Amino Acids as Safe Biostimulants to Improve the Vegetative Growth, Yield, and Fruit Quality of Peach

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The influence of exogenous application of the amino acids Glutamic acid (Glu), Methionine (Met), L-Tryptophan (L-Try), and Lysine (Lys) at concentrations of 250 and 500 ppm was studied relative to the growth of peach trees. The trees were sprayed three times; before flowering, during full bloom, and one month later by 250 ppm Glu + 250 ppm Met + 250 ppm L-Try + 250 ppm Lys (combination 1) and 500 ppm Glu + 500 ppm Met + 500 ppm L-Try + 500 ppm Lys (combination 2), in comparison to trees that were not sprayed (control). A randomized complete block design was used. The individual application of four amino acids positively improved the shoot diameter, leaf chlorophyll, leaf area, and productivity as opposed to not spraying the trees. Additionally, the applied amino acids increased the fruit weight, size, firmness, length, and diameter, and the fruit content from the percentages of total soluble solids (TSS), TSS-acid, and anthocyanin contents, in contrast to the control. They also improved the fruit content from total, reduced, and non-reduced sugars as well as vitamin C and the leaf nutritional content from NPK. The application of combination 2, over the two seasons, was more beneficial.

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INTRODUCTION

Peach (*Prunus persica* L.) is a deciduous tree from the Rosaceae family, with a cultivated area of 1,505 hectares globally, yielding 25 tons. In Egypt, the cultivated area is 13,76 hectares, producing 244 tons (FAO 2021). Peaches are valued as a fresh and versatile functional food, which is suitable for both direct consumption and various applications in the food industry. The consumable parts of the peach, such as the flesh, are abundant in carbohydrates, including the soluble sugars sucrose, glucose, fructose, and sorbitol. Additionally, they contain organic acids, fats, proteins, dietary fiber, minerals, and vitamins, as well as volatile and bioactive compounds. Notably, the peach seed is also a noteworthy source of nutritional and bioactive elements (Reig *et al.* 2023).

Peach, such as the cultivated variety 'Florida Prince', is a delicious and juicy early-season cultivar. Its tolerance limit for coldness is about 150 hours at or below 7.2 °C. Its fruit needs 78 days for development, from fruit set to maturity. The fruit takes 78 days to develop from the time it sets until it matures and has good resistance to heat stress. It is a beautiful, aromatic fruit with 80% of its skin displaying a red blush and faint dark red stripes, which cover most of the surface, with a yellow/orange background splash. The fruit is slightly smaller than a typical peach, featuring uniformly firm yellow flesh and semi-clingstone pits (Olmstead *et al*. 2016).

Utilizing amino acids as biostimulants is a viable strategy in horticultural crops to mitigate the adverse effects caused by environmental stresses. These compounds serve as hormone precursors, play a role in regulating carbon and nitrogen metabolisms, and facilitate nitrogen assimilation (Colla and Rouphael 2015; Bulgari *et al.* 2019). Amino acids, being natural stimulants for plant growth, are widely employed to enhance growth patterns (Mohammadi and Khoshgoftarmanesh 2014; Romero *et al.* 2014). They also contribute to stimulating root growth in plants, thereby improving both water and nutrient absorption capabilities, ultimately leading to increased yield productivity (Souri *et al.* 2017; Khan *et al.* 2019; Noroozlo *et al.* 2019). Furthermore, the external spraying of amino acids greatly improved the uptake of nutrients and leaf mineral content, including essential elements such as iron and zinc (Pranckietienė *et al.* 2015). Moreover, the external application of amino acids facilitates growth, enhances nutrient absorption, triggers leaf pigmentation, promotes chlorophyll biosynthesis, and mitigates chlorophyll decomposition in various crops and this results in increased efficiency in photosynthesis and influences stomatal movement (Souri *et al.* 2017; Mohammadipour and Souri 2019). Spraying of amino acids optimizes processes such as nutrient uptake, translocation, and metabolism. It also contributes to the biosynthesis of vitamins, and biostimulation of growth, and it also raises the resistance to environmental stresses like drought, salinity, and coldness (Alfosea-Simón *et al.* 2020b; Matysiak *et al.* 2020).

