Effect of Foliar Spraying with Seaweed Extracts and Nano-Selenium on Vegetative Characteristics and Productivity of Quinoa Plant

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ABSTRACT

Climate variability presents a significant challenge to global food security in arid and semi-arid regions. A field experiment was conducted at the Experimental Farm of the Faculty of Environmental Agricultural Sciences, Arish University at North Sinai in Egypt. The aim of this study was to test and evaluate the effect of the applied foliar application of seaweed extract (SWE) and selenium-nanoparticles (Se-NPs), individually and in combination, on improvement of vegetative growth and yield of quinoa cultivar (Masr3) across two successive growing winter seasons. A randomized complete block design in a split-plot arrangement was followed with two levels of SWE (0 and 3000 mg/L) and four Se-NPs concentrations (0, 0.5, 1.0, and 2.0 ppm). The results indicated that both SWE and Se-NPs significantly enhanced vegetative and yield traits, with the combined application producing the highest performance across all parameters. Also, the foliar co-application of seaweed extract (3000 mg/L) and nano-selenium (2 ppm) appeared a highly significant enhancement in both vegetative growth parameters and yield components, highlighting a synergistic effect that increased physiological activity, nutrient uptake, and plant productivity. Therefore, integrating bio-stimulants, such as seaweed extract, with low-dose nano-selenium offers a sustainable strategy for improving quinoa productivity under climate stress is suggested. The combined use of natural and nano-based foliar sprays holds potential for broader application in climate-smart agriculture.

Keywords: Quinoa, Selenium Nanoparticles, Seaweed Extract, Sustainable Agriculture, Foliar Spray

INTRODUCTION

Climate change represents one of the most pressing existential threats to global agriculture. This is evidenced by the steady rise in atmospheric CO_2 concentrations from 315.98 ppm in 1959 to 411.43 ppm in 2019 mainly due to anthropogenic activities (IPCC, 2014 and NOAA, 2020). Over the past four decades, this has driven a 0.85°C increase in global temperatures, exacerbating climate extremes, altering precipitation patterns, and increasing the frequency of droughts and floods, particularly in vulnerable regions (Field *et al.*, 2014; Nhamo *et al.*, 2019 and Hussain *et al.*, 2022). Given agriculture's inherent sensitivity to climate variability, these shifts pose unprecedented challenges. Thermal stress disrupts crop phenology and reduces yields during critical growth stages (e.g., anthesis), while indirect effects include increased water scarcity, pest outbreaks, and competition from invasive weeds (Luo, 2011; Zhao *et al.*, 2017 and Shrestha, 2019). These impacts are particularly pronounced in Africa, where limited adaptive capacity endangers more than 60% of the rural population, which relies heavily on rainfed agriculture (Müller, 2013 and Nhamo *et al.*, 2019), thereby threatening global food security (Wheeler and Von Braun, 2013).

In this context, sustainable agricultural transformation requires crop systems that fulfill the triple imperative of climate adaptation, sustainable intensification, and mitigation of greenhouse gas emissions (Chemnitz and Hoer, 2011). Quinoa (*Chenopodium quinoa* Willd.) an ancient Andean pseudo-cereal, offers considerable promise and traditionally is central to Incan diets (Camaggio and Amicarelli, 2014). Quinoa provides exceptional protein quality with a balanced amino acid profile, especially rich in lysine, surpassing many conventional cereals (Nisar *et al.*, 2017 and Vilcacundo & Hernández-Ledesma, 2017). Its leaves are also consumed as low-carbohydrate, mineral-rich greens (AbdEl-Samad *et al.*, 2018 and Pathan *et al.*, 2019), while its bioactive compounds confer antioxidant, antimicrobial, and cardioprotective properties (Filho *et al.*, 2017). Crucially, quinoa demonstrates exceptional resilience to abiotic stresses including salinity, drought, and frost making it suitable for cultivation in marginal soils where traditional crops often fail (FAO & CIRAD, 2015 and Stanschewski *et al.*, 2021). This adaptability has been validated in extreme environments such as the Bolivian Altiplano (Geerts *et al.*, 2008 and Jacobsen, 2014), positioning quinoa as a strategic crop for climate-resilient food systems (Vega-Gálvez *et al.*, 2010).

However, fully unlocking quinoa's potential under intensifying climate stress necessitates innovative agronomic strategies. Emerging biostimulant technologies show particular promise, with seaweed extracts (e.g., *Sargassum*, *Ulva*) acting as natural supplements rich in macro-/micronutrients, phytohormones, and vitamins (Hernández-Herrera *et al.*, 2014). The foliar application enhances nutrient uptake,

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as exemplified by more than 90% increases in NPK absorption in onions, while stimulating photosynthesis and improving stress tolerance (Almaroai & Eissa, 2020 and Hussain *et al.,* 2021). Recent evidence demonstrates their efficacy across multiple crops; for instance, foliar sprays of seaweed extract obtained a significant increase of biomass and relative water content (RWC) in drought-stressed common bean, improve photosynthetic rates in soybean and enhance osmoprotectants and physiological resilience in faba bean, also, spraying seaweed extracts has increased significantly morphological parameters tomato's growth under salt stress (Ziaei & Pazoki, 2022; Mannan *et al.,* 2023; El Boukhari *et al.,* 2023 and Sherif *et al.,* 2025).

Simultaneously, selenium-nanoparticles (Se-NPs) exhibit low toxicity, high bio-compatibility, and potent antioxidant/antimicrobial activities (Arshad *et al.,* 2021), mitigating abiotic stress by enhancing antioxidant enzyme activity, reducing reactive oxygen species (ROS), and improving metabolic processes (Zhu *et al.,* 2017 and Liu *et al.,* 2022). Compelling evidence supports the efficacy of Se-NPs across diverse crops. Foliar applications of Se-NPs across diverse crops increased biomass, chlorophyll, and antioxidant activity while reducing oxidative damage in drought-stressed soybean (Zeeshan *et al.,* 2024) and tomato, where they boosted photosynthesis by over 100% (Zhong *et al.,* 2024). Similar benefits, such as enhanced stomatal conductance and membrane stability, have been observed in grapevine and wheat, with Se-NPs often outperforming other selenium forms (Daler *et al.,* 2024 and Hasanuzzaman *et al.,* 2024). Furthermore, their application has improved yields in crops under both drought and salinity stress (Rady *et al.,* 2021).

Despite these robust individual benefits across diverse crops, no peer-reviewed studies have investigated the integrated foliar application of seaweed extracts and Se-NPs under abiotic stress (drought/salinity). This represents a critical research gap, particularly for quinoa a climate-resilient yet underutilized crop. This study, therefore, aims to evaluate the synergistic application of nano-selenium and seaweed extracts as foliar Bio-stimulants to enhance quinoa's physiological performance, nutritional quality, and yield stability under climate-induced stress. We hypothesize that this integrated nano-bio-enhancement approach leverages complementary mechanisms seaweed-mediated nutrient and phytochemical delivery, and Se-NP-enhanced antioxidant and osmotic regulation to provide a sustainable pathway for climate-resilient agriculture and global food security, with particular relevance for the vulnerable, rainfed systems that dominate regions.

