International Journal of Nutrology
(Official Journal of the ABRAN - Brazilian Association of Nutrology)

DOI: 10.54448/ijn26SI304

ORIGINAL ARTICLE

Synergistic effects of spray with selenium and succinic acid and adding seaweed extract in lemon transplants growth and leaves mineral content

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DOI: https://doi.org/10.54448/ijn26SI304
Received: 04-28-2026; Revised: 07-01-2026; Accepted: 08-14-2026; Published: 08-15-2026; IJN-id: e26SI304

Editor: Dr. Fernando Alberto Carrasco Naranjo, MD, MSc, MPH.

Abstract

This experiment was conducted in wooden shade belonging to Department of Horticulture and Landscape Engineering, College of Agricultural Engineering Sciences, Univ. Baghdad in Abu Ghraib, during 2025 growing season, using local lemon transplants. 162 uniform transplants were brought in for experiment. Factors of study experiment included a spraying with selenium at three concentrations; without spray (S_0), spraying at 5 mg.L^{-1} (S_5) and spraying at 10 mg.L^{-1} (S_{10}), As for succinic acid spray, they were sprayed in three levels, without spray (A_0), spraying at 100 mg.L^{-1} (A_{100}) and spraying at 200 mg.L^{-1} (A_{200}) and addition of two levels of seaweed extract to soil, without addition (F_0), and 20 ml. transplant^{-1} (F_{20}). A factorial experiment was conducted using a randomized complete block design (RCBD) with three replications and three transplants per experimental unit. Experimental results showed that selenium spray at 10 ml.L^{-1}(S_{10}) significantly increased in plant height of 8.52 cm, highest leaf area of 27.23 cm^2, leaves nitrogen content of 2.09 %, phosphor content of 0.348 % and leaves potassium content of 1.82 %. Results also showed that succinic acid spray especially at 200 mg.L^{-1} (A_{200}), showed significant superiority in increased in plant height of 8.75 cm, leaf area of 29.06 cm^2, leaves nitrogen content of 2.01%, phosphor of 0.345 % and leaves potassium content of 1.82 %. Seaweed extract adding also affected, especially adding 20 ml.transplant^{-1} (F_{20}) and gave highest increasing of plant height of 8.95 cm, highest leaf area of 27.84 cm^2, leaves nitrogen content of 2.06%, phosphor of 0.348 % and leaves potassium content of 1.74 %. Twice and triple interactions between study factors significantly affected in all studied traits.

Keywords: Succinic acid. Growth. Lemon. Leaf mineral.

Introduction

One of most significant varieties of citrus in genus Citrus is lemon (*Citrus limon*). Its trees are small, evergreen trees that can grow up to six meters in height. Depending on species, its petioles can have wings or not, and its leaves are pale green. The blade is leathery, smooth, and varies in size, shape, and level of serration. It possesses tiny, sharp spines, oil glands, and many embryos in its seeds. It has médium-sized, crimson-white flowers and new growth that is crimson in hue. When ripe, fruits are long and have a pale-yellow color **[1,2]**.

Citrus trees have a unique status because of their economic, medicinal, and nutritional value. Whether eaten fresh or dried, they have a high nutritional value since they contain health-promoting vitamins C and B1. In addition, they have a high proportion of carbohydrates and minerals including calcium, potassium, phosphorus, magnesium, iron, sulfur, sodium, and other components. Pectin, which is utilized in numerous food sectors, is also present in them [3,4]. In terms of production volume, lemons are the third most significant citrus fruit in the world. India is ranked one, then Mexico, China, Argentina, and Brazil, in that order. 22,000,000 tons of lemons were produced worldwide [5].

In terms of amounts of lemons produced locally, Wasit Governorate came in first, followed by Salah al-Din and Diyala. There were an estimated 291,487 productive lemon trees in Iraq, with an average output of 18.4 kg per tree and a total production of 5,375 tons [6]. In terms of yield per tree and overall output, Iraq's lemon production is regarded as low when compared to global production. This is due to the neglect of essential tree care practices, including integrated fertilization programs, irrigation, pruning, fruit storage, and marketing, despite the product's commercial desirability in local markets.

