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RESEARCH PAPER

Response of Chemical Fertilizer and Zinc-Solubilizing Biofertilizer (ZSB) on Growth, Yield, and Economic Performance of Wheat (*Triticum aestivum* L.)

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ABSTRACT

Field experiment was carried out during the *Rabi* season (November–March) of 2018–19 at the Agricultural Research Sub-Station, Sumerpur, Pali, under Agriculture University, Jodhpur, Rajasthan, India to evaluate the response of chemical fertilizer and zinc-solubilizing biofertilizer (ZSB) on the growth, yield, and economic performance of wheat (*Triticum aestivum* L.). The experiment was conducted using a randomized complete block design (RCBD) comprising seven treatments, each replicated four times. Growth, yield attributes and yield were recorded and statistically analysed. The results revealed that all the measured growth and yield attributes of wheat responded positively to the application of the recommended dose of fertilizers (RDF) and its graded levels in combination with ZSB. Among the treatments, the combination of 100% NPK along with ZSB applied as a seed treatment at 650 g ha^{-1} (T_4) exhibited a significant improvement in growth, yield components and yield compared to all treatment receiving 75% NPK + ZSB. However, T_4 did not exhibit any significant difference over the control treatment receiving 100% NPK alone. Furthermore, the T_4 treatment recorded the highest net return and benefit-cost (B:C) ratio (2.96), indicating that the integration of zinc-solubilizing biofertilizer with the recommended dose of NPK is not only agronomically effective but also exhibits economic advantage.

HIGHLIGHTS

- Maximum plant height (101.00 cm) was achieved with T_4 (100% NPK + ZSB at 650 g ha^{-1}), showing a 3.19% increase over control. Treatments with reduced NPK (75%) recorded lower heights, with T_7 (94.45 cm) showing a 3.50% reduction.
- Grain number per spike was highest in T_4 (42.68 grains, +5.38% over control), while T_2 and T_6 were statistically similar. Treatments with 75% NPK showed significant declines (–7.53% to –8.94%), and test weight remained statistically unaffected.
- Grain yield peaked at 42.23 q ha^{-1} in T_4 (+3.94% over control), with straw yield also highest (60.03 q ha^{-1}, +8.05%). Biological yield followed the same trend, though overall improvements were statistically non-significant, indicating limited impact of ZSB under prevailing soil conditions.
- T_4 (100% NPK + ZSB at 650 g ha^{-1}) delivered the best economic returns—gross return ₹ 1,16,595 ha^{-1}, net return ₹ 77,254 ha^{-1}, and B:C ratio of 2.96—closely followed by T_6 (B:C ratio 2.93).

Keywords: Wheat, Growth, Productivity and Profitability, Zinc-solubilizing biofertilizer

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Wheat (*Triticum aestivum* L.) is one of the most important staple food crops in the world, providing a major share of calories and protein to the global population. In India and many other developing countries, wheat occupies a central position in food security and rural livelihoods. However, sustaining high productivity in wheat has become increasingly challenging due to soil fertility depletion, nutrient imbalances, and the continuous reliance on chemical fertilizers without adequate replenishment of micronutrient and bioinoculants. Among the micronutrients, zinc (Zn) plays a vital role in plant growth and development. It is involved in several physiological and biochemical processes such as enzyme activation, protein synthesis, auxin metabolism, and membrane integrity (Suganya and Saravanan, 2016). Despite its importance, zinc deficiency is widespread in agricultural soils, particularly in calcareous, sandy, and high-pH soils where zinc availability to plants is low. In India, approximately 50% of cultivated soils are reported to be zinc-deficient, leading to poor crop performance, reduced grain yield, and lower nutritional quality of food grains (Cakmak, 2009). Chemical fertilizers are the primary source of nutrients for crop production, but their imbalanced or excessive use often leads to nutrient antagonism and environmental degradation (Zhou *et al*. 2024). Zinc availability is low under slightly alkaline soils due to high pH, which causes it to precipitate as insoluble zinc hydroxide or carbonate or to bind with clay minerals. This makes the zinc inaccessible to plants, despite its presence in the soil (Khan *et al*. 2023). In this context, the integration of biofertilizers, especially zinc-solubilizing bacteria (ZSB), has emerged as an eco-friendly and sustainable approach to improve zinc availability and uptake by plants. These beneficial microorganisms convert insoluble forms of zinc (such as zinc oxide, zinc carbonate, and zinc phosphate) into soluble and plant-available forms through the production of organic acids and other metabolites (Gupta *et al*. 2025). The combined use of graded doses of chemical fertilizers along with zinc solubilizing biofertilizers can enhance nutrient-use efficiency, maintain soil health, and increase wheat productivity under zinc-deficient conditions (Yadav *et al*. 2023). Such integrated nutrient management practices not only reduce the dependence on costly chemical inputs but also contribute to sustainable agricultural systems. Therefore, the present investigation "Response of chemical fertilizer and zinc-solubilizing biofertilizer (ZSB) on growth, yield, and economic performance of wheat (*Triticum aestivum* L.) under field condition was undertaken.

