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Agronomic fortification of wheat (*Triticum aestivum* L.) using biosynthesized zinc nanoparticles

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Abstract

Research was carried out at the Green Nanotechnology Laboratory, University of Agricultural Sciences, Dharwad, Karnataka, with a specific emphasis on the biosynthesis of zinc nanoparticles using *Pseudomonas* and actinobacteria. The zinc nanoparticles were biosynthesized and characterized through UV-Visible spectroscopy, Particle Size Analyzer (PSA), Scanning Electron Microscope (SEM), (EDX), X-Ray Diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR). After biosynthesis and characterization of the nanoparticles (NPs), a field study was conducted to fortify the wheat crop using biosynthesized zinc nanoparticles. In wheat seed priming @ 500 ppm and foliar spraying @ 500 ppm at panicle initiation stage with zinc nanoparticles biosynthesized through actinobacteria (T₆) recorded significantly higher productive spikes per square meter (259.33 m⁻²), number of grains per spike (48.50), 1,000 grain weight (42.35 g), grain yield (46.75 q ha⁻¹), straw yield (64.71 q ha⁻¹), zinc content (grain 54.98 ppm and straw 65.75 ppm), zinc uptake (grain 257.03 g ha⁻¹, straw 425.49 g ha⁻¹ and total zinc uptake 682.52 g ha⁻¹), net returns (₹ 63,746 ha⁻¹) and benefit cost ratio (2.49) which was on par with seed priming @ 500 ppm and foliar spraying @ 500 ppm at panicle initiation stage with zinc nanoparticles biosynthesized through *Pseudomonas* (T₃) and commercial zinc nanoparticles (T₉).

Keywords: Actinobacteria, biosynthesis, nanoparticles, seed priming, zinc

Introduction

Wheat is a major food crop cultivated globally, providing food for 35 per cent of the world's population (Mohammadi-joo *et al.*, 2015) [15]. The most of wheat that is grown on a worldwide is hexaploid, and extensively utilised to produce a variety of baked food products including bread, there is a substantial impact on human health based on the composition and nutritional quality of the wheat. The most of the wheat types grown today are nutrient poor, especially in Fe and Zn. The most of these minerals are lost during the milling process, which makes them scarce in the human diet and causes malnutrition. Nearly 2 billion people worldwide, especially those in Asia and Africa, suffering from hidden hunger due to their reliance on cereal crops, particularly wheat, for their daily diet (Prom-U-Thai *et al.*, 2020) [19]. These deficits are particularly widespread among the growing children, pregnant and lactating women and manual labours in highly developed countries. Zn and Fe are the micronutrients that are most commonly linked to micronutrient deficiency globally. Low availability of microelements in soil may be a contributing factor to the decreased level of essential nutrients in crops, due to sub optimal abiotic circumstances, such as abnormally high or low temperature, pH, a lack of water, anaerobic conditions, and the presence of other components (Manojlovic *et al.*, 2019) [16]. The prevalence of micronutrient deficiencies is higher in humid temperate and tropical regions, where there is extensive leaching caused by excessive precipitation. Another factor is the usage of plant types which have a poor capacity to store adequate amounts of microelements in their edible parts (Jalal *et al.*, 2020) [10].

Zn is essential for the synthesis and activation of several hormones (auxin and gibberellin) and enzymes that enhance seed germination per cent and seedling growth. Additionally, Zn plays a important role in biosynthesis of proteins, carbohydrates, lipids, and nucleic acids in plants (Sturikova *et al.*, 2018) [22].

Zn nanoparticles (Zn NPs) are among the top three most manufactured and used engineered nanoparticles (Zhang *et al.*, 2015) [30]. ZnO nanoparticles, one of the best source for preventing Zn deficiency and enhancing crop quality and productivity (Dimkpa *et al.*, 2015) [6]. Zn NPs have an impact on plant metabolism at the molecular level by activating antioxidants and reductases, as well as influencing the synthesis of plant hormones (Timilsina and Chen, 2021) [28]. Zn can serve as a cofactor for P-solubilizing enzymes like phosphatase and phytase, and nano-ZnO boosted their activity in the soil (Raliya *et al.*, 2015) [20].