Grains are often among agricultural products with the highest selenium content, and amount of selenium in plant tissues is dependent on its concentration in soil. Plants require limited levels of selenium, but study in this field is still in its infancy and more time is needed to learn more about function of selenium in plants life cycle and negative consequences of either excess or shortage. In this sense, it has been established that selenium plays a role in glutathione peroxidase enzyme's action system, which shields cells' internal structure from oxidation. It is also widely present in tissues, coupled to amino acids where a sulfur atom is swapped out for a selenium atom. It is still up for dispute how important selenium is for plants. Selenium can postpone senescence, boost seedling growth, and strengthen plants' resistance to oxidative stress brought on by UV exposure. It has recently been demonstrated to control the water status of plants in high-temperature and drought environments. Enhancing antioxidant activity linked to elevated glutathione peroxidase (GSH-Px) activity somewhat mitigates the stress brought on by senescence. Additionally, selenium helps to reduce elements toxicity. Sulfur and selenium are two nutrients that are absorbed through similar pathways and have extremely similar chemical characteristics [7,8].

Some experiments were conducted that studied effect of spraying selenium on growth of fruit trees. An experiment was conducted with aim of studying effects of spraying selenium at 50 ppm on growth and production of orange trees of Valencia cultivar, either in combination with spraying potassium silicate and Nile power compound [9] found that there was a significant increase in shoot length, their thickness, and leaf area when spraying selenium compared to not spraying. In order to assess effects of spraying with nano-selenium at various concentrations and its interaction with irrigation water quality on chemical properties, nutrient content, and chlorophyll content, a study by [10] was also carried out on three citrus rootstocks. The results indicated that treatment with nano-selenium at a concentration of 2 mg.L^{-1} resulted in a significant increase in nitrogen and phosphorus concentrations in leaves as well as a marked increase in total chlorophyll content in comparison to control treatment.

According to the systematic nomenclature of organic compounds, succinic acid (also called amber acid or butanedioic acid) is a dicarboxylic acid with the chemical formula $C_2H_6O_4$, which can alternatively be expressed as $C_2H_4(COOH)_2$. It exists as colorless crystals with outstanding water solubility under normal circumstances. Succinates are this acid's salts and esters. The 17th century saw the discovery of succinic acid. On an industrial scale, it has been separated from lignite, amber, and a variety of plants and critters. The material has demonstrated its versatility as an energy source and is a crucial part of all living things' metabolic activities. This acid in a variety of ways affects plants. It strengthens root system, promotes green mass formation, improves nutrients absorption from soil, and facilitates young transplants rapid adaptation to new environments. Additionally, it strengthens plant immunity and promotes disease recovery.

Additionally, it speeds up commencement of flowering and fruiting, increases production of chlorophyll in plant cells, and aids in removal of nitrates and other toxins from plants. In addition to improving fruit quality and quantity, this helps plants adapt to adverse natural conditions including drought and high humidity. Fruit cuttings are encouraged to root and growth of vegetative buds is stimulated by a solution of this acid. It helps plants better adapt to their surroundings even though it is not a fertilizer [11,12]. Very few studies have been conducted to determine response of fruit trees to succinic acid spraying.

One such study, by [13] conducted a study aimed at determining effect of spraying two levels of succinic acid, at 150 and 300 ppm, and comparing them to a control treatment on pear trees. They found that chlorophyll content of leaves and ratio of carbohydrates to nitrogen increased with spraying of succinic acid. [14] Demonstrated that spraying Le-Conte pear trees with succinic acid at concentrations of 250 and 500 ppm had a clear positive effect on most of studied traits. It led to an increase in leaf area and chlorophyll content, improved leaf nitrogen, phosphorus, and potassium content, and increased carbohydrate and C/N ratios compared to control. The results showed that 500-ppm concentration achieved best performance in most traits compared to lower concentration or control.

For secondary metabolic activities, which support development of numerous plant growth processes, seaweed extracts are good biostimulants. Numerous elements, including nitrogen, phosphorus, potassium, sodium, calcium, boron, copper, iron, magnesium, manganese, and zinc, are found in these extracts. These nutrients in extract cooperate with a number of growth-promoting compounds, such as proteins, amino acids, auxins, cytokinins, and antioxidants. Plant nutritional status is improved, photosynthetic efficiency is increased, root growth is encouraged, vegetative growth is improved, and production and quality are both increased by this synergistic action. Additionally, it strengthens plant's immune system, increasing its resilience to insects and illnesses. As a result, plant fertilization has made use of these extracts **[15,16]**.

