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Synergistic Effects of Nano-Silicon and IQ Combi on Yield Traits of Wheat under Saline Irrigation

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ABSTRACT

Background: Salinization negatively affects plant growth and development, removing up to 1.5 million hectares of farmland from production annually. Objective: Evaluate the synergistic of Nano-fertilizers on yield traits of wheat Triticum aestivum below saline irrigation. Methodology: two factorial plot experiments were conducted during Autumn 2022 and 2023 in Diyala, IRAQ. The plants were irrigated every 18 days from planting with three NaCl irrigation levels: 0 (distilled water), 50, and 75 mM. A foliar application of nano fertilizer was sprayed after the third leaf appeared every 15 days, three times in total. Results: The salinity significantly decreased the yield component, biological yield, and harvest index, while the synergistic effects of (S), (Q), and (M) increased by 52.86%, 15.81%, and 18.84% in 2022 and 41.05%, 20.65% and 22.62 in 2023 growth season, respectively. Additionally, the most significant effects of the synergistic nano-fertilizer on catalase, peroxidase, and Proline under salinity were 23.84%, 70.00%, and 79.78% in 2022 and 24.50%, 73.33% and 74.36% in 2023, respectively. Conclusions: The application of nano-fertilizers enhanced yield parameters and increased the antioxidant enzymes as part of the plant's defense mechanism against oxidative stress. Over time, this response to developing salinity-tolerant wheat varieties with strong antioxidant defense systems.

Keywords: Nano- Silicon, wheat, salt stress.
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INTRODUCTION

Wheat (Triticum spp.) is one of the most important food crops in the world in terms of the area harvested, production, and nutrition, as it supplies about 19% of the calories and 21% of the protein to the world's population (1). In Iraq, saline irrigation presents a significant challenge to wheat production, primarily due to the country's arid climate and the high salinity of its water sources. Saline irrigation affects wheat crops by inducing osmotic stress, ion toxicity, and nutrient imbalances, which collectively impair plant growth and yield. The osmotic stress caused by high salinity levels reduces water uptake, leading to stunted growth and decreased biomass (2). Ion toxicity, especially from sodium Na+ and chloride Cl- ions, disrupts cell capabilities and damages plant tissues, exacerbating increased inhibition (3).

Nano-silicon is essential in improving plant physiology, especially under stress. It improves plant growth and yield by strengthening mobile partitions, improving photosynthesis, and regulating water uptake. Nano-silicon additionally creates defensive boundaries that reduce pathogen penetration and mitigate abiotic stresses like salinity and drought. Studies have proven its role in activating antioxidant protection systems, which assist in scavenging reactive oxygen species and enhancing plant resilience and fitness. Additionally, nano-silicon complements nutrient uptake and usage, similarly contributing to essential plant vigor (4,5).

IQ Combi, a bio-stimulant product, has been of interest to agriculture because it enhances crop productivity and pressure tolerance. It carries a mix of lively ingredients, which includes amino acids, seaweed extracts, and different plant increase-selling substances (Fe: 6.24%, Zn: 6.11%, Mn : 6.05%, Cu:0.Fifty two%. Bo: 0.25%, Mo: zero.25%). Studies indicate that IQ Combi improves nutrient uptake efficiency, enhances root development, and stimulates physiological strategies like photosynthesis and enzyme hobby in plant life (6). IQ Combi has shown promise in mitigating these results by enhancing nutrient uptake, stress tolerance, and normal plant health. Its application improves root improvement, water-use performance, and resistance to abiotic stresses, contributing to better increase and yield under saline conditions. These outcomes contribute to improved boom, yield, and fine of vegetation under numerous environmental stresses, which include drought and salinity (7,1). Research indicates that IQ Combi's software can benefit sustainable agriculture by decreasing chemical inputs while preserving or growing crop productivity.

Recent literature explores the synergistic advantages of mixing nano-silicon with bio-stimulants to decorate crop resilience below strain situations. Nano-silicon reinforces plant mobile partitions, regulates water uptake, and activates antioxidant defenses in opposition to oxidative strain. Bio-stimulants, such as amino acids and seaweed extracts, stimulate physiological strategies like nutrient absorption and root improvement. Together, those technologies enhance plant tolerance to abiotic stresses like drought and salinity, improving boom and yield. Studies indicate that the mixed application of nano-silicon and bio-stimulants can mitigate pressure-triggered damage more efficiently than both remedies by offering a sustainable method to improve crop productivity (7,1). The aims of the studies were to evaluate the combined outcomes of nano-silicon and IQ Combi on yield traits of wheat Triticum aestivum L. "cultivar IPA 99" below saline situations.

