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RESPONSE OF CITRUS ROOTSTOCKS TO ARGININE AND TRYPTOPHAN

A.M. ALMOUSAWI*, S.M. NASER, and F.S. SALMAN

Department of Horticulture and Forestry, Kerbala Agriculture Directorate, Kufa, Iraq
*Corresponding author's emails: sabraoassociateeditors@gmail.com, abrarm.almossawi@uokufa.edu.iq
Email addresses of co-authors: suham.alasede@uokufa.edu.iq, furqans.alabbasy@uokufa.edu.iq

SUMMARY

The following research on citrus (*Citrus aurantium* L.) rootstocks transpired in 2020 at the Citrus Production Nursery of the Directorate of Horticulture and Forestry, Al-Hindiyya District, Iraq. The study aimed to explore the effect of foliar application of amino acids on citrus rootstocks and their various characteristics. The experiment was factorial in a randomized complete block design with two factors and three replications. The first factor included four citrus rootstocks (*Citrus aurantium*, Troyer citrange, Volkameriana, and Swingle citrumelo), while the second factor included four amino acid treatments, i.e., control, arginine (250 mg L^{-1}), tryptophan (150 mg L^{-1}), and arginine (250 mg L^{-1}) + tryptophan (150 mg L^{-1}), symbolized as A1, A2, A3, and A4, respectively. Results showed the citrus rootstock Swingle citrumelo emerged superior in seedling height, stem diameter, number of leaves, and contents of carbohydrate, nitrogen, phosphorus, and potassium, with average values of 123.75 cm, 1.13 cm, 96.88 leaves $seedling^{-1}$, 13.86%, 1.55%, 0.46%, and 1.51%, respectively. Amino acids' foliar application had a significant effect, with the treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) excelling in the seedling height and diameter, the number of leaves, and contents of chlorophyll, carbohydrates, nitrogen, phosphorus, and potassium. Corresponding average values were 110.55 cm, 1.23 cm, 104.23 leaves $seedling^{-1}$, 136.98 mg 100 g^{-1}, 14.41%, 1.60%, 0.52%, and 1.58%.

Keywords: *Citrus aurantium* L., rootstocks, amino acids, vegetative growth, biochemical traits, qualitative and yield traits

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Key findings: The presented study revealed the citrus (*Citrus aurantium* L.) rootstock Swingle citrumelo had the best vegetative growth and biochemical properties, while the rootstock Volkameriana had the highest chlorophyll content. The combined foliar application of the amino acids (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) showed the best performance in vegetative growth and biochemical properties.

INTRODUCTION

Citrus (*Citrus aurantium* L.) is a member of the Rutaceae family, originating in Southeast Asia. Its fruit contains potassium, calcium, iron, magnesium, sodium, sulfur, and phosphorus, which are essential elements for good health in humans. Citrus is an economic input to the Arab's national revenue that could have a horizontal expansion by extending farming areas and vertically by adopting good rootstocks and types with advanced scientific procedures for better fruit yield per plant (Langgut, 2017).

Given the larger genotypic variations in citrus species procured from diverse sources, finding the right rootstock for grafting citrus types is crucial. It has also become important due to the mutual physiological relationship among the rootstocks and the taste, as the rootstock affects growth, productivity, quality, and disease resistance in fruits. The citrus roots may also vary in nutrient absorption and distribution within the plants (Morales-Alfaro *et al.,* 2023).

In the second half of the last century, various citrus rootstocks' development has succeeded and served in grafting. It is because using the right rootstock guarantees trees are resistant to different environmental conditions and citrus diseases, whether through the root or vegetative system, with the highest productivity. The root affects the graft by affecting its strength, the height and age of the trees, their structure, vegetative growth, the duration of the different stages of growth, the beginning of flowering, and fruit set. Therefore, the use of rootstocks in citrus was one of the critical processes in the multiplication of citrus and its impact on economic returns (Bowman and Joubert, 2020). Numerous citrus studies showed the rootstocks influence the vegetative, production, and quality development of the grafts (Legua *et al*., 2011; Al-Janabi and Mohammed, 2020). In a study on six citrus rootstocks, local orange, Brazilian and Spanish orange, Troyer citrange, Numi Rangpur lime Volkameriana, and local orange root Volkameriana exhibited considerable variations for growth, fruit yield, and quality variables (Hafez, 2006).