Numerous experiments were conducted to determine roles that seaweed extracts play in growth of fruit trees. In one experiment, following was carried out **[17]** included three levels of spraying of seaweed extract (Kelpak), 0, 4 ml.L^{-1} and 6 ml.L^{-1} and results that sprayed seaweed extract at levels 6 ml.L^{-1}superiority of control treatment and gave highest leaf area, leaves chlorophyll content, leaves dry weight and leaves carbohydrates content. In experiment of **[18]** application of seaweed extract at a concentration of 30 ml improved chemical characteristics of local lemon transplants by raising values of macronutrients (N, P, and K) and micronutrients (Cu, Fe), as well as content of chlorophyll in leaves, this improved transplants' physiological characteristics and their vegetative and root growth. Due to importance of these factors in enhancing growth of recently planted or transplanted plants, as well as paucity of research on role of succinic acid and selenium in growth of lemon transplants, study sought to determine effect of spraying these two substances in enhancing growth and nutrient content of leaves by combining them with seaweed extract.

Materials and Methods

This experiment was conducted in wooden shade belonging to Department of Horticulture and Landscape Engineering, College of Agricultural Engineering Sciences, Univ. Baghdad in Abu Ghraib, during 2025 growing season, using local lemon transplants. 162 uniform transplants were brought in for experiment. Factors of study experiment included a spraying with selenium at three concentrations, without spray (S_0), spraying at 5 mg.L^{-1} (S_5) and spraying at 10 mg.L^{-1} (S_{10}), As for succinic acid spray, they were sprayed in three levels, without spray (A_0), spraying at 100 mg.L^{-1} (A_{100}) and spraying at 200 mg.L^{-1} (A_{200}) and addition of two levels of seaweed extract to soil ,without addition (F_0), and 20 ml.transplant^{-1} (F_{20}). A factorial experiment was conducted using a randomized complete block design (RCBD) with three replications and three transplants per experimental unit. Two-year-old transplants budded onto sour orange rootstock were selected and planted in 10 kg plastic pots (30 cm diameter) filled with a 4:1 peat moss soil mixture in 10 May, 2025. Transplants were sprayed in mid-May with six applications, one month apart, and seaweed extract was added during same period one month apart. The results were analyzed using the LSD test at a probability level of 0.05 **[19]**.

Following parameters were determined in experimental season: Increased in transplant height (cm): was measured by metric tape measure at beginning (15-5-2025) and end of experiment (30-12-2025), according to difference between them and that such an increase in transplant height. Leaf area (cm^2): five leaves were taken from middle position of shoot randomly and measuring leaf area (cm^2) by using a Digimizer program. Leaf Mineral Content: in 25-11-2025 samples of ten leaves from middle shoots. Nitrogen was estimated by micro-kjeldahl method of **[20]** while phosphorus and potassium was estimate the chromatic by using spectrophotometer by **[21]**.

Results and Discussion

Effects of spraying with selenium and succinic acid and add seaweed extract and their interaction on increased in plant height and leaf area in lemon transplants

Data concerning effect of experimental treatments on increased in plant height and leaf area are listed in Tables 1 and 2. data cleared that, selenium spray at 10 ml.L^{-1}(S_{10}) significantly increased in plant height of 8.52 cm and highest leaf area of 27.23 cm^2, while lower values of these traits was in S_0 treatment. Tables (1 and 2) also shows that succinic acid spray especially at 200 mg.L^{-1} (A_{200}) , showed significant superiority in increased in plant height of 8.75 cm and leaf area of 29.06 cm^2, lowest results for these two traits were observed in water spray-only treatment. Also, adding seaweed extract to experiment pots also affected in plant height and leaf area, especially adding 20 mL.transplant^{-1} (F_{20}) and gave highest increasing of plant height of 8.95 cm and highest leaf area of 27.84 cm^2, while lower values of these traits was in F_0 treatment. Twice and triple interactions between experimental treatments had a significant effect on same two traits.

