Evaluation of the Role of Nano-Zinc Fertilizer in Improving Yield Traits of Common Bean Plants Grown under Salt Stress

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ABSTRACT

This study was conducted in the greenhouse of the College of Education for Women, University of Tikrit Longitude and latitude lines, during the agricultural season 2025-2026, with the aim of evaluating effect of foliar spraying with zinc oxide nanoparticles (ZnO-NPs) at concentrations (0, 25, 50, 75 mg L^{-1}) on improving yield traits and its components of green beansplants (Phaseolus vulgaris L.) grown under different levels of salt stress (NaCl) at concentrations (0, 1, 3, 5 g L^{-1}). The experiment was designed The results showed that according to a randomized complete block design (RCBD) as a factorial study. salt stress, especially at the high concentration (5 g L^{-1}), led to a significant decrease in all yield traits, including the number of pods, pod length and diameter, weight of 100 seeds, and biological yield. In contrast, spraying with zinc oxide nanoparticles achieved a significant superiority in improving these traits, with the concentration of 75 mg/L (N3) recording the highest averages for the number of pods Furthermore, the (45.75 pods $plant^{-1}$), plant yield (133.60 g $plant^{-1}$), and harvest index (40.80%). interaction results revealed the ability of nano-zinc to mitigate the negative effects of salinity; the N3S0 interaction treatment achieved the best results, while the addition of zinc helped maintain good production levels under salt stress conditions compared to control treatments. These improvements may be attributed to the role of zinc in activating metabolic enzymes, improving photosynthesis efficiency, and enhancing the plant's reproductive processes.

Keywords: Nano-zinc, salt stress, green beans

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a plant belonging to the Fabaceae family and is one of the important vegetable crops widely distributed worldwide. It is cultivated extensively in tropical, subtropical, and temperate regions, except for the Arctic continent. Due to its high nutritional, economic, and medicinal value, its green pods contain 90.14 g water, 2.31 g protein, 0.5 g fat, 6.41 g carbohydrates, and 3.4 g fiber, providing 33 kcal per 100 g. They are also rich in mineral elements such as calcium, iron, magnesium, phosphorus, potassium, sodium, copper, manganese, and zinc, as well as a range of vitamins including C, B1, B2, and B3 (USDA, 2018). Global production of green beans reached 24,752,853 tons per hectare from a cultivated area of 1,934,328 hectares, with China ranking first globally with a production of 17,200,000 tons per hectare, followed by Indonesia, India, and Turkey in fourth place (FAO, 2021). It is a crop rich in nutrients (carbohydrates 52-76%, protein 14-33%, amino acids such as lysine 6.4-7.6 g/100 g), in addition to its nutritional content, it contains bioactive compounds such as anti-inflammatories, Zinc (Zn) is a).1phenolic acids, and flavonoids (micronutrient essential for plant life cycles and growth, although it is absorbed in relatively). It is considered an essential 2small quantities (element for metabolic processes and growth in plants, and its deficiency can disrupt many plant metabolic processes, including carbohydrate and protein synthesis, ultimately reducing production). Some consider zinc the fourth most 3quality (important nutrient determining yield after Salt).4nitrogen, phosphorus, and potassium (stress is one of the most significant environmental factors negatively affecting plant growth and productivity, inhibiting them. It disrupts the absorption of water and nutrients, which reflects on the vegetative traits of the plant. This accumulative process of salinity can lead to visible symptoms such as leaf curling,). 5yellowing, wilting, and a decrease in yield (Salinity also affects physiological and biochemical processes, inhibiting growth, accelerating senescence, and in severe cases, may lead to plant death. These effects are reflected in anatomical changes in the plant, such as increased thickness of certain tissues and improved water absorption capacity as an).6adaptive mechanism to cope with salt stress (

The study aims to:

1. Evaluate the effect of nano-zinc fertilizer on improving the growth, yield, and some anatomical traits of common bean plants.
2. Study the impact of salt stress on the vegetative growth, yield, and some anatomical traits of common bean plants.
3. Determine the optimal concentration of nano-zinc fertilizer that achieves the best growth and yield response under different salinity levels.
4. Identify the effect of the interaction between zinc oxide nanoparticles and salt stress treatments on growth, yield traits, and some anatomical traits of common bean plants.

