Mitigating the Harmful Effects of Hydrogen Peroxide by Spraying Zinc and the Amino Acid Selenocysteine on Okra Plants

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Abstract
This study was conducted in the experimental field of the College of Agriculture, University of Diyala, during the spring season of 2024. The research aimed to find effective strategies to counteract oxidative free radicals, specifically hydrogen peroxide (H_2O_2), and to understand certain physiological effects and adaptations of plants under stress conditions. The experiment was designed using the Split-Split Plot Design within a Randomized Complete Block Design (RCBD) with three replications. The main factor was hydrogen peroxide treatments at three concentrations (0, 3, and 6 mg L^{-1}), (hydrogen peroxide). The second factor was foliar application at two concentrations (0 and 100 mg Zn L^{-1}),(zinc). In sub split factor was foliar spraying with the amino acid selenocysteine at three concentrations (0, 25, and 50 mg L^{-1}), while the third factor was (selenocysteine). Okra plants of the Iraqi cultivar "Al-Bateera" were used in the experiment. The research was carried out according to the randomized complete block design (RCBD)and the split-plot system. The results indicated a reduction in the negative effects of hydrogen peroxide spraying on selenium percentage, leaf area, and the availability of nitrogen, phosphorus, and potassium in the soil when using the second concentration of zinc spraying (Zn100 mg L^{-1}), with recorded averages of 42.72 leaves per plant, 703.06 cm^2 leaf area,N 45.93 mg kg^{-1} soil,P 19.89 mg kg^{-1} soil, and 158.66 mg kg^{-1} soil. Additionally, the negative effects of moisture stress were mitigated across all studied traits by applying the highest selenocysteine concentration (50 mg L^{-1}). The combined treatment (Se50 + Zn100) outperformed the control across all parameters. Furthermore, the interaction (H6 + Se50 + Zn100) exhibited superior performance compared to (H6 + Se0 + Zn0) in all evaluated traits. The observed increase in the availability of essential nutrients in the soil is attributed to the role of zinc and selenocysteine in enhancing plant water and nutrient uptake efficiency while strengthening the plant's defense system against hydrogen peroxide-induced stress.

Key words: Hydrogen Peroxide, Zinc, Amino Acid Selenocysteine,Okra.

Introduction

This study examines the impact of biotic and abiotic stress on plants, leading to significant physiological changes such as the production of reactive oxygen species (ROS), reduced photosynthetic efficiency, and membrane damage, ultimately affecting yield and quality (1). Hydrogen peroxide (H_2O_2) is a type of ROS capable of damaging various cellular

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structures when excessively present in plants. However, it also acts as a potent signaling molecule mediating various physiological and biochemical processes (2.(

The presence of micronutrients plays a crucial role in enhancing plant growth under oxidative stress conditions. Foliar application of nutrients improves plant physiology, growth, and productivity (3). Zinc acts as an antioxidant and is essential for enzyme activation. It plays a critical role in auxin biosynthesis, promoting plant growth, regulating water uptake, and enhancing plant resistance to stress through foliar application. Additionally, zinc regulates various metabolic activities, including xylem development, sugar transport, cell wall structure, membrane permeability, and protein and carbohydrate metabolism (4.(

Amino acids are essential sources of nitrogen and are rapidly absorbed by plants, serving as key transporters of organic nitrogen. They play vital physiological roles in plant growth by influencing multiple metabolic pathways. Studies indicate a correlation between certain amino acids, such as selenocysteine, and stress resistance, starch biosynthesis, and protein interactions (5). Selenocysteine is recognized as the 21st amino acid in the genetic code, structurally similar to cysteine (Cys) but with selenium replacing sulfur. This subtle substitution grants selenocysteine (Sec) distinct chemical properties compared to cysteine. Sec is found in selenoproteins, which are involved in cellular maintenance, immune response, hormone regulation, and oxidative stress management (6.(

Okra (Abelmoschus esculentus L. Moench) is a vegetable crop belonging to the Malvaceae family. Native to Africa, it is widely cultivated in tropical and subtropical regions. It is a common summer vegetable grown for its seed-rich pods, which are cooked. Okra is widely used in culinary applications and has therapeutic benefits, including a high iodine content that aids in preventing goiter. Its leaves possess anti-inflammatory properties and are used in treating dysentery ((7 8)). Additionally, okra contains bioactive compounds such as flavonoids and ketones, which contribute to its antidiabetic, anticancer, antihypertensive, and antimicrobial properties (9.(

In Iraq, okra occupies a significant place in agricultural production and marketing, being cultivated across all provinces. However, according to a report by the Iraqi Ministry of Planning, Agricultural Statistics Directorate (2023), there has been a decline in okra production in recent years (10.(

The objectives of this study aimed to:

.1 To investigate the application of zinc and the amino acid selenocysteine in mitigating the harmful effects of hydrogen peroxide stress on okra plants.