Table 1. Effects of spraying with selenium and succinic acid and add seaweed extract and their interaction on increased in plant height (cm) in lemon transplants.

Selenium (S)	Seaweed extract (F)	Succinic acid (A)			S × F
		A_0	A_{100}	A_{200}	
S_0	F_0	4.82	5.15	5.64	5.20
	F_{20}	7.20	7.37	9.00	7.86
S_5	F_0	5.37	5.95	6.39	5.90
	F_{20}	7.81	8.11	10.47	8.80
S_{10}	F_0	5.90	6.77	7.87	6.85
	F_{20}	8.06	9.39	13.11	10.19
L.S.D 0.05			2.52		1.45
		S × A			S
S_0		6.01	6.26	7.32	6.53
S_5		6.59	7.03	8.43	7.35
S_{10}		6.98	8.08	10.49	8.52
L.S.D 0.05			1.78		1.03
		F × A			F
F_0		5.36	5.95	6.63	5.98
F_{20}		7.70	8.29	10.87	8.95
L.S.D 0.05			1.45		0.84
A		6.53	7.12	8.75	
L.S.D 0.05			1.03		

Source: Own authorship.

Interactions between selenium spray and addition seaweed extract significantly affected in plant height and leaf area especially interaction treatment ($S_{10}F_{20}$) of 10.19 cm and 26.14 cm^2, respectively while (S_0F_0) interaction treatment gave lowest results for these two traits. Interactions between succinic acid spray and addition seaweed extract significantly affected especially when interaction treatment ($A_{200}F_{20}$) and gave 10.87 cm as increased in plant height and 31.61 cm^2 as leaf area while (A_0F_0) interaction treatment gave lowest results for these two traits. Interaction between selenium and succinic spray especially interaction treatment ($S_{10}A_{200}$) as it gave highest increased in plant height of 10.49 cm and highest leaf area of 30.46 cm^2 in comparison with control treatment (S_0A_0), which gave lowest results for both increase in plant height and leaf area. Triple interactions between study factors had a significant effect in these traits especially ($S_{10}A_{200}F_{20}$) treatment.

Table 2. Effects of spraying with selenium and succinic acid and add seaweed extract and their interaction on increased in leaf area (cm^2) in lemon transplants.

Selenium (S)	Seaweed extract (F)	Succinic acid (A)			S × F
		A_0	A_{100}	A_{200}	
S_0	F_0	18.84	21.50	25.69	22.01
	F_{20}	22.12	26.18	29.93	26.08
S_5	F_0	19.45	22.06	26.04	22.52
	F_{20}	25.83	23.48	31.82	27.04
S_{10}	F_0	20.62	23.69	27.84	24.05
	F_{20}	27.30	30.87	33.08	30.42
L.S.D 0.05			3.78		2.18
		S × A			S
S_0		20.48	23.48	27.81	24.04
S_5		22.64	22.77	28.93	24.78
S_{10}		23.96	27.28	30.46	27.23
L.S.D 0.05			2.67		1.54
		F × A			F
F_0		19.64	22.42	26.51	22.86
F_{20}		25.08	26.84	31.61	27.84
L.S.D 0.05			2.18		1.26
A		22.36	24.63	29.06	
L.S.D 0.05			1.54		

Source: Own authorship.

Treatment with selenium foliar spray affected plant growth due to increased plant mineral content (Tables 3-5), higher photosynthetic efficiency, stimulation of antioxidants, creation of a good hormonal balance for plant growth, increased primary and secondary metabolic efficiency, and increased osmotic solute levels, thus increasing plant resistance to environmental stresses **[22,23]**, which was reflected in increased plant growth rates.

These results are also attributed to role of succinic acid, as this acid has numerous effects on plants. It enhances absorption of nutrients from soil, stimulates green mass growth, strengthens root system, helps young transplants adapt quickly to new conditions, aids in removing nitrates and other toxins from plant, and accelerates chlorophyll synthesis in plant cells, thus promoting improved vegetative growth **[12]**.

