



To What Extent Can Foliar Application of Nutrients and Hydrogen Peroxide Alleviate Soil Salinity Stress and Disease Severity in Potato Production?



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SOIL SALINITY stress is considered one of the most damaging abiotic stresses that worsen under climate change particularly in arid and semi-arid regions, limiting plant productivity and reducing several crop yields. The current study was conducted in an open field under abiotic (saline soil) and biotic stress (early blight disease caused by *Alternaria solani*) to evaluate the protective effects of selected nutrients (i.e., B, K, and Se), and H₂O₂ on potato crop. Foliar applied H₂O₂ alone or with a combination with of studied nutrients was effective in mitigating the adverse effects of studied stresses on growth and yield of potato. Foliar application of H₂O₂ + K promoted the vegetative growth parameters, chlorophyll content by more than 50% as compared to the control, whereas this treatment led to increase by 116, and 35.4% in total tuber weight and marketable tuber yield, respectively. The same trend was observed in plants treated with H₂O₂ + K which recorded the highest values in total carbohydrates and dry matter of potato compared to the control. The increase in ascorbate peroxidase, and catalase were 97.3 and 98.2 % compared to the control when potato treated with H₂O₂ and (Se + K), respectively. Whereas, the decrease rate in the electrolyte leakage were 43.7 and 34.1% in both seasons, respectively when potato plants treated with H₂O₂ + K. Surprisingly, foliar applied H₂O₂ treatments were found to be the best anti-stressor against studied disease (*Alternaria solani*), which recorded the lowest severity values (6.2, 8.1, and 10.6 %), for (H₂O₂ and K), H₂O₂ and (H₂O₂ and B), respectively in the first season. Among all treatments, foliar applied H₂O₂ + K was achieved the highest values of total net return (3,356 and 3,118 \$/ha), and economic efficiency (1.90 and 1.82) in both seasons, respectively. This study confirmed that the combined foliar application of selected nutrients with H₂O₂ is better than their sole application against studied stresses. This work also opens more windows to investigate other nutrients in different combinations against abiotic and/or biotic stresses.

Keywords: Ascorbate peroxidase; Boron; Catalase; Chlorophyll content; Potassium; Selenium; Tuber yield.

1. Introduction

Under climate change, the global soil salinity is considered one of the main and widespread challenges that hinder sustainable development goals related to agriculture, global food security, environmental sustainability, resource conservation, and nutrition (Mukhopadhyay et al. 2021; Sahab et al. 2021). Worsening the situation, climate change can increase the risks of soil salinity and land degradation especially in water-scarce regions (Kramer et al. 2025). The main problems of saline soils include the ionic toxicity (mainly Na⁺), osmotic stress, and oxidative damage as well as accumulation of excessive soluble salts causing oxidative stress and limiting plant growth and crop productivity (Zhu et al. 2024). Mitigation of soil salinity is a crucial issue that can be achieved through many approaches such as molecular breeding of salt-tolerant crops (Liang et al. 2024; Zhang et al. 2025), using of halophytes (Bazihizina et al. 2024), gypsum (Xu et al. 2023), biochar (Su et al. 2024), and many nutrients including silicon (Manimaran et al. 2025), selenium (Shalaby et al. 2017; Abdi et al. 2023), boron (Qu et al. 2024), and potassium (Han et al. 2022), as well as beneficial microbes (Gupta et al. 2023), organic amendments (Irin and Hasanuzzaman 2024; Li et al. 2025) and nanomaterials (Kwaslema and Michael 2024; Upadhyay et al. 2025).

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It is well-known that plant nutrition is considered one of the most effective approaches of reducing different stresses in agricultural crops (Kumari et al. 2022). Application of nutrients against soil salinity stress on cultivated plants was and still a crucial approach in mitigation of salinity stress. These nutrients can be applied to plants through mineral fertilization, organic and biofertilizers as well as nanofertilizers (Zafar et al. 2024). It is reported that organic fertilizers can manage saline soils sustainability by improving soil C and N pools (from 12 to 80 %), along with promoting the microbial activities (Ansari et al. 2024). Among these nutrients, boron, potassium and selenium are important elements for plant nutrition under stress. Boron is considered an anti-stressor by mitigating salinity stress and enhancing plant growth (Younis et al. 2024). Potassium is well-known that the only essential element which included in any plant component but control more than 60 enzymes in plants (Johnson et al. 2022). Potassium can totally control the detoxification of reactive oxygen species (ROS), promote protein synthesis, and photosynthesis under salinity stress (Anil Kumar et al. 2024). Selenium is the essential “poison” for human and animal nutrition, but a beneficial nutrient for plants (Hasanuzzaman et al. 2022). This element can mitigate the oxidative stress by modulating the plant antioxidant defense system, and enhancing salinity tolerance (Amerian et al. 2024; Mishra et al. 2025).

Among all reactive oxygen species, hydrogen peroxide can play a central role in regulating plant development and responses to stressful conditions (Shalaby et al. 2021; Qureshi et al. 2022). Hydrogen peroxide (H_2O_2) has a significant regulatory actor interrelated with signal transduction in different plants. H_2O_2 can also induce plants subjected to myriad of abiotic stresses by maintain cellular homeostasis and producing a free radical oxidative stress (Nazir et al. 2020). Under salinity stress, H_2O_2 can promote the accumulation of methylglyoxal (MG), inhibit the activity of plastid triose phosphate isomerase (pdTPI) and stimulate the sulfenylation of pdTPI at cysteine (Fu et al. 2023). H_2O_2 can activate genes involved in conferring tolerance and plant stress defense mechanism (Anam et al. 2024).