MATERIALS AND METHODS

3.1: Experiment Location and Setup

The experiment was conductedin the greenhouse of the scientific departments affiliated with the College of Education for Women / University of Tikrit for the agricultural season 2025-2026, from October 13, 2025, to January 17, 2026, to study the effect of salt stress at concentrations (0, 1, 3, 5 g L^{-1}) and the addition of zinc oxide at concentrations (0, 25, 50, 75 mg L^{-1}) on the growth and yield of common bean plants according to the following steps:

3.2: Source of Used Seeds

Common bean seeds (*Phaseolus vulgaris* L.) of the American variety GIA BEAN were obtained from local markets in Baghdad Governorate, with germination rates of 97% and 98%, respectively, tested on filter paper in Petri dishes. This variety is designated for protected cultivation, resistant to rot diseases, high-yielding, and tolerant to various environmental conditions.

3.3: Soil Preparation, Conditioning, and Planting Method

This experiment was conducted in the greenhouse of the scientific departments, College of Education for Women, University of Tikrit, on October 13, 2025, using plastic pots for planting with a height of (35 cm), a diameter of (25 cm), and a capacity of (12 kg) of soil. The pots were filled with a mixture of loamy soil and peat moss in a 2:1 ratio, with the addition of urea and superphosphate fertilizers according to the recommended rates. The soil was obtained from the Tigris River basin, air-dried, and sieved using a 2 mm mesh sieve. The total number of treatments was (16) experimental treatments, with (48) experimental units for the complete experiment across three replicates. Irrigation and other agricultural operations were carried out according to plant needs. The number of plants per experimental unit Start with 5 plants , Then thin to 3 plants seeds planted per hole. After germination and ensuring plant health, thinning was performed so that each pot contained three plants. The chemical and physical properties of the soil were analyzed in the soil laboratory of the College of Agriculture / University of Tikrit, as shown in Table (1).

Table 1: Physical and chemical properties of the field soil before planting

Characteristics	Unit of measurement	Value
Soil pH	-	7.20
(EC)	$mmho.cm^{-1}$	0.30
($CaCO_3$)	%	22
Available nitrogen	Ppm	10
Phosphorus	Ppm	5
Potassium	Ppm	132
(Silt)	%	18
(Clay)	%	14
(Sand)	%	68
(Soil texture)	-	Sandy loam

The physical and chemical properties of the field soil were analyzed in the soil laboratory of the College of Agriculture / University of Tikrit

. **Table (1) Monthly averages of maximum and minimum temperatures (°C) and relative humidity (%)**

Date	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)
13–22/10/2025	32	16	40
23–31/10/2025	31	15.5	38
01–10/11/2025	24	10.5	55
11–20/11/2025	23	9.5	58
21–30/11/2025	23.5	10	57
01–10/12/2025	17	6	70
11–20/12/2025	16	5	72
21–31/12/2025	16.5	5.5	71
01–10/01/2026	14.5	4	65
11–17/01/2026	14	3.8	64

Experimental Design:

The experiment was conducted using a Randomized Complete Block Design (RCBD) as a factorial experiment consisting of two factors: the first factor was salt stress (NaCl) at four concentrations (0, 1, 3, 5 g/L), and the second factor was zinc oxide nanoparticles (ZnO-NPs) at four concentrations (0, 25, 50, 75 mg/L). Thus, the total number of experimental treatments was (16) with three replications. The number of experimental units was (48), with (3) plants per experimental unit. Data were collected from the three plants in each experimental unit to study growth traits, yield traits, chemical traits, and anatomical traits (26).

3.5: Study Factors:

The experiment included two factors:

3.5.1: First Factor:

Addition of four levels of sodium chloride (NaCl):

S0: Without addition (distilled water)
S1: Dissolving 1 g in one liter of distilled water.
S2: Dissolving 3 g in one liter of distilled water.
S3: Dissolving 5 g in one liter of distilled water.

The mentioned concentrations were dissolved in one liter of distilled water for addition to the plant soil in two batches. The first batch was added on (October 28, 2025), and the second batch was added 10 days after the first, with the same concentrations.

A surfactant (e.g., Tween-20 at 0.1%) was added to improve foliar absorption.

with zinc oxide nanoparticles (ZnO NPs), denoted as N, at four levels:

N0: Spraying with distilled water only.
N1: Spraying with zinc oxide nanoparticles at a concentration of 25 mg per liter of distilled water.
N2: Spraying with zinc oxide nanoparticles at a concentration of 50 mg per liter of distilled water.
N3: Spraying with zinc oxide nanoparticles at a concentration of 75 mg per liter of distilled water.

3.5.2: Second Factor:

The zinc oxide nanoparticles were procured from a supplier in Baghdad, with details shown in Appendix (12). They were prepared by weighing 25 mg of zinc and dissolving it in 1 liter of distilled water for the N1 treatment, 50 mg of zinc in 1 liter of distilled water for the N2 treatment, and 75 mg of zinc in 1 liter of distilled water for the N3 treatment. Spraying was carried out in the early morning in two batches: the first on (November 2, 2025) and the second 10 days after the first (November 12, 2025) for the experiment.