METHODOLOGY

Yield and yield components of wheat as affected by different salinity water levels and two kinds of nano-fertilizer were studied in a field experiment. Two factorial field experiments were conducted during the growing seasons (autumn) of 2022 and 2023 in one of the fields of Baqubah District, Diyala Governorate, IRAQ. The experiments followed a randomized complete block design with three replications. The wheat cultivar 'IPA 99' was used in the experiments. The optimal density of the cultivar is 10 seeds will be snow in each pot 4 cm deep, filled approximately with 20 kg of the above-mentioned soil table (1 and 2). The pots were immediately irrigated after planting. Salt stress treatments were applied 18 days after planting (at the 3–4 leaf stage). The plot was prepared and divided, and the treatments were distributed using a split-split plot design (R.C.B.D). The salinity factor M was set in the mean plots and the nano-silicon S in the sub-plots, while the third factor IQ Combi Q was cut in the sub-sub plots. The wheat plants will be exposed to foliar application of distilled water, two levels of IQ Combi 1 and 2 g/l, and two levels of nano-silicon 1.6 and 3.2 mmol/l, which will be applied three times. Also, the plants were irrigated 18 days from planting with three NaCl irrigation levels at 0 (distilled water), 50, and 75 mM. A nano foliar application will be sprayed after the third leaf appears, and the spraying process will repeat every 15 days.

Table (1): Some chemical and physical properties of the experimental soil before planting

Chemical properties	(pH)	ECe(dsm^{-1})	N(mg kg^{-1})	P(mg kg^{-1})	K(mg kg^{-1})	Na(ml. l^{-1})	Cl(ml. l^{-1})
	8.07	16.13	13.45	4.02	204.55	1.83	1.88
Physical properties	Sand ($g.kg^{-1}$)	Silt ($g.kg^{-1}$)	Clay ($g.kg^{-1}$)	Soil texture			
	39.5	43.7	1.6	loam			

Table (2): The Average maximum and minimum temperature and rainfall in both growth seasons

Growth seasons	Average maximum temperature	Average Minimum temperature	The mean of rainfall
2022	22.63	10.58	185.8 mm
2023	23.29	10.044	138.8 mm

1. Yield and Yield Components (ton.ha-1)

When the crop plants matured, spikes from each pot were collected to determine the average spike weight per pot, and then the spikes were threshed to count (grain weight, grain number, gall number) per pot.

2. Biological yield (ton.ha-1)

The biological yield was calculated by the summation of straw and grain weight per pot.

3. Harvest Index (HI)(%):

The Harvest Index was determined by calculating the ratio between grain yield and biological yield (7).

$$HI = \text{Grain yield} / \text{Biological yield} \times 100$$

4. Determination of Catalase Activity (CAT)(U/g)

Extract the enzyme from plant tissues and determine CAT activity by measuring the decomposition of hydrogen peroxide at 240 nm using a spectrophotometer (8).

5. Determination of Peroxidase Activity (POD) (U/g)

Extract the enzyme from plant tissues and determine POD activity by measuring the oxidation of guaiacol in the presence of hydrogen peroxide. Measure the increase in absorbance at 470 nm using a spectrophotometer (9).

6. Proline Determination(μmole/g)

Extract proline from plant tissues using sulfur salicylic acid and quantify it using ninhydrin method. Measure the absorbance at 520 nm using a spectrophotometer (10).

Statistical analysis

An experimentally designed statistical analysis was carried out using the Genestat Computer Program with a 0.05 significance level (95% confidence).