MATERIAL AND METHODS

1. Experimental Location

The field experiment was carried out at the Experimental Farm of the Faculty of Environmental Agricultural Sciences, Arish University, situated in North Sinai, Egypt (31°08'04.3"N, 33°49'37.2"E). The study extended over two consecutive winter growing seasons: 2023/2024 and 2024/2025. The experimental site is located in a semi-arid climate and meteorological data recorded during the two growing seasons are presented in Table 1.

Soil Mechanical and Chemical Analyses

The Soil and Water Department (SWD) conducted mechanical and chemical soil analyses during both growing seasons. The soil from the 0-30 cm depth was a sandy loam, with a particle size distribution of 67.1% coarse sand, 19% fine sand, 11.2% clay, and 2.7% silt. Chemical characterization revealed an alkaline soil with a pH of 8.519, an electrical conductivity of 1.7 dS m^{-1}, and a calcium carbonate content of 3.95%. The soil exhibited low organic content, with 1.09 $g.kg^{1}$ of organic carbon and 1.88 $g.kg^{1}$ of organic matter. The concentrations of soluble cations (in meq/L^{-1}) were 2.9 for Ca^{++}, 2.65 for Na^{+}, 2.18 for Mg^{++}, and 0.47 for K^{+}, while soluble anion concentrations were 2.41 for HCO_3^- and 1.29 for Cl^-.

Cultivated Plant

Quinoa cultivar "Masr3." Certified seeds were obtained from the Agricultural Research Center (ARC), Ismailia, Egypt was cultivated in this experiment.

Table 1. Meteorological data of El-Arish, North Sinai, region during quinoa growing seasons of 2023/2024 and 2024/2025

Months	Average temperature (°C)	Minimum Air Temperature (°C)	Maximum Air Temperature (°C)	Average Relative Humidity (%)	Total precipitation (mm)	Solar Radiation (MJ/m^2/day)
First season 2023-2024						
October-2023	24.91	21.99	28.95	68.43	6.05	15.72
November-2023	21.88	18.84	26.15	69.31	5.45	12.49
December-2023	17.19	13.54	21.92	69.69	6.55	9.68
January-2024	14.89	11.23	19.36	67.18	22.25	11.36
February-2024	13.42	10.09	17.50	75.76	19.65	14.32
March-2024	16.13	11.96	21.43	68.82	5.95	19.78
April-2024	20.36	15.90	26.30	68.78	2.30	23.33
May-2024	22.56	18.13	28.29	61.92	1.05	25.33
Average and Sum	18.92	15.21	23.74	68.74	138.5	16.50
Second Season 2024-2025						
October-2024	19.46	16.14	23.75	67.68	5.70	13.01
November-2024	15.62	12.04	20.22	62.57	9.70	11.27
December-2024	14.57	10.89	19.55	70.60	6.50	11.93
January-2025	12.94	9.66	17.09	67.48	19.80	12.60
February-2025	17.49	13.03	23.31	64.22	11.20	19.24
March-2025	19.49	14.96	25.58	61.63	6.10	21.61
April-2025	22.96	17.93	29.22	57.66	8.70	26.82
May-2025	17.50	13.52	22.67	64.55	67.70	16.64
Average and Sum	19.46	16.14	23.75	67.68	5.70	13.01

Source: Central Laboratory for Agricultural Climate (CLAC, Egypt).

3. Foliar spray materials

Nanoparticles

Selenium nanoparticles (SeNPs) were synthesized via chemical reduction according to Selmani et al. (Selmani et al., 2020). Briefly, an aqueous solution of sodium selenite (Na_2SeO_3, 1 mM; Chem-Lab, Belgium) was mixed with L-ascorbic acid (0.1 M; Loba-Chemie, India) and a chitosan solution (1 wt% in 1% acetic acid; medium molecular weight, deacetylation degree ≥85%; Loba-Chemie, India) acting as a capping agent under constant magnetic stirring at ambient temperature. The resulting SeNPs, characterized by an average diameter of 70 ± 10 nm as determined by transmission electron microscopy (TEM), were subsequently applied as a foliar spray. For this application, a commercially available nano-selenium formulation obtained from Nano Gate Company (Egypt) was utilized.

Tests:

Optical Properties: UV-Vis absorption spectra were obtained on Cary series UV-Vis- NIR, Australia

Size & Shape: Transmission Electron Microscopy (TEM) analysis was carried out using a JEOL JEM-2100 high-resolution TEM operating at an accelerating voltage of 200 kV. For sample preparation, a drop of the colloidal suspension was placed onto a Formvar carbon-coated copper grid (300 mesh, Ted Pella) and allowed to dry under ambient conditions.

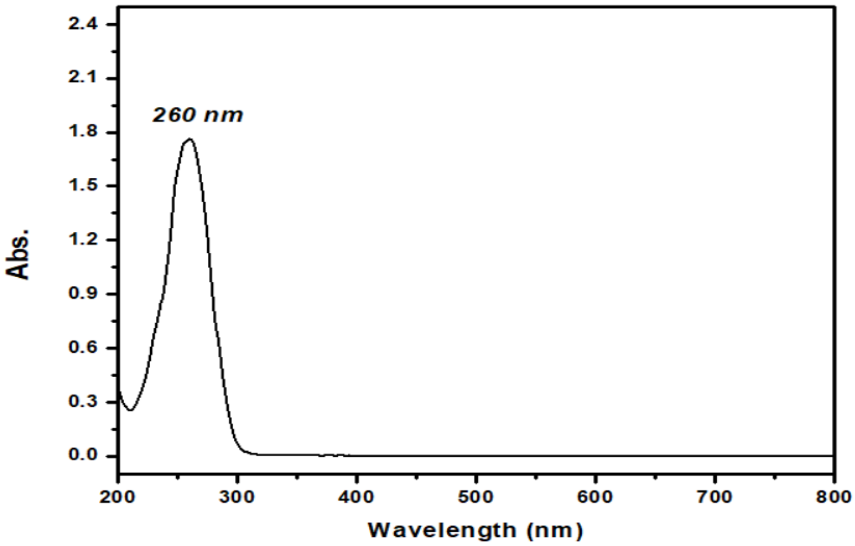

Figure 1. shows the optical absorption of the prepared selenium nanoparticles

Data provided by Nano-Gate Company (manufacturer of the nano-selenium product).