3.6: Studied Traits of the Experiment.

Three homogeneous plants from each experimental unit were relied upon, and their average was taken at the end of the growing season.

3.6.2: Yield Traits.

3.6.2.1: Number of pods per plant $(pod.plant^{-1})$

This trait was measured by counting the number of pods from three plants in the experimental unit and calculating their average.

3.6.2.2: Pod length $(cm.plant^{-1})$

Pod length was measured from the beginning to the end of the pod using a measuring tape for five randomly selected pods from each experimental unit, and then the average length was calculated.

3.6.2.3: Pod diameter $(mm.plant^{-1})$

Pod diameter was measured using a Vernier Digital Caliper.

3.6.2.4: Average pod weight $(g.plant^{-1})$

This trait was calculated by dividing the yield of the experimental unit by the number of pods,):7according to the following equation (

$$\text{Average pod weight} = \frac{\text{Yield of experimental unit}}{\text{Number of pods in the experimental unit}}$$

3.6.2.5: Plant yield $(g.plant^{-1})$

Pod yield per plant was calculated according to):7the following equation (

$$\text{Pod yield per plant} = \frac{\text{Yield of experimental unit}}{\text{Number of plants in the experimental unit}}$$

3.6.2.6: Number of seeds per pod (seed.pod^{-1})

This trait was calculated by counting the number of seeds in pods from five randomly selected pods from the experimental unit, dividing by their number, and calculating the average.

3.6.2.7: Weight of 100 seeds (g)

This trait was measured by counting 100 seeds from each experimental unit and then calculating their average weight.

3.6.2.8: Plant biological yield (g.plant^{-1}):

Plant biological yield was calculated as follows: (Seed weight + plant dry weight) for three plants, and its average was extracted for each experimental unit.

3.6.2.9: Harvest index (%): It was estimated according to the following equation:

Harvest Index (%) = (Economic yield) / (Biological yield) × 100

4-1 Results:

4-1-2-1: Number of pods per plant (pod.plant^{-1})

The results in Table ( ) showed significant differences in the above trait for zinc oxide nanoparticle concentration. The N3 concentration achieved the highest average of 45.75 pods.plant^{-1}, while the N0 concentration recorded the lowest average of 31.58 pods.plant^{-1}. We also note that the average effect of salt differed significantly; the results showed that the S0 concentration gave the highest average number of pods, reaching 43.75 pods.plant^{-1}, while the S3 concentration recorded the lowest average of 36.58 pods.plant^{-1}. Regarding the interaction results between zinc oxide and salt stress treatments, the effect was significant. The N3S0 treatment gave the highest value of 54.3 pods.plant^{-1}, while the N0S1 treatment gave the lowest value of 26.7 pods.plant^{-1}.

Table 1 Effect of zinc oxide nanoparticles and salt stress on the number of pods per plant (pod.plant^{-1})

Nano zinc oxide	Salinity stress				Average zinc
	S0	S1	S2	S3	
N0	37.3 d	26.7 g	33.3 e	29.0 f	d31.58
N1	41.7 c	36.7 d	35.3 de	30.7 f	0 c36.1
N2	41.7 c	42.7 c	40.3 c	46.3 b	b42.75
N3	54.3 a	42.7 c	45.7 b	40.3 c	a45.75
Average salt	a43.75	b37.2	b38.65	b36.58	

4-1-2-2: Pod length (cm.plant^{-1})

The results in Table () indicate significant differences among zinc oxide nanoparticle concentrations. The N3 concentration recorded the highest mean pod length value, reaching 15.88 cm, compared to the N0 concentration, which recorded the lowest mean pod length value of 14.10 cm. Meanwhile, from the table of salt effect results, we observe no significant difference, as the S1 concentration gave the highest mean pod length of 15.23 cm, while the S2 concentration recorded the lowest mean pod length of 14.83 cm. The interaction between the studied concentrations also showed a significant effect on this trait, as the N3S1 treatment achieved the highest pod length value of 16.8 cm compared to the N0S3 treatment, which recorded the lowest value of 13.4 cm.