Applying Glu has demonstrated positive effects even in stressful conditions by mitigating physiological damage. This is achieved through the promotion of protein formation and the activation of antioxidant enzymes (Okumoto *et al.* 2016; Teixeira *et al.* 2017). Additionally, Glu application has been associated with improved yield and enhanced berry quality in grape (Stino *et al.* 2017; González-Santamaría *et al.* 2018). Met is a crucial amino acid that plays a significant role in various physiological functions within plants. The restriction of this amino acid can jeopardize plant survival, as it serves as a potent regulator in the growth and development of plants experiencing water scarcity (Mehak *et al.* 2021). Being a fundamental amino acid, Met actively contributes to a range of physiological functions and effectively regulates the development of plants under conditions of water deficit (You *et al.* 2019). L-Try acts as a signal-transducing molecule and facilitates the preparation of nutrients by plants (Teixeira *et al.* 2017). Lys is an amino acid that participates in various responses to abiotic and biotic stresses through the saccharine pathway (Arruda and Barreto 2020).

Hence, the current research was undertaken to explore the beneficial impact of applying Glu, Met, Lys, and Try as eco-friendly biostimulants, which can improve the performance of peach trees to produce good yields with high fruit quality characteristics.

EXPERIMENTAL

Materials and Methods

Applied treatments, location, and experimental design

The experiment, conducted in 2022 and 2023, involved 10-year-old 'Florida Prince' peach trees grafted onto Nemaguard peach rootstock. These trees were planted with a spacing of 3×4 meters in sandy soil within a private orchard under drip irrigation, situated in the Rashid region of El-Beheira governorate, Egypt. The physicochemical analysis of the experimental soil followed the protocol outlined by Sparks *et al.* (2020) and is exhibited in Table 1. Sixty-six peach trees, chosen for uniform vigor, were selected for the study, and subjected to identical agricultural practices throughout the two seasons.

Table 1. Analysis of the Experimental Soil

<table>
<tr><td>Sand</td><td>Silt</td><td>Clay</td><td colspan="2">Textural Class</td><td>Organic Matter</td><td>pH</td><td>$CaCO_3$</td><td colspan="2">EC (dS/m) (Soil Extraction 1:5)</td></tr>
<tr><td>93.5%</td><td>3.5%</td><td>3%</td><td colspan="2">Sandy</td><td>0.3%</td><td>7.9</td><td>4.8%</td><td colspan="2">0.810</td></tr>
<tr><td colspan="3">Soluble Anions (meq/L)</td><td colspan="4">Soluble Cations (meq/L)</td><td colspan="3">Available Nutrients (mg/kg)</td></tr>
<tr><td>HCO_3^-</td><td>CL^-</td><td>SO_4^{--}</td><td>Ca^{++}</td><td>Mg^{++}</td><td>Na^+</td><td>K^+</td><td>N</td><td>P</td><td>K</td></tr>
<tr><td>2.1</td><td>2.50</td><td>4.18</td><td>2.20</td><td>3.46</td><td>2.12</td><td>1.22</td><td>115</td><td>17.8</td><td>307</td></tr>
</table>

The trees were exogenously sprayed three times: before flowering, during full bloom, and one month later using various treatments: water (control), Glu, Met, L-Try, and Lys amino acids at the concentration of 250 and 500 ppm, and by their combinations: 250 ppm Glu + 250 ppm Met + 250 ppm L-Try + 250 ppm Lys (combination 1) and 500 ppm Glu + 500 ppm Met + 500 ppm L-Try + 500 ppm Lys (combination 2). The experimental design followed a randomized complete block design, with each treatment consisting of six replicates (six trees).