Increased micronutrient levels in crops can be achieved through biofortification (Dhaliwal *et al.*, 2022) [5]. Biofortified crops have been demonstrated to increase the consumption of micronutrients and significantly improve human health (Praharaj *et al.*, 2021) [31]. The three main strategies for biofortification are agronomic, conventional plant breeding, and plant breeding utilising genetic engineering. Agronomic biofortification is considered to be the simplest way to increase the levels of microelements in crops because it focuses on supplying micronutrients that can be directly absorbed by the plant through application with mineral or foliar fertilisers or the improvement of the solubilization and mobilisation of mineral elements in the soil. One of the most affordable methods to lessen dietary mineral deficit in humans is agronomic biofortification (Szerement *et al.*, 2022) [26].

Nanotechnology may help bring about a new technological revolution in agriculture. Several problems with conventional biofortification could potentially resolved by nanotechnology (Shakiba *et al.* 2020) [21]. It is possible to produce nanofertilizers using nanomaterials because of their high surface-to-volume ratio, gradual and controlled release at target places, and other characteristics (Feregino-Perez *et al.*, 2018) [8]. The encapsulation of nutrients with nanomaterials results in efficient nutrient absorption by plants, due to the gradual or controlled release of nanoparticles and simple passage through biological barriers by nanoparticles entering the plant vascular system (De La Torre-Roche *et al.*, 2020). In comparison to conventional fertilisers, long-term delivery of plants via nanofertilizers enables enhanced crop growth. As nanofertilizers are added in small amounts, these also prevent soil from becoming burdened with the by-products of chemical fertilisers and reduce the environmental hazards (Silva *et al.*, 2018) [23]. Unlike chemical fertilisers, nanofertilizers can be synthesized and applied based on the crop's nutritional needs and the status of the soil's nutrient levels using biosensors (Kah *et al.*, 2018) [12]. Additionally, nanofertilizers, as opposed to chemical fertilisers, allow for high mineral bioavailability to plants due to their smaller size, greater reactivity, and higher surface area (Liu and Lal, 2015) [15].

Materials and Methods

Biosynthesis, characterization and standardization of Zn nanoparticles and lab experiments were done in Green Nanotechnology Laboratory, University of Agricultural Sciences, Dharwad. At the Microbial Genetics Laboratory, Department of Agricultural Microbiology, UAS, Dharwad, *Pseudomonas* and actinobacterial isolates were collected and screened. The field study was carried out during the *rabi* season of 2022-23 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. Geographically Dharwad is situated in the Northern Transition Zone (Zone 8) of Karnataka which lies between 15° 26' North latitude, 75° 07' East longitudes with an altitude of 678 m above MSL (mean sea level). The data on weather parameters viz., rainfall, temperature

(maximum and minimum) and relative humidity recorded at Main Agricultural Research Station, Dharwad during cropping period of 2022-23 and for the past 72 years.

The soil at the experimental site was characterized as deep black (vertisols). Before start of the experiment, composite soil samples were collected from the experimental sites at a depth of 0 to 30 cm. These soil samples were air-dried, powdered, passed through a 2 mm sieve, and then analyzed for their physical and chemical properties. The textural class of experimental soil was clayey and pH-7.79; EC-0.28 dS m⁻¹; organic carbon- 0.51%; available nitrogen- 268.45 kg ha⁻¹; phosphorus- 35.04 kg ha⁻¹; potassium -342.26 kg ha⁻¹; zinc- 0.56 ppm and iron - 7.12 ppm.

The study was carried out using a Randomized Complete Block Design (RCBD), twelve treatments replicated three times. Wheat seeds of the UAS 334 variety were collected from the Main Agricultural Research Station in Dharwad. The seeds were sown at a rate of 150 kg per hectare, evenly distributed in furrows spaced 20.0 cm apart using a wooden marker, and subsequently covered with soil manually. The sowing was taken up on November 21, 2022. Seeds were primed with biosynthesized zinc nanoparticles solution at 500 ppm, for a period of six hours for respective treatments. Nitrogen, phosphorus, and potassium were applied as urea, diammonium phosphate, and muriate of potash, respectively. Fertilizers (100: 75: 50 kg N: P₂O₅: K₂O kg ha⁻¹) was applied at basal and remaining 50 kg N was top dressed at 30 DAS. Crop received six irrigations during crop period.

