *et al.*, 2020) [64].

Leaf size is an important reflection of overall vegetative growth of the plants. All three major leaf size related parameters *i.e.*, leaf length, leaf width and leaf area influence both growth and development of plants (Yin *et al.*, 2003) [65]. The availability of nitrogen in the leaves also affects the leaf area (Grindlay, 1997) [66]. In the present study, the leaf length and leaf width was found maximum in the treatment T11 (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%), T_{12} (NPK *i.e.*, 100% recommended dose + Nano-Urea 50%+ Nano-Zinc 100%) respectively The results of present investigation indicated that there was an enhancing effect of Nano-Urea and Nano-Zinc on vegetative growth *i.e.*, leaf width and leaf length. A similar increase in leaf size (*i.e.*, leaf length, width, and leaf area) was recorded upon the foliar spray of ZnO nanoparticles, at the concentration of 500-1000 ppm, when compared to no Zn leaf samples (Kisan *et al.*, 2015) [67].

Yield attributes

Plant nutrition is a key contributing factor in the yield and yield related attributes. Further, the initial growth advantage by nutri-priming may help in early establishment leading to a higher yield. Seed priming by nano-fertilizers could be even more beneficial than the conventional fertilizers. In the present study, the pod length of rat tail reddish was observed maximum in the treatment T9 (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100%).The use of nano-fertilizers (*i.e.*, 0.1% Nano-Zinc + 0.2% Nano-Urea at 30 DAS) gave the highest pod length in pea. It may be attributed to the increase in the division and elongation of their cells that reflected in increased pod length (Sathyan, 2022) [63]. The number of pods per plant is one of the most crucial factors that determined the yield. In the present work, the number of pods per plant was found maximum in the treatment T_{12} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 50%+ Nano-Zinc *i.e.*, 100%). In an experiment, the foliar application of Nano-Nitrogen and Nano-Zinc increased number of pods in cowpea (Salim *et al.*, 2023) [68]. Further, the use of nano-fertilizers (*i.e.*, 0.1% Nano-Zinc + 0.2% Nano-Urea at 30 DAS) in pea was associated with the increase in number of pods (Sathyan, 2022) [63]. Pod yield is an important parameter in determining the productivity in rat tail radish. In the present work, the pod yield was found maximum in the treatment T_{11} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100%+ Nano-Zinc *i.e.*, 100%). A similar increase in pod yield in peanut was observed under nano-zinc fertilizer treatment in comparison to the conventional Zn-fertilizer.The nano scale zinc oxide (ZnO) recorded significantly higher pod yield (to the extent of 34%) in comparison to the cheated bulk ZnSO4 (Prasad *et al.*, 2012) [53]. Moreover, spraying of mango treeswith nano-zinc at 1 mg/L before flowering improved their yield (Zakzouk, 2017) [69]. Besides nano-zinc, nano-urea is also known to contribute in improving yield in some crop plants. The treatment with 50% *i.e.*, recommended dose of Nitrogen + 50% N through Nano urea produced the maximum yield in rice (Midde *et al.*, 2022) [57]. In another experiment, the treatment with 100% recommended dose of nitrogen and 50% recommended dose of nitrogen as basal + one Nano-Nitrogen spray at before flowering recorded higher yield in mustard (Navya *et al.*, 2022) [70].