Therefore, the current study focuses on the impact of some selected nutrients (boron, potassium and selenium), and hydrogen peroxide in ameliorating the salinity stress and disease severity caused by *Alternaria solani* in potato production. Up to now, a number of studies have investigated the individual foliar application of studied nutrients or H_2O_2 on potato but few studies focused on the combined foliar application, especially with reference to Catalase and ascorbate peroxidase activities in addition to vegetative and yield parameters.

2. Materials and Methods

2.1. Experimental location and design

Two field experiments were performed at Horticulture Department Farm, Faculty of Agriculture, Kafrelsheikh University, Egypt during two successive winter growing seasons (i.e., 2023/2024 and 2024/2025). The main aim of this study was to evaluate the ameliorated effect of hydrogen peroxide and nutrients (B, K, and Se) foliar applications on the growth, quality, antioxidant activity and yield of potato crop. The experimental site is located at Kafr El-Sheikh city (N 31° 5' 52.162", E 56° 57' 31.716"). The physical and chemical properties of the experimental soil before planting from the depth of 0 – 30 cm according to Sparks et al. (2020) were tabulated in **Table 1**.

2.2. Field experiments and treatments

The main treatments included foliar application of B, Se, K, and hydrogen peroxide forming eight treatments beside the control or unsprayed plants (**Table 2**), in a field study using a randomized complete block design with three replications making a total of 27 experimental plots. The area of each plot was 14 m² comprising 4 rows, 5 m in length and 0.70 m in width and the in-row spacing was 25 cm. Healthy potato tubers (seeds) Spunta cultivar were planted on middle of the ridge and covered with the soil at 16th and 5th of November in both seasons, respectively and harvested after 120 days from planting. Different cultural practices including irrigations, fertilizations, hilling weeds, pest and diseases control were achieved as recommended for potato production guidelines according to the Ministry of Agriculture (Egyptian Ministry of Agriculture and Land Reclamation, 2023). All treatments were applied as foliar application at three times (i.e., 40, 55 and 70 days after planting; DAP). Concerning hydrogen peroxide, the applied dose was 20 mM L⁻¹ as prepared using hydrogen peroxide (50% solution) fulfilled by Power Chemical Company, Egypt. The applied dose of selenium (10 mg L⁻¹) was prepared from sodium hydrogen selenite (HNaO₃Se; Oxford Laboratory Reagent). Potassium was prepared from the commercial fertilizer of potassium sulfate (K₂SO₄ at 50 % K₂O) at the rate of 1000 mg L⁻¹. Regarding the applied boron, the source was boric acid (H₃BO₃, contained 17% B) at a rate of 100 mg L⁻¹.

Table 1. Main characteristics of soil used before conducting the experiments during growing seasons.

Soil analyses	Season 2023/2024	Season 2024/2025
Soil texture	Clay	Clay
Sand, %	20.8	21.7
Silt, %	24.8	25.0
Clay, %	54.4	53.3
pH (in 1:2.5 suspension)	8.56	8.68
EC (dS m ⁻¹)	4.29	4.35
Available N (mg kg ⁻¹)	20.4	24.8
Available P (mg kg ⁻¹)	08.9	10.8
Available K (mg kg ⁻¹)	247	272
Available B (mg kg ⁻¹)	1.35	1.57
Available Se (mg kg ⁻¹)	0.28	0.21

Table 2. Description of used treatments in the field experiments within the current study.

Treatment code	Treatment abbreviation	Details of the treatments
T1	Control	Untreated plants
T2	H ₂ O ₂	Spraying H ₂ O ₂ at the rate of 20 mM L ⁻¹
T3	Se	Spraying selenium at the rate of 10 mg L ⁻¹
T4	K	Spraying potassium at the rate of 1000 mg L ⁻¹
T5	B	Spraying boron at the rate of 100 mg L ⁻¹ as boric acid
T6	H ₂ O ₂ + K	Spraying both of H ₂ O ₂ (20 mM L ⁻¹) and potassium (1000 mg L ⁻¹)
T7	H ₂ O ₂ + B	Spraying both of H ₂ O ₂ (20 mM L ⁻¹) and boron (100 mg L ⁻¹)
T8	Se + K	Spraying both of selenium (10 mg L ⁻¹) and potassium (1000 mg L ⁻¹)
T9	Se + B	Spraying both of selenium (10 mg L ⁻¹) and boron (100 mg L ⁻¹)

2.3. Physiological and biochemical measurements

Vegetative growth traits including plant height (cm), number of leaves, number of branches, fresh and dry weights (g) per potato plants were measured at 80 days after planting (DAP). Relative color reading of chlorophyll content (SPAD) was also measured by SPAD meter (Minolta, Co., Ltd, Japan) at 80 DAP according to Yadava (1986). Five plants were randomly taken from each plot for measurements. The activities of catalase (CAT) and ascorbate peroxidase (APX) were determined in plant tissues on the 4th fully expanded potato leaf tip at 80 DAT, according to Aebi (1984), and Hossain and Asada (1984), respectively. Electrolyte leakage of potato plants was measured by an electrical conductivity meter (EC meter) at 80 DAP in both seasons according to Lutts et al. (1996). Total dry matter was determined by oven drying at 70°C to constant mass. The dry matter was computed as a percentage based on the ratio of dry to fresh mass. Superoxide level and activity was calculated by the methodology of Okuda et al. (1991). It was assessed in potato leaves at 80 DAP using the method of Elstner and Heupel (1976) by observing nitrate formation from hydroxyl amine.