RESULTS

The effects of nano-silicon and IQ Combi on yield traits of wheat *Triticum aestivum* L. "cultivar IPA 99" under saline conditions were pointed as below:

1. Yield components.

The Results indicated that the salinity mean (M), (S), and (Q) significantly affected yield components. The salinity reduced the yield component, especially with the increasing water saline concentration in the growth seasons. The percentage effect of salinity and nano-fertilizer on yield components are shown in Figure (1). The salinity (M) effect percentage reduced the yield components by -12.85 and -15.36 %, while with applied (S), the Yield component was increased by 11.04 and 12.20%. Nevertheless, the effect with (Q) fertilizer increased by 22.64 and 12.22% in the 2022 and 2023 seasons. Besides, when the interaction between (S x M), the yield component was increased by 27.21 and 21.97 %, and for (QxM), interaction increased by 42.73 and 25.32%. Ultimately, the synergistic effects of SxQxM increased the yield component by 52.86 and 41.05 % throughout the 2022 and 2023 seasons.

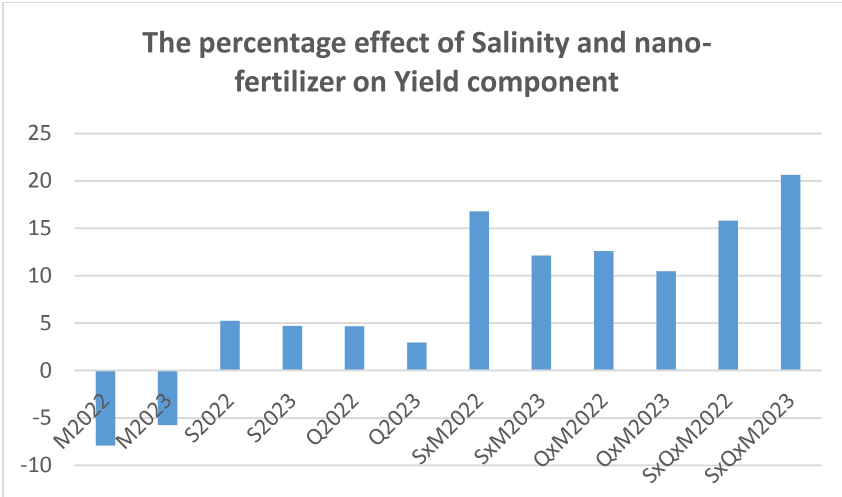

Figure (1): S, Q, and M affect the yield components through the 2022 and 2023 growth seasons

2. Biological yield (ton.ha-1)

Figure (2) shows the significant effect of salinity M and nano- fertilizer S and Q on the biological yield. The impact percentages of salinity and nano-fertilizers on biology yield are illustrated in Figure 2. Salinity (M) reduced the biology yield by -7.91 and -5.75%. In contrast, the application of the nano-silicon fertilizer (S) increased biology yield by 5.26% to 4.70%, while the IQ Combi fertilizer (Q) also improved yield components to an increase of 4.69 and 2.94%. Notably, when S applaud under salinity stress (SxM), the biology yield increased by 16.78 and 12.35%. Similarly, foliar application of IQ Combi fertilizer under salinity effect (QxM) increased yield components from 12.62 and 10.49%. Ultimately, the combined synergistic effects of nano-silicon, IQ Combi fertilizer, and salinity (SxQxM) led to a substantial increase in biology yield, ranging by 15.81 and 20.65%.

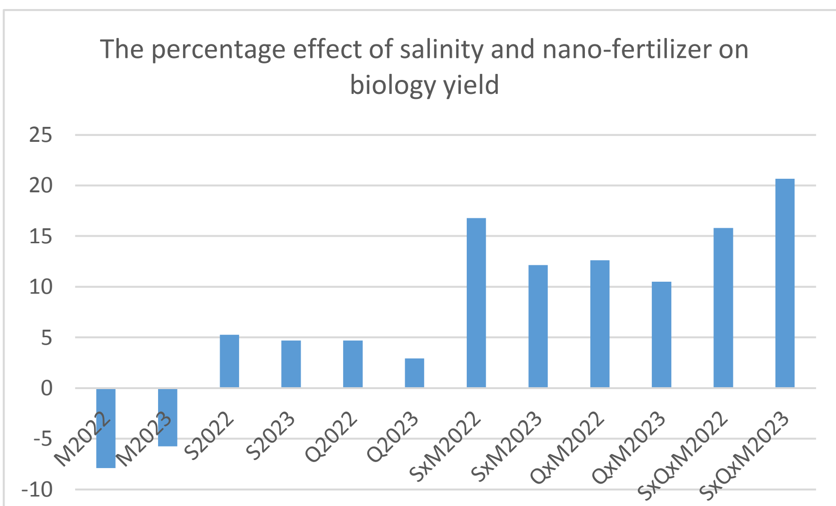

Figure (2): S, Q, and M affect the Biology yield through the 2022 and 2023 growth seasons