Quality attributes

Total soluble solids are an indicator of the presence of solutes in a liquid (plant sap). An increase in the TSS may be attributed the proportionate increase in the assimilatory carbohydrate produced during photosynthesis. In the present study, the highest TSS was recorded in treatment T_5 (Nano-Zinc *i.e.*, 100%). Application of some nano-fertilizers *i.e.*, Zinc and Boron are known to increase the TSS. An increase in TSS was recorded in radish with the application of Nano-Zinc and nano-urea (Upasna *et al.*, 2023) [71]. In the present study, ascorbic acid content was found to be maximum the treatment T11 (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%). A similar increase in ascorbic acid content was recorded in green chilli after the foliar application of Nano-Nitrogen and zinc (Kanavi *et al.*, 2023) [72]. However, the application of Nano-Zn alone also enhanced ascorbic acid content in spinach (Zafar *et al.*, 2022) [73]. Proteins perform a variety of functions in plant cells, such as transport of nutrients, enzymatic activities, and several other physiological responsibilities (Robbin *et al.*, 1987) [74]. Nitrogen is an essential constituent of proteins. Zinc also plays a key role in the enzymatic activities as well as in protein synthesis (Hamzah Saleem *et al.*, 2022) [75]. In the present study, the highest protein content was observed in the treatment T_{12} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 50% + Nano-Zinc *i.e.*, 100%). In an experiment, the application of both Iron and Zinc increased protein content in corn (Munirah *et al.*, 2015) [76].The application of Nano-Zinc increased protein content in sunflower (Seleiman *et al.*, 2020) [77] and pearl millet (Tarafdar *et al.*, 2014) [78].In another experiment, the combinations of 75% Nano-N through drip irrigation and 25% Nano-N in foliar applicationincreased protein content in lettuce (Sharaf-Eldin*et al.*, 2022) [79].The role of nitrogen was responsible for the rise in chlorophyll levels in plant leaves. Additionally, nitrogen contributes to the synthesis of several vitamins and enzymes. It also plays a significant role in a number of physiological processes (Tisdale and Nelson, 1966) [80]. In the present study, chlorophyll content was found to be maximum in the treatment T_{11} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 100% + Nano-Zinc *i.e.*, 100%). Both nano-urea and nano-zinc have been reported to improve the chlorophyll content in plants. The application of both Nano-Urea and Nano-Zinc in cowpea resulted in increased chlorophyll synthesis (Salim *et al.*, 2023) [68]. A similar increase in amount of chlorophyll was observed in tomato by spraying it with 100 ppm nano-particles of zinc oxide (Sun *et al.*, 2020) [71]. Further, in cucumber, the chlorophyll content was enhanced by increasing the concentration of Nano-N (Abdel Wahab *et al.*, 2019) [81]. The similar observations were recorded in wheat, where the chlorophyll content increased with the application of Nano-Zinc oxide (Ramesh *et al.*, 2014) [82]. Just like chlorophyll, carotenoids are also affected by the nutrient status of the plant. In the present study, the highest carotenoid content was observed in the treatment T_{12} (NPK *i.e.*, 100% recommended dose + Nano-Urea *i.e.*, 50% + Nano-Zinc *i.e.*, 100%). The use of both nano-urea and nano-zinc have been reported in other crops to increase the carotenoid content. The application of Nano-Urea led to the increase in carotenoid content in red radish (Mahmoud *et al.,* 2019) [83]. Further, the carotenoid content in fodder maize was recorded to be highest in the seed priming and coating treatments with nano-particles of Zinc oxide (Tonday *et al.,* 2021) [84]. Generally, the anti-oxidant abilities and other health advantages of plants are related to their phenolic compounds (Elzaawely *et al.,* 2007; Dai and Mumper, 2010) [85-86]. Various workers have reported that the seed soaking/priming can increase antioxidant activity in crops (Islam and Becerra, 2012) [87]. In the present study, the phenolic content was observed maximum in the treatment T12 (NPK *i.e.,* 100% recommended dose + Nano-Urea *i.e.,* 50% + Nano-Zinc *i.e.,* 100%). Flavonoids are a group of polyphones, which are widely known for their antioxidant properties (Kukic *et al.,* 2006; Dai and Mumper, 2010) [88-86]. In the present study, the flavonoid content was observed maximum in the treatment T_{11} (NPK *i.e.,* 100% recommended dose + Nano-Urea *i.e.,* 100% + Nano-Zinc *i.e.,* 100%). A similar increase in the flavonoid content was also recorded in potato with the application of Nitrogen (Jin *et al.,* 2014) [89]. In another experiment, the treatment with nano-particles of Zn (0.3%) increased the flavonoid content in spinach (Zafar *et al.,* 2022) [73].

Benefit-cost ratio

Nanotechnology has the potential to change the usage pattern of the chemical fertilizers and reduced their dosage (Chen and Yada, 2011; Prasad *et al*., 2014) [9-10], thereby increasing profits (Singh, 2017) [90]. In the present study, the highest B:C ratio was observed in the treatment T11 (NPK *i.e.,* 100% recommended dose + Nano Urea *i.e.,* 100% + Nano Zinc *i.e.,* 100%). There are several other reports in which the increase in profits due to the usage of nano-fertilizers has been reported. The foliar application of Nano-Zinc (30 kg/ha) + Nano-urea (4 ml/l) increased benefit-cost ratio in maize (Ninama *et al.,* 2023) [91]. In potato also, similar results were observed with the application of 100% recommended dose of NPK+ foliar Nano-Nitrogen + foliar Nano-Zinc (Chauhan *et al.,* 2023) [59], in sweet corn, with the application of NPK along with the foliar application of Nano-Zinc increased benefit-cost ratio (Rajesh *et al.,* 2021) [92]. The application pattern of the nano-fertilizers (seed priming or foliar spray) is also linked to variation in input costs. Seed priming is even more economical than foliar application due to low volume of the nano-agent used.