Vegetative Parameters

At the end of the growing seasons, the diameter for four shoots from each side on each tree/replicate was measured in cm by using a Digital Vernier Caliper in both seasons. The leaf total chlorophyll was measured using a digital chlorophyll meter (SPAD 502 Plus, Konica Minolta, Inc., Tokyo, Jap) by taking 10 reads from the mature leaves from each replicate/tree. The average leaf area (cm^2) was determined using Eq. 1 (Mosa *et al.* 2021).

$$\mathrm{LA} = -0.5 + (0.23 \times L/W) + (0.67 \times L \times W) \quad (1)$$

where LA is the leaf area (cm^2), L is the leaf length (cm), and W is the leaf width (cm).

Fruit Yield

Yield was estimated for the period May 2022 to 2023 in the units of kg per tree and in ton per hectare.

Fruit Quality, Fruit Physical Characteristics

After harvest, 30 fruits were chosen randomly from each replicate, and their weight (g), seed weight (g), length (cm), and diameter (cm) were measured. Fruit firmness ($lb/inch^2$) was determined using a Magness and Taylor pressure tester equipped with a 7/18-inch plunger. Fruit size (cm^3) was assessed by measuring the volume of displaced water after immersing the fruit. Total soluble solids (TSS%) were measured using a hand refractometer (ATAGO Co. LTD., Tokyo, Japan).

Fruit Chemical Characteristics

Anthocyanin content was determined during the coloration stage (mg/100 g fresh weight peel) following the method outlined by Nangle *et al.* (2015). The ascorbic acid content in the juice was assessed through titration with 2,6-dichloro phenol-indo-phenol and expressed in milligrams in mg/100 mL of juice. Total and reducing sugars contents were quantified calorimetrically using the Neilsen arsenate-molybdate colorimetric method (Nielsen 2010).

Fruit acidity, expressed as a percentage and measured in terms of malic acid content, was determined in fruit juice using a titration method with 0.1 N sodium hydroxide, employing phenolphthalein as an indicator (AOAC 2005). The TSS-acid ratio was computed by dividing the TSS value by the titratable acidity value.

Mineral Content in Leaves

In June 2022 to 2023, 30 leaves were collected from each tree (Arrobas *et al.* 2018) for the determination of macronutrient mineral contents. The leaves were first washed in tap water and then rinsed with distilled water. Subsequently, they were dried in an oven at 70 °C until a consistent weight was achieved, followed by crushing.

The samples underwent digestion with H_2SO_4 and H_2O_2. Nitrogen content was quantified using the micro-Kjeldahl method (Wang *et al.* 2016), phosphorus was determined using the vanadomolybdate method (Weiwei *et al.* 2017), and potassium was measured utilizing a flame photometer (SKZ International Co., Ltd., Jinan Shandong, China) (Chapman 2021).

Statistical Analysis

Results were analyzed by using a one-way analysis of variance analysis (ANOVA) for a Randomized Complete Block Design (RCBD) design. The least significant difference at 0.05 was used to compare the means of the treatments as described by Snedecor and Cochran (2021).

RESULTS

Vegetative Growth Parameters

The results presented in Table 2 indicate a substantial increment in shoot thickness, leaf area, and total chlorophyll content with the foliar application of Glu, Try, Met, Lys, and their combinations, compared to untreated trees, during both experimental seasons. Notably, the impact of 500 ppm from Try surpassed the effect of Glu at the same concentration in both seasons. Furthermore, the most effective treatment that gave the highest increments in shoot thickness, and leaf area was combination 2 when compared with the utilized treatments in 2022 to 2023. The increments in leaf total chlorophyll were (26.0 and 28.3%) by the spraying of combination 2 comparing with not treated trees in the first and the second season.