2.4. Potato yield and quality

Tubers number and total yield per plant (g) were measured by counting and weighing tubers harvested of all plants in each plot at 120 DAP. Marketable tuber yield per hectare (Mg ha⁻¹) was calculated from tuber yield per plant. Quality parameters also were considered by measuring total carbohydrate and dry matter content. Total carbohydrates were determined by using a colorimetric method as described by Dubois et al. (1956).

2.5. Disease severity

Disease severity of natural infection with early blight disease caused by *Alternaria solani* of potato plants was assessed and recorded at 100 DAP. Ten plants of each treatment were scored based on visual disease symptoms from each treatment as described by Rao et al. (2016). General overview with a time table of the treatments and sampling during this study presented in the following flowchart (**Figure 1**).

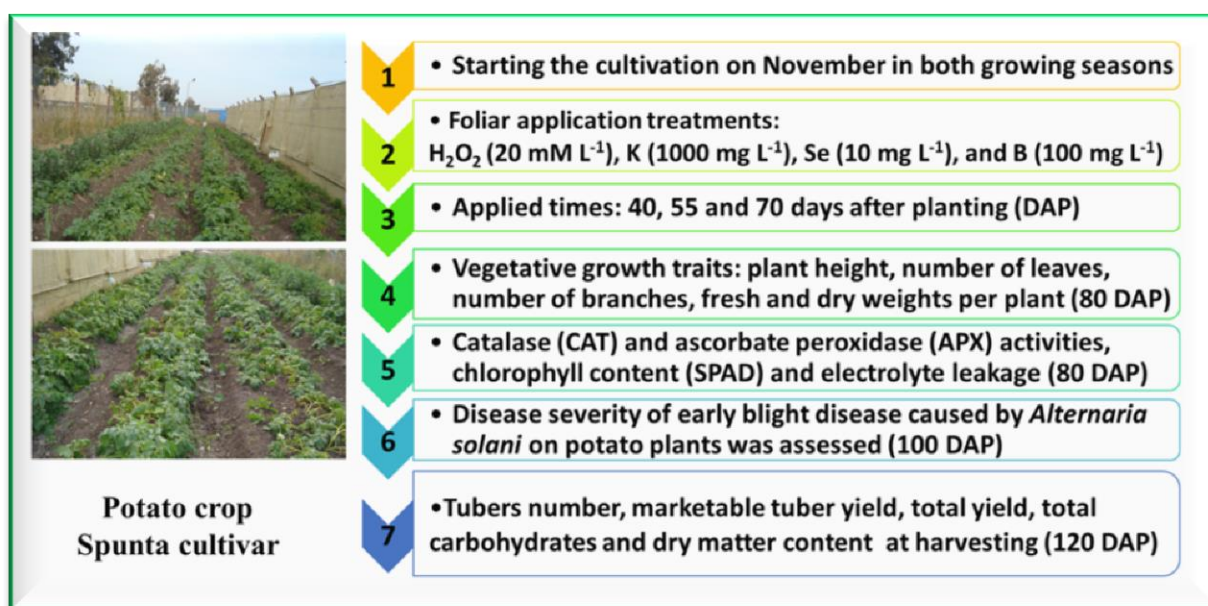


Fig. 1. Time table of the treatments and different measurements.

2.6. Economic evaluation

Economic evaluation of potato yield was calculated for all treatments included the estimating the total costs, net return and economic efficiency. The total costs were deducted from the total cash returns in both seasons as the resultant was the net return. Economic efficiency was also calculated according to **Doll and Orazem (1992)** by using the following equation:

$$\text{Net return (\$ ha}^{-1}\text{)} = \text{Total net return (\$ ha}^{-1}\text{)} - \text{Total costs (\$ ha}^{-1}\text{)}$$

$$\text{Economic efficiency} = \text{Total net return (\$ ha}^{-1}\text{)} / \text{total costs (\$ ha}^{-1}\text{)}$$

2.7. Statistical analyses

All data of the current investigation were analyzed using analysis of variance (ANOVA) appreciate for randomized complete block design with three replications (Gomez and Gomez 1984), performed with the CoStat Computer software package. A post-hoc Duncan's Multiple Range Test was used to compare significant treatment means (Snedecor and Cochran, 1989).

3. Results

3.1. Vegetative attributes

In the current study, selected vegetative parameters of potato including plant height, number of leaves or branches per plant, dry and fresh weight of shoots per plant were measured (**Table 3**). In general, the combined application of nutrients along with H₂O₂ (mainly H₂O₂ plus B or H₂O₂ plus K) recorded the higher values of previous attributes. Potato plants treated with H₂O₂ plus K were gained the highest values of all studied plant height (52.7; 56.7 cm), number of leaves (43.6 and 45.7), number of branches (5.0 and 5.5), shoot fresh weight (243 and 255 g) and shoot dry weight (21.2 and 24.8 g), in both seasons respectively followed by H₂O₂ plus B application. Interestingly, studied vegetative parameters for any combined application of nutrients from B, K, and Se were higher than the control in both seasons. All studied parameters were significantly influenced by foliar applied treatments except the number of branches per plant in the first season. The increasing rate was 53.6, 54.1, 38.9, 11.9 and 35.0 % in the first season for the vegetative attributes (from plant height to shoot dry weight) compared to the control, respectively.

Table 3. Response of potato vegetative attributes to applied treatments.