Conclusion

In summary, the study evaluated the impact of seed priming with Nano-Urea and Nano-Zinc fertilizers on various growth attributes in plants. Notable findings include the reduced days to 50% germination and flowering in specific treatments, such as T2 and T11. Additionally, significant differences were observed in plant height, number of leaves per plant, number of branches per plant, leaf length, leaf width, and leaf area among different treatments. For instance, treatment T12 exhibited the maximum plant height and leaf width, while treatment T9 showed the highest leaf area. Conversely, treatment T6 consistently displayed the minimum values across multiple parameters. These results underscore the potential of seed priming with Nano-fertilizers to enhance plant growth and productivity, although further studies are warranted to validate these findings across different plant species and environmental conditions.

References

1. Sangthong S, Weerapreeyakul N, Barusrux S. Plausible extraction technique for cancer chemo preventive isothiocyanate compounds from the *Raphanus sativus* L. var. caudatus Alef. Eur J Cancer. 2014;(50):192.
2. Wiersema JH, Leon B. World economic plants: a standard reference. CRC press; 1999.
3. Schippers RR. *Raphanus sativus* L. [Internet] Record from PROTA4U. Grubben GJH, Denton OA, editors. PROTA (Plant Resources of Tropical Africa / Ressourcesvégétales de l'Afriquetropicale), Wageningen, Netherlands; 2004. Accessed 21 June 2022.
4. Wallace JS. Increasing agricultural water use efficiency to meet future food production. Agric Ecosyst Environ. 2000;82(1-3):105-119.
5. Dhananjaya J. Organic studies in radish (*Raphanus sativus* L.) varieties. Department of Horticulture Collage of Agriculture, Dharwad University of Agriculture Science, Dharwad. 2007;580(5):12-13.
6. Thind SK. Package of practices for cultivation of vegetables. 2021:107-118.
7. Savci S. An agricultural pollutant: chemical fertilizer. Int J Environ Sci Dev. 2012;3(1):73.
8. Davis KF, Rulli MC, Seveso A, D'Odorico P. Increased food production and reduced water use through optimized crop distribution. Nat Geosci. 2017;10(12):919-924.
9. Chen H, Yada R. Nanotechnologies in agriculture: new tools for sustainable development. Trends Food Sci Technol. 2011;22(11):585-594.
10. Prasad R, Kumar V, Prasad KS. Nanotechnology in sustainable agriculture: present concerns and future aspects. Afr J Biotechnol. 2014;13(6):705-713.
11. De Rosa MC, Monreal C, Schnitzer M, Walsh R, Sultan Y. Nanotechnology in fertilizers. Nat Nanotechnol. 2010;5(2):91.
12. Manjunatha SB, Biradar DP, Aladakatti YR. Nanotechnology and its applications in agriculture: A review of journal farm Science. J Nanosci Nanotechnol. 2016;29(1):1-13.
13. Zulfiqar F, Navarro M, Ashraf M, Akram NA, Munné-Bosch S. Nanofertilizer use for sustainable agriculture: Advantages and limitations. Plant Sci. 2019;289:110270.
14. Rameshaiah GN, Pallavi J, Shabnam S. Nano fertilizers and nano sensors–an attempt for developing smart agriculture. Int J Eng Res Gen Sci. 2015;3(1):314-320.
15. Bruce TJ, Matthes MC, Napier JA, Pickett JA. Stressful "memories" of plants: evidence and possible mechanisms. Plant Sci. 2007;173(6):603-608.
16. Arnott A, Galagedara L, Thomas R, Cheema M, Sobze JM. The potential of rock dust nanoparticles to improve seed germination and seedling vigor of native species: A review. Sci Total Environ. 2021;775:145139.
17. Mahakham W, Sarmah AK, Maensiri S, Theerakulpisut P. Nanopriming technology for enhancing germination and starch metabolism of aged rice seeds using phytosynthesized silver nanoparticles. Sci Rep. 2017;7(1):8263.
18. An J, Hu P, Li F, Wu H, Shen Y, White JC, Giraldo JP. Emerging investigator series: molecular mechanisms of plant salinity stress tolerance improvement by seed priming with cerium oxide nanoparticles. Environ Sci Nano. 2020;7(8):2214-2228.
19. Ye Y, Cota-Ruiz K, Hernández-Viezcas JA, Valdes C, Medina-Velo IA, Turley RS, *et al*. Manganese nanoparticles control salinity-modulated molecular responses in *Capsicum annuum* L. through priming: A sustainable