3. Harvest Index (HI) percentage:

The moderate to high salinity increase decreased the wheat crop Harvest Index (HI). The negative effect of saline stress was highly noticeable in M2 compared with M0 treatments. According to the result in Figure (3), the reduction in the Harvest Index due to salinity (M) ranged from -8.08 and -7.30%. Applying nano-silicon fertilizer (S) increased the Harvest Index by 4.09% to 3.73%. Similarly, the IQ Combi fertilizer (Q) improved the Harvest Index with increases ranging from 8.82% to 7.32%. Furthermore, the software of (S) (SxM) expanded the Harvest Index from 9.88% to 8.62% underneath salinity stress. Likewise, the (Q) application of (QxM) caused a boom in the Harvest Index by means of 13.64% to 12.93%. Ultimately, the synergistic results of nano-silicon, IQ Combi fertilizer, and salinity (SxQxM) extensively greater the Harvest Index, with will increase ranging from 18.84% to 22.62% through the growth season 2022 and 2023, respectively.

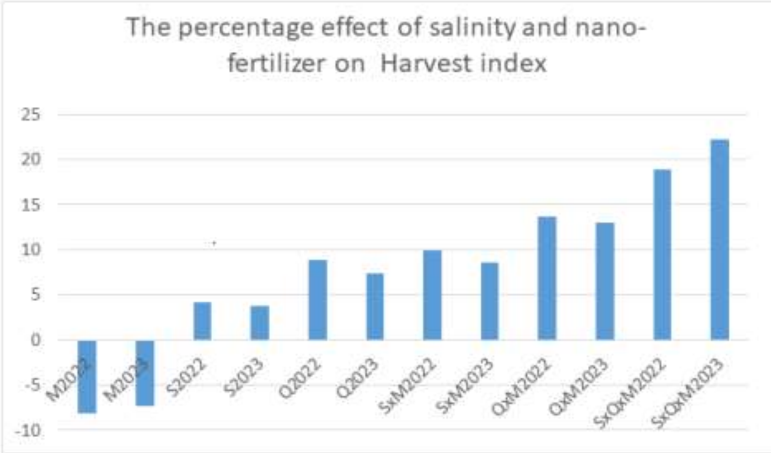

Figure (3): S, Q, and M affect the Harvest index through the 2022 and 2023 growth seasons

4. Catalase (CAT) (U/g):

Figure (4) shows the significant difference between the Catalase mean under the salinity conditions. The catalase percentage due to salinity (M) ranged from 18.11% to 13.10%. Also, with an application of nano-silicon fertilizer (S), the range was 4.60% to 4.05 %. Similarly, the IQ Combi fertilizer (Q) improved the catalase range from 4.68% to 4.10 %. Furthermore, nano-silicon fertilizer (SxM) interaction ranged from 18.18% to 19.40%. Likewise, foliar application of IQ Combi fertilizer (QxM) increased the catalase by 25.71% to 13.88 %. Ultimately, the synergistic effects of nano-silicon, IQ Combi fertilizer, and salinity (SxQxM) significantly increased the catalase from 23.84% to 24.50% through the growth season 2022 and 2023, respectively.

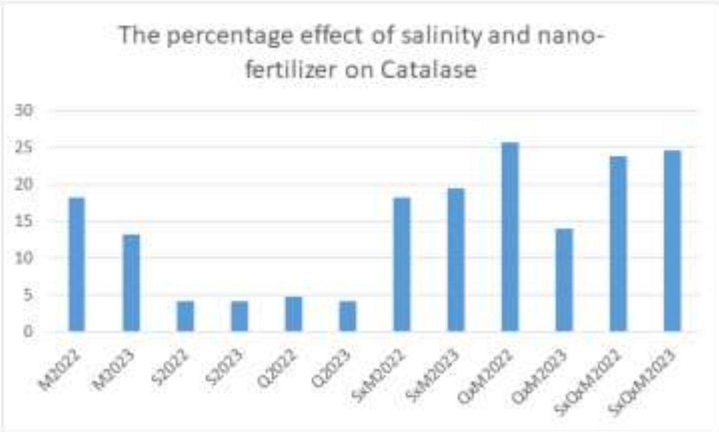

Figure (4): S, Q, and M affect the Catalase through the 2022 and 2023 growth seasons