Table 2 Effect of zinc oxide nanoparticles and salt stress on pod length (cm.plant^{-1})

Nano zinc oxide	Salinity stress				Average zinc
	S0	S1	S2	S3	
N0	**14.4 cd**	**14.1 cd**	**14.5 c**	**13.4 d**	**0 d14.1**
N1	**14.9 bc**	**15.1 bc**	**14.5 c**	**15.1 b**	**0 c14.9**
N2	**15.4 bc**	**14.9 bc**	**15.2 b**	**16.0 ab**	**b15.38**
N3	**15.8 a**	**16.8 a**	**15.1 bc**	**15.8 ab**	**a15.88**
Average salt	**a 15.13**	**3 a15.2**	**a14.83**	**a15.08**	

4-1-2-3: Pod diameter (mm.plant^{-1})

It is evident from Table () that the levels of zinc oxide nanoparticles differed significantly in their effect, as the N3 level recorded the highest average pod diameter of 10.30 mm compared to the N0 level, which gave the lowest average of 9.36 mm. Meanwhile, from the table of salt effect results, we observe no significant difference, as the results showed convergence in values between concentrations. The S0 concentration recorded the highest average pod diameter of 9.87 mm, while the S3 concentration recorded the lowest average of 9.68 mm. Regarding the interaction results between the two studied factors, the effect was significant for this trait, as the N3S0 treatment achieved the highest pod diameter value of 10.60 mm compared to the N0S2 treatment, which recorded the lowest value of 8.88 mm .

Table 3 Effect of zinc oxide nanoparticles and salt stress on pod diameter (mm.plant^{-1})

Nano zinc oxide	Salinity stress				Average zinc
	S0	S1	S2	S3	
N0	**9.57ec**	**9.75ec**	**8.88e**	**9.24edc**	**d9.36**
N1	**9.73ab**	**9.11ed**	**9.81bc**	**9.70ad**	**9 c9.5**
N2	**9.56eb**	**9.57ec**	**10.14ab**	**9.84eb**	**b9.78**
N3	**10.60a**	**10.53ab**	**10.11dc**	**9.94ac**	**0 a10.3**
Average salt	**7 a9.8**	**a9.74**	**4 a9.7**	**a9.68**	

4-1-2-4: Average pod weight (g.plant^{-1})

From the results in Table (), we observe significant differences between zinc oxide nanoparticle concentrations. The N3 concentration gave the highest average pod weight value of 5.718 g compared to the N0 concentration, which recorded the lowest average pod weight value of 4.703 g. As for the results of the salt stress effect, they showed no significant effect between its levels, with the S0 level achieving the highest average pod weight of 5.873 g, while the S3 level gave the lowest average of 4.733 g. Meanwhile, the interaction table between the studied factors shows a significant difference in effect, with the N3S0 treatment excelling by achieving the highest pod weight value of 6.50 g compared to the N0S3 treatment, which recorded the lowest value of 4.08 g.

Table 4 Effect of zinc oxide nanoparticles and salt stress on average pod weight (g.plant^{-1})

Nano zinc oxide	Salinity stress				Average zinc
	S0	S1	S2	S3	
N0	5.39 cd	4.48 f	4.86 ef	4.08 g	c4.703
N1	5.99 b	5.24 cd	4.84 e	4.45 f	0 b5.13
N2	5.61 c	6.15 b	5.07 de	5.88 b	a5.678
N3	6.50 a	6.39 ab	5.46 cd	4.52 f	a5.718
Average salt	a5.873	a5.565	b5.058	c4.733	

4-1-2-5: Plant yield (g.plant^{-1})

It is clear to us from the results in Table (6) that zinc oxide concentrations significantly affected the plant yield trait. The N3 concentration recorded the highest average plant yield, reaching 133.60 g, compared to the N0 concentration, which recorded the lowest average plant yield of 91.03 g. As for the salt results, they showed a significant effect, with the S0 level giving the highest average plant yield of 124.40 g, while the S3 level gave the lowest average of 96.40 g. Meanwhile, the interaction results between zinc oxide and salt showed a significant effect, with the N3S0 treatment excelling by achieving the highest plant yield value of 147.40 g compared to the N0S3 treatment, which recorded the lowest value of 79.91 g.

Table 6 Effect of zinc oxide nanoparticles and salt stress on plant yield (g.plant^{-1})

Nano zinc oxide	Salinity stress				Average zinc
	S0	S1	S2	S3	
N0	102.40 h	96.54 i	85.25 k	79.91 l	d91.03
N1	111.00 fg	94.95 i	90.90 j	84.22 k	c95.26
N2	136.70 c	125.94 e	123.4 e	108.40 g	0 b123.6
N3	147.40 a	144.39 b	129.5 d	113.10 f	0 a133.6
Average salt	0 a124.4	b115.46	0 c107.3	0 d96.4	

4-1-2-6: Number of seeds per pod (seed.pod^{-1})

Table (5) shows that the averages of zinc oxide differed significantly in their effect, as the N3 concentration excelled with the highest average number of seeds, reaching 6.3 seeds/pod, compared to the N0 concentration, which gave the lowest average of 5.0 seeds/pod. The results of the salt stress effect showed a significant difference in the trait of number of seeds per pod, as the S0 concentration recorded the highest average of 6.5 seeds/pod, while the S2 concentration gave the lowest average of 5.0 seeds/pod. The results of the interaction between zinc oxide concentration and salt stress concentration also showed a significant effect, as the N3S0 treatment exhibited the highest value for number of seeds per pod, reaching 7.0 seeds/pod, compared to the N0S2 treatment, which recorded the lowest value of 4.4 seeds/pod.