approach for agriculture. ACS Sustainable Chem Eng. 2020;8(3):1427-1436.
20. Abbasi Khalaki M, Moameri M, Asgari Lajayer B, Astatkie T. Influence of nano-priming on seed germination and plant growth of forage and medicinal plants. Plant Growth Regul. 2021;93:13-28.
21. Pirzada T, de Farias BV, Mathew R, Guenther RH, Byrd MV, Sit TL, *et al*. Recent advances in biodegradable matrices for active ingredient release in crop protection: Towards attaining sustainability in agriculture. Curr Opin Colloid Interface Sci. 2020;48:121-136.
22. De La Torre-Roche R, Cantu J, Tamez C, Zuverza-Mena N, Hamdi H, Adisa IO, *et al*. Seed biofortification by engineered nanomaterials: a pathway to alleviate malnutrition? J Agric Food Chem. 2020;68(44):12189-12202.
23. Sharifi R, Mohammadi K, Rokhzadi A. Effect of seed priming and foliar application with micronutrients on quality of forage corn (*Zea mays*). Environ Exp Biol. 2016;14(4).
24. Abdel-Aziz HMM, Hasaneen MNA, Omer AM. Impact of engineered nanomaterials either alone or loaded with NPK on growth and productivity of French bean plants: Seed priming vs foliar application. S Afr. J Bot. 2019;125:102-108.
25. Esper Neto M, Britt DW, Lara LM, Cartwright A, dos Santos RF, Inoue TT, Batista MA. Initial development of corn seedlings after seed priming with nanoscale synthetic zinc oxide. Agronomy. 2020;10(2):307.
26. Rekha C, Poornima G, Manasa M, Abhipsa V, Devi JP, Kumar HTV, Kekuda TRP. Ascorbic acid, total phenol content and antioxidant activity of fresh juices of four ripe and unripe citrus fruits. Chem Sci Trans. 2012;1(2):303-310.
27. Sharma A, Sharma I, Pati PK. Post-infectional changes associated with the progression of leaf spot disease in Ashwagandha (*Withania somnifera*). J Plant Pathol. 2011;93(2):397-405.
28. Ardekani MRS, Hajimahmoodi M, Oveisi MR, Sadeghi N, Jannat B, Ranjbar AM, Gholam N, Moridi T. Comparative antioxidant activity and total flavonoid content of Persian pomegranate (*Punica granatum* L.) cultivars. Iran J Pharm Res. 2011;10(3):519-524.
29. Singleton VL, Orthofer R, Lamuela-Raventós RM. Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. Methods Enzymol. 1999;299:152-178.
30. Kapoor D, Kaur S, Bhardwaj R. Physiological and biochemical changes in *Brassica juncea* plants under Cd-induced stress. BioMed Res Int. 2014;2014:1-13.
31. Zangeneh M, Omid M, Akram A. A comparative study on energy use and cost analysis of potato production under different farming technologies in Hamadan province of Iran. Energy. 2010;35(7):2927-2933.
32. Verma SK, Asati BS, Tamrakar SK, Nanda HC, Gupta CR. Effect of organic components on growth, yield and economic returns in potato. Potato J. 2011;38(1):51-55.
33. Umesh MR, Manjunatha N, Shankar MA, Jagadeesha N. Influence of nutrient supply levels on yield, nutrient uptake, grain quality and economics of corn (*Zea mays* L.) in Alfisols of Karnataka. Indian J Dryland Agric Res Dev. 2014;29(1):73-78.
34. Mohammadi A, Tabatabaeefar A, Shahin S, Rafiee S, Keyhani A. Energy use and economic analysis of potato production in Iran a case study: Ardabil province. Energy Convers Manage. 2008;49(12):3566-3570.
35. Kah M, Kookana RS, Gogos A, Bucheli TD. A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues. Nat Nanotechnol. 2018;13(8):677-684.
36. Liu R, Lal R. Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. Sci Total Environ. 2015;514:131-139.
37. Naderi MR, Abedi A. Application of nanotechnology in agriculture and refinement of environmental pollutants. J Nanotechnol. 2012;11(1):18-26.
38. Mousavi SR, Rezaei M. Nanotechnology in agriculture and food production. J Appl Environ Biol Sci. 2011;1(10):414-419.
39. Srilatha B. Nanotechnology in agriculture. J Nanomed Nanotechnol. 2011;2(7).
40. Ditta A. How helpful is nanotechnology in agriculture? Adv Nat Sci: Nanosci Nanotechnol. 2012;3(3):033002.
41. Shang Y, Hasan MK, Ahammed GJ, Li M, Yin H, Zhou J. Applications of nanotechnology in plant growth and crop protection: a review. Molecules. 2019;24(14):2558.
42. do Espirito Santo Pereira A, Caixeta Oliveira H, Fernandes Fraceto L, Santaella C. Nanotechnology potential in seed priming for sustainable agriculture. Nanomaterials. 2021;11(2):267.
43. Rehman HU, Maqsood S, Basra A, Farooq M. Field appraisal of seed priming to improve the growth, yield and quality of direct seeded rice. Turk J Agric. 2011;35:357-65.
44. Singh H, Jassal RK, Kang JS, Sandhu SS, Kang H, Grewal K. Seed priming techniques in field crops-A review. Agric Rev. 2015;36(4):251-264.
45. Soleimanzadeh H. Effect of seed priming on germination and yield of corn. Int J Agric Crop Sci. 2013;5(4):366-369.
46. Ullah A, Farooq M, Hussain M, Ahmad R, Wakeel A. Zinc seed priming improves stand establishment, tissue zinc concentration and early seedling growth of chickpea. J Anim Plant Sci. 2019;29:1046-1053.
47. Abbas SQ, Hassan MU, Hussain B, Rasool T, Ali Q. Optimization of zinc seed priming treatments for improving the germination and early seedling growth of Oryza sativa. Adv Life Sci. 2014;2(1):31-37.
48. Rameshraddy, Pavithra GJ, Rajashekar Reddy BH, Salimath M, Geetha KN, Shankar AG. Zinc oxide nanoparticles increases Zn uptake, translocation in rice with positive effect on growth, yield and moisture stress tolerance. Indian J Plant Physiol. 2017;22:287-294.
49. Zheng L, Hong F, Lu S, Liu C. Effect of nano-TiO_2 on strength of naturally aged seeds and growth of spinach. Biol Trace Elem Res. 2005;104:83-91.
50. Tuiwong P, Lordkaew S, Veeradittakit J, Jamjod S, Prom-u-thai C. Efficacy of nitrogen and zinc application at different growth stages on yield, grain zinc, and nitrogen concentration in rice. Agronomy. 2022;12(9):2093.
51. Laware SL, Raskar S. Influence of zinc oxide nanoparticles on growth, flowering and seed productivity in onion. Int J Curr Microbiol Sci. 2014;3(7):874-881.
52. Ali MR, Mehraj H, Jamal Uddin AFM. Effects of foliar application of zinc and boron on growth and yield of summer tomato. J Biosci Agric. Res. 2015;6(1):512-517.
53. Prasad T, Sudhakar P, Sreenivasulu Y, Latha P, Munaswamy V, Reddy KR, *et al*. Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. J Plant Nutr. 2012;35(6):905-927.