Regarding increased vegetative growth resulting from addition of seaweed extract, this may be attributed to extract's content of macro- and micronutrients and plant hormones, particularly auxins and cytokinins, which play a vital role in promoting growth, stimulating plant height, and encouraging lateral branching. As results above indicate, transplants treated with seaweed extract exhibited good vegetative growth. This may be due to its content of essential growth nutrients such as nitrogen, phosphorus, and potassium (Tables 3-5), as well as vitamins, amino acids, and organic acids. These nutrients have a wide range of effects on plant physiology, leading to increased absorption by plant and positively influencing vegetative growth in trees **[24,25]**.

Effects of spraying with selenium and succinic acid and adding seaweed extract and their interaction on leaf N, P, K content in lemon transplants

Data concerning effect of experimental treatments on leaves nitrogen, phosphor and potassium are listed in Tables 3, 4 and 5. Data cleared that, selenium spray at 10 ml.L^{-1}(S_{10}) significantly increased in leaves nitrogen content of 2.09 %, phosphor content of 0.348 % and highest leaves potassium content of 1.82 %, while lower values of these leaves content was in S_0 treatment.

Tables 3, 4 and 5 also shows that succinic acid spray especially at 200 mg.L^{-1} (A_{200}), showed significant superiority in leaves nitrogen content of 2.01%, phosphor of 0.345 % and leaves potassium content of 1.82 %, lowest results for these three minerals content were observed in water spray-only treatment. Also, adding seaweed extract to experiment pots also affected in leaves N, P, K content, especially adding 20 ml.transplant^{-1} (F_{20}) and gave highest leaves nitrogen content of 2.06% , phosphor of 0.348 % and highest leaves potassium content of 1.74 %, while lower values of these mineral content was in F_0 treatment.

Twice and triple interactions between experimental treatments had a significant effect on same three minerals content. Interactions between selenium spray and addition seaweed extract significantly affected in leaves nitrogen, phosphor and potassium content especially interaction treatment ($S_{10}F_{20}$) of 2.15%, 0.374% and 1.89 %, respectively while (S_0F_0) interaction treatment gave lowest results for these minerals content. Interactions between succinic acid spray and addition seaweed extract significantly affected especially when interaction treatment ($A_{200}F_{20}$) and gave 2.10 % as leaves nitrogen content, 0.366 % as leaves phosphor content and 1.80 % as leaves potassium content while (A_0F_0) interaction treatment gave lowest results for these three traits. Interaction between selenium and succinic spray especially interaction treatment ($S_{10}A_{200}$) as it gave highest leaves nitrogen content of 2.15 %, phosphor of 0.362 % and highest leaves potassium content of 1.84 % in comparison with control treatment (S_0A_0), which gave lowest results for these traits. Triple interactions between study factors had a significant effect in these minerals content especially ($S_{10}A_{200}F_{20}$) treatment.

Table 3. Effects of spraying with selenium and succinic acid and add seaweed extract and their interaction on leaf nitrogen (%) content in lemon transplants.

Selenium (S)	Seaweed extract (F)	Succinic acid (A)			S × F
		A_0	A_{100}	A_{200}	
S_0	F_0	1.74	1.77	1.83	1.78
	F_{20}	1.92	1.93	1.99	1.94
S_5	F_0	1.80	1.85	1.87	1.84
	F_{20}	2.00	2.09	2.09	2.06
S_{10}	F_0	1.98	2.03	2.08	2.03
	F_{20}	2.10	2.15	2.22	2.15
L.S.D 0.05			0.09		0.05
			S × A		S
S_0		1.83	1.85	1.91	1.86
S_5		1.90	1.97	1.98	1.95
S_{10}		2.04	2.09	2.15	2.09
L.S.D 0.05			0.06		0.04
			F × A		F
F_0		1.84	1.88	1.92	1.88
F_{20}		2.00	2.03	2.10	2.06
L.S.D 0.05			0.05		0.03
A		1.92	1.95	2.01	
L.S.D 0.05			0.04		

Source: Own authorship.

