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Effect of zinc-based fertilizer on nutrient content and uptake by barley (*Hordeum vulgare* L.) crop under saline condition

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Abstract
The field experiment conducted during the *rabi* season of 2021-22 at the Agricultural Research Sub-station in Vallabhnagar, Udaipur, Rajasthan, aimed to assess the influence of zinc-based fertilizers on the nutrient content and uptake by barley (*Hordeum vulgare* L.) crop. The experimental design followed a split plot arrangement, with main plot treatments consisting of a control, 5 kg Zn per hectare as soil application, and seed treatment with zinc solubilizing bacteria (ZSB) at a rate of 5 ml per kg of seed. The sub plot treatments included a control and three foliar sprays of nano Zn at 5 ml per litre of water, applied at 15, 30, and 45 days after sowing. Each treatment was replicated three times. The soil application of zinc @ 5 kg Zn ha^{-1} along with foliar spray of nano Zn @ 5 ml per litre of water at 45 days after sowing had significantly influenced nutrient content and uptake by barley crop.

Keywords: Foliar application, nano Zn, barley, nutrient content, nutrient uptake

1. Introduction

Barley (*Hordeum vulgare* L.) is an important cereal crop that holds significant agricultural and economic value worldwide. It is a versatile and resilient crop that is cultivated in diverse climatic conditions, making it one of the most widely adapted and cultivated cereal grains. Barley is a member of the grass family (*Poaceae*) and is classified as a cool-season annual crop. It has been cultivated for thousands of years and has served as a staple food source, livestock feed, and raw material for the brewing and malting industries. Barley is renowned for its hardiness, adaptability, and ability to withstand adverse environmental conditions (Kumar *et al.*, 2022) [11].

One of the distinctive features of barley is its exceptional tolerance to various abiotic stresses, including drought, cold, and salinity. This adaptability has made barley an attractive crop in regions with challenging growing conditions, where other crops may struggle to thrive. Additionally, barley exhibits remarkable genetic diversity, allowing for the selection and development of cultivars with improved agronomic traits and stress tolerance (Sharma *et al.*, 2021) [16]. Barley's ability to survive and produce acceptable yields under saline soil conditions makes it an important crop in regions affected by salinity.

Among the essential nutrients, zinc plays a vital role in various plant physiological processes, including nutrient metabolism, enzyme activation, and stress tolerance. Zinc is a cofactor for numerous enzymes involved in carbohydrate and protein metabolism, growth regulation, and defense mechanisms. Adequate zinc nutrition is crucial for maintaining optimal plant growth, development, and overall productivity (Yadav *et al.*, 2020) [26].

Recent findings from a global investigation conducted by the Food and Agriculture Organization (FAO) have shed light on the widespread deficiency of zinc, making it the most commonly deficient micronutrient, particularly in the soils of semi-arid regions around the world. This deficiency of zinc is considered a critical component of hidden hunger in plants, highlighting its significant role in plant nutrition.

Approximately 50% of the soils used for cereal production globally exhibit low levels of plant-available zinc, leading to not only reduced grain yield but also compromised nutritional quality of the crops (Graham *et al.*, 1992; Çakmak *et al.*, 1996; Graham and Welch, 1996) [9, 2, 8]. Unlike other micronutrients, zinc deficiency is prevalent in various climates, including both cold and warm regions, and across a wide range of soil types, such as acidic, alkaline, heavy, or light soils (Graham *et al.*, 1992) [9].

In India, Singh (2008) [19] reported deficiencies of zinc, iron, manganese, copper, boron, and molybdenum in 48%, 12%, 5%, 4%, 33%, and 13% of soils, respectively. Specifically, a significant proportion of soils in Rajasthan have been found to be deficient in zinc (Yadav, 2008; Singh *et al.*, 2013) [25, 21]. Coarse textured soils with medium organic carbon content have been identified as having low zinc availability (Singh and Singh, 1981) [18]. Consequently, the inadequate supply of zinc in these soils further exacerbates the negative impact on crop yields. As a result, it is imperative to address and prioritize the application and utilization of zinc in agricultural practices.

Given the global prevalence of zinc deficiency and its adverse effects on crop productivity, it becomes crucial to give serious consideration to the application and utilization of zinc. By addressing zinc deficiencies in soils, farmers can mitigate the detrimental consequences on crop yields and ensure improved agricultural productivity. Thus, prioritizing zinc supplementation and adopting effective strategies for its application is of paramount importance in sustaining crop production and enhancing overall food security.