The experimental details was T₁- seed priming with BS (Bacterial (*Pseudomonas*) synthesized) ZnNPs @ 500 ppm; T₂- foliar spraying with BS ZnNPs @ 500 ppm; T₃- seed priming @ 500 ppm + foliar spraying @ 500 ppm with BS ZnNPs; T₄- seed priming with ABS (actinobacterial synthesized) ZnNPs @ 500 ppm; T₅- foliar spraying with ABS ZnNPs @ 500 ppm; T₆- seed priming @ 500 ppm + foliar spraying @ 500 ppm with ABS ZnNPs; T₇- seed priming with commercial ZnNPs @ 500 ppm; T₈- foliar spraying with commercial ZnNPs @ 500 ppm; T₉- seed priming @ 500 ppm + foliar spraying @ 500 ppm with commercial ZnNPs; T₁₀- foliar spraying with ZnSO₄ @ 0.5%; T₁₁- RDF (recommended dose of fertilizers-100:75:50, N:P₂O₅:K₂O kg ha⁻¹, respectively) and T₁₂-control (without any fertilizer application). Foliar spraying at panicle initiation stage of the crop is common for all the foliar applied treatments. RDF-100:75:50, N: P₂O₅: K₂O kg ha⁻¹ common for all the treatments.

Yield and yield attributes

The number of productive spikes (effective tillers per square meter) in each net plot was noted during harvest by counting the number of ear-bearing tillers. Ten spikes randomly chosen from each plot during harvest to record the number of grains per spike. These selected spikes were individually threshed, and the number of grains per spike was recorded. Grains from the net plot were collected to measure the 1000 grain weight, also expressed in grams (g). The overall biomass yield for each net plot was recorded during harvest. After the threshing process, grains were separated, cleaned, and weighed. The straw yield per net plot was calculated by deducting the total grain weight from the total biomass for the respective treatment. Subsequently, the grain and straw yields of the plots were quantified in kg per hectare (kg ha⁻¹).

Nutrient content and uptake

The wheat grains were crushed with a grinder. Initially, the samples were digested using HNO₃ and HClO₄. After digestion with HNO₃ and HClO₄, the samples were analyzed for nutrient

concentrations using an atomic absorption spectrometer as given by Lindsay and Norvell in 1978. The nutrient uptake was calculated based on the plants' nutrient content and dry matter production, using the following formula.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{dry matter (kg ha}^{-1}\text{)}$$

Economics

Net returns (₹ ha⁻¹) = Gross returns (₹ ha⁻¹) – Cost of cultivation (₹ ha⁻¹)

$$\text{Benefit cost ratio} = \frac{\text{Gross returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

Statistical analysis

The data collected from the experiment at various growth stages were subjected statistical analysis following the method given by Gomez and Gomez (1984). The significance level used in the 'F' test was P = 0.01 (1%) and P = 0.05 (5%). The critical difference (CD) at 1% and 5% levels was computed whenever the 'F' test was given significant results. The mean values of treatments were separately subjected to Duncan Multiple Range Test (DMRT) using the corresponding error mean sum of squares and degrees of freedom.

Results and Discussion

Effect of biosynthesized zinc nanoparticles on yield and yield components in wheat

Seed priming @ 500 ppm and foliar spraying @ 500 ppm with zinc nanoparticles (ZnNPs) biosynthesized by actinobacteria recorded significantly higher productive spikes per square meter (259.33 m⁻²), number of grains per spike (48.50) and test weight (42.35 g) which is on par with seed priming @ 500 ppm and foliar spraying @ 500 ppm with ZnNPs biosynthesized by *Pseudomonas* (48.23, 1.81 g and 42.17 g, respectively) and commercial zinc nanoparticles (47.90, 1.80 g and 41.94 g, respectively) (Table 1). Seed priming @ 500 ppm and foliar spraying @ 500 ppm at panicle initiation stage with ZnNPs biosynthesized from actinobacteria, *Pseudomonas* and commercial zinc nanoparticles increased the wheat yield by 17.58, 16.27 and 15.56 per cent, respectively over control treatment (Table 2). The grain mass increased as compared to the control after the application of zinc nano-fertilizer. Increased individual grain sink strength is indicated by the greater thousand grain weight (Armin *et al.*, (2014) [2]. Phytohormones, particularly cytokinins play a significant role in increased sink size by encouraging cell proliferation in the early stages of seed filling by Janmohammadi *et al.* (2016) [11]. A sufficient Zn supply might have enhanced the supply of other nutrients and regulated the overall plant growth and development and resulted in an increase in the number of panicles per square meter. The