Table 2. Spraying Effect of Glu, Try, Met, and Lys Amino Acids and their Combinations on Shoot Thickness, Leaf Area and Leaf Total Chlorophyll of Peach During 2022 to 2023

Treatment		**Shoot Thickness (mm)**		**Leaf Area (cm^2)**		**Total Chlorophyll (SPAD)**	
		2022	2023	2022	2023	2022	2023
Control		0.30e	0.32f	0.32c	0.33e	32.33d	34.67c
Glu	250 ppm	0.32cde	0.33ef	0.35c	0.35d	33.00d	35.00c
	500 ppm	0.33cde	0.36cd	0.35bc	0.38cd	39.33b	43.00b
Try	250 ppm	0.33cde	0.34def	0.35c	0.37cd	36.33c	41.67b
	500 ppm	0.37b	0.41b	0.40ab	0.41b	43.67a	42.33b
Met	250 ppm	0.33cde	0.33f	0.34c	0.36d	32.67d	37.33c
	500 ppm	0.36bc	0.39bc	0.36bc	0.40bc	40.00b	42.67b
Lys	250 ppm	0.31de	0.32f	0.34c	0.35d	32.33d	35.00c
	500 ppm	0.34bcd	0.39bc	0.36bc	0.38cd	40.33b	43.33b
Combination	1	0.33cde	0.36de	0.35bc	0.38cd	38.67bc	41.67b
	2	0.43a	0.44a	0.42a	0.44a	43.67a	48.33a
$LSD_{0.05}$		0.03	0.03	0.04	0.02	2.61	2.95

The same letters in the same column indicate no significant differences between treatments.

Fruit Yield

The results shown in Table 3 indicated that the spraying of Glu, Try, Met, Lys, and their combinations improved the fruit weight and fruit yields in the two seasons. Additionally, the application of 500 ppm from each one of Try, Met, and Lys was more effective than the application of 250 ppm from Glu, Try, Met, and Lys in their effects in enhancing the fruit weight and fruit yields. Combination 2 gave the highest and notable results in fruit weight (29.2 and 27.5%), and fruit yields in kg or in ton per hectare by (14.8 and 15.9%) in contrast to not treated trees in the first and second seasons respectively. The concentration of 500 ppm from each one of the sprayed amino acids was more effective than the application of 250 ppm.

Table 3. Spraying Effect of Glu, Try, Met, and Lys Amino Acids and their Combinations on Fruit Weight and Fruit Yields of Peach During 2022 to 2023

Treatment		**Fruit Weight (g)**		**Fruit Yield (kg)**		**Fruit Yield (ton/h)**	
		2022	2023	2022	2023	2022	2023
Control	0	55.00d	59.67e	141.69d	143.55d	113.35d	114.84d
Glu	250 ppm	55.67d	62.00de	140.97d	144.14d	112.78d	115.31d
	500 ppm	68.67b	77.00b	150.08c	159.25bc	120.06c	127.40bc
Try	250 ppm	63.00c	71.33c	145.96cd	155.95c	116.77cd	124.76c
	500 ppm	73.67a	76.67b	156.64b	163.95b	125.31b	131.16b
Met	250 ppm	57.67d	65.33d	145.69cd	155.71c	116.55cd	124.57c
	500 ppm	75.33a	78.00b	157.51b	160.13bc	126.01b	128.11bc
Lys	250 ppm	57.33d	61.67de	143.02d	147.75d	114.42d	118.20d
	500 ppm	75.00a	77.67b	151.35bc	161.16bc	121.08bc	128.93bc
Combination	1	66.67bc	75.33bc	149.99c	156.18c	119.99c	124.95c
	2	77.67a	82.33a	166.39a	170.74a	133.11a	136.59a
$LSD_{0.05}$		3.95	4.18	5.98	6.17	4.78	4.93

The same letters in the same column indicate no significant differences between treatments.

Physical Fruit Characteristics

The data presented in Table 4 indicates the positive impact of spraying Glu, Try, Met, and Lys amino acids, as well as their combinations on the enhancement of fruit weight, seed weight, and fruit firmness compared to untreated trees in both experimental seasons. The highest effect of Glu, Try, Met, and Lys amino acids at 500 ppm gave more increases in flesh fruit weight, seed weight and fruit firmness than those at 250 ppm in the two seasons. Additionally, the most notable results were obtained by the use of combination 2 in contrast to the individual application of the amino acids in the two seasons.