In recent years, potential of zinc-based fertilizers is explored as a strategy to mitigate the adverse effects of salinity on nutrient dynamics in crops, including barley. Zinc-based fertilizers can enhance the availability and uptake of zinc, thereby promoting the activity of zinc-dependent enzymes involved in nutrient acquisition and utilization.

Therefore, the present study is conducted to investigate the effect of zinc-based fertilizer on nutrient content and uptake by barley crops grown in saline soil conditions. To evaluate the response of barley to zinc-based fertilizer application and its potential in mitigating the detrimental effects of salinity on nutrient dynamics. Specifically, we will examine the impact of zinc-based fertilizers on the uptake and assimilation of essential nutrients, including nitrogen, phosphorus, potassium and zinc in barley plants grown in saline soil.

2. Materials and Methods

2.1 Description of the study area

The experiment was carried out at the Agriculture Research Sub Station Farm located in Vallabhnagar, Udaipur, Rajasthan. The research site has geographical coordinates approximately at 24° 38' North latitude and 73° 42' East longitude. Situated at an average altitude of 633 meters above sea level, it is located just 45 km east of Udaipur, Rajasthan. The experimental site falls within agro-climatic zone IVa of Rajasthan, which is classified as the Sub-Humid Southern Plain and Aravalli Hills region. The Sub-Humid Southern Plain and Aravalli Hills region typically experiences a semi-arid climate, with hot summers and relatively mild winters. The region is influenced by the Aravalli Range, which affects local rainfall patterns and creates variations in soil types and topography.

2.2 Experimental design and treatments

The experiment utilized a split-plot design with three main plot treatments involving different zinc sources and four sub-plot treatments involving nano zinc application at various time intervals. The experiment was replicated three times to ensure reliable results and reduce potential variability. This design allowed for the simultaneous evaluation of both main plot treatments (zinc sources) and sub-plot treatments (nano zinc application timing) to comprehensively analyze their individual and combined effects on the study variables.

Details of treatments and their symbols

	Treatments	Symbols
	Main Plot (Soil application and seed treatment)	
i.	Control	Zn_0
ii.	5 kg Zn ha^{-1} (soil application)	Zn_{SA}
iii.	Zinc solubilizing bacteria @ 5 ml kg^{-1} of seed (Seed treatment)	Zn_{ST}
	Sub Plot (Foliar application)	
i.	Control	NP_0
ii.	Foliar spray of nano Zn @ 15 DAS	NP_{15}
iii.	Foliar spray of nano Zn @ 30 DAS	NP_{30}
iv.	Foliar spray of nano Zn @ 45 DAS	NP_{45}

2.3 Application protocol of fertilizers

In the experimental setup, the recommended doses of nitrogen (N) and phosphorus (P) were 60 kg ha^{-1} and 20 kg ha^{-1}, respectively. These nutrients were applied using urea for nitrogen and diammonium phosphate (DAP) for phosphorus. Zinc was applied in the form of zinc sulphate, with the quantity varying based on the treatment. During sowing, the total amount of phosphorus and zinc, along with half of the nitrogen, were applied by placing them in furrows. The remaining half of the nitrogen was divided into two equal splits and applied during subsequent irrigations. Additionally, nano zinc was sprayed on the plants using a concentration of 5 ml per liter of water, following the specific treatment protocol. This foliar application of nano zinc was carried out as per the treatment requirements.

2.4 Nutrient content and uptake

The N, P, K and Zn contents in the grain and straw samples were examined after the threshing of the harvested barley crop. Plant analysis for the determination of nutrient content in gain and straw were done with the standard procedures viz., Nitrogen concentration in plant (both seed and stover) was determined by Kjeldahl's method, Phosphorus by colorimetric method, Potassium by flame photometer (Jackson, 1973) [10] and Zn content is determined by atomic absorption spectrophotometer (Lindsay and Norvell, 1978) [12]. The concentration of nitrogen, phosphorus and potassium were expressed in percent whereas concentration of zinc as ppm. The uptake of these nutrients was calculated using following methods and nitrogen, phosphorus, and potassium uptake expressed in kg ha^{-1} whereas zinc in g ha^{-1}.

$$\text{Major nutrient uptake by seed (kg ha}^{-1}) = \frac{\text{Nutrient content (\%) in seed x Seed yield}}{100}$$

$$\text{Major nutrient uptake by stover (kg ha}^{-1}) = \frac{\text{Nutrient content (\%) in straw x Straw yield}}{100}$$

$$\text{Micro nutrient uptake by seed (mg kg}^{-1}) = \frac{\text{Nutrient content (\%) in seed x Seed yield}}{1000}$$

$$\text{Micro nutrient uptake by stover (mg kg}^{-1}) = \frac{\text{Nutrient content (\%) in straw x Straw yield}}{1000}$$

2.5 Statistical Analysis

The experimental data were subjected to statistical analysis of variance using the procedure outlined by Panse and Sukhatme (1985) [13]. The 'F' test was employed to evaluate the significance of the observed differences. To compare the means, the critical difference (CD) was calculated at a 5% level of significance. This allowed for the interpretation and comparison of the findings in a statistically rigorous manner.