MATERIALS AND METHODS

The field experiment was conducted during the *Rabi* season of 2018 at the Agricultural Research Sub Station, Sumerpur, situated at latitude 25.09°N, longitude 73.05°E, and an altitude of 272 meters above mean sea level. The experimental site falls under a semi-arid climatic condition. Before the initiation of the experiment, composite soil samples were collected from the 0–15 cm soil depth and analyzed for their physico-chemical properties. The soil was classified sandy loam in texture, slightly alkaline in reaction (pH 8.2), with low organic carbon (0.36 %), low available nitrogen (200 kg ha^{-1}), low available phosphorus (19.40 kg ha^{-1}), and medium available potassium (260.0 kg ha^{-1}). The treatments consisted of graded levels of chemical fertilizer (NPK) combined with and without zinc solubilizing biofertilizer (ZSB). There were seven treatments namely recommended dose of100% NPK as control (T_1), 100% NPK + ZSB at 500 gha^{-1} seed treatment (T_2), 75% NPK + ZSB at 600 g ha^{-1}seed treatment (T_3), 100% NPK + ZSB at 650 g ha^{-1} seed treatment (T_4), 75% NPK + ZSB AT 700 g ha^{-1}seed treatment (T_5), 100% NPK + ZSB at 750 g ha^{-1}seed treatment (T_6), 75% NPK + ZSB T 800 g ha^{-1}seed treatment (T_7) replicated four times and arranged in a randomized block design (RBD). Wheat (*Triticum aestivum* L.) varietyGW1shown on 13.12.2018 and harvested on maturity. Certified seeds were procured from Agricultural Research Sub Station, Sumerpur. The plot size was 4.5 m x 3 m. The seeds were treated with the zinc solubilizing biofertilizer prior to sowing as per the treatment requirement. For the treatments involving biofertilizer, wheat seeds were inoculated with a zinc solubilizing bacterial culture obtained from ATC, Sumerpur. The inoculant was mixed with jaggery (10% solution) as an adhesive and uniformly coated on the seed at a rate of 25 g inoculant per kg seed. The inoculated seeds were air-dried in shade for 30 minutes before sowing. All standard agronomic practices such as irrigation, weed control, and pest management were uniformly adopted across treatments to ensure normal crop growth. Growth, yield attributes, and yield parameters were recorded at appropriate growth stages. Data collected from various parameters were statistically analyzed using the analysis of variance (ANOVA) technique appropriate for the Randomized Block Design (Gomez and Gomez, 1984). The significance of different source of variance was tested by error mean square of Fisher's "F" test at probability level 0.05. Fisher and Yate's tables were consulted for significance. The value of standard error of mean (SEm±) and the critical difference (CD) to compare the difference between the treatment means.