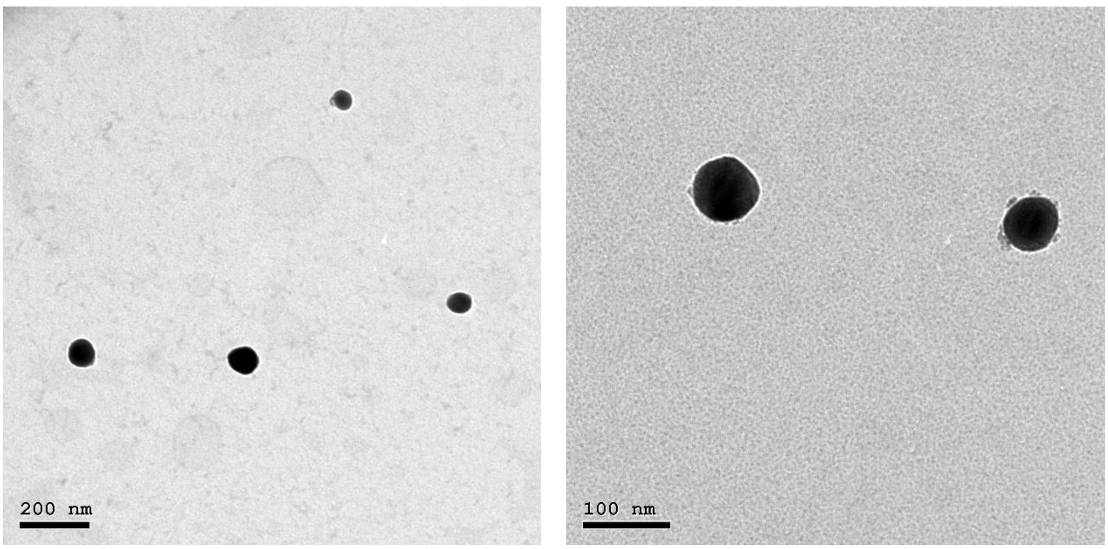

Figure2. Shows the TEM images of the prepared sample

Data provided by Nano-Gate Company (manufacturer of the nano-selenium product).

Seaweed extract (SWE)

Seaweed extract foliar spray was used as a commercial product, sourced from Evergreen Agricultural Development Company. The marine-derived compound exhibits the following composition: 0.9% nitrogen (N), 4% phosphorus pentoxide (P_2O_5), 10% potassium oxide (K_2O), and 0.5% sulfur (S). Additional constituents include 16% alginate and 50% organic matter as previously specified." pH: 8- 10, solubility in water: 100%.

Experimental Design and Field Layout

The experiment was conducted within a total cultivated area of 180 m^2. Seeds were sown on 3rd December using manual drilling. Rows were spaced 50 cm apart, with 30 cm between hills (planting stations) within each row. All recommended agronomic practices for quinoa cultivation were accurately implemented. Additionally, the experimental plots were uniformly fertilized with NPK (19:19:19) at a rate of 50 kg per feddan(4200m^2), , applied in two split doses: the first at sowing and the second 40 days after sowing. Farmyard manure was incorporated at a rate of 20 m^3 per feddan during soil preparation. Plant population management proceeded as follows: one month after sowing, seedlings were thinned to 5 plants per hill. Subsequently, at 45 days after sowing (45DAS), plants were further thinned to a single plant per hill. The experimental treatments followed a Randomized Complete Block Design (RCBD) with three replications. A split-plot arrangement was used based on two factors:

1. Main plots: Two concentrations of seaweed extract (SWE) foliar spray 0 mg L^{-1} (control) and 3000 mg L^{-1} was applied at 45 DAS.

2. Sub-plots: Four concentrations of nano-selenium (Se-NPs) as foliar spray (0, 0.5, 1.0, and 2.0 ppm) was applied at 30 DAS.

This factorial combination of SWE concentrations (2 levels) and Se-NPs concentrations (4 levels) resulted in a total of eight experimental treatments (2 × 4 = 8), representing all possible interactions between the two factors. Treatments were systematically randomized within each block.

Recorded Data

The following vegetative traits data were recorded 90 days after sowing:

(plant height (cm)-number of leaves- leaf area (cm^2)-number of shoots- root length (cm)- root number - Leaves weight(g)-Shoot weight (g)- Root weight (g) - Inflorescences number - Inflorescences weight(g))

The following yield components are obtained 120 days after sowing:

(Seed cluster number - Seed cluster weight(g)- Seed weight/ plant(g)- 1000 seeds weight(g)- Seed yield (kg/ feddan)

Statistical Analysis

The experimental data from both growing seasons were statistically processed using the MSTAT-C software package. A one-way analysis of variance (ANOVA) was performed to determine the significance of the results, as described by Snedecor and Cochran (1990). Mean values were then separated and compared using Duncan's multiple range test at a significance threshold of $P \leq 0.05$ (Duncan, 1955).

RESULTS AND DISCUSSION

1. Effect of seaweed extracts and nano-selenium as foliar spray on quinoa vegetative traits and their interaction:

The data presented in Tables (2 and 3) demonstrate that the foliar application of seaweed extract had a significantly positive impact on all assessed vegetative traits in both growing seasons, except for the number of inflorescences in the first season, where the effects were not statistically significant. The affected vegetative traits included (plant height, number of leaves, leaf area, number of shoots, root length, root number, leaves weight, shoot weight, root weight, inflorescences number, inflorescences weight).

This consistent response across two successful growing seasons confirms the efficacy of seaweed extract as a bio-stimulant capable of enhancing overall vegetative growth in treated plants. The observed improvements can be attributed to the bioactive compounds present in seaweed extract, which are known to promote cell division, elongation, and nutrient uptake, thereby positively influencing vegetative performance under field conditions.

Numerous studies have demonstrated that SWEs significantly enhance vegetative growth and crop yield across various plant species such as tomato (*Solanum lycopersicum*), soybean (*Glycine max*), and a range of vegetable crops. Documented benefits include increased shoot and root biomass, enhanced root length, greater leaf area, and higher numbers of flowers and fruits all critical indicators of plant vigor and productivity (Yuan *et al.,* 2016; Gholizadeh *et al.,* 2017 and Ali *et al.,* 2019; 2020). In quinoa, for instance, SWE application led to marked improvements in vegetative traits.

The efficacy of SWEs is attributed not to their nutritional content, which is often minimal compared to conventional fertilizers, but to their rich composition of biologically active compounds. These include natural phytohormones (auxins, cytokinins, gibberellins), amino acids, polyphenols, and betaines, which act as signaling molecules that stimulate physiological processes (Khan *et al.,* 2009; Mattner *et al.,* 2013 and Shukla *et al.,* 2019). These compounds promote cell division, root development, and delay of senescence through hormonal regulation (Mattner *et al.,* 2013 and Arioli *et al.,* 2020).

Seaweed extracts have also been shown to significantly improve root morphology by increasing lateral root branching, fine root density, and root surface area, enhancing water and nutrient uptake under challenging conditions (Senthuran *et al.,* 2019). In *Arabidopsis* and other model crops, SWE application has been linked to robust root systems that support superior plant establishment (Santaniello *et al.,* 2017 and Islam *et al.,* 2020).

Beyond vegetative growth, seaweed extracts play a significant role in enhancing tolerance to abiotic and biotic stresses. They have been shown to activate antioxidant enzyme systems and trigger immune signaling pathways, such as systemic acquired resistance and cytokinin–auxin modulation. This contributes to reduced pest infestations and improved resilience to environmental stresses (Gençsoylu, 2016 and González Castro *et al.,* 2019).