3. Result and Discussion

3.1 Effect of soil application and seed treatment with zinc on nutrient content and uptake by barley

The results of field experiment in Table 1 and 2 reveals significant effects of soil application of zinc and seed treatment with zinc solubilizing bacteria on nutrient content and uptake by barley crop. The study indicates that these treatments have a notable influence on the nitrogen (N), potassium (K), and zinc (Zn) content, as well as their uptake by grain and straw compared to the control group. The results further demonstrate that the highest concentration of these nutrients and their uptake by grain and straw were observed with soil application of zinc at a rate of 5 kg Zn per hectare (Zn_{SA}). The N, K, and Zn content increased to an extent of 14.01, 25.0 and 23.04 percent in grain and 25.92, 8.26 and 23.03 percent in straw with soil application of zinc @ 5 kg Zn ha^{-1} (Zn_{SA}) over control (Zn_0) respectively. Regarding phosphorus (P) content, both grain and straw showed a decrease with soil application of zinc and seed treatment with zinc solubilizing bacteria compared to the control group. The observed reduction in phosphorus concentration resulting from zinc application can be attributed to the antagonistic relationship between zinc and phosphorus. The presence of elevated zinc levels may create obstacles in the absorption and translocation of phosphorus from the roots to the shoots of plants (Reddy and Yadav, 1994) [15]. This interference can limit the movement of phosphorus within the plant, leading to reduced phosphorus concentration in plant tissues. Data presented in table 2 reveals that N, P, K, and Zn uptake increased by 40.33, 16.74, 53.87 and 51.44 percent by grain and 55.07, 14.35, 33.03 and 51.88 percent by straw under soil application of zinc @ 5 kg Zn ha^{-1} (Zn_{SA}) over control (Zn_0) respectively. Zinc plays a vital role as both a structural constituent and a co-factor for numerous enzymes involved in essential metabolic processes within plants. These processes include protein metabolism, carbohydrate metabolism, auxin metabolism, and enzymatic activities related to photosynthesis and respiration (Alloway, 2008) [1]. When it comes to nutrient interactions, zinc has shown a positive correlation with nitrogen. The application of zinc fertilizer has been found to increase the content and uptake of nitrogen by barley in both grain and straw (Singh *et al.,* 2021) [20]. This increase in nitrogen concentration also leads to a higher total uptake of nitrogen by the plant. Dangi and Pandey (2021) [6] observed that increase in zinc content and uptake in rice grain and straw at harvest can be attributed to the presence of a greater amount of zinc in the soil solution due to zinc fertilizer application. This increased availability of zinc in the soil solution may have facilitated its absorption by the plant through the phloem, resulting in higher zinc content and uptake in the harvested plant parts. The interactions between zinc and nitrogen, along with the facilitated absorption of zinc through the phloem, contribute to the overall nutrient dynamics and uptake efficiency in barley (Sharma *et al.,* 2019) [17]. Similar results are also reported by Chaudhary *et al.* (2014) [3]; Singh (2017) [22]; Todawat *et al.* (2017) [24]; and Chaure *et al.* (2019) [2]. Singh and Kumar (2016) [23] reported that zinc plays a crucial role in enhancing nutrient availability and uptake, even in saline soil conditions. It acts as a cofactor for enzymes involved in nutrient uptake and utilization, facilitating the efficient absorption and transport of essential nutrients. Additionally, zinc supplementation in saline soil promotes root development and elongation, which allows for greater nutrient exploration and uptake from the soil. It helps in the activation of enzymes involved in metabolic processes related to nutrient absorption and assimilation.