Table 4. Spraying Effect of Glu, Try, Met, and Lys Amino Acids and their Combinations on Flesh Fruit Weight, Seed Weight and Fruit Firmness of Peach During 2022 to 2023

Treatment		Flesh Fruit Weight (g)		Seed Weight (g)		Fruit Firmness (lb/inch^2)	
		2022	2023	2022	2023	2022	2023
Control		43.67d	49.00d	11.33c	10.67ef	10.17g	10.03f
Glu	250 ppm	45.33d	50.33d	10.33c	11.67def	10.17g	10.07f
	500 ppm	55.00b	59.67bc	13.67ab	17.33a	10.90cde	10.93cd
Try	250 ppm	50.67c	58.00c	12.33bc	13.33b-e	10.58ef	10.53de
	500 ppm	60.00a	62.00b	13.67ab	14.67abc	11.30b	11.33bc
Met	250 ppm	47.33cd	52.33d	10.33c	13.00cde	10.33fg	10.43ef
	500 ppm	61.33a	62.33b	14.00ab	15.67abc	11.23bc	11.50b
Lys	250 ppm	46.33d	51.67d	11.00c	10.00f	10.43fg	10.07f
	500 ppm	59.33a	62.00b	15.67a	15.67abc	11.03bcd	11.30bc
Combination	1	54.40b	61.00bc	12.27bc	14.33bcd	10.80de	10.60de
	2	63.00a	66.33a	14.67a	16.00ab	11.70a	11.93a
LSD at $_{0.05}$		3.40	3.50	2.08	2.48	0.33	0.40

The same letters in the same column indicate no significant differences between treatments.

Table 5. Spraying Effect of Glu, Try, Met, and Lys Amino Acids and their Combinations on Fruit Volume, Length and Diameter of Peach During 2022 to 2023

Treatment		Fruit Volume (cm^3)		Fruit Length (cm)		Fruit Diameter (cm)	
		2022	2023	2022	2023	2022	2023
Control		68.33e	73.33e	3.43g	3.73e	3.50f	3.83f
Glu	250 ppm	69.67e	74.00e	3.50fg	4.03e	3.47f	4.17de
	500 ppm	80.67c	88.67bc	4.40c	4.77bcd	4.63ab	4.47bcd
Try	250 ppm	75.33d	85.33 c	4.07d	4.47d	4.23cd	4.33cd
	500 ppm	87.33ab	89.33b	4.80b	5.00b	4.70a	4.70b
Met	250 ppm	70.00e	78.33d	3.87de	4.70bcd	3.97de	4.40bcd
	500 ppm	85.00b	87.33bc	4.70b	4.93b	4.73a	4.60bc
Lys	250 ppm	70.00e	75.33de	3.77ef	4.67bcd	3.87e	4.00ef
	500 ppm	86.33b	89.67b	4.57bc	4.87bc	4.70a	4.53bc
Combination	1	80.67c	89.33b	4.37c	4.53cd	4.40bc	4.43bcd
	2	90.67a	94.33a	5.33a	5.63a	4.83a	5.10a
LSD$_{0.05}$		3.83	3.56	0.28	0.31	0.27	0.28

The same letters in the same column indicate no significant differences between treatments.

The results presented in Table 5 demonstrate the positive impact of foliar application of exogenous amino acids, including Glu, Try, Met, and Lys, as well as their combinations, on fruit volume, length, and diameter in comparison to untreated trees during the 2022-2023 period. It was seen that the exogenous application of Glu, Try, Met, and Lys at 500 ppm was more effective in their effect in increasing these parameters than the application of 250 ppm in the two seasons. Additionally, the most effective treatment was the combination 2 in the two seasons.