RESULTS AND DISCUSSION

Growth Attribute

Plant height showed noticeable variation among the different treatments (Table 1). The maximum plant height (101.00 cm) was recorded with T_4 (100% NPK + ZSB at 650 g ha^{-1}), followed closely by T_6 (99.85 cm) and T_2 (99.50 cm). These treatments recorded an increase of 3.19%, 2.01%, and 1.66% respectively over the control (T_1). The increase in plant height under these treatments could be attributed to improved nutrient availability and enhanced zinc solubilization by ZSB, which promotes better root development and nutrient uptake. On the other hand, reduced plant height was observed in treatments receiving only 75% NPK (T_3, T_5, and T_7), indicating that nutrient supply at sub-optimal levels could not fully support vegetative growth. The minimum plant height (94.45 cm) was recorded in T_7 (75% NPK + ZSB at 800 g ha^{-1}), showing a 3.50% reduction over control. Similarly, ZSB inoculation with fertilizer showed non-significant improvements in growth attributes of wheat under alkaline or zinc-deficient soils (Kamran *et al*. 2017).

Yield Attributes

The number of grains per spike followed a similar trend as plant height. The highest number of grains (42.68) was produced under T_4 (100% NPK + ZSB at650 g ha^{-1}), which was 5.38% higher than the control. Treatments T_2 (41.88 grains) and T_6 (41.83 grains) were statistically at par with T_4, suggesting that ZSB inoculation, particularly with full NPK application, enhanced reproductive development. The data presented in the Table 1, revealed that the number of grain/spike and test weight of wheat were not significantly influenced by the application of different treatments over the control (100% NPK). In contrast, all treatments with 75% NPK (T_3, T_5, and T_7) recorded a considerable decline in grain number (ranging from –7.53% to –8.94% compared to control). This might be due to restricted nutrient supply affecting floret fertility and grain filling. Test weight was least influenced by the treatments, as differences were statistically non-significant. Prathap *et al*. (2022) confirmed the findings and reported that different treatments consisting NPK + Zn sources along with bioinoculants showed non-significant response on the test weight of rice as compared to NPK alone.

Effect on Yields

Grain yield exhibited variation among the different treatments (Table 1). The highest yield (42.23 q ha^{-1}) was recorded in T_4 (100% NPK + ZSB at 650 g ha^{-1}), representing a 3.94% increase over control (40.63 q ha^{-1}). This was closely followed by T_6 (42.17 q ha^{-1}) and T_2 (41.25 q ha^{-1}), which showed 3.79% and 1.53% increases, respectively. Straw yield varied among the different treatments (Table 2). The highest straw yield (60.03 q ha^{-1}) was obtained with T_4 (100% NPK + ZSB at 650 g ha^{-1}), which recorded an 8.05% increase over the control (T_1). Treatments T_2 (58.83 q ha^{-1}) and T_6 (58.11 q ha^{-1}) also showed positive responses, with 5.89% and 4.59% increases over control, respectively. This improvement in straw yield could be attributed to better vegetative growth, enhanced nutrient availability, and improved root activity due to the synergistic effect of ZSB inoculation along with recommended NPK fertilization. Biological yield (grain + straw yield) followed a similar pattern to straw yield. The highest biological yield (102.27 q ha^{-1}) was obtained with T_4, showing a 6.32% increase over control, followed by T_6 (100.28 q ha^{-1}, + 4.25%) and T_2 (100.07 q ha^{-1}, + 4.03%). This clearly demonstrates the beneficial effect of ZSB inoculation when applied with 100% NPK, leading to enhanced overall plant productivity. Although these treatments showed slight improvements in grain, straw and biological yield over the control (100% NPK), the effects were not significant, indicating that ZSB inoculation did not substantially enhance production under the existing soil conditions. Raut *et al.* (2019) reported

Table 1: Response of chemical fertilizer and zinc-solubilizing biofertilizer (ZSB) on growth, yield attributes and yield of wheat

Treatment	Plant height (cm)	% changes over control	No. of grains/ spike	% changes over control	Test weight (g)	% changes over control	Grain yield (q ha^{-1})	% changes over control
T_1	97.88	—	40.50	—	40.22	—	**40.63**	—
T_2	99.50	1.66	41.88	3.41	40.34	0.30	41.25	1.53
T_3	95.40	-2.53	36.88	-8.94	38.91	-3.26	36.89	-9.21
T_4	101.00	3.19	42.68	5.38	40.51	0.72	**42.23**	3.94
T_5	94.63	-3.32	37.35	-7.78	38.55	-4.15	37.12	-8.64
T_6	99.85	2.01	41.83	3.28	40.34	0.30	42.17	3.79
T_7	94.45	-3.50	37.45	-7.53	38.77	-3.61	37.24	-8.34
SEm±	1.45	—	1.23	—	0.59	—	0.98	—
CD (p=0.05)	4.32	—	3.65	—	1.76	—	2.91	—