Amino acids are natural substances that stimulate plant growth, improve fertilization and disease resistance, provide energy for protein formation, fulfill the plant's nitrogen demands, and avoid internal ammonia poisoning (Nateghpour *et al*., 2021). Spraying ready-made amino acids on the vegetative portion and with irrigation water helps plant leaves and roots to quickly absorb arginine, enabling the plant to use them immediately and spare manufacturing energy for important physiological processes (Baqir *et al*., 2019). Nucleotides, a fundamental component of proteins, generate essential molecules, which boost the plant's physiological activities.

Amino acids also include coenzymes and numerous porphyrins, chelating micronutrients and helping plants absorb and transfer them. Several studies showed amino acids impact the horticultural plants' development and output differently, depending on the dose, spraying duration, plant type, and cultivar (Abd-Zeid and Al-Abbasi, 2021; Traband *et al.,* 2023). Washington navel oranges and Anna apples had equal fruit setting, number of fruits/tree, fruit size and weight, fruit yield, and quality rose (Eissa, 2007). Based on the above discussion, the relevant study aimed to evaluate the four different rootstocks of citrus and the influence of foliar application of amino acids, particularly arginine and tryptophan, on the vegetative growth, morphological, fruit yield, and quality parameters.

MATERIALS AND METHODS

The presented research on citrus (*Citrus aurantium* L.) rootstocks, commencing in 2020, transpired in the Citrus Production Nursery of the Directorate of Horticulture and Forestry, Al-Hindiyya District, Iraq. The study aimed to investigate the effect of foliar application of amino acids (arginine and tryptophan) on the four citrus rootstocks and their various characteristics. The experiment layout was in a randomized complete block design with factorial arrangements of two factors and three replications. The first factor included four citrus rootstocks (*Citrus aurantium*, Troyer citrange, Volkameriana, and Swingle citrumelo), while the second factor comprised four amino acid treatments, i.e., control, arginine (250 mg L^{-1}), tryptophan (150 mg L^{-1}), and arginine (250 mg L^{-1}) + tryptophan (150 mg L^{-1}), symbolizing them as A1, A2, A3, and A4, respectively.

The citrus production nursery provided six-month-old citrus rootstocks with arginine (99%) from the Japanese firm (TCI) and tryptophan from the Indian company. Thus, there were 16 treatments and three replications, totaling 48 experimental units with five seedlings in each treatment. Hence, the experiment employed 240 pre-prepared seedlings (80 each rootstock) (Table 2). The following vegetative and chemical properties reached assessment during the research period.

Data recorded

At the end of the experiment in December 2016, three seedlings, taken from each treatment, underwent measuring for the following characteristics:

Vegetative growth traits

Average seedling height (cm) measurement began from the soil surface to the highest tip of the main stem, using metric tape. Calculating the average diameter (cm) of the main stem continued by measuring the diameters of seedlings using Vernia feet at a height of 10 cm from the soil surface, and then averaged for each experimental unit. The number of leaves per seedling in each experimental unit also incurred counting.

Biochemical characteristics

In the analytical laboratory of the University of Kufa, Iraq, 0.5 g of the fifth leaf from the growing apex of each treatment became the sample to measure the total chlorophyll content. The dye solution, as separated from the paper tissue, used Whatman No. 1 filter paper, with the process repeated to extract the remaining dyes with another 5 ml of acetone until bleaching the tissue. Upon collecting the filtrate, the volume's completion to 15 ml used acetone before reading. Using a spectrophotometer, collecting optical absorption had values at 645 and 663 nm, with the following equation used to determine the chlorophyll (mg 100 g^{-1}) (Ranganna, 1977):

$$\text{Total chlorophyll} = 20.2 \times D(645) + 8.02 \times D(663)(V/W \times 1000) \times 100$$