3.2 Effect of foliar application of nano zinc on nutrient content and uptake by barley

The foliar spray of nano zinc significantly influences the N, K and Zn content, their uptake by grain and straw over control whereas, phosphorus content in both grain and straw decreased with foliar spray of nano zinc application (Table 1 and 2). The maximum concentration of N, P and Zn nutrients and their uptake by grain and straw were observed with foliar spray of nano Zn at 45 DAS (NP_{45}). The N, K, and Zn content increased to an extent of 4.21, 20.0 and 16.20 percent in grain and 21.22, 5.69 and 16.19 percent in straw with foliar spray of nano Zn at 45 DAS (NP_{45}) over control respectively. The N, P, K, and Zn uptake increased by 28.77, 20.40, 48.31 and 43.57 percent by grain and 49.10, 4.66, 28.96 and 41.76 percent by straw with foliar spray of nano Zn at 45 DAS (NP_{45}) over control respectively. The higher content and uptake of nutrients observed with nano fertilizers compared to conventional fertilizers can be attributed to several factors. One of the main reasons is the small size of nano particles, which provides a larger surface area. This increased surface area allows the nano particles to hold a greater amount of nutrients and slowly release them, thereby enhancing the use efficiency of nutrients for efficient uptake by the crop.

Moreover, nano-scale zinc particles have lower hydrophilicity and are more dispersible in lipophilic substances compared to ions present in conventional fertilizers. This characteristic enables the nano particles to easily penetrate through the leaf surface, facilitating their uptake by the plant. Furthermore, the high mobility of nano particles contributes to their effectiveness. They can readily move within the plant, including transportation through the phloem, to other parts of the plant such as grains and straw. This mobility ensures a more efficient distribution of nutrients throughout the plant, leading to increased nutrient content in harvested parts. The findings of Gonzalez-Melendi *et al.* (2008) [7] support the notion that nano particles have enhanced mobility and can transport nutrients effectively. Additionally, the study conducted by Prasad *et al.* (2012) [14] specifically focused on peanut seeds and reported higher zinc content in seeds when nano zinc oxide (ZnO) was applied compared to zinc sulfate ($ZnSO_4$). These results are in agreement with the findings of Prasad *et al.* (2012) [14], suggesting that nano zinc fertilizers can indeed increase the nutrient content in crops. Overall, the use of nano fertilizers, such as nano zinc, offers advantages in terms of nutrient availability, slow release, ease of uptake, and improved mobility, contributing to higher nutrient content and uptake in plants.

Choudhary *et al.* (2021) [5] report that nano fertilizers can alleviate the adverse effects of salinity stress on plants. They can help regulate osmotic balance and minimize oxidative damage caused by saline conditions. By reducing stress, nano fertilizers improve nutrient uptake and utilization in barley plants.

Table 1: Effect of different sources of zinc on nutrient content of barley

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Zinc (ppm)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Main Plot (Soil application and seed treatment)								
Zn_0 = Control	1.57	0.27	0.39	0.14	0.44	1.21	41.70	38.51
Zn_{SA} = 5 kg Zn ha^{-1} (soil application)	1.79	0.34	0.37	0.13	0.55	1.31	51.31	47.38
Zn_{ST} = Z.S.B. @ 5 ml kg^{-1} of seed (Seed treatment)	1.75	0.31	0.38	0.13	0.51	1.26	47.80	44.13
S.Em±	0.02	0.003	0.003	0.002	0.005	0.013	0.59	0.55
CD (P= 0.05)	0.08	0.013	0.010	0.006	0.04	0.06	2.32	2.14
Sub Plot (Foliar application)								
NP_0 = Control	1.66	0.27	0.39	0.14	0.45	1.23	42.26	39.03
NP_{15} = Foliar spray of nano Zn at 15 DAS	1.70	0.30	0.38	0.13	0.50	1.25	47.23	43.81
NP_{30} = Foliar spray of nano Zn at 30 DAS	1.72	0.32	0.38	0.13	0.52	1.28	48.92	45.17
NP_{45} = Foliar spray of nano Zn at 45 DAS	1.73	0.33	0.38	0.12	0.54	1.30	49.11	45.35
S.Em±	0.018	0.004	0.003	0.002	0.006	0.016	0.59	0.55
CD (P= 0.05)	0.052	0.012	NS	0.006	0.03	0.02	1.76	1.64