5. Peroxidase (POD) (U/g):

Salinity pressure drastically impacts the hobby of peroxidase enzymes in wheat. Like Catalase CAT, the peroxidase POD activity in S, Q, and M treatments showed a significant increase in both (S, Q, M) (P<0.05) groups (Figure 5). The peroxidase percentage was increased due to salinity treatment (M) from 59.00% to 61.53%. Also, nano-silicon fertilizer was applied from 20.58% to 27.02%. Similarly, IQ Combi fertilizer (Q) application improved peroxidase concentration from 32.14% to 39.39%. Furthermore, the interaction of nano-silicon fertilizer and salinity (SxM) increased the peroxidase percentages ranging from 100.00% to 81.00%. The foliar application of IQ Combi fertilizer increased peroxidase concentration from 87.5% to 100.00% under salinity stress. Ultimately, the synergistic effects of nano-silicon, IQ Combi fertilizer, and salinity (SxQxM) significantly enhanced peroxidase concentration, increasing from 70.00% to 73.33%.

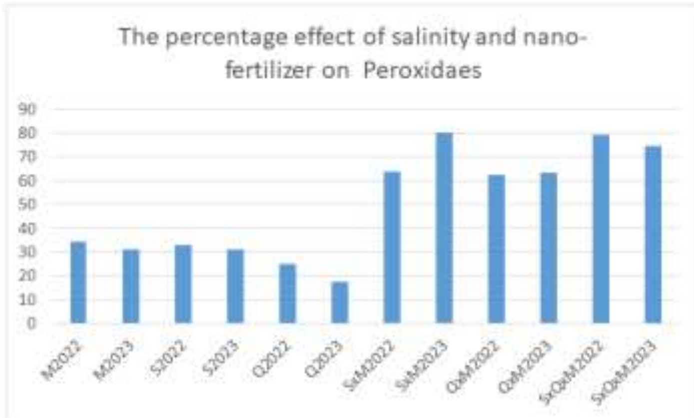

Figure (5): S, Q, and M affect the Peroxidase through the 2022 and 2023 growth seasons

6. Proline in Plants (µmole/g):

Free Proline content shows off variation in most of the wheat flora underneath salinity stress Figure (6) general loose Proline amino acids of the three factors S, Q, and M (P < 0.05). The Salinity (M) increased the Proline concentration from 34.60% to 30.66%. While the Nano-silicon Fertilizer (S) increased, the Proline concentration ranged from 33.36% to 31.60%. Also, the IQ Combi Fertilizer (Q) increased Proline concentration improved, ranging from 25.39% to 17.18%. However, nano-silicon fertilizer and salinity interaction (SxM) applications increased proline concentration from 63.74% to 80.07%. Furthermore, the IQ Combi Fertilizer and Salinity Interaction (QxM) increased Proline concentration from 62.24% to 63.30%. The Synergistic Effects of Nano-silicon, IQ Combi Fertilizer, and Salinity (SxQxM) concentration significantly enhanced, increasing from 79.78% to 74.36%.

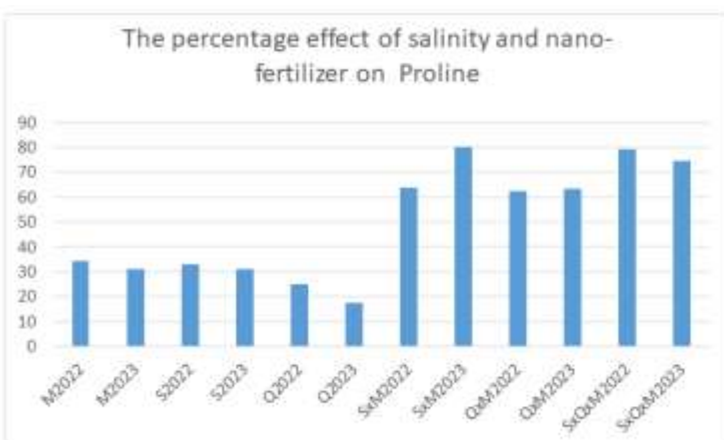

Figure (6): S, Q, and M affect the Proline through the 2022 and 2023 growth seasons. (µmole/g)