increase in the number of grains per panicle might have been caused by its stimulation of physiological processes such as photosynthesis, translocation, and assimilation of photosynthates, as well as the formation of more spikelets during the spikelet initiation process, which ultimately led to the formation of more number of grains per panicle (Talib *et al.*, 2016) [27]. Improvements in biochemical and physiological processes that might be due to Zn which acted as a cofactor for a number of enzymes, finally impacted on better crop growth and yield. Zinc nanoparticles have the capacity to pass through the surface of leaves and release Zn ions across the cuticle due to their extremely smaller size. In addition to that, the highest thousand grain weight suggested that the cytokinin hormone's enhanced activity has resulted in larger individual grain sink size. Application of zinc nanoparticles resulted in the highest grain yield, and this might be because of the smaller size and greater surface area of nano fertilisers, which improved the absorption and translocation of Zn in plant tissue (Bihmidine *et al.*, 2013) [3]. The increase in overall yield is the result of zinc, which helps in increasing the fertilisation percentage during the blooming stage. This facilitated the transport of photosynthetic byproducts to the pollen grains, enhancing their vitality (Al-Tameemi *et al.*, 2019) [1].

Effect of biosynthesized ZnNPs on nutrient content and nutrient uptake in wheat

Seed priming @ 500 ppm and foliar spraying @ 500 ppm with ZnNPs biosynthesized from actinobacteria, *Pseudomonas* and commercial zinc nanoparticles recorded significantly higher grain zinc content (27.59, 24.90 and 24.73%, respectively), straw zinc content (21.35, 19.73 and 19.47%, respectively) and total uptake of zinc (43.00, 39.49 and 38.50%, respectively) in wheat (Table 3 & 4). Singh *et al.*, 2019 [24] revealed that due to their small size, nanoparticles are easily passes through the membrane pores inside cells, further increasing their bioavailability. Nanoparticles' increased capabilities are due to quick absorption and bioavailability and due to their huge surface area. The use of zinc nanoparticles rather than zinc sulphate, wheat grain, root, and stem zinc content increased dramatically. This might be due to increased zinc translocation into grain due to improved source-sink channels and increased usage efficiency of ZnNPs in comparison to zinc sulphate (Yadav *et al.*, 2023) [29]. Foliar spraying of Zn nanoparticles increased grain zinc content due to its enhanced effectiveness of ZnO-NPs compared to zinc sulphate is attributed to the smaller size of the nanoparticles, which promotes adherence to the leaf surface, with the slow dissolution of the ZnO-NPs (Du *et al.*, 2019). Zinc application improves plant physiology as evidenced by increased photosynthesis, nitrogen absorption, auxin activity, thermotolerance, and water usage efficiency. Therefore, by applying more zinc, wheat grain zinc concentration might grow significantly as stated by Sher *et al.* (2022) [22].

Table 1: Yield attributes of wheat as influenced by seed priming and foliar spraying with biosynthesized zinc nanoparticles

Treatment details	Productive spikes (m ⁻²)	Number of grains per spike	Test weight (g)
T ₁ - SP with BS ZnNPs	240.67 ^b	43.73 ^b	40.63 ^b
T ₂ - FS with BS ZnNPs	243.00 ^b	44.60 ^{bc}	40.75 ^b
T ₃ - SP + FS with BS ZnNPs	256.33 ^a	48.23 ^a	42.17 ^a
T ₄ - SP with ABS ZnNPs	242.67 ^b	43.40 ^{bc}	40.67 ^b
T ₅ - FS with ABS ZnNPs	246.00 ^b	45.37 ^b	40.82 ^b
T ₆ - SP + FS with ABS ZnNPs	259.33 ^a	48.50 ^a	42.35 ^a
T ₇ - SP with commercial ZnNPs	238.67 ^b	42.93 ^c	40.54 ^b
T ₈ - FS with commercial ZnNPs	241.33 ^b	43.87 ^{bc}	40.69 ^b
T ₉ - SP + FS with commercial ZnNPs	254.67 ^a	47.90 ^a	41.94 ^a
T ₁₀ - FS with ZnSO ₄ @ 0.5%	230.33 ^c	40.53 ^d	39.43 ^c
T ₁₁ - RDF (100-75-50 kg N-P-K/ha)	221.67 ^d	38.10 ^e	38.35 ^d
T ₁₂ - Control	197.33 ^e	32.23 ^f	35.64 ^e
S.Em.±	2.81	0.81	0.36

SP-Seed priming; FS-Foliar spraying; BS-Bacterial (*Pseudomonas*) synthesized; ABS-actinobacterial synthesized; Seed priming @ 500 ppm and foliar spraying @ 500 ppm are common for all nano treated treatments; RDF common for all treatments except control