.2 To examine the interaction between zinc and selenocysteine in enhancing the plant's resilience against hydrogen peroxide-induced stress.

Material and Methods

The experiment was conducted during the spring season of 2024 at the research station affiliated to Department of Horticulture and Landscape Engineering, College of Agriculture, University of Diyala. The study was carried out on march month 1, 2024, to October 15, 2024, using seeds of the Iraqi okra cultivar "Bateera." The soil was prepared by cleaning, plowing, and forming raised beds with a width of 60 cm, upon which two drip irrigation lines were laid. The okra seeds were sown alternately along the bed, with a spacing of 40 cm between plants in a single row, at a rate of four seeds per hole, which were later

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thinned to one plant upon germination. Drip irrigation lines were installed, with a 1-meter spacing between each line. The soil of the plastic house was analyzed in the soil laboratory at the College of Agriculture, University of Diyala. Soil samples were randomly collected from a depth of 0–30 cm and thoroughly mixed.

The experiment included three levels of hydrogen peroxide (0, 5, and 10 mg L^{-1}), labeled as (H0, H1, H2), two levels of foliar zinc application (0 and 100 mg L^{-1}) in the form of Zn-EDTA, labeled as (Zn0, Zn100), and three levels of selenocysteine foliar spraying (0, 5, and 100 mg L^{-1}), labeled as (Se0, Se1, Se2). The plants were sprayed with hydrogen peroxide 15 days after germination, followed by zinc application, and then selenocysteine. The spraying process was repeated three times at different intervals, with foliar application conducted early in the morning.

All treatments received identical agronomic practices following standard okra production methods. Irrigation was provided as needed, and preventive pesticide applications were performed to protect against diseases and pests. A balanced chemical fertilizer containing N, P, and K (20:20:20) was applied via fertigation in three doses: the first one week after planting, and the subsequent doses at two-week intervals. Weeding was carried out whenever necessary.

The experiment was designed as a factorial trial using a Split-Split Plot Design within a Randomized Complete Block Design (RCBD) with three replications. Hydrogen peroxide treatments were assigned as the main plots, zinc foliar application as the subplots, and selenocysteine foliar spraying as the sub-subplots. Statistical analysis was conducted using SPSS software, and means were compared using Duncan’s Multiple Range Test at a significance level of 0.05.

Studied Traits

- Leaf Area ($cm^2 plant^{-1}$(

Measured using an Area Meter or based on fresh weight. The average weight of 20 fully developed leaves from each experimental unit was taken at the end of the experiment, and discs of known area were cut from each leaf and weighed. The total leaf area was then calculated using the equation provided by Dvornic (1965:(

Total Leaf Area=Number of leaves per plant×Average leaf area\text{Total Leaf Area} = \text{Number of leaves per plant} \times \text{Average leaf area {

- Nitrogen, Phosphorus, Potassium, and Selenium Content

-Available nitrogen concentration in soil, mg N kg-1 soil. Measured by the method described in (Black 1965b) and (Bremner 1965(

-Concentration of available phosphorus in the soil, mg P kg-1 soil. Measured by the method Sommers and Olsen (1982) and others (1982.(

-Available potassium concentration in soil is mg K kg-1 soil. Measured by the method described in Page et al. (1982.(

-Selenium content was analyzed using an atomic absorption spectrometer, following the procedure described by Marczenok and Lenarczyk (1976.(

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Table (1): Some Chemical and Physical Properties of the Field Soil Before Planting