Note: *T_1 = 100% NPK (Control), T_2 = 100% NPK + ZSB at 500 g ha^{-1} seed treatment, T_3 = 75% NPK + ZSB at 600 g ha^{-1} seed treatment, T_4 = 100% NPK + ZSB at 650 g ha^{-1} seed treatment, T_5 = 75% NPK + ZSB at 700 g ha^{-1} seed treatment, T_6 = 100% NPK + ZSB at 750 g ha^{-1} seed treatment, T_7 = 75% NPK + ZSB at 800 g ha^{-1} seed treatment. NPK: N:P: –120:60:0 kg ha^{-1}*

Table 2: Response of chemical fertilizer and zinc-solubilizing biofertilizer (ZSB) on straw yield and benefit cost ratio of wheat

Treatment	Straw Yield (q ha^{-1})	% changes over control	Biological yield (q ha^{-1})	% changes over control	HI (%)	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
T_1	55.56	—	96.19	—	42.24	38978	111067	72089	2.85
T_2	58.83	5.89	100.08	4.03	41.23	39303	113975	74672	2.90
T_3	50.57	-8.98	87.46	-9.08	42.24	38634	100908	62274	2.61
T_4	60.03	8.05	102.27	6.32	41.29	39341	116595	77254	2.96
T_5	51.26	-7.74	88.37	-8.13	42.01	38659	101723	63064	2.63
T_6	58.11	4.59	100.28	4.25	42.04	39366	115495	76130	2.93
T_7	52.90	-4.79	90.14	-6.29	41.31	38684	102793	64109	2.66
SEm±	1.63	—	2.44	—	0.50	—	—	2664	0.07
CD (p=0.05)	4.83	—	7.25	—	1.49	—	—	7916	0.20

similar trend in groundnut and reported that the treatment receiving 100% fertilizer + FYM at 5 t ha-1 + ZnO + ZnSB gave numerically higher groundnut pod yield (27.22 q ha^{-1}) compared to 100% fertilizer + FYM at 5 t ha^{-1} alone (26.56 q ha^{-1}) but the increment was statistically non-significant. This indicates that the application of fertilizer, zinc fertilizer along with zinc-solubilizing bacteria did not produce a significant 100 improvement in pod yield over % fertilizer alone under the given soil and environmental conditions. Harvest index (HI), varied slightly among treatments but remained statistically non-significant. Yadav *et al.* (2023) found similar minor difference or non-significant observation in the harvest index (%) of wheat in absolute control and NPK alone as compared to NPK with various bioinoculants.

Effect on Economics

Recommended dose of fertilizer (100% NPK) along with ZSB application had positive response on the economics of the wheat crop. The treatment (T_4) combining 100% NPK + ZSB at 650 g ha^{-1} fetched maximum gross return (₹ 1,16,595 ha^{-1}), net return (₹ 77,254 ha^{-1}) and B:C ratio (2.96) (Table 2). This was closely followed by T_6 with a B:C ratio of 2.93.

CONCLUSION

Based on the result of the experimentation treatment T_4(100% NPK + ZSB at 650 g ha^{-1} seed treatment) gave highest grain yield (42.23 qha^{-1}) and B:C ratio (2.96), indicating that the integration of zinc-solubilizing biofertilizer with the recommended dose of fertilizer is economically advantageous, but not significant over 100% NPK alone. This result suggests that NPK fertilizer and ZSB have less effect than seasonal variations or others anthropic factors.

FUTURE SCOPE OF THE WORK

The present study revealed that ZSB in combination with 100% NPK did not significantly enhance wheat yield over 100% NPK, likely due to the slightly alkaline soil conditions limiting zinc solubilization. Future investigations should focus on integrating NPK with various zinc sources ($ZnSO_4$, Zn-EDTA, nano-zinc) along with ZSB to improve zinc availability.

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