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Table 2: Grain yield, straw yield and harvest index of wheat as influenced by seed priming and foliar spraying with biosynthesized zinc nanoparticles

Treatment details	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Harvest index
T ₁ - SP with BS ZnNPs	4306 ^{de}	6056 ^b	0.42 ^a
T ₂ - FS with BS ZnNPs	4439 ^{bc}	6185 ^b	0.42 ^a
T ₃ - SP + FS with BS ZnNPs	4623 ^a	6428 ^a	0.42 ^a
T ₄ - SP with ABS ZnNPs	4325 ^{cde}	6113 ^b	0.41 ^a
T ₅ - FS with ABS ZnNPs	4461 ^b	6210 ^b	0.42 ^a
T ₆ - SP + FS with ABS ZnNPs	4675 ^a	6471 ^a	0.42 ^a
T ₇ - SP with commercial ZnNPs	4247 ^e	6029 ^b	0.41 ^a
T ₈ - FS with commercial ZnNPs	4382 ^{bcd}	6136 ^b	0.42 ^a
T ₉ - SP + FS with commercial ZnNPs	4595 ^a	6397 ^a	0.42 ^a
T ₁₀ - FS with ZnSO ₄ @ 0.5%	4113 ^f	5832 ^c	0.41 ^a
T ₁₁ - RDF (100-75-50 kg N-P-K/ha)	3976 ^g	5643 ^d	0.41 ^a
T ₁₂ - Control	1764 ^h	3237 ^e	0.35 ^b
S.Em.±	44.20	61.54	0.01

SP-Seed priming; FS-Foliar spraying; BS-Bacterial (*Pseudomonas*) synthesized; ABS-actinobacterial synthesized; Seed priming @ 500 ppm and foliar spraying @ 500 ppm are common for all nano treated treatments; RDF common for all treatments except control

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Table 3: Zinc concentration in wheat as influenced by seed priming and foliar spraying with biosynthesized zinc nanoparticles

Treatment details	Zinc concentration (ppm)	
	Grain	Straw
T ₁ - SP with BS ZnNPs	46.29 ^c	61.32 ^b
T ₂ - FS with BS ZnNPs	50.95 ^b	60.75 ^b
T ₃ - SP + FS with BS ZnNPs	53.82 ^a	64.87 ^a
T ₄ - SP with ABS ZnNPs	46.35 ^c	61.62 ^b
T ₅ - FS with ABS ZnNPs	51.26 ^b	60.94 ^b
T ₆ - SP + FS with ABS ZnNPs	54.98 ^a	65.75 ^a
T ₇ - SP with commercial ZnNPs	45.89 ^c	60.42 ^b
T ₈ - FS with commercial ZnNPs	50.83 ^b	59.96 ^b
T ₉ - SP + FS with commercial ZnNPs	53.75 ^a	64.73 ^a
T ₁₀ - FS with ZnSO ₄ @ 0.5%	47.32 ^c	57.07 ^c
T ₁₁ - RDF (100-75-50 kg N-P-K/ha)	43.09 ^d	54.18 ^d
T ₁₂ - Control	40.53 ^e	51.27 ^e
S.Em.±	0.84	0.98

SP-Seed priming; FS-Foliar spraying; BS-Bacterial (*Pseudomonas*) synthesized; ABS-actinobacterial synthesized; Seed priming @ 500 ppm and foliar spraying @ 500 ppm are common for all nano treated treatments; RDF common for all treatments except control

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Table 4: Zinc uptake at harvest as influenced by seed priming and foliar spraying with biosynthesized zinc nanoparticles in wheat

Treatment details	Zinc uptake (g ha ⁻¹)		
	Grain	Straw	Total
T ₁ - SP with BS ZnNPs	199.32 ^c	371.35 ^{bc}	570.68 ^{cd}
T ₂ - FS with BS ZnNPs	226.17 ^b	375.74 ^{bc}	601.91 ^b
T ₃ - SP + FS with BS ZnNPs	248.81 ^a	416.98 ^a	665.79 ^a
T ₄ - SP with ABS ZnNPs	200.46 ^c	376.68 ^{bc}	577.15 ^{cd}
T ₅ - FS with ABS ZnNPs	228.67 ^b	378.44 ^b	607.11 ^b
T ₆ - SP + FS with ABS ZnNPs	257.03 ^a	425.49 ^a	682.52 ^a
T ₇ - SP with commercial ZnNPs	194.89 ^c	364.27 ^c	559.17 ^d
T ₈ - FS with commercial ZnNPs	222.74 ^b	367.91 ^{bc}	590.65 ^{bc}
T ₉ - SP + FS with commercial ZnNPs	246.98 ^a	414.08 ^a	661.06 ^a
T ₁₀ - FS with ZnSO ₄ @ 0.5%	194.63 ^c	332.83 ^d	527.46 ^e
T ₁₁ - RDF (100-75-50 kg N-P-K/ha)	171.33 ^d	305.95 ^e	477.28 ^f
T ₁₂ - Control	71.49 ^e	165.96 ^f	237.46 ^g
S.Em.+	3.59	4.32	7.99