No.	Trait	Value	Unit
1	pH (1:1)	7.5	—
2	Electrical Conductivity (EC 1:1)	4.13	dS m^{-1}
3	Organic Matter	1.72	g kg^{-1}
4	Calcium Carbonate ($CaCO_3$)	152.13	g kg^{-1}
5	Available Nitrogen	16.32	mg kg^{-1}
	Available Phosphorus	9.17	mg kg^{-1}
	Available Potassium	183.26	mg kg^{-1}
	Available Zinc	0.63	mg kg^{-1}
6	Sand Content	572	g kg^{-1}
	Clay Content	235	g kg^{-1}
	Silt Content	193	g kg^{-1}
7	Soil Texture	Sandy Clay Loam	—

Results and Discussion:

Leaf Area (cm^2(

The statistical analysis results presented in Table 2 showed significant differences between the experimental factors for the leaf area trait. The spraying of hydrogen peroxide at level 0 resulted in the highest average leaf area of 815.42 cm^2, compared to level 6, which recorded the lowest average of 501.99 cm^2. Meanwhile, the treatment with zinc at level 100 significantly outperformed, with a value of 703.06 cm^2, compared to level 0, which had the lowest value of 640.27 cm^2. As for the amino acid selenocysteine treatment, the spraying at level 50 significantly outperformed with the highest value of 842.79 cm^2, compared to level 0, which recorded the lowest value of 514.44 cm^2. The results from the same table indicated significant differences for the two-way interaction between the study treatments for the leaf area trait. The interaction treatment of hydrogen peroxide at level 0 + zinc at level 100 showed significant superiority, reaching 866.93 cm^2, compared to the interaction of hydrogen peroxide at level 6 + zinc at level 0, which recorded the lowest value of 484.84 cm^2. The two-way interaction treatment of hydrogen peroxide at level 0 + selenocysteine at level 50 achieved the highest value of 1017.73 cm^2, compared to the interaction of hydrogen peroxide at level 6 + selenocysteine at level 0, which recorded the lowest value of 369.59 cm^2. Regarding the two-way interaction treatment of zinc at level 100 + selenocysteine at level 50, the highest value of 892.81 cm^2 was achieved, compared to the interaction of zinc at level 0 + selenocysteine at level 0, which recorded the lowest value of 491.06 cm^2. As for the three-way interaction, significant differences in the leaf area trait were observed. The three-way interaction treatment of hydrogen peroxide at level 0 + zinc at level 100 + selenocysteine at level 50 achieved the highest value of 1114.56 cm^2, compared to the two-way interaction treatment of hydrogen peroxide at level 6 + zinc at level 0 + selenocysteine at level 0, which recorded the lowest value of 354.58 cm^2.

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Table 2. Effect of Hydrogen Peroxide Treatment Combined with Zinc and Selenocysteine on the Leaf Area (cm²plant) of Okra Plants .

Zinc foliar spray	And selenocysteine	Spraying with hydrogen peroxide(mg L⁻²)			selenocysteine and spray
		0	3	6	
Zn0	0	607.93i	510.67 k	354.58 o	491.06 f
	25	762.90 e	685.11 g	463.00 m	637.00 d
	50	920.89 b	820.46 d	636.95 h	792.76 b
Zn 100	0	669.12 g	559.75 J	384.60 n	537.82 e
	25	817.10 d	726.58 f	491.95 l	678.54 c
	50	1114.56a	882.99c	680.99 g	892.81 a
Interaction of hydrogen peroxide and zinc spray		Spraying with hydrogen peroxide(mg L⁻²)			Zinc spray averages
		0	3	6	
Zn0		763.91 b	672.08 d	484.84 f	640.27 b
Zn100		866.93 a	723.11 c	519.14 e	703.06 a
Interaction of hydrogen peroxide and selenocysteine spray		Spraying with hydrogen peroxide(mg L⁻²)			Selenocystin spray averages
		0	3	6	
Se 0		638.53 f	535.21 g	369.59 i	514.44 c
Se 25		790.00 c	705.84 d	477.47 h	657.77 b
Se 50		1017.73a	851.72 b	658.92 e	842.79 a
peroxide spray Hydrogen averages		815.42 a	697.59 b	501.99c	

*The numbers with similar symbols and letters do not differ significantly according to the Duncan test at a 5% probability level. The following letters represent treatments: Zn0: No zinc spraying, Zn100: Zinc spraying at a concentration of 100 mg L⁻ ¹, Se0: No selenocysteine spraying, Se25: Selenocysteine spraying at a concentration of 25 mg L⁻ ¹, Se50: Selenocysteine spraying at a concentration of 50 mg L⁻ ¹, H0: No hydrogen peroxide spraying, H3: Hydrogen peroxide spraying at a concentration of 3 mg L⁻ ¹, H6: Hydrogen peroxide spraying at a concentration of 6 mg L⁻ ¹.