Table 2. Effect of seaweed extracts and nano-selenium as foliar spray on plant height, number of leaves, leaf area, number of shoots, root length, root number of quinoa vegetative growth after 90 days from sowing during two successive growing seasons 2023/2024-2024/2025

Characters / Factors	Plant height (cm)	Leaves number	Leaves area (cm^2)	Shoot number	Root length (cm)	Root number
First season 2023/2024						
Seaweed						
Without	94.417b	303.500a	91.770a	23.000b	25.083b	15.50b
With	104.250a	353.646b	104.513b	24.917a	28.083a	17.50a
Nano selenium ppm						
0	81.83c	220.00d	79.89d	19.333d	20.17d	11.50d
0.5	99.00b	314.17c	92.38c	22.167c	24.67c	16.00c
1	103.33b	343.75b	102.44b	25.500b	28.50b	18.00b
2	113.17a	436.38a	117.85a	28.833a	33.00a	20.50a
Second season 2024/2025						
Seaweed						
Without	92.083b	329.333b	85.698b	17.167b	24.083b	15.000b
With	100.583a	360.000a	97.435a	21.167a	26.000a	17.000a
Nano selenium ppm						
0	78.00d	287.50d	79.32c	13.33d	19.00d	12.00d
0.5	95.67c	318.17c	86.30c	17.83c	22.33c	14.67c
1	102.00b	352.83b	95.48b	21.33b	27.33b	17.50b
2	109.67a	420.17a	105.16a	24.17a	31.50a	19.83a

Table 3. Effect of seaweed extracts and nano-selenium as foliar spray on leaves weight, shoot weight, root weight, inflorescences number, inflorescences weight of quinoa vegetative growth after 90 days from sowing during two successive growing seasons 2023/2024-2024/2025

Characters / Factors	Leaves weight (g)	Shoot weight (g)	Root weight (g)	Inflorescences number	Inflorescences weight (g)
First season 2023/2024					
Seaweed					
Without	97.750b	107.083b	23.792b	28.792a	18.500b
With	122.833a	131.500a	26.583a	30.917a	25.583a
Nano selenium ppm					
0	82.33d	89.17c	16.667d	24.83d	14.33d
0.5	95.67c	103.83c	22.333c	28.00c	20.67c
1	120.08b	128.33b	28.833b	31.83b	24.00b
2	143.08a	155.83a	32.917a	34.75a	29.17a
Second season 2024/2025					
Seaweed					
Without	99.42b	98.833b	19.917b	26.333b	16.083b
With	119.92a	117.667a	25.000a	27.917a	24.583a
Nano selenium ppm					
0	90.33d	78.83d	15.83d	21.00d	13.50d
0.5	99.83c	96.50c	19.33c	25.67c	17.67c
1	116.00b	111.00b	23.50b	29.33b	22.33b
2	132.50a	146.67a	31.17a	32.50a	27.83a

Collectively, the evidence strongly supports the classification of SWEs as highly effective, non-nutritional plant bio-stimulants. Their multifaceted action, ranging from enhanced growth and yield to improved stress resistance and crop quality, positions them as sustainable agricultural tools in modern farming systems (Mattner *et al.*, 2013; Ali *et al.*, 2020 and Arioli *et al.*, 2020). The results obtained from this study are consistent with the findings of previously published research, in chronological order, including those of Almaroai & Eissa (2020); Hussain *et al.* (2021); Ziaei & Pazoki (2022); Mannan *et al.* (2023) and El Boukhari *et al.* (2023).

Regarding nano-selenium impact on vegetative growth, the results presented in Tables (2 and 3) revealed clear and consistent improvements across all measured parameters in both growing seasons. Traits such as plant height, number of leaves, leaf area, number of shoots, root length, root number, leaves weight, shoot weight, root weight, inflorescences number, and inflorescences weight, all showed substantial enhancement, particularly under the 2 ppm treatment. These enhancements were progressive with increasing nano-selenium concentration and were most evident in biomass-related traits, especially root and shoot weights, which reflected a strong physiological response.

The observed improvements can be attributed to the unique properties of nano-selenium (Se-NPs), including high bioavailability, increased surface reactivity, and a controlled release pattern that enables more effective interaction with plant metabolic systems (Liu & Lal, 2015 and El-Ramady *et al.*, 2018). Additionally, Se-NPs is known to stimulate the antioxidant defense system, activating enzymes such as SOD, CAT, and peroxidases, which play a critical role in reducing oxidative damage, delaying senescence, and maintaining photosynthetic efficiency under both normal and stress conditions (Hasanuzzaman *et al.*, 2014 and Hussein *et al.*, 2019). Collectively, these results confirm that nano-selenium, even at low concentrations, acts as an effective bio-stimulant, enhancing vegetative growth and contributing to the plant's resilience in the face of environmental variability. The results obtained from this study are in agreement with those reported by Rady *et al.* (2021); Daler *et al.* (2024); Hasanuzzaman *et al.* (2024); Zeeshan *et al.* (2024) and Zhong *et al.* (2024), respectively.

The combined foliar application of seaweed extract at 3000 mg/L and nano-selenium at two ppm resulted in a significant synergistic effect on vegetative growth traits across both seasons. This dual treatment resulted in significant improvements in plant height, number of leaves, leaf area, number of shoots, root length, root number leaves weight, shoot weight, root weight, inflorescences number, inflorescences weight (Tables 4 and 5). Compared to individual applications, the combined treatment consistently outperformed other treatments, indicating a positive interaction between the bioactive compounds present in seaweed extract and the high bioavailability of nano-selenium. The results suggest that seaweed extract may have improved nutrient uptake and hormone activity. At the same time, nano-selenium enhanced antioxidant defense and stress resilience, together creating optimal conditions for robust vegetative development.

The observed enhancement in vegetative growth under the combined application of seaweed extract and nano-selenium likely stems from a synergistic interplay between metabolic stimulation and stress mitigation. While seaweed extract boosts endogenous hormonal activity and cellular expansion processes, nano-selenium reinforces the plant's antioxidant machinery and stabilizes physiological functions under fluctuating field conditions. This functional integration appears to have amplified resource assimilation, particularly in root and shoot biomass, resulting in a more vigorous vegetative profile than that achieved by either treatment alone. The consistency of this response across seasons supports the conclusion that their combined effect is not merely additive, but rather functionally synergistic, optimizing both growth potential and resilience.