Estimating total soluble carbohydrates in leaves proceeded with adding 0.25 g dry weight from each experimental unit to 10 ml of distilled water, then centrifuged at 1500 rpm for 10 min in the Laboratory of the University of Kufa, Iraq. Adding distilled water to 10 ml of filtrate continued mixing with 1 ml of 5% phenol reagent and 5 ml of concentrated sulfuric acid before incubation at 25 °C–35 °C for 30 min in a water bath. Spectrophotometers measuring dissolved carbohydrates used 490 nm color intensity. The glucose standard curve's development employed the following steps: 1 ml of each glucose concentration (40, 30, 20, 10, 0, and 50 mg L^{-1}), adding 1 ml of phenol (5%) and 5 ml of concentrated sulfuric acid, leaving it for 10 min before reading it at the same wavelength, and then drawing the standard curve through optical density readings for different glucose concentrations (Herbert *et al.,* 1971).

In each experimental unit, gathering the mature leaves from various citrus rootstock seedlings occurred during the same year, then washed and dried in an electric oven at 60 °C until weight stability. Their grinding engaged

Table 1. Response of citrus rootstocks to foliar application of arginine and tryptophan for seedling height.

Fertilizer combinations	Citrus rootstocks				Means (cm)
	Sour orange	Troyer citrange	Volkameriana	Swingle citrumelo	
A1	74.80	90.20	92.40	106.70	91.03
A2	78.10	95.70	94.60	117.70	96.53
A3	82.50	101.20	96.80	125.40	101.47
A4	92.40	106.70	97.90	145.20	110.55
Means (cm)	81.95	98.45	95.42	123.75	
$LSD_{0.05}$ Fertilizer combinations = 1.354, Rootstocks = 1.354, Interaction = 2.708					

the electric mill to measure the nitrogen, phosphorus, and potassium contents. The procedure comprised the following: taking 200 mg in each experimental unit and digesting in Pyrex flasks with 3 ml concentrated sulfuric acid for 24 hours (Cresser and Parsons, 1979); heating the 1 ml concentrated sulfuric acid and 1 ml perchloric acid to a clear solution and cooling until the liquid is 50 ml. Using the Micro Kjeldahl apparatus, researchers assessed nitrogen and nutrients in the filtered solution, with the percentage of phosphorus also measured with ammonium molybdate and ascorbic acid at 620 nm by spectrophotometer (Al-Sahhaf, 1989). The potassium percentage determination employed a flame-photometer (Ren *et al.*, 2019).

Statistical analysis

All the data recorded in the field experiment for various variables sustained scrutiny according to the analysis of variance (ANOVA) as per the randomized complete block design (Steel and Torrie, 1980). The least significant difference ($LSD_{0.05}$) test helped to compare and separate further the various means. For all the analyses, the study utilized the statistics software GenStat12.

RESULTS AND DISCUSSION

Seedling height

For seedling height, the citrus (*Citrus aurantium* L.) rootstocks indicated significant differences (Table 1). The rootstock Swingle citrumelo showed the highest average (123.75 cm), followed by Sour orange, Troyer citrange, and Volkameriana, with plant heights of 81.95, 98.45, and 95.42 cm, respectively. The genotypic differences among the citrus cultivars may have been due to genetic variables affecting the vegetative growth features, which favorably appeared in physiological activities needed for root and vegetative growth. Past studies also observed varied values for plant growth, fruit yield, and quality in different citrus rootstocks (Hafez, 2006; Legua *et al*., 2011).

Treatments with foliar application of amino acids further exhibited notable differences in seedling height (Table 1). The treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) excelled by giving the highest rate of plant height (110.55 cm) compared with the control treatment (91.03 cm). The reason may be due to the positive role of amino acids in stimulating vital activities, especially the growth and elongation processes. Similarly, the faster and better expansion of cells could be due to their direct entry through the stomata into the cells. Moreover, the entry of amino acids into building proteins helped the growth of plant tissues (Al-Janabi and Mohammed, 2020).

The interaction effects between the citrus rootstocks and amino acid foliar treatments also revealed significant differences for the citrus seedling height (Table 1). The A4 treatment (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) with rootstock Swingle citrumelo achieved the supreme interaction effects, amounting to 145.20 cm, while the A1 treatment with Sour orange gave the lowest interaction for plant height (74.80 cm).