Table 5 Effect of zinc oxide nanoparticles and salt stress on the number of seeds per pod (seed.pod⁻ ¹)

Nano zinc oxide	Salinity stress				Average zinc
	S0	S1	S2	S3	
N0	5.9 c	5.4 d	4.4 f	4.4 f	b5.0
N1	6.3 b	4.9 e	4.8 e	5.3 d	b5.3
N2	6.6 ab	6.4 b	4.7 ef	6.4 b	a6.0
N3	7.0 a	6.9 a	5.9 c	5.5 d	a6.3
Average salt	a6.5	b5.9	5.0 d	c5.4	

4-1-2-7: Weight of 100 seeds (g)

We observe from Table (7) that the averages of zinc oxide nanoparticles show significant differences among them, as the N3 concentration recorded the highest value for 100-seed weight, reaching 29.99 g, compared to the N0 concentration, which recorded the lowest average of 22.82 g. As for the salt results, they showed a significant effect, with the S0 level giving the largest average for 100-seed weight, reaching 31.14 g, while the S3 level recorded the lowest average of 22.29 g. Meanwhile, the interaction table between zinc concentration and salt showed a significant effect, as the N3S0 treatment gave the highest value of 36.45 g, while the N0S3 treatment recorded the lowest value of 18.83 g.

Table 7 Effect of zinc oxide nanoparticles and salt stress on the weight of 100 seeds (g)

Nano zinc oxide	Salinity stress				Average zinc
	S0	S1	S2	S3	
N0	29.17 bc	21.49 f	21.78 f	18.83 g	c22.82
N1	26.52 d	21.81 f	22.27 f	22.28 f	c23.22
N2	32.42 b	30.83 b	23.02 ef	23.84 ef	b27.53
N3	36.45 a	30.72 b	28.58 c	24.20 e	a29.99
Average salt	a31.14	b26.21	c23.91	c22.29	

4-1-2-8: Plant biological yield (g.plant⁻ ¹)

Through the results in Table (8), we observe significant differences among the averages of nano-zinc, as the N3 treatment recorded the highest value of 58.38 g compared to the lowest value recorded for the N0 treatment, which reached 33.18 g. Regarding the salt data, it differed significantly in its effect, with the S0 concentration recording the highest value of 52.96 g, while the S3 concentration gave the lowest average of 36.53 g. The interaction results between nano-zinc and salt also showed a significant effect, with the N3S0 concentration giving the highest value for biological yield, reaching 75.31 g, compared to the N2S3 concentration, which gave the lowest value of 31.75 g.

Table 8 Effect of zinc oxide nanoparticles and salt stress on biological yield (g.plant^{-1})

Nano zinc oxide	**Salinity stress**				**Average zinc**
	S0	**S1**	**S2**	**S3**	
N0	**32.28 gh**	**33.45 g**	**34.98 g**	**32.02 gh**	**d33.18**
N1	**44.70 f**	**50.14 d**	**44.38 f**	**35.76 g**	**c43.75**
N2	**59.56 c**	**49.56 d**	**48.36 de**	**31.75 h**	**b47.31**
N3	**75.31 a**	**62.68 b**	**48.97 de**	**46.57 ef**	**a58.38**
Average salt	**a52.96**	**6 b48.9**	**c44.17**	**d36.53**	

4-1-2-9: Harvest index (%)

The results in Table (9) indicate that zinc oxide concentrations had a significant effect, with the N3 level excelling by achieving the highest average harvest index of 40.80%, while the N0 level recorded the lowest average of 34.48%. Regarding the salt results, they differed significantly in their effect, as the S0 level achieved the highest average harvest index of 45.27%, while the S3 level gave the lowest average of 31.76%. From the same table, the interaction results between the two studied factors showed a significant effect, with the N3S0 treatment giving the highest harvest index value of 48.53%, contrary to the N0S3 treatment, which recorded the lowest value of 29.15%.