Table 4. Interaction of seaweed extracts and nano-selenium effects as foliar spray on plant height, number of leaves, leaf area, number of shoots, root length, root number of quinoa vegetative growth after 90 days from sowing during two successive growing seasons 2023/2024-2024/2025

seaweed	Selenium concentration ppm	Plant height (cm)	Leaves number	Leaves area (cm^2)	Shoot number	Root length (cm)	Root number
First season 2023/2024							
Without Seaweed	0 ppm	81.0d	200.00h	76.89e	18.33f	18.33f	11.00f
	0.5 ppm	91.0c	282.00f	89.20cd	21.67de	23.33e	15.00d
	1 ppm	95.3c	313.00e	94.84c	24.67c	27.67cd	17.00c
	2 ppm	110.3b	419.00b	106.15b	27.33b	31.00b	19.00b
With Seaweed	0 ppm	82.6d	240.00g	82.89de	20.33e	22.00e	12.00e
	0.5 ppm	107.0b	346.33d	95.55c	22.67d	26.00d	17.00c
	1 ppm	111.3ab	374.50c	110.04b	26.33bc	29.33bc	19.00b
	2 ppm	116.0a	453.75a	129.56a	30.33a	35.00a	22.00a
Second season 2024/2025							
Without Seaweed	0 ppm	77.00e	277.33e	75.54f	11.67e	18.33f	11.00g
	0.5 ppm	88.33d	297.33e	81.49ef	15.67d	22.00de	14.00e
	1 ppm	97.00c	337.00d	87.79de	19.00c	26.00c	16.33c
	2 ppm	106.00b	405.67b	97.97bc	22.33b	30.00b	18.67b
With Seaweed	0 ppm	79.00e	297.67e	83.11ef	15.00d	19.67ef	13.00f
	0.5 ppm	103.00b	339.00d	91.12cd	20.00c	22.67d	15.33d
	1 ppm	107.00b	368.67c	103.17b	23.67b	28.67bc	18.67b
	2 ppm	113.33a	434.67a	112.34a	26.00a	33.00a	21.00a

Table 5. Interaction of seaweed extracts and nano-selenium effects as foliar spray on leaves weight, shoot weight, root weight, inflorescences number, inflorescences weight of quinoa vegetative growth after 90 days from sowing during two successive growing seasons 2023/2024-2024/2025

seaweed	Selenium concentration ppm	Leaves weight (g)	Shoot weight (g)	Root weight (g)	Inflorescences number	Inflorescences weight (g)
First season 2023/2024						
Without Seaweed	0 ppm	76.67g	83.3e	15.67g	23.33f	12.67f
	0.5 ppm	90.67ef	93.3de	21.00e	27.00e	16.67e
	1 ppm	98.17de	110.3cd	27.67c	30.67c	20.00d
	2 ppm	125.50c	141.3b	30.83b	34.17ab	24.67c
With Seaweed	0 ppm	88.00f	95.00de	17.67f	26.33e	16.00e
	0.5 ppm	100.67d	114.33c	23.67d	29.00d	24.67c
	1 ppm	142.00b	146.33b	30.00b	33.00b	28.00b
	2 ppm	160.67a	170.33a	35.00a	35.33a	33.67a
Second season 2024/2025						
Without Seaweed	0 ppm	84.33g	71.33e	14.00e	20.00g	11.33f
	0.5 ppm	91.33f	88.00d	17.67d	25.00e	14.33e
	1 ppm	100.67e	93.33d	20.67c	29.00c	17.67d
	2 ppm	121.33c	142.67a	27.33b	31.33b	21.00c
With Seaweed	0 ppm	96.33e	86.33d	17.67d	22.00f	15.67de
	0.5 ppm	108.33d	105.00c	21.00c	26.33d	21.00c
	1 ppm	131.33b	128.67b	26.33b	29.67c	27.00b
	2 ppm	143.67a	150.67a	35.00a	33.67a	34.67a

2- Effect of seaweed extracts and nano-selenium as foliar spray on quinoa yield component and their interaction

The positive impact of seaweed extract and nano-selenium on quinoa yield components such as seed cluster number and weight, seed weight per plant, 1000 seed weight, and total seed yield was demonstrated across both seasons. As shown in Table (6), the individual application of SWE at 3000 mg/L and nano-selenium at 2 ppm each led to significant improvements in all measured yield traits compared to the control. Moreover, the combined application of both treatments resulted in the highest values across all parameters**,** as presented in Table (7)**,** indicating a strong synergistic effect.

For example, total seed yield per feddan increased markedly under the combined treatment compared to all other treatments, reflecting enhanced reproductive efficiency and better overall plant performance. Likewise, seed weight per plant and 1000 seed weight were significantly increased, suggesting improved assimilate translocation and grain filling capacity. A similar trend was observed in seed cluster number and weight, highlighting enhanced flowering and seed set.

Seaweed extract likely contributed to these enhancements through its phytohormonal content and biologically active compounds, which are known to improve flowering, pollination, and seed development (Khan *et al.*, 2009; Shukla *et al.*, 2019 and Arioli *et al.*, 2020). The stimulation of carbohydrate metabolism and nutrient remobilization may explain the higher seed weights and better yield quality observed under SWE treatment (Ali *et al.*, 2020).

Nano-selenium also exhibited a key role in boosting yield performance. The yield traits recorded under 2 ppm Se-NPs (Table 6) support previous findings on the role of selenium in enhancing antioxidant defense, delaying senescence, and sustaining photosynthetic activity during reproductive stages (El-Ramady *et al.*, 2018; Hasanuzzaman *et al.*, 2014 and Hussein *et al.*, 2019). These effects likely helped stabilize physiological processes during flowering and grain development, resulting in superior yield traits.

Table 6. Effect of seaweed extracts and nano-selenium as foliar spray on seed cluster number, seed cluster weight, seed weight/ plant, 1000 seed weight, seed yield of quinoa yield components after 120 days from sowing during two successive growing seasons 2023/2024-2024/2025

Characters Factors	Seed cluster number	Seed cluster weight (g)	Seed weight/ plant (g)	1000 seed weight (g)	Seed yield (kg/feddan)
First season 2023/2024					
Seaweed					
Without	34.083b	85.683b	49.083b	4.342b	2061.50b
With	35.417a	98.000a	54.000a	4.483a	2268.00a
Nano selenium ppm					
0	30.83c	74.67d	35.00d	4.10d	1470.0d
0.5	31.33c	86.53c	44.33c	4.33c	1862.0bc
1	36.50b	95.50b	56.50b	4.50b	2373.0ab
2	40.33a	110.67a	70.33a	4.72a	2954.0a
Second season 2024/2025					
Seaweed					
Without	28.333b	85.667b	51.750b	4.258b	2173.50b
With	30.333a	93.083a	57.000a	4.517a	2394.00a
Nano selenium ppm					
0	24.50d	74.50d	37.50d	4.13c	1575d
0.5	27.83c	84.67c	49.17c	4.30bc	2065c
1	31.17b	91.83b	60.50b	4.45b	2541b
2	33.83a	106.50a	70.33a	4.67a	2954a

Table 7. Interaction of seaweed extracts and nano-selenium effects as foliar spray on seed cluster number, seed cluster weight, seed weight/ plant, 1000 seed weight, seed yield of quinoa yield components after 120 days from sowing during two successive growing seasons 2023/2024-2024/2025