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Available Nitrogen in Soil (mg kg^{-1} soil)

The statistical analysis results in Table 3 show significant differences between the experimental factors for the ready nitrogen percentage in the soil. The spraying of hydrogen peroxide at the 0 level resulted in the highest average for this trait, reaching 55.64 mg kg^{-1} soil, compared to the 6 level, which recorded the lowest average of 36.12 mg kg^{-1} soil. As for the zinc treatment, spraying at the 100 level significantly exceeded the others, with a value of 45.93 mg kg^{-1} soil, compared to the 0 level, which recorded the lowest value of 44.98 mg kg^{-1} soil. Regarding the selenocysteine amino acid treatment, the spraying at the 50 level significantly showed the highest value, reaching 66.23 mg kg^{-1} soil, compared to the 0 level, which gave the lowest value of 22.54 mg kg^{-1} soil.

The table also indicates significant differences for the two-way interaction between the study treatments for ready nitrogen percentage in the soil. The two-way interaction spraying of hydrogen peroxide at the 6 level + zinc at the 100 level showed a significant superiority of 56.10 mg kg^{-1} soil compared to the two-way interaction spraying of hydrogen peroxide at the 0 level + zinc at the 0 level, which recorded the lowest value of 35.79 mg kg^{-1} soil. The two-way interaction of spraying hydrogen peroxide at the 6 level + selenocysteine at the 50 level recorded the highest value of 79.32 mg kg^{-1} soil, compared to the interaction of spraying hydrogen peroxide at the 0 level + selenocysteine at the 0 level, which recorded the lowest value of 17.97 mg kg^{-1} soil. Regarding the two-way interaction between zinc at the 100 level + selenocysteine at the 50 level, it achieved the highest value of 67.13 mg kg^{-1} soil, compared to the interaction of zinc at the 0 level + selenocysteine at the 0 level, which recorded the lowest value of 22.28 mg kg^{-1} soil.

As for the three-way interaction, significant differences were observed in the nitrogen content in the soil. The three-way interaction of spraying hydrogen peroxide at the 6 level + zinc at the 100 level + selenocysteine at the 50 level achieved the highest value of 80.34 mg kg^{-1} soil, compared to the two-way interaction of spraying hydrogen peroxide at the 0 level + zinc at the 0 level + selenocysteine at the 0 level, which recorded the lowest value of 17.72 mg kg^{-1} soil.

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Table 3: Treatment of the harmful effect of hydrogen peroxide by spraying zinc and the amino acid selenocysteine on available nitrogen in the soil (mg kg^{-1} soil(

Zinc foliar spray	And selenocysteine	Spraying with hydrogen peroxide(mg L^{-2})			and selenocysteine spray
		0	3	6	
Zn0	0	17.72 l	20.99 k	28.13 j	22.28 d
	25	38.33i	44.56 h	59.14 e	47.34 c
	50	51.31 g	66.40 d	78.30 b	65.34 b
Zn 100	0	18.22 l	21.63 k	28.54 j	22.80 d
	25	38.65 i	45.53 h	59.41 e	47.86 c
	50	52.53 f	68.52 c	80.34 a	67.13 a
Interaction of hydrogen peroxide and zinc spray		Spraying with hydrogen peroxide(mg L^{-2})			Zinc spray averages
		0	3	6	
Zn0		35.79 f	43.98 d	55.19 b	44.98 b
Zn100		36.46 e	45.23 c	56.10 a	45.93 a
of hydrogen Interaction peroxide and selenocysteine spray		Spraying with hydrogen peroxide(mg L^{-2})			Selenocystin spray averages
		0	3	6	
Se 0		17.97 i	21.31 h	28.34 g	22.54 c
Se 25		38.49 f	45.04 e	59.27 c	47.60 b
Se 50		51.92 d	67.46 b	79.32 a	66.23 a
peroxide spray Hydrogen averages		55.64 a	44.60 b	36.12 c	