Table 9 Effect of zinc oxide nanoparticles and salt stress on harvest index (%)

Nano zinc oxide	**Salinity stress**				**Average zinc**
	S0	**S1**	**S2**	**S3**	
N0	**40.33 c**	**34.38 f**	**34.05 f**	**29.15 g**	**c34.48**
N1	**46.77 b**	**41.83 c**	**36.46 e**	**30.18 g**	**b38.81**
N2	**45.46 b**	**41.35 c**	**38.85 d**	**34.63 f**	**a40.07**
N3	**48.53 a**	**48.36 a**	**33.24 f**	**33.06 f**	**0 a40.8**
Average salt	**a45.27**	**b41.48**	**c35.65**	**d31.76**	

The role of zinc in the antioxidant system

membrane stability This is a very important point in salt stress research

results of the statistical analysis revealed significant differences in some yield traits, such as the number of seeds per pod, pod length, pod diameter, and harvest index, as shown in Tables 1, 2, 3, and 4, concerning the zinc oxide nanoparticle treatment. This is attributed to the role played by the zinc element when sprayed on leaves in stimulating the vegetative growth of the plant. Zinc contributes to increasing the number of leaves, individual leaf area, total leaf area of the plant, in addition to the number of nodes, stem diameter, and total chlorophyll content, as illustrated in Tables 35, 36, 37, 38, 39, 41, and 42. This, in turn, leads to improved efficiency of the photosynthesis process and an increase in its products, positively reflecting on the increase of compounds resulting from). 8metabolic processes within the plant (Regarding the increase in the number of seeds formed per pod, this can be attributed to zinc's role in activating the plant's reproductive processes by stimulating pollen grains, which positively reflects on the increase in the number). These results agree with 9of fertilized ovules ( ) regarding the 10what was indicated by (significant effect of zinc spraying on yield traits in the faba bean plant. They are also consistent), as their study 11with what was mentioned by (showed that spraying zinc on common bean plants led to significant differences in yield traits. It is evident from the results of the pod length table that there are significant differences among nano-zinc oxide levels, with the N3 concentration giving the highest average pod length of 15.88 cm, while the N0 concentration recorded the lowest average of 14.10 cm. This superiority may be attributed to zinc's role in stimulating the activity of enzymes associated with metabolic processes within the plant, which contributes to improving growth and increasing photosynthetic efficiency, positively reflecting on the increase in pod length. This result aligns 2), who indicated 1with what was obtained by (significant differences in the pod length trait. It is also clear from the results shown that spraying with zinc had a significant effect on the traits of plant yield and biological yield, as it led to a clear increase in the average yield compared to the control treatment. This is due to the important physiological role of the zinc element in the plant, as it contributes to improving the increase in dry matter accumulation, in addition to its positive effect on yield components such as the total number of pods, number of seeds per pod, and weight of 100 seeds, which positively reflected on increasing plant yield and biological yield. These results agree with the findings of) regarding the effect of zinc spraying on 3(1 increasing grain yield, as well as with the results), which indicated a significant effect of 14of (zinc spraying on the biological yield trait. Regarding the effect of salt stress, the results showed that it caused a decrease in most yield traits, while nano-zinc oxide showed a positive effect in mitigating the impact of salinity and improving yield components. The study results indicated that salt stress negatively affected most yield traits and their components, leading to a decrease in the number of pods per plant due to the impact on flowering and fertilization processes under saline conditions, which reflects on pod formation and productivity. This agrees). Salt stress also 15with what was indicated by (caused a reduction in pod length due to its effect on cell elongation and division caused by the decrease in the plant's water potential and the). 16hindrance of water and nutrient absorption (The results also showed a decrease in the number of seeds per pod under the influence of salt stress due to weak fertilization and disruption of physiological processes associated). The effect of salinity 17with seed formation (was also negatively reflected on seed weight, as salinity reduces the efficiency of photosynthesis and limits the transport of photosynthetic products to seeds, thus reducing the). 18accumulation of carbohydrates within them (As for the biological yield, it decreased due to the impact of salt stress on plant growth and dry matter accumulation, caused by osmotic effects and ion toxicity. This may also affect the harvest index due to the imbalance in the distribution of photosynthetic products between vegetative and , 20). This result aligns 19reproductive growth (with the findings of (21, 22), who indicated a significant effect on yield traits when adding The study results levels of salt to the pea plant. also indicated that the interaction between salt stress levels and nano-zinc oxide treatments had a noticeable effect on the yield traits of the common bean plant. High salinity levels led to a clear decline in the number of pods per plant, the number of seeds per pod, as well as a decrease in plant yield. This can be explained by the fact that increasing salt concentration in the growing medium lowers the water potential and increases the accumulation of sodium and chloride ions in plant tissues, causing a dysfunction in several physiological processes within the plant and negatively affecting flower and pod formation, which ultimately reflects on the reduction of yield components (23). In contrast, treatments that included the addition of nano-zinc oxide showed relative improvement in some yield traits compared to treatments exposed to salt stress only. This is attributed to the important physiological role of zinc as an essential micronutrient for plant growth, as it participates in activating many vital enzymes, enters the structure of proteins, and regulates growth and cell division processes. It also contributes to improving flower and pod formation and increasing the number of seeds within them, which positively reflects on yield components under salt stress conditions (24). These results agree with the findings of (25), who indicated that the addition of nano-zinc oxide contributed to mitigating the negative effects of salt stress on the pea plant by improving some physiological and growth traits of the plant, which positively reflected on plant performance under saline conditions(27).