54. Subramani T, Velmurugan A, Bommayasamy N, Swarnam TP, Ramakrishna Y, Jaisankar I, Singh L. Effect of Nano Urea on growth, yield and nutrient use efficiency of Okra under tropical island ecosystem. Int J Agric Sci. 2023;19(1):134-139.
55. Bahmanyar MA, Mashaee SS. Influences of nitrogen and potassium top dressing on yield and yield components as well as their accumulation in rice (*Oryza sativa*). Afr J Biotechnol. 2010;9(18):2648-2653.
56. Abd Alqader OA, Al-Jobouri SM, Eshoaa LM. Effect of nitrogenous and urea nano-hydroxyapatite fertilizer on growth and yield of two cultivars of broad bean (*Vicia faba* L.). Euphrates J Agric Sci. 2020;12(2):202-227.
57. Midde SK, Perumal MS, Murugan G, Sudhagar R. Performance of different sources of nitrogen under different establishment methods of rice (*Oryza sativa*). Crop Res. 2022;57(5and6):292-296.
58. Mahajan P, Dhoke SK, Khanna AS. Effect of nano-ZnO particle suspension on growth of mung (*Vigna radiata*) and gram (*Cicer arietinum*) seedlings using plant agar method. J Nanotechnol. 2011;13(2):54-61.
59. Chauhan A Pallvi, Rattan P, Ludarmani, Sharma A. Effect of pre-soaking of potato (*Solanum tuberosum* L.) tubers in nano-urea and nano-zinc on its growth, quality and yield. Pharma Innov J. 2023;12(7):980-995.
60. Lawlor DW. Carbon and nitrogen assimilation in relation to yield: mechanisms are the key to understanding production systems. J Exp Bot. 2002;53(370):773-787.
61. Ghidan AY, Kahlel AMS, Al-Antary TM. Effect of nanotechnology liquid fertilizers on yield and nitrogenous compounds of broad bean (*Vicia faba* L.). Fresenius Environ Bull. 2020;29(6):41244128.
62. Vairavan K, Ramasamy M, Srinivasan K. Studies on the effect of micronutrients in Urdbean. Indian J Pulses Res. 1997;10:252-253.
63. Sathyan D. Effect of nano nutrients on pea growth and yield (*Pisum sativum* L.). Pharma Innov J. 2022;11(9):1895-1898.
64. Mishra B, Sahu GS, Mohanty LK, Swain BC, Hati S. Effect of nano fertilizers on growth, yield and economics of tomato variety Arka Rakshak. Indian J Pure Appl Biosci. 2020;8:200-204.
65. Yin X, Lantinga EA, Schapendonk AH, Zhong X. Some quantitative relationships between leaf area index and canopy nitrogen content and distribution. Ann Bot. 2003;91(7):893-903.
66. Grindlay DJC. REVIEW Towards an explanation of crop nitrogen demand based on the optimization of leaf nitrogen per unit leaf area. J Agric Sci. 1997;128(4):377-396.
67. Kisan B, Shruthi H, Sharanagouda H, Revanappa SB, Pramod NK. Effect of nano-zinc oxide on the leaf physical and nutritional quality of spinach. Agrotechnology. 2015;5(1):135.
68. Salim SS, Shimi GJ, Pillai S, Raj SK, Shruthy ON. Effect of foliar application of nano-N and nano-Zn on growth and yield attributes in bush type vegetable cowpea (Vigna unguiculata subsp. *unguiculata* (L.) Verdcourt). Pharma Innov J. 2023;12(5):1073-1076.
69. Zakzouk UAI. Improving growth, flowering, fruiting and resistance of malformation of mango trees using nano-zinc. Middle East J Agric Res. 2020;6(3):673-681.
70. Navya K, Sai Kumar R, Krishna Chaitanya A, Sampath O. Effect of nano nitrogen in conjunction with urea on growth and yield of mustard (*Brassica juncea* L.) in Northern Telangana Zone. Methodology. 2021;22.