Stem diameter

The results showed remarkable variations occurred among the citrus genotypes belonging to different origins for the trait diameter (Table 2). The rootstock Swingle citrumelo provided the widest average (1.13 cm), while three other citrus genotypes, Sour orange, Troyer citrange, and Volkameriana, gave averages of 0.87, 0.98, and 1.08 cm, respectively. The difference in stem diameter in citrus rootstocks may be due to genetic factors, as genetic diversity affects the plant's morphological characteristics. A difference in the genetics of the stem diameter could exist among the varied species and cultivars of the same species (Hayat *et al.,* 2022).

Spraying with amino acids caused significant differences in stem diameter (Table 2). The amino acid treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) had the greatest rate (1.23 cm) compared with the control treatment (0.84 cm). Methionine starts the formation of ethylene, chloride, and glutamate, which are plant hormone stimulators helping synthesize plant tissues. As part of the guard cell osmotic system, these also regulate the stomata opening, boosting photosynthetic efficiency. Tryptophan initiates auxin synthesis and increases gibberellins and auxin cytokines in plants, which accelerates cell division and differentiation and, eventually, enhances the stem diameter (Nag *et al.,* 2001).

The findings further indicated the significant interaction effects between the two applied factors (Table 2). The broadest seedling diameter resulted in the amino acid treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) application with the rootstock Swingle citrumelo (1.28 cm), while the control treatment (A1) gave the least interaction effect with the rootstock Sour orange, giving an average of 0.64 cm for stem diameter.

Leaves per seedling

Observably, significant differences emerged among the different citrus rootstocks in the number of leaves per seedling (Table 3). The rootstock Swingle citrumelo rootstock achieved

Table 2. Response of citrus rootstocks to foliar application of arginine and tryptophan for the seedling stem diameter.

Fertilizer combinations	Citrus rootstocks				Means (cm)
	Sour orange	Troyer citrange	Volkameriana	Swingle citrumelo	
A1	*0.64*	*0.83*	*0.89*	*1.02*	*0.84*
A2	*0.70*	*0.95*	*1.05*	*1.07*	*0.94*
A3	*0.84*	*1.03*	*1.14*	*1.17*	*1.05*
A4	*1.31*	*1.12*	*1.22*	*1.28*	*1.23*
Means (cm)	*0.87*	*0.98*	*1.08*	*1.13*	
$LSD_{0.05}$ Fertilizer combinations = 0.01489, Rootstocks = 0.01489, Interaction = 0.02978					

Table 3. Response of citrus rootstocks to foliar application of arginine and tryptophan for the number of leaves per seedling.

Fertilizer combinations	Citrus rootstocks				Means (leaves $seedling^{-1}$)
	Sour orange	Troyer citrange	Volkameriana	Swingle citrumelo	
A1	*51.70*	*73.70*	*77.00*	*78.10*	*70.13*
A2	*70.40*	*86.90*	*84.70*	*89.43*	82.86
A3	*87.89*	*93.50*	*91.30*	*103.40*	*94.02*
A4	*96.80*	*104.50*	*99.00*	*116.60*	*104.23*
Means (leaves $seedling^{-1}$)	*76.70*	*89.65*	*88.00*	*96.88*	
$LSD_{0.05}$ Fertilizer combinations = 1.179, Rootstocks = 1.179, Interaction = 2.359					

the most number of leaves (96.88 leaves seedling^{-1}), while three other rootstocks, Sour orange, Troyer citrange, and Volkameriana, gave averages of 76.70, 89.65, and 88.00 leaves seedling^{-1}, respectively. Variations in the number of leaves in citrus seedlings can refer to the diversity in the genetic makeup of genotypes. Differences in genes can lead to different traits, including the number of leaves and other morphological and fruit yield-related traits (Abd-Zeid and Al-Abbasi, 2021; Traband *et al.,* 2023).