Conclusions

1. Effect of Salt Stress: The common bean plant is considered a salt-sensitive crop, as high levels of NaCl (especially 5 g/L) caused a deterioration in growth efficiency and inhibition of physiological processes, leading to a decrease in plant yield and total biological yield.
2. Efficiency of Nano-Zinc: Foliar spraying with zinc oxide nanoparticles proved highly effective in stimulating vegetative growth and yield, and this effect is directly proportional to the increase in concentration, with the concentration of 75 mg/L playing the most prominent role in enhancing yield components.
3. Protective Role of Nanotechnology: Nano-zinc acts as a stress mitigator; its concentrations succeeded in improving the plant's ability to withstand osmotic effects and the toxicity of salt ions, thereby maintaining the continuity of metabolic processes and the formation of seeds and pods under stress conditions.
4. Improvement of Quality and Quantity: The role of nano-zinc was not limited to increasing the number of pods but extended to improving qualitative and quantitative traits such as pod diameter, seed weight, and harvest index, indicating an improved efficiency in transporting photosynthetic products from source to sink (pods).
5. Biological Interaction:The optimal response of the common bean plant is achieved through balancing the provision of micronutrients in their nano-form with controlling soil salinity, as the combined treatments showed clear superiority over the individual treatments.

Resources

1. Devi M., S.Dhanalakshmi, GE.Thillai Govindarajan, BA Tanisha, Talluri Sonalika, JE Ruth, T Avinash, C Jethendra Sri, K Logeswaran, and M Nithish Ramasamy. (2020). A Review on Phaseolus vulgaris Linn . Pharmacogn J. 12(5): 1160-1164.
2. Shrivastav, P., Prasad, M., Singh, T. B., Yadav, A., Goyal, D., Ali, A.,&Dantu, P. K. (2020). Role of nutrients in plant growth and development. In Contaminants in agriculture: Sources, impacts and management (pp. 43-59). Cham: Springer International Publishing.
3. Pandey, S. N. (2020). Role of micronutrients in biochemical responses of crops under abiotic stresses. In Sustainable Agriculture in the Era of climate change (pp. 93-112). Cham: Springer International Publishing.
4. Das, S. and Green, A. P.(2016). Zinc in Crops and Human Health. Part1.In:Singh, U., Praharaj, C. S., Singh, S. S. and Singh N.(eds): Biofortification of Food Crops. Springer.New Delhi Heidelberg. New York Dordrecht London , pp:31-40.
5. Liu, C.Y.; Yan, M.; Huang, X.B.; Yuan, Z.H. Effects of NaCl stress on growth and ion homeostasis in pomegranate tissues. Eur. J. Hortic. Sci. 2020, 85, 42–50.
6. Zhang, Y., Hu, S., Wang, X., Yue, J., Chen, D., Han, M., ... & Wang, H. (2025). Response of anatomical structure and active component accumulation in Apocynum venetum L.(Apocynaceae) under saline stress and alkali stress. Plants, 14(14), 2223.
7. Abdul-Hadi, Saadoun, Jamal Ahmed Abbas and Kadhim Mohammed Abdullah. (2010). Effect of Foliar Application of Nutrient Solution and Potassium Fertilization on the Growth and Yield of the Local Variety of Green Pea Plant *Pisium sativum* L. *Kufa Journal for Agricultural Sciences*, 2(1): 13-24.
8. **El-Tohamy,W.A.; and N.H.M. El-Greadly.(2007**).Physiological responses, growth, yield and quality of snap beans in response to foliar application of yeast, vitamin e and zinc . Australian Journal of Basic and Applied Sciences.1(3): 294-299.
9. **eixeira, I.R., A.B. Boren and G.A.A. Araujo, (2004).** Manganese and zinc leaf application on common bean grown on a cerrado soil. Agric. (Braz.), 61:77-81.
10. Al-Selawi, Razaq Lafta Atiyah, Ahmed Hamid Saoudi, and Hamid Abd Khashan Al-Fartousi. (2018). Effect of Spraying with Concentrations of Zinc on the Growth and Yield of Two Varieties of Broad Bean (Vicia faba L.). University of Thi-Qar Journal of Agricultural Research, 7(1): 1-14.
11. **Salehin, F. and S. Rahman. (2012**). Effects of zinc and nitrogen fertilizer and their application method on yield and yield components of (*Phaseolus vulgaris* L.) .Agricultural Sciences. 3(1):9-13.
12. Bakala.N; I. Jibat and B. Idao.2022. Evaluation and selection of improved food Barley (Hordeum vulgare L.) varieties in the highland areas of western guji; southern Oromia. J.plant sci current Res.2 (6):129-137.
13. Sultana, S., Naser, H. Á., Shil, N. C., Akhter, S.,&Begum, R. A. (2016). Effect of foliar application of zinc on yield of wheat grown by avoiding irrigation at different growth stages. Bangladesh Journal of Agricultural Research, 41(2), 323-334.
14. Khalifa, T. H., Mariey, S. A., Ghareeb, Z. E., Khatab, I. A.,&Alyamani, A.