Numbers with similar symbols and letters do not differ significantly according to the Duncan test at a 5% probability level. The following letters represent the treatments: Zn0: No zinc spray, Zn100: Zinc spray at 100 mg L^{-1}, Se0: No selenocysteine spray, Se25: Selenocysteine spray at 25 mg L^{-1}, Se50: Selenocysteine spray at 50 mg L^{-1}, H0: No hydrogen peroxide spray (mg L^{-1}), H3: Hydrogen peroxide spray at 3 mg L^{-1}, H6: Hydrogen peroxide spray at 6 mg L^{-1}

Available Phosphorus in Soil (mg kg^{-1} Soil) The statistical analysis results in Table 4 showed significant differences between the experimental factors for the available phosphorus in the soil. The spraying of hydrogen peroxide at level 0 resulted in the highest average for the phosphorus content in the soil, which was 23.89 mg kg^{-1}, compared to level 6, which had the lowest average of 15.70 mg kg^{-1}. Meanwhile, the experiment with zinc spraying at level 100 showed a

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significant improvement, with a value of 19.89 mg kg^{-1} compared to level 0, which recorded a lower value of 19.29 mg kg^{-1}. As for the amino acid selenocysteine treatment, the spraying at level 50 showed the highest value of 27.04 mg kg^{-1} compared to the level 0 treatment, which gave the lowest value of 13.07 mg kg^{-1}.The results in the same table also showed significant differences for the interaction between the experimental treatments for available phosphorus in the soil. The spraying interaction between hydrogen peroxide at level 6 and zinc at level 100 achieved a significant improvement of 24.29 mg kg^{-1} compared to the interaction between hydrogen peroxide at level 0 and zinc at level 0, which recorded the lowest value of 15.50 mg kg^{-1}. As for the interaction between hydrogen peroxide at level 6 and selenocysteine at level 50, the highest value was 32.13 mg kg^{-1} compared to the interaction between hydrogen peroxide at level 0 and selenocysteine at level 0, which recorded the lowest value of 9.82 mg kg^{-1}. Regarding the interaction between zinc at level 100 and selenocysteine at level 50, the highest value was 27.34 mg kg^{-1} compared to the interaction between zinc at level 0 and selenocysteine at level 0, which recorded the lowest value of 12.73 mg kg^{-1}.As for the triple interaction, significant differences were observed in the phosphorus content in the soil. The triple interaction between hydrogen peroxide at level 6, zinc at level 100, and selenocysteine at level 50 recorded the highest value of 32.38 mg kg^{-1} compared to the triple interaction between hydrogen peroxide at level 0, zinc at level 0, and selenocysteine at level 0, which recorded the lowest value of 9.62 mg kg^{-1}

Table 4. Mitigation of the Harmful Effect of Hydrogen Peroxide by Spraying Zinc and the Amino Acid Selenocysteine on Available Phosphorus in Soil (mg kg^{-1} Soil(

Zinc foliar spray	And selenocysteine	Spraying with hydrogen peroxide(mg L^{-2})			and selenocysteine spray
		0	3	6	
Zn0	0	9.62 m	12.64 l	15.94 i	12.73 f
	25	14.28 j	18.30 g	22.66 f	18.41 d
	50	22.62 f	25.74 d	31.88 b	26.74 b
Zn 100	0	10.02 m	13.38 k	16.82 h	13.41 e
	25	14.68 j	18.47 g	23.66 e	18.93 c
	50	23.01 f	26.62 c	32.38 a	27.34 a
Interaction of hydrogen peroxide and zinc spray		Spraying with hydrogen peroxide(mg L^{-2})			averages Zinc spray
		0	3	6	
Zn0		15.50 f	18.89 d	23.49 b	19.29 b
Zn100		15.90 e	19.49 c	24.29 a	19.89 a

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Interaction of hydrogen peroxide and selenocysteine spray	Spraying with hydrogen peroxide(mg L^{-2})			Selenocystin spray averages
	0	3	6	
Se 0	9.82 i	13.01 h	16.38 f	13.07 c
Se 25	14.48 g	18.38 e	23.16 c	18.67 b
Se 50	22.81 d	26.18 b	32.13 a	27.04 a
Hydrogen peroxide spray averages	23.89 a	19.19 b	15.70 c	