The foliar application of amino acid combinations also caused a noteworthy effect on the number of leaves per seedling (Table 3). The amino acid treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) excelled by giving the highest average (104.23 leaves seedling^{-1}) compared to the control treatment (70.13 leaves seedling^{-1}). The role of amino acids in the process of photosynthesis was that glycine and glutamic acid, as two basic compounds, contribute to the formation of chlorophyll and proteins, which are considered catalysts for cell elongation and division. This reflects positively on the increased activity of vital processes within the plant and, thus, can be evidence of an increase in the number of leaves in the plant (Al-Falahi and Abdullah, 2017).

The interaction effects between the citrus rootstocks and spraying amino acid treatments also revealed substantial differences for leaves per seedling in citrus (Table 3). However, the highest interaction effects were evident with the combination of amino acid treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) with rootstock Swingle citrumelo (116.60 leaves seedling^{-1}). Meanwhile, the amino acid control treatment (A1) with cultivar Sour orange revealed the least interaction effect (51.70 leaves seedling^{-1}).

Leaf chlorophyll content

Citrus rootstocks displayed considerable variances in leaf chlorophyll content (Table 4). The rootstock Volkameriana performed best by giving the maximum average of chlorophyll content (107.44 mg 100 g^{-1}), while the three other rootstocks, Sour orange, Troyer citrange, and Swingle citrumelo, showed averages of 98.34, 103.02, and 77.91 mg 100 g^{-1}, respectively. The differences among the citrus rootstocks for chlorophyll content may be due to the varied nature of the genetic makeup of the citrus cultivars (Costanzo *et al.,* 2020).

Similarly, the foliar application of amino acid combinations caused a remarkable effect on the chlorophyll content (Table 4). The amino acid treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) excelled by providing the premier chlorophyll content (136.98 mg 100 g^{-1}) versus the control treatment (A1), which showed the lowest content (59.54 mg 100 g^{-1}). This may be attributable to the positive role of amino acids in the photosynthesis process, as glycine and glutamic are two basic compounds contributing to building chlorophyll molecules (El-Gioushy *et al.,* 2018).

The outcomes further indicated significant interaction effects existed between the two applied factors for chlorophyll content in citrus rootstocks (Table 4). The highest interaction manifested with amino acid treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) with the rootstock Volkameriana (162.80 mg 100 g^{-1}). However, the control treatment (A1) with rootstock Swingle citrumelo showed the lowest leaf chlorophyll content (47.85 mg 100 g^{-1}).

Total soluble carbohydrates

The results indicated significant differences surfaced among citrus genotypes (Table 5). The citrus rootstock Swingle citrumelo excelled with the carbohydrates' percentage of 13.86%, while the other three citrus genotypes, viz., Sour orange, Troyer citrange, and Volkameriana, demonstrated the total soluble carbohydrates percentages of 12.18%, 12.68%, and 12.18%, respectively. The leaf content of nutrients and compounds, including carbohydrates, could refer to the uniqueness of the rootstock Swingle citrumelo and the nature of its root system, distinct with a strong and dense root system in citrus (Ruiz *et al.*, 2001).

Table 4. Response of citrus rootstocks to foliar application of arginine and tryptophan for leaf chlorophyll content.

Fertilizer combinations	Citrus rootstocks				Means (mg 100 g^{-1})
	Sour orange	Troyer citrange	Volkameriana	Swingle citrumelo	
A1	70.73	60.94	58.63	47.85	59.54
A2	75.90	87.78	78.54	67.98	77.55
A3	110.33	124.74	129.80	85.69	112.64
A4	136.40	138.60	162.80	110.11	136.98
Means (mg 100 g^{-1})	98.34	103.02	107.44	77.91	
$LSD_{0.05}$ Fertilizer combinations = 2.591, Rootstocks = 2.591, Interaction = 5.182					

Table 5. Response of citrus rootstocks to foliar application of arginine and tryptophan for total soluble carbohydrates in leaves.

Fertilizer combinations	Citrus rootstocks				Means (%)
	Sour orange	Troyer citrange	Volkameriana	Swingle citrumelo	
A1	10.56	11.99	9.68	12.76	11.25
A2	11.86	12.21	11.85	13.64	12.39
A3	12.19	12.27	13.64	14.19	13.07
A4	14.12	14.25	14.41	14. 85	14.41
Means (%)	12.18	12.68	12.40	13.86	
$LSD_{0.05}$ Fertilizer combinations = 0.1110, Rootstocks = 0.1110, Interaction = 0.2221					

Table 6. Response of citrus rootstocks to foliar application of arginine and tryptophan for the nitrogen in the leaves.