71. Upasna, Kaur A, Rattan P, Ludarmani, Sharma A. Effect of seed priming by nano-urea and nano-zinc on the growth, yield and quality of radish (*Raphanus sativus* L.). Pharma Innov J. 2023;12(10):604-617.
72. Kanavi GJ, Sunil C, Salimath SB, Mallikarjuna HB, Kadam PV, Jeevan HR. Evaluation of the Effect of Foliar Nano Nitrogen and Zinc on Chlorophyll (SPAD) and Qualitative Traits of Green Chilli in Comparison with Urea and ZnSO4. Int J Environ Clim Change. 2023;13(9):2317-2322.
73. Zafar S, Perveen S, Kamran Khan M, Shaheen MR, Hussain R, Sarwar N, *et al*. Effect of zinc nanoparticles seed priming and foliar application on the growth and physio-biochemical indices of spinach (*Spinacia oleracea* L.) under salt stress. PLoS One. 2022;17(2):14.
74. Robbins CT, Hanley TA, Hagerman AE, Hjeljord O, Baker DL, Schwartz CC, *et al*. Role of tannins in defending plants against ruminants: reduction in protein availability. Ecology. 1987;68(1):98-107.
75. Hamzah Saleem M, Usman K, Rizwan M, Al Jabri H, Alsafran M. Functions and strategies for enhancing zinc availability in plants for sustainable agriculture. Front Plant Sci. 2022;13:1033092.
76. Munirah N, Khairi M, Nozulaidi M, Jahan M. The effects of zinc application on physiology and production of corn plants. Aust J Basic Appl Sci. 2015;9(2):362-367.
77. Seleiman MF, Alotaibi MA, Alhammad BA, Alharbi BM, Refay Y, Badawy SA. Effects of ZnO nanoparticles and biochar of rice straw and cow manure on characteristics of contaminated soil and sunflower productivity, oil quality, and heavy metals uptake. Agronomy. 2020;10(6):790.
78. Tarafdar JC, Raliya R, Mahawar H, Rathore I. Development of zinc nanofertilizer to enhance crop production in pearl millet (*Pennisetum americanum*). Agric Res. 2014;3:257-262.
79. Hafeez BMKY, Khanif YM, Saleem M. Role of zinc in plant nutrition-a review. Am J Exp Agric. 2013;3(2):374-391.
80. Sharaf-Eldin MA, Elsawy MB, Eisa MY, El-Ramady H, Usman M, Zia-ur-Rehman M. Application of nano-nitrogen fertilizers to enhance nitrogen efficiency for lettuce growth under different irrigation regimes. Pak J Agric Sci. 2022;59(3):367-379.
81. Tisdale SL, Nelson WL. Soil fertility and fertilizers. Soil Sci. 1966;101(4):346.
82. Abdel-Aziz HMM, Hasaneen MNA, Omer AM. Impact of engineered nanomaterials either alone or loaded with NPK on growth and productivity of French bean plants: Seed priming vs foliar application. S Afr J Bot. 2019;125:102-108.
83. Ramesh M, Palanisamy K, Babu K, Sharma NK. Effects of bulk and nano-titanium dioxide and zinc oxide on physio-morphological changes in Triticum aestivum Linn. J Global Biosci. 2014;3(2):415-422.
84. Mahmoud AWM, Abdelaziz SM, El-Mogy MM, Abdeldaym EA. Effect of Foliar Zno and Feo Nanoparticles Application on Growth and Nutritional Quality of Red Radish and Assessment of Their Accumulation on Human Health. Agriculture/Pol'nohospodárstvo. 2019;65(1):16-19.
85. Tondey M, Kalia A, Singh A, Dheri GS, Taggar MS, Nepovimova E, Krejcar O, Kuca K. Seed priming and coating by nano-scale zinc oxide particles improved vegetative growth, yield and quality of fodder maize (*Zea mays*). Agronomy. 2021;11(4):729.
86. Elzaawely AA, Xuan TD, Tawata S. Essential oils, kava