DISSCUSION

According to observations about the significant differences in yield traits (Figure 1), especially under varying concentrations of salinity and nanofertilizers. It seems clear that nano-fertilizers (S and Q) play a crucial role in influencing production outcomes. Also, increasing differences with higher concentrations indicate a dose-dependent relationship where higher concentrations amplify the effects on the yield traits. Besides, the similarity in effects might be attributed to the nano-sized particles and the types of fertilizers, which could enhance their efficiency and uptake by plants, leading to similar yield component outcomes. It was also noted that there are slightly significant differences between yield traits, with productivity being higher in the second agricultural season. This may be due to the increase rain falling in the second season, which slightly impacted productivity. Nevertheless, the reduction of yield traits also may be of salt stress which caused osmotic pressure, ionic imbalance and ionic toxicity (11). Besides, this may be due to nano-silicon which enhances the plant's ability to tolerate salinity by strengthening cell walls and improving water uptake. Also, the IQ Combi is likely a nutrient formulation that can provide essential micro and macronutrients and the combined effect of nutrients can promote better overall plant growth and development and that may improve nutrient availability can lead to higher grain yield and better quality (12,13). Also, the combined application of nano-silicon and IQ Combi might have a synergistic effect, resulting in greater improvements in yield traits than either treatment alone, this because the plant has sufficient nutrients for optimal growth, and together, these treatments could provide a more holistic approach to mitigating salinity stress, (14,15). The reduces oxidative damage caused by salt stress, thereby improving plant health and yield (16). Also, the nano-fertilizer can enhance photosynthetic efficiency and picture protection in plants. This is done by way of optimizing gasoline change and retaining chlorophyll content, that's important under pressure conditions like high salinity (17). Besides, these types of fertilizer play a position in regulating nutrient uptake and enhancing metabolic approaches, leading to better boom and improvement of wheat. This includes the uptake of crucial vitamins and the reduction of toxic ions' uptake, thereby improving standard plant vitamins and yield (18). Besides, the Silicon contributes to the structural integrity of plant life by using strengthening cell partitions. This will help to enhance the plant's resistance to accommodations and mechanical stresses, that's beneficial for maintaining plant uprightness and making sure better grain filling beneath saline situations (19). However, the Silicon impacts the hormonal balance inside vegetation, promoting the synthesis of increase hormones whilst mitigating pressure hormones. This hormonal balance supports better growth and higher yields even under adverse conditions. It seems that combined with other growth-promoting compounds like IQ Combi, which may contain essential micronutrients and bio stimulants, the overall effect on wheat yield is enhanced. These compounds work synergistically to improve plant health, growth, and productivity (17). Besides, nano-silicon can improve the plant's water use efficiency by using regulating the outlet and remaining of stomata, therefore lowering water loss through transpiration (20. 21). This is particularly beneficial under saline conditions where water availability and quality are compromised (22,23). Moreover, nano-silicon deposition in plant tissues strengthens cell walls, making them more robust and resistant to salinity-induced damage. This structural reinforcement helps in maintaining better plant physiology, leading to improved biomass and yield under stress conditions (24).

The results presented in (Figure 4,5 and 6) illustrate the impact of salinity, nano-silicon fertilizer, and IQ Combi fertilizer on the enzymatic concentration in wheat leaves. Catalase and Peroxidase a key antioxidant enzyme that helps mitigate oxidative stress by decomposing hydrogen peroxide into water and oxygen. Salinity stress typically induces oxidative stress in plants, leading to an upregulation of antioxidant enzymes like catalase and peroxidase. This moderate increase indicates that plants are responding to the oxidative stress caused by salinity by enhancing their antioxidant defenses. Previous studies have shown that salinity stress leads to the production of reactive oxygen species (ROS), which in turn stimulates the activity of antioxidant enzymes (23,25).

The application of nano-silicon is known to improve plant tolerance to abiotic stresses, along with salinity, with the aid of enhancing antioxidant enzyme activities (26,13). The version in catalase awareness shows the effectiveness of nano-silicon is situation-established. However, the top restriction shows a big ability for nano-silicon to enhance catalase interest, thereby improving stress tolerance. Studies have established that silicon can mitigate oxidative damage through upregulating antioxidant enzyme activities in flowers (27).