Numbers with similar symbols and letters do not differ significantly according to the Duncan test at a 5% probability level. The following letters represent the treatments: Zn0: No zinc spray, Zn100: Zinc spray at 100 mg L^{-1}, Se0: No selenocysteine spray, Se25: Selenocysteine spray at 25 mg L^{-1}, Se50: Selenocysteine spray at 50 mg L^{-1}, H0: No hydrogen peroxide spray (mg L^{-1}), H3: Hydrogen peroxide spray at 3 mg L^{-1}, H6: Hydrogen peroxide spray at 6 mg L^{-1}

The statistical analysis results in Table 5 sowing that the significant differences in the available potassium content in the soil among the experimental factors. Spraying with hydrogen peroxide at 0 mg L^{-1} resulted in the highest potassium content, reaching 172.25 mg kg^{-1}, while the 6 mg L^{-1} level recorded the lowest value of 140.75 mg kg^{-1}. Zinc spraying also had a significant effect, with the 100 mg L^{-1} level showing a higher potassium content (158.66 mg kg^{-1}) compared to the 0 mg L^{-1} level (156.98 mg kg^{-1}). Similarly, selenocysteine spraying at 50 mg L^{-1} led to the highest potassium content of 189.37 mg kg^{-1}, whereas the 0 mg L^{-1} level recorded the lowest value of 109.16 mg kg^{-1}. There were also significant interactions between the treatments. The combination of hydrogen peroxide at 6 mg L^{-1} and zinc at 100 mg L^{-1} resulted in a potassium content of 172.80 mg kg^{-1}, which was

significantly higher than the 139.39 mg kg^{-1} recorded for the combination of 0 mg L^{-1} hydrogen peroxide and 0 mg L^{-1} zinc. The interaction between hydrogen peroxide at 6 mg L^{-1} and selenocysteine at 50 mg L^{-1} showed the highest potassium content at 203.31 mg kg^{-1}, while the lowest value (98.30 mg kg^{-1}) was recorded for the 0 mg L combination of both treatments. The interaction of zinc at 100 mg L^{-1} with selenocysteine at 50 mg L^{-1} led to the highest potassium content of 189.83 mg kg^{-1}, compared to the lowest value of 107.80 mg kg^{-1} in the absence of both treatments. In the three-way interaction, the combination of hydrogen peroxide at 6 mg L^{-1}, zinc at 100

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mg L^{-1}, and selenocysteine at 50 mg L^{-1} resulted in the highest potassium content (203.41 mg kg^{-1}), while the absence of all three treatments recorded the lowest value (95.84 mg kg^{-1}.(

Table 5: Mitigating the Adverse Effect of Hydrogen Peroxide by Foliar Spraying of Zinc and the Amino Acid Selenocysteine on Available Potassium in Soil (mg kg^{-1} soil)

Zinc foliar spray	And selenocysteine	Spraying with hydrogen peroxide(mg L^{-2})			and selenocysteine spray
		0	3	6	
Zn0	0	95.84 p	108.11 n	119.46 l	107.80 f
	25	151.89 J	178.38 f	192.42 d	174.23 d
	50	170.45 h	193.12 c	203.20 a	188.92 b
Zn 100	0	100.76 o	109.35 m	121.4 k	110.52 e
	25	153.73 i	179.64 e	193.53 c	175.63 c
	50	171.82 g	194.25 b	203.41 a	189.83 a
Interaction of hydrogen peroxide and zinc spray		Spraying with hydrogen peroxide(mg L^{-2})			Zinc spray averages
		0	3	6	
Zn0		139.39 f	159.87 d	171.69 b	156.98 b
Zn100		142.10 e	161.08 c	172.80 a	158.66 a
Interaction of hydrogen peroxide and selenocysteine spray		Spraying with hydrogen peroxide(mg L^{-2})			Selenocystin spray averages
		0	3	6	
Se 0		98.30 i	108.73 h	120.46 g	109.16 c
Se 25		152.81 f	179.01 d	192.98 c	174.93 b
Se 50		171.14 e	193.68 b	203.31 a	189.37 a
Hydrogen peroxide spray averages		172.25 a	160.47 b	140.75 c	