Treatments	Plant height (cm)	No. of leaves /plant	No. of branches /plant	Shoot fresh weight (g/plant)	Shoot dry weight (g/plant)
2023/2024 season					
Control	34.3 f	28.3 d	3.6 a	214 e	15.7 g
H ₂ O ₂	45.5 c	41.4 ab	4.6 a	233 b	18.8 cd
Se	43.6 d	39.1 b	4.5 a	235 b	19.5 b
K	45.1 c	41.5 ab	4.8 a	228 c	18.1 e
B	38.9 e	37.6 c	3.3 a	220 d	16.9 f
H ₂ O ₂ + K	52.7 a	43.6 a	5.0 a	243 a	21.2 a
H ₂ O ₂ + B	48.3 b	41.8 ab	4.2 a	235 b	19.7 b
Se + K	44.7 c	41.2 ab	4.1 a	244 a	20.9 b
Se + B	44.9 c	40.7 b	4.2 a	236 b	20.1 b
F. test	**	**	NS	**	**
2024/2025 season					
Control	40.2 e	30.5 d	3.9 c	225 e	18.4 d
H ₂ O ₂	52.7 ab	44.3 a	4.8 b	245 c	22.1 b
Se	48.8 c	40.8 bc	4.5 b	250 bc	22.9 b
K	52.9 ab	42.5 b	4.7 b	236 d	20.8 c
B	45.5 cd	40.1 bc	3.8 c	233 d	20.3 c
H ₂ O ₂ + K	56.7 a	45.7 a	5.5 a	255 b	24.8 ab
H ₂ O ₂ + B	55.1 a	43.8 ab	4.6 b	264 a	25.4 a
Se + K	50.2 b	43.1 ab	4.4 b	257 b	25.1 a
Se + B	49.6 b	42.2 b	4.5 b	250 bc	23.5 b
F. test	**	**	*	**	**

Different letters denote statistical differences among treatments according to Duncan's multiple range test ($p < 0.05$). NS: non-significant

3.2. Chlorophyll content

The impact of applied treatments was observed and evaluated on the chlorophyll content (SPAD) in potato leaves (**Figure 2**). In general, all values of studied treatments in the first season were higher than those in the second one. The control plants recorded the lowest values (41.4 and 35.5 SPAD) in both seasons compared to the other treatments of nutrients and/or hydrogen peroxide. As reported in case of vegetative parameters, the highest values of chlorophyll content were recorded by H₂O₂ plus K (47.9 and 44.4 SPAD) followed H₂O₂ singly by (46.8 and 42.6 SPAD) in both seasons, respectively. The increasing rate in chlorophyll content of the plants treated with H₂O₂ plus K was 15.7% compared to the control.

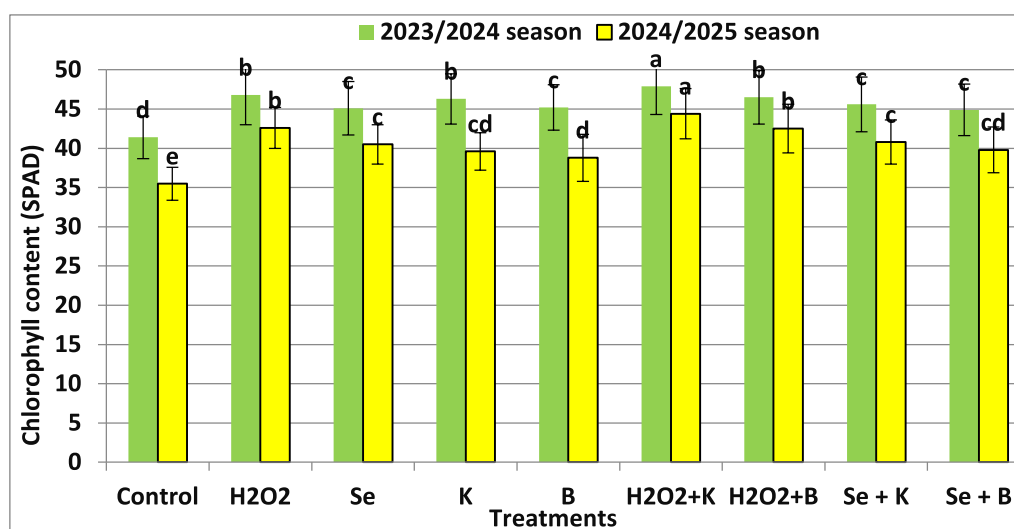


Fig. 2. Impact of different treatments on chlorophyll content of potato leaves at 80 DAP in both seasons. Different letters denote statistical differences among treatments according to Duncan's multiple range test ($p < 0.05$).

3.3. Potato tuber yield and quality

Potato crop production and its quality were evaluated in the present study. The measuring parameters of potato production were tuber weight (g/plant), tuber number /plant and marketable tuber yield (ton/ha; **Table 4**), whereas the quality attributes were tuber dry matter (%), Se content in potato tubers (ppm), and total carbohydrates (%; **Table 5**). As the previous trend for the vegetative growth and chlorophyll parameters, the highest values in potato yield and quality were belonged the H₂O₂ plus B followed by H₂O₂ plus K. The most obvious finding to emerge from the previous analysis is that Se content in potato tubers did not follow the previous trend. The combined foliar application of Se + K or Se + B produced the highest tubers content of Se among all treatments. The increase rate was 116, 19.6, 41.3, 17.7 and 35.4% in total tuber weight, total tuber number, marketable tuber yield, total carbohydrates and dry matter of potato compared to the control (438 g, 5.1, 31.35 ton and 30.5%) in the first season, respectively.

Table 4. Effect of different applied treatments on potato yield and quality during both years.