Similarly, the IQ Combi fertilizer is effective in enhancing catalase pastime. Bio-stimulants are acknowledged to decorate plant increase and strain tolerance by improving antioxidant enzyme activities and nutrient uptake (28). This synergy probably effects from nano-silicon's position in improving nutrient uptake, cellular structure, and pressure signaling pathways (29).

The result inducted that the Proline content in wheat plants exhibits variation under salinity stress due to several physiological, biochemical, and genetic factors. One of this factors was acts as an osmolyte, helping plants to maintain osmotic balance under salt stress by balancing the cellular osmotic pressure and protecting cellular structures. Also, the increasing of salinity induces the accumulation of Proline, aiding in osmotic adjustment, which varies among different wheat genotypes and environmental conditions (30,31). However, Proline functions as an antioxidant, scavenging reactive oxygen species (ROS) generated under salt stress. And The capacity of different wheat genotypes to synthesize and accumulate proline in response to ROS can result in variations in proline content (32,33). The salinity stress involved in proline biosynthesis (such as pyrroline-5-carboxylate synthetase) and degradation (such as proline dehydrogenase) varies among wheat varieties, influencing the proline content. The Variations in the regulation of these enzyme activities under salinity stress contribute to differences in proline accumulation (34,35). Never the less, plant hormones like abscisic acid (ABA) play a crucial role in regulating Proline biosynthesis under salt stress. Besides, the differences in hormonal signaling and sensitivity among wheat plants can lead to variations in Proline content (36,37).

CONCLUSION

Salinity stress negatively impacts wheat yield components, biological yield, and harvest index. However, the application of S and Q nanoparticles has been shown to mitigate these effects, enhancing yield parameters. Initially, salinity stress triggers an increase in antioxidant enzymes such as catalase and peroxidase, along with proline concentration, as part of the plant's defense mechanism against oxidative stress. Over time, or under severe salinity, this response diminishes, underscoring the need for developing salinity-tolerant wheat varieties with strong antioxidant defense systems.

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التأثيرات التآزرية للنانو سيليكون و IQ Combi على صفات إنتاج القمح تحت الري بالملوحة

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الخلاصة

الخلفية : تعتبر الملوحة احدى المؤثرات السلبية لنمو وتطور النباتات ، اذ يلاحظ تملح 1.5 مليون هكتار من الارضي الزراعة سنويا. **الهدف :** دراسة تاثير الاسمدة النانوية على بعض صفات الانتاجية لمحصول الحنطة المروية بالمياه المالحة. **طريقة العمل :** تم اجراء تجربتين في الحقل باستخدام السنادين لزراعة نبات الحنطة خلال موسمين في سنة 2022 و2023 في محافظة ديالى – العراق ، تم ري الحنطة بمياه مالحة كل 18 يوما اذ كان تركيز ملح NaCl فيها صفر و50 و75 ملي مول، وقد تم رش النبات بالاسمدة النانوية بعد ظهور الورقة الثالثة وبمعدل مرة كل 15 يوم ولثلاثة مرات. **النتائج:** كان لتاثر الملوحة اثر سلبي على صفة حاصل الحبوب والمحصول البايولوجي ودليل الحصاد ، في حين ادى تداخل تاثير الاسمدة النانوية الى زيادة هذه الصفات بمعدل 52.86 و 15.81 و18.84 % خلال 2022 و41.05 و20.65 و22.62 خلال 2023 ،على التوالي . كما ادى التداخل الاسمدة النانوية الى ارتفاع النسبة المئوية للكتليز والبيروكسديز و الحامض الاميني البرولين الى 23.84 و70.00 و79.78 % خلال 2022 و24.50 و73.33 و74.36 خلال 2023 ،على التوالي. **الاستنتاجات:** أدى استخدام الأسمدة النانوية إلى وزيادة الحاصل من خلال زيادة الإنزيمات المضادة للأكسدة كجزء من آلية دفاع ضد الإجهاد التأكسدي .وبمرور الوقت، يجب تطوير أصناف قمح تتحمل الملوحة مع أنظمة دفاعية قوية مضادة للأكسدة.

الكلمات المفتاحية : السماد النانوي ، الحنطة ، الاجهاد الملحي .