This increase in content of elements in transplants leaves is due to role of selenium, as spraying selenium compensated transplants for harmful effects of abiotic stress, especially drought stress and late planting, due to activation of synthesis of enzymatic antioxidants catalase and peroxidase and non-enzymatic antioxidants such as ascorbate and glutathione, and increase in gene expression of genes responsible for drought resistance. This improves internal content of mineral elements in transplants **[26]**. Spraying with succinic acid also increased nutrient content of leaves because succinic acid is an important agricultural organic compound due to its ability to enhance physiological processes in plants, improve their resistance to biotic stresses, and thus improve transplants growth (Tables 1 and 2), thereby increasing nutrient content of their leaves **[12]**. As for effect of adding seaweed extract, Tables (3-5) show that there is a significant effect of adding this extract on content of lemon transplants leaves of nutrients, especially nitrogen, phosphorus and potassium, and its clear effect on increasing percentage of mineral elements of the plant. This increase is due to this extract containing macronutrients, especially N, P and K, as well as micronutrients, which are often easily absorbed by plant roots, thus increasing their percentage in plant **[24]**.

Table 4. Effects of spraying with selenium and succinic acid and add seaweed extract and their interaction on leaf phosphor (%) content in lemon transplants.

Selenium (S)	Seaweed extract (F)	Succinic acid (A)			S × F
		A_0	A_{100}	A_{200}	
S_0	F_0	0.302	0.307	0.316	0.308
	F_{20}	0.324	0.331	0.342	0.332
S_5	F_0	0.311	0.320	0.324	0.318
	F_{20}	0.337	0.344	0.364	0.348
S_{10}	F_0	0.314	0.320	0.331	0.322
	F_{20}	0.352	0.378	0.393	0.374
L.S.D 0.05			0.027		0.016
			S × A		S
S_0		0.313	0.319	0.329	0.320
S_5		0.324	0.332	0.344	0.333
S_{10}		0.333	0.349	0.362	0.348
L.S.D 0.05			0.019		0.011
			F × A		F
F_0		0.309	0.315	0.324	0.316
F_{20}		0.337	0.351	0.366	0.348
L.S.D 0.05			0.016		0.009
A		0.323	0.333	0.345	
L.S.D 0.05			0.011		

Source: Own authorship.

Table 5. Effects of spraying with selenium and succinic acid and add seaweed extract and their interaction on leaf potassium (%) content in lemon transplants.

Selenium (S)	Seaweed extract (F)	Succinic acid (A)			S × F
		A_0	A_{100}	A_{200}	
S_0	F_0	1.55	1.63	1.63	1.60
	F_{20}	1.57	1.59	1.67	1.63
S_5	F_0	1.58	1.63	1.70	1.63
	F_{20}	1.62	1.75	1.82	1.73
S_{10}	F_0	1.67	1.84	1.78	1.67
	F_{20}	1.85	1.92	1.90	1.89
L.S.D 0.05			0.12		0.07
			S × A		S
S_0		1.56	1.61	1.65	1.60
S_5		1.60	1.69	1.76	1.68
S_{10}		1.76	1.88	1.84	1.82
L.S.D 0.05			0.08		0.05
			F × A		F
F_0		1.60	1.70	1.70	1.66
F_{20}		1.68	1.75	1.80	1.74
L.S.D 0.05			0.07		0.04
A		1.64	1.72	1.75	
L.S.D 0.05			0.05		

Source: Own authorship.

Conclusion

Results of this study confirm that integration of spraying with selenium and succinic acid with soil addition of seaweed extract represents an effective strategy for improving vegetative growth and nutritional efficiency of lemon transplants. The three-interaction led to best performance in almost all studied traits, highlighting possibility of adopting these treatments within integrated management programs for production of strong and high-quality lemon transplants, with need to conduct future studies to evaluate their effect in fruiting and field production stages.

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Author contributions: Conceptualization, methodology, investigation, data collection, formal analysis, data interpretation, supervision, writing—original draft: All authors.

Acknowledgment

Not applicable.

Ethical Approval

Not applicable.

Informed Consent

Not applicable.

Funding

Not applicable.

Data Sharing Statement

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request, and all data is stored following privacy and ethical guidelines

Conflict of Interest

The authors declare no competing interests.

Similarity Check

It was applied by Ithenticate@.

Application of Artificial Intelligence (AI)

Not applicable.

Peer Review Process

It was performed.

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