Treatments	Total tuber weight (g/plant)	Total tuber number /plant	Marketable tuber yield (ton/ha)
2023/2024 season			
Control	438 e	5.1 a	31.35 e
H ₂ O ₂	864 b	5.6 a	40.70 bc
Se	715 c	5.3 a	36.95 cd
K	662 d	5.7 a	37.70 c
B	629 d	5.3 a	33.19 d
H ₂ O ₂ + K	947 a	6.1 a	44.30 a
H ₂ O ₂ + B	876 b	5.7 a	41.15 b
Se + K	883 b	5.8 a	41.60 b
Se + B	855 b	5.5 a	39.92 bc
F. test	**	NS	**
2024/2025 season			
Control	475 e	5.4 a	33.15 d
H ₂ O ₂	1019 b	6.3 a	41.80 b
Se	1001 b	6.2 a	40.04 c
K	989 c	6.6 a	40.55 c
B	843 d	5.8 a	33.75 d
H ₂ O ₂ + K	1123 a	6.8 a	46.05 a
H ₂ O ₂ + B	1018 b	6.1 a	41.75 b
Se + K	989 c	6.3 a	40.95 bc
Se + B	979 c	5.9 a	40.15 c
F. test	**	NS	**

Different letters denote statistical differences among treatments according to Duncan's multiple range test ($p < 0.05$). NS: non-significant

Table 5. Effect of different applied treatments on selenium content, total carbohydrates and dry matter percentages of potato tubers in both seasons.

Treatments	Se content in potato tubers (ppm)		Total carbohydrates (%)		Dry matter (%)	
	1 st season	2 nd season	1 st season	2 nd season	1 st season	2 nd season
Control	0.053 f	0.074 g	30.5 e	31.3 d	18.1 e	18.6 d
H ₂ O ₂	0.183 e	0.209 f	35.9 d	36.6 c	23.6 b	24.3 b
Se	0.740 c	0.815 b	37.3 c	36.8 c	22.8 c	23.9 b
K	0.731 c	0.457 d	31.4 e	32.2 d	24.2 a	24.7 ab
B	0.251 d	0.334 e	35.8 d	36.3 c	19.8d	20.3 c
H ₂ O ₂ + K	0.154 e	0.226 f	35.9 d	37.5 c	24.5 a	25.3 a
H ₂ O ₂ + B	0.853 b	0.699 c	37.5 c	38.2 c	23.9 b	24.4 ab
Se + K	1.816 a	2.023 a	40.7 b	41.5 b	23.4 b	24.6 ab
Se + B	1.998 a	2.019 a	41.6 a	42.7 a	22.8 c	24.1 b
F. test	**	**	**	**	**	**

Different letters denote statistical differences among treatments according to Duncan's multiple range test ($p < 0.05$)

3.4. Potato enzyme activities and electrolyte leakage

The biochemical attributes in potato leaves were evaluated by measuring both enzyme activities (catalase and ascorbate peroxidase) and electrolyte leakage (**Table 6**). These findings are somewhat surprising given the fact that about Se and H₂O₂ and their role under salinity stress. Concerning CAT activity, Se is alone or in a combination with K or B achieved significantly the higher values among all foliar treatments, whereas H₂O₂ was recorded this trend regarding APX. Regarding the electrolyte leakage, the best foliar application of treatments that significantly decreased this parameter was H₂O₂ + K (36.8 and 39.1 %), respectively in both seasons. The increase rate in APX, and CAT were 97.3 and 98.2 % compared to the control when potato treated with H₂O₂ and (Se + K), respectively. Whereas, the decrease rate in the electrolyte leakage were 43.7 and 34.1% in both seasons, respectively when potato plants treated with H₂O₂ + K.

Table 6. Response of enzyme activities (catalase and ascorbate peroxidase) and electrolyte leakage to applied treatments in potato.

Treatments	Electrolyte leakage (%)		Catalase (CAT)	Ascorbate peroxidase (APX)
	2023/2024	2024/2025	$\mu\text{M H}_2\text{O}_2 \text{ g}^{-1} \text{ FW min}^{-1}$	
Control	65.4 a	59.3 a	331 e	18.8 d
H ₂ O ₂	39.9 d	42.7 d	581 b	37.1 a
Se	39.5 d	41.8 e	639 a	31.5 bc
K	45.7 c	46.6 c	410 c	19.5 d
B	53.3 b	50.1 b	383 d	18.7 d
H ₂ O ₂ + K	36.8 e	39.1 f	593 b	36.7 a
H ₂ O ₂ + B	39.6 d	40.7 f	584 b	30.6 c
Se + K	40.4 d	46.9 c	656 a	33.9 b
Se + B	46.9 c	44.6 c	630 a	33.5 b
F. test	**	**	**	**

Note: enzymes activities were measured only in the second season

Different letters denote statistical differences among treatments according to Duncan's multiple range test ($p < 0.05$)

3.5. Disease severity

After 100 days from planting, the disease severity of natural infection with early blight disease caused by *Alternaria solani* of potato plants was evaluated. The response of potato plants to foliar applied treatments was presented by calculating the disease severity percentage (**Figure 3**). The highest value of this disease severity can be noticed for the control treatment (up to 50.3 %), followed by the plants treated with B alone (up to 35.7 %), whereas the best tolerant plants (lower to 6.2%) treated with H₂O₂ + K. Surprisingly, foliar application of H₂O₂ treatments were found to be the best anti-stressor against studied disease (*A. solani*), which recorded the lowest severity values (6.2, 8.1, and 10.6 %), for (H₂O₂ + K), H₂O₂ and (H₂O₂ + B), respectively in the first season.