Fertilizer combinations	Citrus rootstocks				Means (%)
	Sour orange	Troyer citrange	Volkameriana	Swingle citrumelo	
A1	0.97	1.23	1.24	1.39	1.21
A2	1.18	1.29	1.41	1.56	1.36
A3	1.38	1.46	1.51	1.60	1.49
A4	1.61	1.58	1.54	1.65	1.60
Means (%)	1.28	1.39	1.42	1.55	
$LSD_{0.05}$ Fertilizer combinations = 0.01437, Rootstocks = 0.01437, Interaction = 0.02873					

The amino acids' foliar application also caused a meaningful impact on the percentage of carbohydrates (Table 5). The treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) outshone by giving the topmost percentage (14.41%) compared with the control treatment (A1), with the lowest percentage of carbohydrates (11.25%). Amino acids play a vital role in the manufacturing process of carbohydrates in crop plants. These acids can help provide the plant with energy and raw materials for manufacturing carbohydrates through the process of photosynthesis. This process includes converting energy from light to chemical energy in the form of glucose and other carbohydrates (Lu *et al.,* 2023).

The interaction effects between the citrus rootstocks and spraying treatments with amino acids also revealed notable differences (Table 5). The greatest interaction effects for carbohydrate percentage were visible with the treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) with rootstock Swingle citrumelo (14.85%), while the control treatment (A1) with rootstock Volkameriana gave the lowest percentage (9.68%).

Nitrogen (%)

For nitrogen percentage, the citrus rootstocks indicated prominent variances (Table 6). The citrus cultivar Swingle citrumelo emerged, leading for the average percentage of nitrogen in the leaves (1.55%). The three other rootstocks, Sour orange, Troyer citrange, and Volkameriana, resulted with percentages of 1.28%, 1.39%, and 1.42%, respectively. The reason could be the superiority of the rootstock

in the number of leaves (Table 3), which would contribute to increasing the activity of the process of absorption and transfer of elements from the soil to the plant. Thus, it could explain the rise in nitrogen content in the leaves. It may also be due to genetic differences between the rootstocks, which play an important role in the availability and absorption of nitrogen by the plants, with some roots found more effective in absorbing this element (Rapisarda *et al.,* 2005).

On amino acids' foliar application treatments, observably, significant differences existed among their nitrogen percentages (Table 6). The amino acid treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) yielded the greatest percentage of nitrogen (1.60%) versus the control treatment (1.21%). The plants use amino acids to build proteins; the nitrogen content in their leaves increases due to the heightened activity of vital processes, including nitrogen absorption. This nitrogen boosts plant development and vitality and improves numerous critical processes (Muhammad and Latif, 2022).

For the interaction between citrus roots and spraying treatments with amino acids, remarkable variations appeared in the percentage of nitrogen (Table 6). The highest nitrogen percentage was prominent in the interaction of A4 treatment (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) with rootstock Swingle citrumelo (1.65%), while the control treatment (A1) with Sour orange gave the lowest percentage (0.97%)

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Phosphorus (%)

Results revealed sizable differences among the citrus rootstocks for phosphorus percentage (Table 7). The rootstock Swingle citrumelo was superior for the average percentage of phosphorus in the leaves (0.46%), while the other rootstocks, Sour Orange, Troyer citrange, and Volkameriana, showed the percentage of 0.44%, 0.43%, and 0.44%, respectively. Rootstocks may differ among themselves in the efficiency of their roots in absorbing nutrients. This difference could be due to the strength of the root system, which increases the absorption of nutrients and, thus, increases the content of these elements in the citrus leaves (Zambrosi *et al.,* 2013).