(2022). Effect of organic amendments and nano-zinc foliar application on alleviation of water stress in some soil properties and water productivity of barley yield. *Agronomy*, *12*(3), 585.

15. **Zhu, J. K. (2001).** Plant salt tolerance. Trends in Plant Science, 6(2), 66–71.
16. **Dursun, A., Güvenç, I., and Turan, M. (2002).** Effect of different levels of humic acid on seedling growth and macro- and micro-nutrient contents of tomato and eggplant. Acta Agriculturae Scandinavica, Section B, 52(1), 7–11.
17. **Suh, J. S., Lee, K. H.,&Kim, J. H. (2001).** Effects of humic substances on plant growth and nutrient uptake. Korean Journal of Soil Science and Fertilizer, 34(4), 249–255.
18. **Greenway, H., and Munns, R. (1980).** Mechanisms of salt tolerance in nonhalophytes. Annual Review of Plant Physiology, 31(1), 149–190.
19. **Donald, C. M., and Hamblin, J. (1976).** The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Advances in Agronomy, 28, 361–405.
20. Yassin, S. Kh., Abdulrahman, H. B. A.-D.,&Abdulrahman, A. J. (2023). Effect of nano-fertilization and planting in plastic tubes of different diameters on the qualitative characteristics of two strawberry varieties. IOP Conference Series: Earth and Environmental Science, 1214(1), 012023. https://doi.org/10.1088/1755-1315/1214/1/012023
21. Al-Hayani, Laith Mohammed Abbas. (2015). Biology of the Leaf Miner Liriomyza spp. (Diptera: Agromyzidae) on Tomato and Climbing Bean Crops under Plastic House Conditions. Master's Thesis, College of Agriculture, Tikrit University.
22. Yassin, S. K., Abdulrahman, A. J.,&Abdulrahman, H. B. A. D. (2023). Effect of nano-fertilization and planting in plastic tubes of different diameters on the growth and yield of two strawberry varieties. IOP Conference Series: Earth and Environmental Science, 1259(1), 012046. https://doi.org/10.1088/1755-1315/1259/1/012046
23. Rizwan, M., Ali, S., Ibrahim, M., Farid, M., Adrees, M., Bharwana, S. A., ...&Abbas, F. (2015). Mechanisms of silicon-mediated alleviation of drought and salt stress in plants: a review. *Environmental Science and Pollution Research*, *22*(20), 15416-15431.
24. Dimkpa, C. O., Bindraban, P. S., Fugice, J., Agyin-Birikorang, S., Singh, U., & Hellums, D. (2017). Composite micronutrient nanoparticles and salts decrease drought stress in soybean: Micronutrients mitigate drought stress in plants. *Agronomy for sustainable development*, *37*(1), 5.
25. Mustafa, G., Chaudhari, S. K., Manzoor, M., Batool, S., Hatami, M.,&Hasan, M. (2024). Zinc oxide nanoparticles mediated salinity stress mitigation in Pisum sativum: a physio-biochemical perspective. *BMC Plant Biology*, *24*(1), 835.
26. Al-Rawi, Khasha Mahmoud and Abdul-Aziz, Khalaf Allah. (1981). Design and Analysis of Agricultural Experiments, Dar Al-Kutub Printing and Publishing Foundation - University of Mosul. Iraq.
27. Faizan, M., Bhat, J. A., Chen, C., Alyemeni, M. N., Wijaya, L., Ahmad, P., & Yu, F. (2021). Zinc oxide nanoparticles (ZnO-NPs) induce salt tolerance by improving the antioxidant system and photosynthetic machinery in tomato. *Plant Physiology and Biochemistry*, *161*, 122-130.