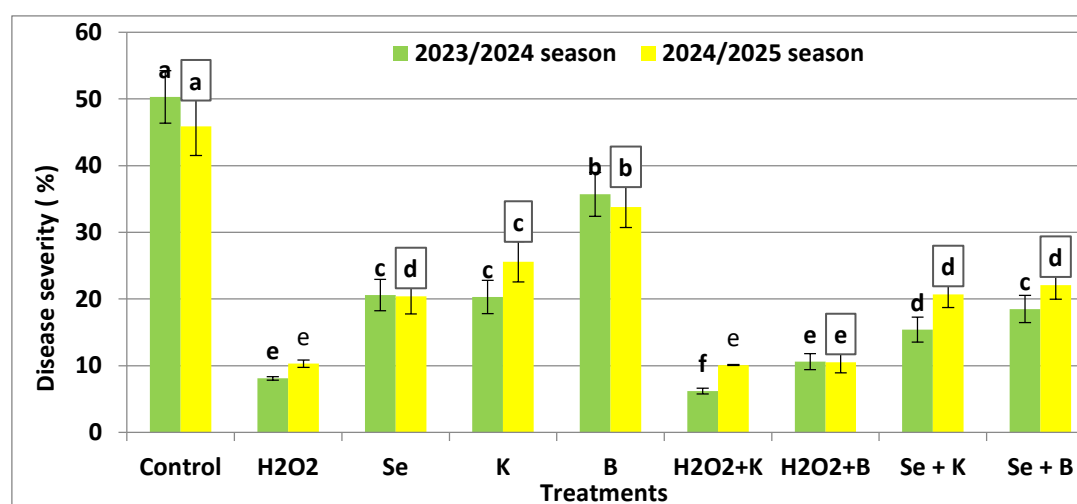


Fig. 3. Effect of different applied treatments on disease severity percent of early blight disease of potato plants in both seasons. Different letters denote statistical differences among treatments according to Duncan's multiple range test ($p < 0.05$).

3.6. Effects of different applied treatments on levels of Superoxide in potato plants

The obtained results in Figure 4 showed that foliar applications considerably reduced levels of superoxide in salt-stressed potato plants. The level of superoxide increased significantly as a result of H_2O_2 + B treatments and Se + B which is bit similar to control treatment. However, treatments of 2, 6 and 8 showed decreased level of superoxide. Interestingly enough that treatments 3, 4 and 5 showed significantly decreased level of superoxide. Low levels of superoxide correlated to high levels of superoxide dismutase (SOD) in potato leaves in most cases.

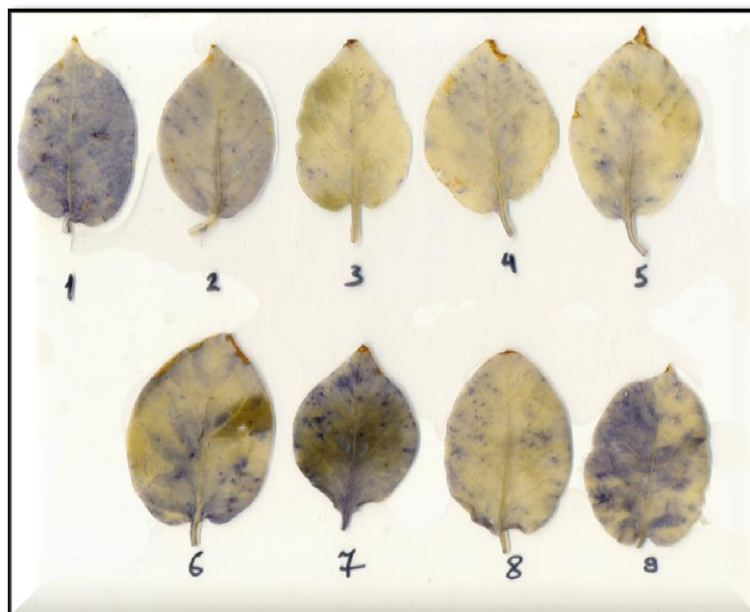


Fig. 4. Superoxide levels in potato leaves at 80 DAP as affected by different foliar treatments.

3.7. Economic evaluation

Economic evaluation of potato yield with all foliar applied treatments was done by estimating the cultivation cost, tubers yield, income (crop value), net return and economic efficiency (Table 7). The total costs were deducted from the total cash returns in both seasons as the resultant was the net return. The inputs were; 3,694 \$ ha^{-1} constant costs (114 \$ fertilizers, 23.8 \$ tillage, 1737 \$ potato seeds, 47.6 \$ planting cost, 57.12 \$ irrigation, 476 \$ pesticides, 142.8 \$ labors, 142.8 \$ harvest and 952 \$ rental value of land area/ha). The outputs included overall return per hectare that calculated as “tuber yield $\times$ the price”, where potato price was 160 \$ per ton of tubers in the first season. The net return was calculated as “Total return ha^{-1} – Total cost ha^{-1} ”. The inputs were; 3741 \$ ha^{-1} constant costs (116 \$ fertilizers, 24.5 \$ tillage, 1761 \$ potato seeds, 48.5 \$ planting cost, 57.4 \$ irrigation, 490 \$ pesticides, 145 \$ labors, 146 \$ harvest and 952 \$ rental value of land area/ha). The outputs were; overall return per hectare that calculated as “tuber yield $\times$ the price”, where potato price was 150 \$ per ton of tubers in the second season. Among all the treatments, foliar applied H_2O_2 + K was achieved the highest values of total net return (3,356 and 3,118 \$/ha), and economic efficiency (1.90 and 1.82) in both seasons, respectively. These values followed by plants treated with Se + K recording (2,929 and 2,358 \$/ha), and (1.786 and 1.623), in both seasons, respectively.