Moreover, amino acids had a significant effect on the phosphorus percentage in citrus leaves (Table 7). The treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) achieved the ultimate percentage of phosphorus (0.52%) compared with the control treatment (0.38%). Amino acids can increase leaf phosphorus content via boosting soil absorption. Amino acids also promote root growth and development, which raises phosphorus absorption. Increasing biological activity may help bacteria decompose organic waste and deliver phosphorus to plants. Integration of these mechanisms can boost leaf phosphorus in sweet oranges (*C. sinensis* L.) (Al-Janabi and Mohammed, 2020).

Furthermore, results indicated significant interaction effects surfaced between the citrus rootstocks and amino acids (Table 7). However, the highest interaction reached was by treating rootstock Swingle citrumelo with the A4 treatment (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) (0.55%), while the control treatment with rootstock Troyer citrange displayed the lowest phosphorus percentage (0.36%).

Table 7. Response of citrus rootstocks to foliar application of arginine and tryptophan for the phosphorus in leaves.

Fertilizer combinations	Citrus rootstocks				Means (%)
	Sour orange	Troyer citrange	Volkameriana	Swingle citrumelo	
A1	0.37	0.36	0.39	0.40	0.38
A2	0.43	0.42	0.41	0.41	0.42
A3	0.45	0.44	0.47	0.50	0.47
A4	0.50	0.49	0.53	0.55	0.52
Means (%)	0.44	0.43	0.45	0.46	
$LSD_{0.05}$ Fertilizer combinations = 0.004278, Rootstocks = 0.004278, Interaction = 0.004278					

Table 8. Response of citrus rootstocks to foliar application of arginine and tryptophan for the potassium in the leaves.

Fertilizer combinations	Citrus rootstocks				Means (%)
	Sour orange	Troyer citrange	Volkameriana	Swingle citrumelo	
A1	1.17	1.19	1.18	1.28	1.20
A2	1.30	1.27	1.28	1.34	1.30
A3	1.38	1.50	1.47	1.67	1.50
A4	1.45	1.58	1.51	1.76	1.58
Means (%)	1.32	1.39	1.36	1.51	
$LSD_{0.05}$ Fertilizer combinations = 0.01350, Rootstocks = 0.01350, Interaction = 0.02700					

Potassium (%)

For potassium percentage, the citrus rootstocks exhibited noticeable differences (Table 8). The citrus cultivar Swingle citrumelo topped by the highest percentage of potassium (1.51%). However, the rootstocks, Sour orange, Troyer citrange, and Volkameriana, emerged with percentages of 1.32%, 1.39%, and 1.36%, respectively. The difference in potassium content in the leaves among the varied citrus rootstocks may refer to the nature of the genetic differences of genotypes used in the study. Past studies revealed the rootstocks of *Citrus reticulata* differed in their ability to absorb and accumulate potassium (Ayoub *et al.,* 2014).

The spraying with amino acid combinations caused a considerable effect on potassium content in the citrus leaves (Table 8). The amino acid treatment A4 (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) surpassed with the maximum percentage (1.58%) compared with the control treatment (1.20%). The increase in potassium content in citrus leaves could be because amino acids can positively contribute to stimulating the absorption of potassium from the soil through the plant's roots, enhancing the potassium necessary for leaf formation and improving plant functions. Additionally, potassium has become a requirement for several vital processes in plants, such as regulating the opening and closing of the leaf stomata and stimulating protein formation. Therefore, the use of amino acids can contribute to enhancing potassium absorption and improving the balance of nutrients in orange trees (El-Gioushy *et al.,* 2018).

For the interaction between citrus rootstocks and spraying treatments with amino acids, significant differences resulted in the percentage of potassium (Table 8). The maximum interaction effects observed were by treating citrus cultivar Swingle citrumelo with the A4 treatment (arginine 250 mg L^{-1} + tryptophan 150 mg L^{-1}) with a potassium percentage of 1.76%. Meanwhile, the control treatment with genotype Sour orange gave the minimum percentage (1.17**%**).

CONCLUSIONS

The citrus (*Citrus aurantium* L.) rootstock Swingle citrumelo was better in most vegetative growth and biochemical traits than the other genotypes. This could refer to the genetic makeup and the extent of adaptation to the environmental conditions in the region. Amino acids also had an effective role in improving the performance of citrus seedlings for vegetative and qualitative characteristics**.**

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