SP-Seed priming; FS-Foliar spraying; BS-Bacterial (*Pseudomonas*) synthesized; ABS-actinobacterial synthesized; Seed priming @ 500 ppm and foliar spraying @ 500 ppm are common for all nano treated treatments; RDF common for all treatments except control

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Table 5: Economics of wheat as influenced by seed priming and foliar spraying with biosynthesized zinc nanoparticles

Treatment details	Net returns (₹ ha ⁻¹)	Benefit cost ratio
T ₁ - SP with BS ZnNPs	56101 ^c	2.33 ^c
T ₂ - FS with BS ZnNPs	58771 ^{bc}	2.39 ^{bc}
T ₃ - SP + FS with BS ZnNPs	62697 ^a	2.47 ^a
T ₄ - SP with ABS ZnNPs	56539 ^c	2.34 ^c
T ₅ - FS with ABS ZnNPs	59192 ^b	2.39 ^b
T ₆ - SP + FS with ABS ZnNPs	63746 ^a	2.49 ^a
T ₇ - SP with commercial ZnNPs	52844 ^d	2.20 ^{de}
T ₈ - FS with commercial ZnNPs	43416 ^g	1.77 ^f
T ₉ - SP + FS with commercial ZnNPs	46003 ^{fg}	1.78 ^f
T ₁₀ - FS with ZnSO ₄ @ 0.5%	51867 ^{de}	2.24 ^d
T ₁₁ - RDF (100-75-50 kg N-P-K/ha)	48891 ^f	2.17 ^e
T ₁₂ - Control	17278 ^h	1.73 ^f
S.Em.+	1004	0.02

SP-Seed priming; FS-Foliar spraying; BS-Bacterial (*Pseudomonas*) synthesized; ABS-actinobacterial synthesized; Seed priming @ 500 ppm and foliar spraying @ 500 ppm are common for all nano treated treatments; RDF common for all treatments except control

Note: Means followed by the same letter (s) did not differ significantly by DMRT (p= 0.05)

Effect of biosynthesized zinc nanoparticles on net returns and benefit cost ratio in wheat

One of the most important criteria for assessing, approving, and widespread acceptance of any technology is its economic viability and acceptability. Net returns, one of indices of economic efficiency in any production system, have a considerable influence on the practical usability and adoption of the production technology. The same plant protection techniques and cultural practises were used in all of the treatments, but the amounts of fertilisers varied. In case of net returns and benefit cost ratio, seed priming @ 500 ppm and foliar spraying @ 500 with ZnNPs biosynthesized through actinobacteria and *Pseudomonas* recorded significantly higher net returns (₹ 63,746 and ₹ 62,697 ha⁻¹, respectively) and benefit cost ratio (2.49 and 2.47, respectively) (Table 5). The percent increase in net returns 30.38 and 28.23 per cent, respectively and benefit cost ratio was 14.74 and 13.82 per cent, respectively over control. Kanjana (2020) reported that foliar application of nano fertilizer recorded higher net returns and benefit cost ratio. However biosynthesized nanoparticles and commercial nanoparticles have shown similar results in wheat, but biological method of

synthesis is more efficient. This might be due to producing zinc nanoparticles commercially is more expensive than biological method.

Conclusions

Biosynthesis of nanoparticles using microorganisms is considered to be an environmentally friendly and cost effective approach. Farmers can replace the conventional zinc and iron source with nano forms to obtain the higher net returns, where biosynthesized nanoparticles could be alternative to chemical nanoparticles in terms of high cost and pollution hazards. Seed priming and foliar spraying with biosynthesized zinc nanoparticles at panicle initiation stage recorded significantly higher yield and yield attributes, nutrient content, net returns and benefit cost ratio.

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