Table 7. Economic evaluation of different treatments and different parameters.

Treatments	Overall return (\$/ha)		Total cost (\$/ha)		Total net return (\$/ha)		Economic efficiency	
	First season	Second season	First season	Second season	First season	Second season	First season	Second season
Control	5,016	4,972	3,693	3,751	1,322	1,221	1.358	1.326
H_2O_2	6,512	6,270	3,717	3,775	2,794	2,494	1.752	1.661
Se	5,912	6,060	3,712	3,770	2,199	2,289	1.592	1.607
K	6,032	6,082	3,713	3,771	2,318	2,311	1.624	1.613
B	5,310	5,062	3,700	3,758	1,609	1,313	1.435	1.347
H_2O_2 + K	7,088	6,907	3,731	3,789	3,356	3,118	1.900	1.823
H_2O_2 + B	6,584	6,262	3,718	3,776	2,865	2,485	1.771	1.658
Se + K	6,656	6,142	3,726	3,784	2,929	2,358	1.786	1.623
Se + B	6,387	6,022	3,713	3,771	2,673	2,250	1.720	1.597

4. Discussion

Soil salinity stress is considered a global problem facing by several zones all over the world. The present study was carried out to highlight the impact of some selected nutrients (i.e., boron, potassium and selenium), alone and/or in combination with hydrogen peroxide to ameliorate the salinity stress and disease severity in potato. This section needs more justification and explanation to answer the main question of this work: To what extent can foliar application of nutrients and hydrogen peroxide alleviate soil salinity stress and disease severity in potato production? To answer this question, it is recommended to discuss the impact of applied nutrients and hydrogen peroxide in promoting the production of potato under abiotic (salinity), and biotic (blight disease caused by *A. solani*) stress.

Concerning the response of potato to abiotic stress (soil salinity), the vegetative parameters, chlorophyll content, CAT, POX, electrolyte leakage, yield and yield quality were evaluated and discussed in this section. Regarding the vegetative parameters, the most interesting finding was the distinguished role of H_2O_2 under soil salinity stress when applied alone or in a combination with studied nutrients (i.e., B, K, and Se). All studied vegetative attributes of potato were higher after treating with H_2O_2 compared to the control and other treatments. Among foliar applied H_2O_2 treatments, $H_2O_2 + K$ is the best treatment followed $H_2O_2 + B$. What is the expected mechanism of applied H_2O_2 ? Foliar application of H_2O_2 has a mitigate impact on potato under salinity stress through mainly by stimulating the physiological processes, protecting against oxidative damage and enhancing the potato's antioxidant capacity leading to a stronger defense against stress (Mariyam et al. 2023). It could be summarized the main mechanisms of potato against soil salinity stress problems and the action of applied treatments in **Figure 5**. The previous ameliorative impact of H_2O_2 under salinity stress was confirmed on many plants such as bell pepper (Aragão et al. 2023), cotton (Nóbrega et al. 2024), soursop (*Annona muricata* L.) (Capitulino et al. 2023), broccoli (Shalaby et al. 2023), cucumber (Shalaby et al. 2021), passion fruit tree (*Passiflora edulis*) (dos Santos et al. 2024), potato (El-Ghamry et al. 2024), and *Arabidopsis thaliana* (Xiao et al. 2025).

Potassium is an essential nutrient for growth plants, which can promote more than 60 enzymes in plants. In the present study, K alone or in a combination with H_2O_2 or Se has shown a positive correlation with anti-stress action against both biotic and abiotic stress. The role of K in control the forming and translocation of sugars from leaves to tubers of potato under stress is a distinguished issue. The suggested mechanism of applied K under salinity stress may include regulate the ionic homeostasis (by improve root K^+ uptake and K^+/Na^+ ratio), osmotic adjustment (by lower cell water potential, and maintain turgor as a primary osmolyte), antioxidant defense (by activate key antioxidant non- and enzymatic compounds), photosynthesis activity (by regulate stomatal opening, protect chlorophyll, and activate photosynthetic enzymes), and phloem translocation (by enhance phloem transport of photosynthetic or sugars to the tubers) (Basu et al. 2021; Chourasia et al. 2021; Kumari et al. 2021; Naz et al. 2021; Haque et al. 2023; Liu et al. 2025). The observed correlation between the combined foliar application of studied nutrients and H_2O_2 was observable more than the individual application of studied treatments. This might be explained in a synergistic effect under salinity stress.