Seaweed	Selenium concentration ppm	Seed cluster number	Seed cluster weight (g)	Seed weight/ plant (g)	1000 seed weight (g)	Seed yield (kg/feddan)
First season 2023/2024						
Without Seaweed	0 ppm	31.00d	67.33g	33.00f	4.03g	1386.0d
	0.5 ppm	30.67d	78.40f	42.00de	4.27ef	1764.0cd
	1 ppm	35.33c	89.33e	55.33c	4.43cd	2324.0bc
	2 ppm	39.33ab	107.67b	66.00b	4.63b	2772.0ab
With Seaweed	0 ppm	30.67d	82.00f	37.00ef	4.17fg	1554.0d
	0.5 ppm	32.00d	94.67d	46.67d	4.40de	1960.0cd
	1 ppm	37.67bc	101.67c	57.67c	4.57bc	2422.0abc
	2 ppm	41.33a	113.67a	74.67a	4.80a	3136.0a
Second season 2024/2025						
Without Seaweed	0 ppm	23.00g	72.67e	36.33e	4.00e	1526.0e
	0.5 ppm	27.00ef	82.00d	47.33d	4.20d	1988.0d
	1 ppm	30.33cd	85.33cd	57.33c	4.30d	2408.0c
	2 ppm	33.00ab	102.67b	66.00b	4.53bc	2772.0b
With Seaweed	0 ppm	26.00f	76.33e	38.67e	4.27d	1624.0e
	0.5 ppm	28.67de	87.33c	51.00d	4.40cd	2142.0d
	1 ppm	32.00bc	98.33b	63.67b	4.60b	2674.0b
	2 ppm	34.67a	110.33a	74.67a	4.80a	3136.0a

As shown in Table (7), the combined treatment consistently outperformed individual applications, confirming a synergistic interaction between the metabolic effects of SWE and the physiological protection provided by nano-selenium. This combination appeared to optimize source sink relations, extend the grain-filling period, and strengthen sink strength, ultimately leading to improved seed productivity. These results are in line with previous studies by Rady *et al.* (2021); Daler *et al.* (2024); Hasanuzzaman *et al.* (2024); Zeeshan *et al.* (2024) and Zhong *et al.* (2024), and demonstrate the potential of integrating bio-stimulants with nano-materials to improve crop yield under environmental stress sustainably.

CONCLUSION

This study demonstrates that foliar application of seaweed extract (SWE) and selenium-nanoparticles (Se-NPs), whether applied individually or in combination, significantly enhanced the vegetative growth and yield performance of quinoa (cv. Masr3) under arid field conditions in North Sinai across two consecutive seasons. The co-application of SWE at 3000 mg/L and Se-NPs at 2.0 ppm consistently produced the most significant improvements in morphological traits, biomass accumulation, and yield components, reflecting a synergistic interaction between the two treatments. These improvements are likely attributed to the hormonal activity and senescence-delaying effects of SWE, coupled with the antioxidant and nutrient-mobilizing functions of Se-NPs. The findings emphasize the potential of combining natural bio-stimulants with nano-enabled technologies as an innovative and sustainable agronomic practice to enhance crop performance under climate variability. This approach aligns with the principles of climate-smart agriculture and offers a viable alternative to conventional inputs, particularly in resource-limited and stress-prone environments.

REFERENCES

AbdEl-Samad, E., S. Hussin, A. El-Naggar, N. El-Bordeny and S. Eisa. 2018. The potential use of quinoa as a new non-traditional leafy vegetable crop. *Biosci. Res.* 15:3387–3403.

Ali, O., A. Ramsubhag and J. Jayaraman. 2019. Biostimulatory activities of Ascophyllum nodosum extract in tomato and sweet pepper crops in a tropical environment. *PLoS ONE*, 14(5), e0216710. https://doi.org/10.1371/journal.pone.0216710

Ali, O., A. Ramsubhag and J. Jayaraman. 2020. Phytoelicitor activity of Sargassum vulgare and Acanthophora spicifera extracts and their prospects for use in vegetable crops for sustainable crop production. *J. Appl. Phycol.* https://doi.org/10.1007/s10811-019-01934-y

Almaroai, Y. A. and M. A. Eissa. 2020. Role of marine algae extracts in water stress resistance of onion under semi-arid conditions. *J. Soil Sci. Plant Nutr.* 20: 1092–1101.

Arioli, T., S. W. Mattner and P. C. Winberg. 2020. Applications of seaweed extracts in Australian agriculture: Past, present and future. *J. Appl. Phycol.*, 32: 3787–3804. https://doi.org/10.1007/s10811-020-02126-2

Arshad, R., L. Gulshad, I. U. Haq, M. A. Farooq, A. Al-Farga, R. Siddique, M. F. Manzoor and E. Karrar.2021. Nanotechnology: A novel tool to enhance the bioavailability of micronutrients. *Food Sci. Nutr.* 9: 3354–3361. https://doi.org/10.1002/fsn3.2311

Camaggio, G. and V. Amicarelli. 2014. The ancient crop of quinoa for world food security. In: Miśniakiewicz, M., Popek, S. (eds.), *Future trends and challenges in the food sector*. Polish Society of Commodity Science, pp. 90–102.

Chemnitz, C., H. Hoer. 2011. Adapting African agriculture to climate change. *Int. J. Rural Dev.*, 45, 32–35.

Daler, S., N. Korkmaz, T. Kılıç. 2024. Modulatory effects of selenium nanoparticles against drought stress in some grapevine rootstock/scion combinations. *Chem. Biol. Technol. Agric.*, 11. 108. https://doi.org/10.1186/s40538-024-00609-6

Duncan, D. B. 1955. Multiple range and multiple F tests. *Biometrics*, 11(1): 1-42.

El Boukhari, M. E. M., M. Barakate and B. Drissi. 2023. Seaweed extract biostimulants differentially act in mitigating drought stress on faba bean (Vicia faba L.). *J. Plant Growth Regul.*, 42: 5642–5652.

El-Ramady, H., T. Alshaal, N. Elhawat, E. El-Nahrawy, A. Omara, S. El-Nahrawy, T. Elsakhawy, A. A.Ghazi, N. Abdalla and M. Fári.2018. Biological aspects of selenium and silicon nanoparticles in the terrestrial environments. In: *Phytoremediation*. Springer, pp. 235–264. https://doi.org/10.1007/978-3-319-99651-6_11

FAO, CIRAD. 2015. *State of the art report of quinoa in the world in 2013*. Food and Agriculture Organization. (Bazile, D., Bertero, D., Nieto, C., eds.)

Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir and R. C. Genova. 2014. Summary for policymakers. In: *Climate change 2014: Impacts, adaptation, and vulnerability*. Cambridge University Press.

Filho, A. M. M., M. R. Pirozi, J. T. D. S. Borges, H. M. P. Sant'Ana, J. B. P. Chaves and J. S. D. R. Coimbra. 2017. Quinoa: Nutritional, functional, and antinutritional aspects. *Crit. Rev. Food Sci. Nutr.*, 57: 1618–1630.

Geerts, S., D. Raes, M. Garcia, J. Mendoza and R. Huanca. 2008.Crop water use indicators to quantify the flexible phenology of quinoa (Chenopodium quinoa Willd.) in response to drought stress. *Field Crops Res.*, 108: 150–156.

Gençsoylu, İ. 2016. Effect of seaweeds and organic foliar fertilizers on the cotton pests, predators, yield and fiber quality in cotton. *Adnan Menderes Üniv. Ziraat Fak. Derg.* https://doi.org/10.25308/aduziraat.282577

Gholizadeh, A., M. A. Shajari, A. Ghalavand and A. Dolatabadian. 2017. Effect of seaweed (Ascophyllum nodosum) extract on growth and yield of soybean under drought stress conditions. *J. Appl. Res. Plant Physiol.*, 7(2):33–40.