Numbers with similar symbols and letters do not differ significantly according to the Duncan test at a 5% probability level. The following letters represent the treatments: Zn0: No zinc spray, Zn100: Zinc spray at 100 mg L^{-1}, Se0: No selenocysteine spray, Se25: Selenocysteine spray at 25 mg L^{-1}, Se50: Selenocysteine spray at 50 mg L^{-1}, H0: No hydrogen peroxide spray (mg L^{-1}), H3: Hydrogen peroxide spray at 3 mg L^{-1}, H6: Hydrogen peroxide spray at 6 mg L^{-1}

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Selenium Concentration in Leaves(%)

The statistical analysis results from Table 6 revealed significant differences between the experimental factors for the selenium concentration in the leaves. Spraying with hydrogen peroxide at level 0 resulted in the highest mean selenium concentration in the leaves at 0.44%, compared to level 6, which achieved the lowest mean of 0.36%. The zinc treatment at 100 mg L^{-1} level significantly increased the selenium concentration to 0.44%, compared to the 0 mg L^{-1} level, which recorded the lowest concentration of 0.36%. For the selenocysteine treatment, spraying at 50 mg L^{-1} significantly outperformed the other levels, with a value of 0.47%, compared to the 0 mg L^{-1} treatment, which had the lowest value of 0.32%.The table also indicated significant differences for the two-way interactions between the experimental treatments for selenium concentration in the leaves. The interaction of hydrogen peroxide spraying at level 6 + zinc at level 100 resulted in a significant increase, reaching 0.48%, compared to the interaction of hydrogen peroxide at level 0 + zinc at level 0, which resulted in the lowest value of 0.33%. Similarly, the interaction between hydrogen peroxide at level 6 + selenocysteine at level 50 recorded the highest value at 0.52%, compared to the interaction of hydrogen peroxide at level 0 + selenocysteine at level 0, which had the lowest value of 0.29%. The interaction between zinc at level 100 + selenocysteine at level 50 achieved the highest concentration of 0.55%, compared to the lowest concentration of 0.31% for the interaction of zinc at level 0 + selenocysteine at level 0. Regarding the three-way interaction, significant differences in selenium concentration were also observed. The highest value, 0.60%, was recorded for the interaction of hydrogen peroxide at level 6 + zinc at level 100 + selenocysteine at level 50, compared to the interaction of hydrogen peroxide at level 0 + zinc at level 0 + selenocysteine at level 0, which recorded the lowest value of 0.28%.

Table 6. Mitigating the Adverse Effect of Hydrogen Peroxide by Spraying Zinc and the Amino Acid Selenocysteine on Selenium Percentage in Okra Leaves(%)

Zinc foliar spray	And selenocysteine	Spraying with hydrogen peroxide(mg L^{-2})			and selenocysteine spray
		0	3	6	
Zn0	**0**	**0.28 l**	**0.32 jk**	**0.35 i**	**0.31 f**
	25	**0.33 ij**	**0.35 i**	**0.43 f**	**0.37 d**
	50	**0.38 h**	**0.38 h**	**0.45 e**	**0.40 c**
Zn 100	**0**	**0.30 k**	**0.33 j**	**0.37 h**	**0.33 e**
	25	**0.40 g**	**0.43 f**	**0.47 d**	**0.43 b**
	50	**0.50 c**	**0.56 b**	**0.60 a**	**0.55 a**
of hydrogen Interaction peroxide and zinc spray		**Spraying with hydrogen peroxide(mg L^{-2})**			**Zinc spray averages**

	0	3	6	
Zn0	**0.33 e**	**0.35 d**	**0.41 c**	**0.36 b**
Zn100	**0.40 c**	**0.44 b**	**0.48 a**	**0.44 a**
Interaction of hydrogen peroxide and selenocysteine spray	**Spraying with hydrogen peroxide(mg L^{-2})**			**Selenocystin spray averages**
	0	**3**	**6**	
Se 0	**0.29 g**	**0.32 f**	**0.36 e**	**0.32 c**
Se 25	**0.37 e**	**0.39 d**	**0.45 c**	**0.40 b**
Se 50	**0.44 c**	**0.47 b**	**0.52 a**	**0.47 a**
Hydrogen peroxide spray averages	**0.44 a**	**0.39 b**	**0.36 c**	