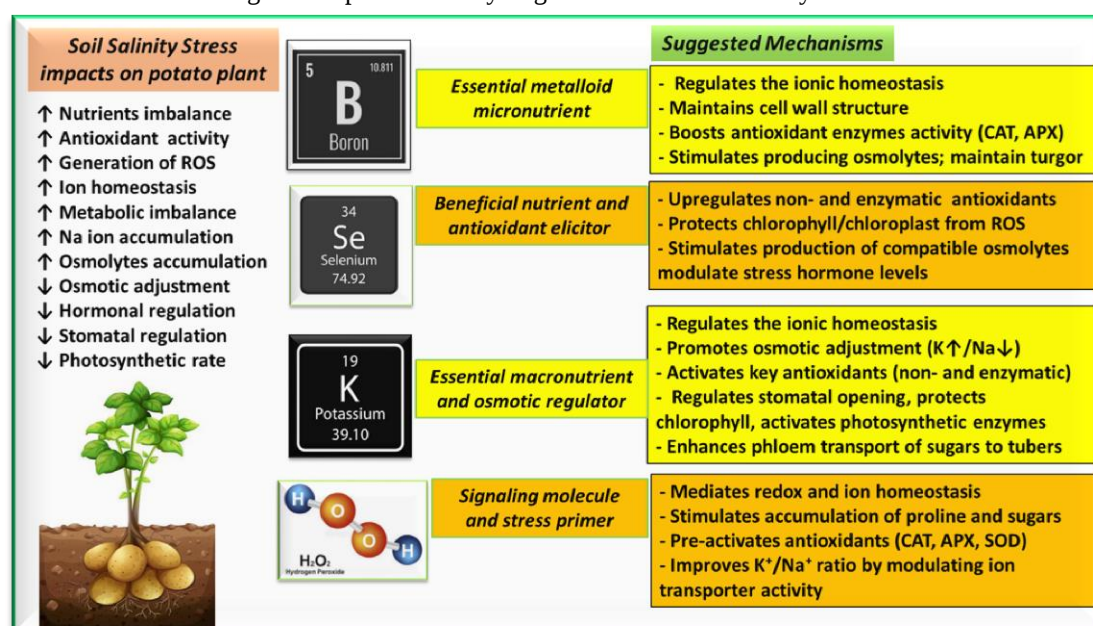


Fig. 5. Different suggested mechanisms in dealing potato with soil salinity stress and the role of selected nutrients and hydrogen peroxide.

Concerning selenium and its role on stressful plants, a long story of this element against stress was issued as reported for human and animal. In the present study, the combined foliar application of Se alone or with B or/and K was compared to the control and other treatments. This element was found to be more effective in increasing the potato tolerant to salinity stress after combined foliar application with B or K. This means that this combined application represents a synergistic approach more than the individual application of studied treatments. What is the suggested mechanism of the ameliorative role of Se against salinity stress? It is well-known that selenium has a protective role against stress in plants along with Se-interact with antioxidants, and phytohormones to promote plant growth (Ikram *et al.* 2024). The role of Se in the present study was obvious and this action was more than perfect when combined with B or K as recorded for the economic efficiency and studied enzyme activities (CAT and APX). The suggested mechanism of Se against studied stress may back to promote the antioxidant defense system by regulating the antioxidant enzymes and boost non-enzymatic antioxidants (ascorbate and glutathione), ion homeostasis (by reducing Na^+ uptake and protecting root functions), osmotic adjustment (by stimulating production of compatible osmolytes like proline, and sugars), and hormonal regulation by modulate stress hormone levels (Nedjimi 2024; Somagattu *et al.* 2024; Abdullah *et al.* 2025).

Boron is considered an essential metalloid micronutrient used for salinity stress mitigation at the cellular, molecular and the whole-plant levels (Qu *et al.* 2024). In the present work, the combined foliar applied H_2O_2 + B achieved the preferable results in all studied parameters in potato under biotic and abiotic stress followed by B + Se then B alone. The most distinguished results was received when B alone foliar applied (higher disease severity), but the more resistant to such disease was achieved after treating potato plants with H_2O_2 + B. The suggested mechanism of applied B against soil salinity and early blight disease caused by *A. solani* might back to antioxidant action by boosting activity of antioxidant enzymes (CAT, APX), osmotic adjustment by stimulate production of osmolytes (mainly proline, sugars), ion homeostasis by improve K^+/Na^+ ratio and reduce Na^+ uptake, membrane stability by stabilize membrane structure, and reduce ion leakage (Qu *et al.* 2024; Younis *et al.* 2024; Vera-Maldonado *et al.* 2024; Camlica 2025).

This study opened new windows about the role of nutrients along with H_2O_2 under both biotic and abiotic stress (soil salinity). The common case study in previous studies was the individual study of these nutrients or H_2O_2 and few studies were carried out in a combination. The combined foliar application of nutrients with/without H_2O_2 could be considered more effective case study as a common in the nature. Our results are in agreement with results of Alkharpotly *et al.* (2018) on Se and B, Tariq *et al.* (2022) on boron, Shalaby *et al.* (2017) and El-Ghamry *et al.* (2024) on Se, Chen *et al.* (2025) on Se, Wilmer *et al.* (2022) on K, Camlica (2025) on both Se and B, Iqbal *et al.* (2023), on H_2O_2 .

5. Conclusions

Several million hectares all over the world are affected by soil salinity. Salinity stress is a very common feature of arid and semi-arid lands, which might cause a huge loss in the agricultural sector with possible increase due to current climate change. The main possible approaches in minimizing salinity stress may include crop breeding and the agronomical strategies. Foliar application of nutrients (i.e., B, K, and Se), and H_2O_2 were selected in the current work against abiotic (soil salinity) and biotic stress (early blight disease caused by *A. solani*). This study confirms that combined foliar application of study nutrients with H_2O_2 recorded the preferable results compared to the individual application or the control. For example, applied B alone was led to higher disease severity from *A. solani* but combined foliar application with H_2O_2 enhanced potato resistance to such disease. The same trend for Se or K can be observed as the combined foliar application can maximize their benefits against both abiotic and biotic stress under the studied conditions. Therefore, this study opens several questions concerning the combinations of different nutrients and their roles under stress.

Declarations

Ethics approval and consent to participate

Author Contributions: All authors helped prepare the MS and agree to publish it.

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