González Castro, A. L., M. Muñoz Ochoa, G. Hernández Carmona and López J. M. Vivas. 2019. Evaluation of seaweed extracts for the control of the Asian citrus psyllid Diaphorina citri. *J. Appl. Phycol.* https://doi.org/10.1007/s10811-019-01768-8

Hasanuzzaman, M., K. Nahar and M. Fujita. 2014. Silicon and selenium: Two vital trace elements that confer abiotic stress tolerance to plants. In: *Emerging technologies and management of crop stress tolerance*. Elsevier, pp. 377–422.

Hasanuzzaman, M., M. R. H. Raihan, A. Siddika. 2024. Selenium and its nanoparticles modulate the metabolism of reactive oxygen species and morpho-physiology of wheat (Triticum aestivum L.) to combat oxidative stress under water deficit conditions. *BMC Plant Biol.*, 24. 578. https://doi.org/10.1186/s12870-024-05282-3

Hernández-Herrera, R. M., F. Santacruz-Ruvalcaba, M. A. Ruiz-López, J. Norrie and G. Hernández-Carmona. 2014. Effect of liquid seaweed extracts on growth of tomato seedlings (Solanum lycopersicum L.). *J. Appl. Phycol.*, 26: 619–628. https://doi.org/10.1007/s10811-013-0078-4

Hussain, H. I., N. Kasinadhuni and T. Arioli. 2021.The effect of seaweed extract on tomato plant growth, productivity and soil. *J. Appl. Phycol.*, 33: 1305–1314.

Hussain, S., M. Mubeen, A. Ahmad, S. Fahad, W. Nasim, H. M. Hammad and S. Parveen. 2022. Using space–time scan statistic for studying the effects of COVID-19 in Punjab, Pakistan. *Environ. Sci. Pollut. Res.*, 29: 30037–30047.

Hussein, H.A., O.M. Darwesh and B.B. Mekki.2019. Environmentally friendly nano-selenium to improve antioxidant system and growth of groundnut cultivars under sandy soil conditions. Biocatal. Agric. Biotechnol. 18. 101080.

IPCC. 2014. *Climate change 2014: Synthesis report*. Intergovernmental Panel on Climate Change.

Islam, M. T., M. M. Hossain, M. A. K.Chowdhury, M. R. Karim, J. A. T. da Silva and Z. H. Shamsuddin. 2020.Seaweed extract as a biostimulant improves the physiological and biochemical attributes of tomato (Solanum lycopersicum). *Saudi J. Biol. Sci.*, 27(10):2652–2659. https://doi.org/10.1016/j.sjbs.2020.07.001

Jacobsen, S. E. 2014. Adaptación y posibilidades para la quinua en las latitudes septentrionales de Europa. In: Bazile, D. (ed.), *Estado del arte de la quinua en el mundo en 2013*. Food and Agriculture Organization, pp. 520–533.

Khan, W., U.P. Rayirath, S. Subramanian, M.N. Jithesh, P. Rayorath, D.M. Hodges, A.T. Critchley, J.S. Craigie, J. Norrie and B. Prithiviraj. 2009. Seaweed extracts as biostimulants of plant growth and development. Journal of plant growth regulation, 28, pp.386-399.

Liu, R., R. Lal. 2015. Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. A review. *Sci. Total Environ.*, 514: 131–139. https://doi.org/10.1016/j.scitotenv.2015.01.104

Liu, R., Y. Deng, M. Zheng, Y. Liu, Z. Wang, S. Yu and R. Li. 2022.Nanoselenium repairs the fruit growth and flavor quality of tomato under the stress of penthiopyrad. *Plant Physiol. Biochem.*, 182: 36–45. https://doi.org/10.1016/j.plaphy.2022.05.026

Luo, Q. 2011. Temperature thresholds and crop production: A review. *Clim. Change*, 109: 583–598.

Mannan, M. A., A. Yasmin, U. Sarker, N. Bari, D. B. Dola, H. Higuchi, S. Ercisli, D. Ali and S. Alarifi. 2023. Biostimulant red seaweed (Gracilaria tenuistipitata var. liui) extracts spray improves yield and drought tolerance in soybean. *PeerJ*, 11, e15588. https://doi.org/10.7717/peerj.15588

Mattner, S. W., I. J. Porter, R. K. Gounder and J. Edwards. 2013. The effect of Ascophyllum nodosum extract on root diseases of field-grown broccoli. *Crop Prot.*, 54:66–71. https://doi.org/10.1016/j.cropro.2013.08.003

Müller, C. 2013. African lessons on climate change risks for agriculture. *Annu. Rev. Nutr.*, 33: 395–411.

Nhamo, L., T. Mabhaudhi and A. Modi. 2019. Preparedness or repeated short-term relief aid? Building drought resilience through early warning in southern Africa. *Water SA*, 45: 75–85.

Nisar, M., D. R. More, S. Zubair and S. I. Hashmi. 2017. Physico-chemical and nutritional properties of quinoa seed: A review. *J. Pharmacogn. Phytochem.*, 6: 2067–2069.

NOAA. 2020. Trends in atmospheric carbon dioxide. National Oceanic and Atmospheric Administration. https://gml.noaa.gov/ccgg/trends/

Pathan, S., F. Eivazi, B. Valliyodan, K. Paul, G. Ndunguru and K. Clark. 2019.Nutritional composition of the green leaves of quinoa (Chenopodium quinoa Willd.). *J. Food Res.*, 8: 55–65.

Rady, M. M., E. S. M. Desoky, S. M. Ahmed, A. Majrashi, E. F. Ali, S. M. A. I. Arnaout, E. Selem. 2021. Foliar nourishment with nano-selenium dioxide promotes physiology, biochemistry, antioxidant defenses, and salt tolerance in Phaseolus vulgaris. *Plants*, 10(6): 1189. https://doi.org/10.3390/plants10061189

Santaniello, A., A. Scartazza, F. Gresta, E. Loreti, A. Biasone, D. Di Tommaso and P.Perata. 2017. Ascophyllum nodosum-based biostimulants enhance Arabidopsis tolerance to drought and salt stress by increasing ABA levels and antioxidant activity. *Front. Plant Sci.*, 8: 1363. https://doi.org/10.3389/fpls.2017.01363

Selmani, A., L. Ulm, K. Kasemets, I. Kurvet, I. Erceg, R. Barbir and I. V. Vrček. 2020. Stability and toxicity of differently coated selenium nanoparticles under model environmental exposure settings. *Chemosphere*, *250*. 126265.

Senthuran, S., B. L. W. K. Balasooriya, S. J. Arasakesary and N. Gnanavelrajah. 2019. Effect of seaweed extract Kappaphycus alvarezii on the growth, yield and nutrient uptake of leafy vegetable Amaranthus polygamous. *Trop. Agric. Res.* https://doi.org/10.4038/tar.v30i1.8319

Sherif, F.K., H.A. Argeaa and A.S. Mostafa. 2025. Does Seaweed Extract as a Biostimulant Ameliorate Tomato Plant's Salt Stress Tolerance?. Alex. Sci. Exch. J., 46(1), pp.43-56.