Numbers with similar symbols and letters do not differ significantly according to the Duncan test at a 5% probability level. The following letters represent the treatments: Zn0: No zinc spray, Zn100: Zinc spray at 100 mg L^{-1}, Se0: No selenocysteine spray, Se25: Selenocysteine spray at 25 mg L^{-1}, Se50: Selenocysteine spray at 50 mg L^{-1}, H0: No hydrogen peroxide spray (mg L^{-1}), H3: Hydrogen peroxide spray at 3 mg L^{-1}, H6: Hydrogen peroxide spray at 6 mg L^{-1}

Discussion of Results

The results of the experiment indicated that spraying the plant with hydrogen peroxide at a concentration of 6 mg L^{-1} caused a significant decrease in all the studied traits. Hydrogen peroxide (H_2O_2) is a type of reactive oxygen species (ROS) that leads to cellular structural damage. It also functions as a strong signaling molecule mediating physiological and biochemical processes in plants (2). Hydrogen peroxide is a weak acid within the ROS group, which is naturally produced inside plant cells. Its concentration increases when plants are exposed to various stresses due to the reduction of two electrons from an oxygen molecule with the help of the enzyme superoxide dismutase (SOD). H_2O_2 participates in several biochemical reactions, and at high concentrations, it causes oxidative damage to enzymes, membrane lipids, proteins, and other cellular components, leading to cell death. It is the only free radical capable of spreading through water channels (Aquaporins) and can travel greater distances inside the cell, causing damage in areas far from where it was produced. However, at lower concentrations, it functions as a signaling molecule, inducing resistance to both biotic and abiotic stresses, and it also contributes to root hair growth, xylem differentiation, lignification, and regulates the stomatal closure and opening processes to optimize plant growth and development (11). Spraying with zinc at a concentration of 100 mg L^{-1} resulted in increased rates of all the studied traits. This can be attributed to the essential role of zinc in plant metabolic activities, as it regulates various enzymes involved in biochemical reactions, leading to the synthesis of chlorophyll and carbohydrates (12). Additionally, zinc plays a crucial role in

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managing reactive oxygen species and protecting plant cells from oxidative stress. It also helps regulate stomatal function by controlling potassium levels in plant cells (13), and it plays a significant role in biomass formation (14). Zinc also contributes to the formation of nucleic acids, proteins, pollen production, fertilization, and germination (15). Zinc is essential for plant growth and development due to its role as a cofactor for about 300 enzymes and proteins involved in cell division, nucleic acid metabolism, and protein synthesis. These findings are consistent with those of. (16) in their study of the effect of foliar zinc application on okra growth, as well as with the results of (17) in evaluating the effects of foliar zinc on the growth and yield of okra. Spraying with the amino acid selenocysteine at a concentration of 50 mg L^{-1} resulted in a significant increase in the studied traits. This can be attributed to the role of selenocysteine in enhancing plant resistance to stress, promoting root and stem growth, improving nutrient uptake, and increasing the number of leaves. The increased leaf number led to enhanced plant activity and chlorophyll production (18). Additionally, the increase in these traits may be due to the action of selenium, a key component of the selenocysteine amino acid, which functions as an antioxidant in plants, granting them the ability to resist various stresses, including salinity, drought, high temperatures, and elevated concentrations of toxic elements and metalloids. The protection mechanism involves enhancing pigment synthesis, photosynthesis rate, and gas exchange.

Selenium also plays an important role in boosting the antioxidant defense system, reducing the accumulation of reactive oxygen species (ROS) and, consequently, oxidative stress (19.(

Conclusions

Spraying plants with hydrogen peroxide at a concentration of 6 mg L^{-1} led to a decrease in all the studied traits.

Spraying with zinc at a concentration of 100 mg L^{-1} improved vegetative growth and yield traits.

Spraying with the amino acid selenocysteine at a concentration of 50 mg L^{-1} resulted in a significant increase in vegetative growth and yield traits.

The interaction between hydrogen peroxide at concentration H0 and zinc at Zn100 showed a significant superiority in vegetative growth and yield traits.

Also, the interaction between hydrogen peroxide at concentration H0 and selenocysteine at Se50 led to a significant superiority in the studied traits.

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