pyrones and phenolic compounds from leaves and rhizomes of *Alpinia zerumbet* (Pers.) BL Burtt. and RM Sm. and their antioxidant activity. Food Chem. 2007;103(2):486-494.
87. Dai J, Mumper RJ. Plant phenolics: extraction, analysis and their antioxidant and anticancer properties. Molecules. 2010;15(10):7313-7352.
88. Kantwa S, Yadav LR. Nano urea: Applications and significance. Just Agriculture. 2022;2(7):1-6.
89. Islam MA, Becerra JX. Analysis of Chemical Components Involved in Germination Process of Rice Variety Jhapra. J Sci Res. 2012;4(1):251-262.
90. Kukic J, Petrovic S, Niketic M. Antioxidant activity of four endemic Stachys taxa. Biol Pharm Bull. 2006;29(4):725-729.
91. Jin X, Hao N, Jiao F, Yang Y, Wang D, Xu C, Zhai R. The effect of nitrogen supply on potato yield, tuber size and pathogen resistance in *Solanum tuberosum* exposed to *Phytophthora infestans*. Afr. J Agric Res. 2014;9(35):2657-2663.
92. Singh MD. Nano-fertilizers is a new way to increase nutrients use efficiency in crop production. Int J Agric Sci. 2017;9(7):0975-3710.
93. Ninama J, Debbarma V, Bhakher R, Meena RK. Response of Zinc and Nano Urea on Growth and Yield of Maize (*Zea mays* L.). Int J Environ. Climate Change. 2023;13(9):1046-1052.
94. Rajesh H, Yadahalli GH, Chittapur BM, Halepyati AS, Hiregoudar SHARA. Growth, yield and economics of sweet corn (*Zea mays* L. Saccarata) as influenced by foliar sprays of nano fertilisers. J Farm Sci. 2021;34(4):381-385.
95. Bradford MM. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Anal Biochem. 1976;72(1-2):248-254.