Shrestha, S. 2019. Effects of climate change in agricultural insect pest. *Acta Sci. Agric.*, 3: 74–80.

Shukla, P. S., E. G. Mantin, M. Adil, S. Bajpai, A. T. Critchley and B. Prithiviraj. 2019. Ascophyllum nodosum-based biostimulants: Sustainable applications in agriculture for the stimulation of plant growth, stress tolerance, and disease management. *Front. Plant Sci.*, 10, 655. https://doi.org/10.3389/fpls.2019.00655

Snedecor, G. W. and W. G. Cochran. 1990. *Statistical methods*. Iowa State University Press.

Stanschewski, C. S., E. Rey, G. Fiene, E. B. Craine, G. Wellman, V. J. Melino and D. Bertero. 2021. Quinoa phenotyping methodologies: An international consensus. *Plants*, 10(9), 1759.

Vega-Gálvez, A., M. Miranda, J.Vergara, E. Uribe, L. Puente and E. A. Martínez. 2010. Nutrition facts and functional potential of quinoa (Chenopodium quinoa Willd.), an ancient Andean grain: A review. *J. Sci. Food Agric.*, 90:2541–2547.

Vilcacundo, R. and B. Hernández-Ledesma. 2017. Nutritional and biological value of quinoa (Chenopodium quinoa Willd.). *Food Microbiol. Funct. Foods Nutr.*, 14: 1–6.

Wheeler, T. and J.Von Braun. 2013. Climate change impacts on global food security. *Science*, 341:508–513.

Yuan, H., X. Chen and X. Zhang. 2016.Effect of seaweed extract on plant growth and yield of tomato under greenhouse conditions. *Agric. Sci.*, 7: 1131–1140. https://doi.org/10.4236/as.2016.79106

Zeeshan, M. 2024. Selenium nanoparticles boost the drought stress response of soybean. *Agronomy*, 14(7): 1372. https://www.mdpi.com/2073-4395/14/7/1372

Zhao, C., B. Liu, S. Piao, X. Wang, D. B. Lobell, Y. Huang and P. Ciais. 2017. Temperature increase reduces global yields of major crops. *Proc. Natl. Acad. Sci. U.S.A.*, 114:9326–9331.

Zhong, Y., H. Cui, H. Li, X. Qiang, Q. Han and H.Liu. 2024. Foliar application of selenium enhances drought tolerance in tomatoes by modulating the antioxidative system and restoring photosynthesis. *Agronomy*, 14(6). 1184. https://doi.org/10.3390/agronomy14061184

Zhu, Z., Y. Chen, G. Shi and X. Zhang. 2017. Selenium delays tomato fruit ripening by inhibiting ethylene biosynthesis and enhancing the antioxidant defense system. *Food Chem.*, 219:179–184. https://doi.org/10.1016/j.foodchem.2016.09.138

Ziaei, M. and A. Pazoki. 2022. Foliar-applied seaweed extract improves yield of common bean (Phaseolus vulgaris L.) cultivars through changes in biochemical and fatty acid profile under irrigation regimes. *J. Soil Sci. Plant Nutr.*, 22: 2969–2979. https://doi.org/10.1007/s42729-022-00860-6

الملخص العربي

تأثير الرش الورقي بمستخلصات الطحالب البحرية والنانو سيلينيوم على الصفات الخضرية وإنتاجية نبات الكينوا

داليا عبد العاطي سليمان

تشكل تقلبات المناخ تحديًا كبيرًا للأمن الغذائي العالمي، لاسيما في المناطق الجافة وشبه الجافة. تم تنفيذ التجربة الحقلية في المزرعة التجريبية التابعة لكلية العلوم الزراعية البيئية، جامعة العريش، والواقعة في شمال سيناء، مصر. تهدف هذه الدراسة إلى تقييم تأثيرات الرش الورقي بمستخلص الطحالب البحرية (SWE) وجزيئات السيلينيوم النانوية (Se-NPs)، سواء عند استخدامها منفردة أو مجتمعة، على النمو الخضري وإنتاجية صنف الكينوا (مصر٣) تحت ظروف الحقل خلال موسمين زراعيين متتاليين في شمال سيناء، مصر. نُفذت التجربة وفق تصميم القطاعات الكاملة العشوائية بنظام القطع المنشقة، حيث شملت معاملات مستخلص الطحالب البحرية مستويين (٠ و٣٠٠٠ ملجم/لتر)، ومعاملات السيلينيوم النانوي أربعة تراكيز (٠، ٠,٥، ١,٠، و٢,٠ جزء في المليون). تم قياس الصفات الخضرية والتي شملت: ارتفاع النبات (سم)، عدد الأوراق، مساحة الورقة (سم^2)، عدد الأفرع، طول الجذر (سم)، عدد الجذور، وزن الأوراق (جم)، وزن السوق (جم)، ووزن الجذور (جم)، عدد النورات، وزن النورات (جم) بالإضافة إلى مكونات المحصول مثل عدد العناقيد البذرية، وزن العناقيد البذرية، وزن البذور للنبات، وزن ألف بذرة، ومحصول البذور للفدان. أظهرت النتائج أن كلًا من SWE و Se-NPs حسّنا بشكل معنوي الصفات الخضرية والمحصولية، حيث حقق التداخل بينهما أعلى أداء في جميع الصفات المدروسة. وقد كان التفاعل بين SWE و Se-NPs فعالًا بشكل خاص في تحسين النمو الخضري ومحصول البذور، ويُعزى ذلك على الأرجح إلى آلية تكاملية تشمل تعزيز النشاط الهرموني، تقوية النظام المضاد للأكسدة، وتحسين امتصاص العناصر الغذائيةأدى الرش الورقي المشترك بمستخلص الطحالب البحرية (بتركيز ٣٠٠٠ ملجم/لتر) والسيلينيوم النانوي (بتركيز ٢ جزء في المليون) إلى تحسين معنوي كبير في كل من الصفات الخضرية ومكونات المحصول، مما يشير إلى وجود تأثير تآزري ساهم في تعزيز النشاط الفسيولوجي للنبات، وكفاءة امتصاص العناصر الغذائية، وزيادة الإنتاجية العامة. وتشير هذه النتائج إلى أن دمج المُحفزات الحيوية مثل مستخلص الطحالب البحرية مع جرعات منخفضة من السيلينيوم النانوي يُعد استراتيجية مستدامة لتحسين إنتاجية الكينوا تحت ظروف الإجهاد المناخي. ويُظهر الاستخدام المشترك للرش الورقي الطبيعي والمعتمد على تقنيات النانو إمكانات واعدة للتوسع في تطبيقه ضمن منظومات الزراعة الذكية المتوافقة مع التغيرات المناخية.

الكلمات المفتاحية:الكينوا، جزيئات السيلينيوم النانوية، مستخلص الطحالب البحرية، الزراعة المستدامة، الرش الورقي.