Table 2: Effect of different sources of zinc on nutrient uptake of barley

Treatment	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})		Zinc (g ha^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Main Plot (Soil application and seed treatment)								
Zn_0 = Control	44.73	11.42	11.11	5.92	12.53	51.20	118.82	162.97
Zn_{SA} = 5 kg Zn ha^{-1} (soil application)	62.77	17.71	12.97	6.77	19.28	68.25	179.95	246.87
Zn_{ST} = Z.S.B. @ 5 ml kg^{-1} of seed (Seed treatment)	56.93	14.99	12.36	6.28	16.59	60.94	155.51	213.45
S.Em±	1.97	0.25	0.32	0.15	0.46	1.37	4.57	4.23
CD (P= 0.05)	7.72	0.96	1.26	0.60	1.79	5.40	17.96	16.60
Sub Plot (Foliar application)								
NP_0 = Control	45.91	11.18	10.78	5.79	12.44	50.93	116.89	161.63
NP_{15} = Foliar spray of nano Zn at 15 DAS	55.19	14.43	12.33	6.25	16.23	60.14	153.35	210.78
NP_{30} = Foliar spray of nano Zn at 30 DAS	58.18	16.10	12.85	6.54	17.59	64.43	165.48	227.38
NP_{45} = Foliar spray of nano Zn at 45 DAS	59.12	16.67	12.98	6.06	18.45	65.68	167.83	229.13
S.Em±	1.25	0.29	0.20	0.15	0.34	1.37	2.94	3.21
CD (P= 0.05)	3.72	0.87	0.58	0.44	1.01	4.08	8.75	9.53

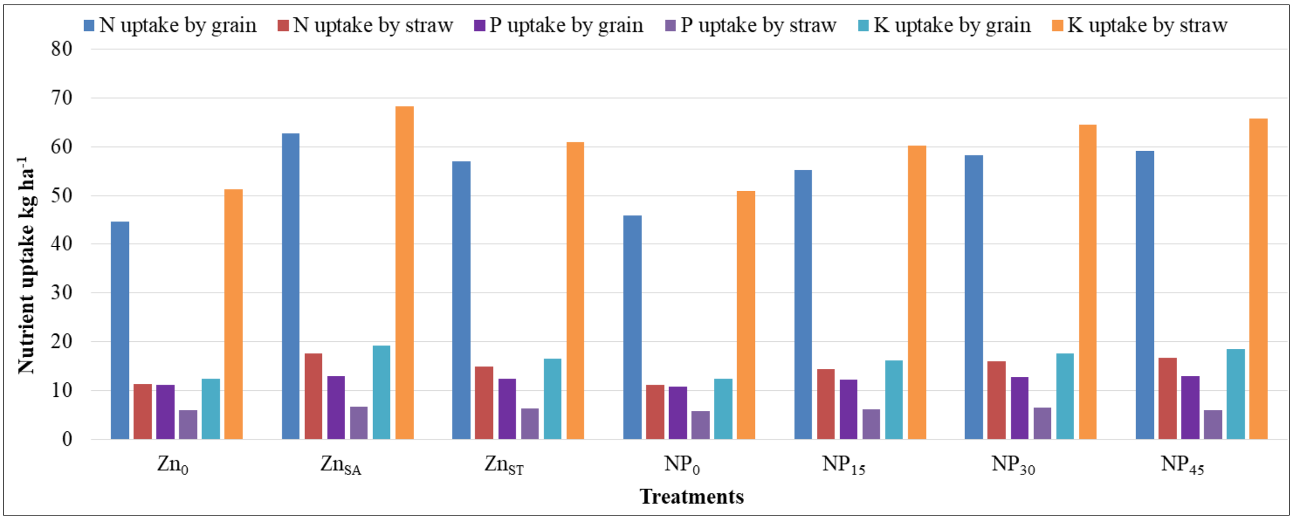

Fig 1: Effect of different sources of zinc on N, P and K uptake of barley

4. Conclusion

From the forgoing result, it was concluded that the combined application of the conventional and nano zinc fertilizers significantly nutrient content and uptake in barley. The treatment combination includes soil application of zinc @ 5 kg Zn ha^{-1} (Zn_{SA}) along with foliar spray of nano zinc at 45 DAS (NP_{45}) increase nutrient content and uptake by barley crop maximum. This approach offers a dual nutrient supply system, utilizing both soil application and foliar absorption to optimize nutrient availability and uptake efficiency. The soil application of zinc conventional fertilizer ensures the presence of zinc in the root zone, facilitating nutrient uptake through the root system. Simultaneously, the foliar application of nano zinc directly supplies zinc to the above-ground plant parts, allowing for efficient nutrient absorption through the leaves. The combined effect of zinc conventional fertilizer and nano zinc foliar application also enhances nutrient use efficiency. By utilizing two different pathways for nutrient absorption, the plant can optimize nutrient uptake and utilization, minimizing nutrient losses and maximizing nutrient assimilation.

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