Fruit Chemical Characteristics

The results in Table 6 illustrate that the use of Glu, Try, Met, and Lys increased the fruit content from soluble solids, and TSS-acid ratio, as opposed to untreated trees. In addition, they diminished the fruit content from acidity in the two seasons. The most significant increments were associated with the application of 500 ppm from Try, Met and Lys rather than the application of 250 ppm from them, while they lowered the fruit acidity. The results showed that the combination 2 was the superior treatment where it remarkably increased TSS percentages (20.4 and 20.3%), anthocyanin content (17.9 and 23.2%) and TSS-acidity (39.8 and 38.4%). Meanwhile, it minimized the fruit acidity percentages (32.3 and 29.7%) in the first and in the second seasons over not treated trees.

Table 6. Spraying Effect Spraying of Glu, Try, Met, and Lys Amino Acids and their Combinations on Fruit Content from TSS, Acidity, TSS-Acid ratio and Anthocyanin During 2022 to 2023

Treatment		TSS (%)		Acidity (%)		TSS-Acid Ratio		Anthocyanin (mg/100 g)	
		2022	2023	2022	2023	2022	2023	2022	2023
Control		8.83e	8.77e	0.82a	0.83a	10.73h	10.53e	0.55d	0.53e
Glu	250 ppm	9.17e	9.00de	0.79ab	0.80ab	11.66g	11.20de	0.54d	0.55de
	500 ppm	9.27e	10.17b	0.65d	0.74c	14.26cd	13.80c	0.58bcd	0.60bc
Try	250 ppm	9.17e	9.43cd	0.71c	0.76bc	12.85ef	12.36d	0.57cd	0.58cde
	500 ppm	10.53b	10.37b	0.66d	0.65d	16.06b	16.09ab	0.637ab	0.63b
Met	250 ppm	9.30de	9.48cd	0.74c	0.80ab	12.52fg	11.87de	0.59bcd	0.55de
	500 ppm	10.17bc	10.23b	0.65d	0.65d	15.66b	15.76b	0.65a	0.63bc
Lys	250 ppm	8.87e	8.83e	0.75bc	0.83a	11.78g	10.60e	0.56d	0.59bcd
	500 ppm	9.80cd	10.27b	0.67d	0.72c	14.70c	14.35c	0.63abc	0.58cde
Combination	1	9.00e	9.83bc	0.66d	0.71c	13.64de	13.81c	0.57d	0.61bc
	2	11.10a	11.00a	0.62d	0.64d	17.81a	17.10a	0.67a	0.69a
$LSD_{0.05}$		0.50	0.53	0.04	0.05	0.91	1.25	0.05	0.05

The same letters in the same column indicate no significant differences between treatments.

The results presented in Table 7 revealed that the foliar application of 500 ppm from Try, Met, and Lys led to an increase in fruit content from total, reduced, and vitamin C (VC) rather than the exogenous spraying of 250 ppm from each one of them in the two seasons. Regarding the fruit content from non-reduced sugars, the results showed that they were significantly increased by the spraying of 500 ppm from Met in the first season and Lys or Glu in the second season. Additionally, the highest increases in fruit content from total and reducing sugars and VC have resulted from the exogenous application of combination 2 rather than the other sprayed treatments.

Table 7. Spraying effect of Glu, Try, Met, and Lys Amino Acids and their Combinations on Fruit Content from Total, Reduced, and Non-Reduced Sugars, and Vitamin C of peach 2022 to 2023

Treatment		**Total Sugars (%)**		**Reducing Sugars (%)**		**Non- Reduce Sugars (%)**		**Vitamin C (mg/100 mL)**	
		2022	2023	2022	2023	2022	2023	2022	2023
Control		7.80c	7.67e	3.23f	3.62c	4.57abc	4.04bcd	7.43d	7.47e
Glu	250 ppm	7.90c	7.67e	3.29f	3.76c	4.61abc	3.91cd	7.62cd	7.87de
	500 ppm	8.07c	8.73bc	4.02bc	4.00c	4.04c	4.73a	7.93cd	8.63a-c
Try	250 ppm	7.97c	8.13d	3.67de	3.82c	4.29bc	4.31a-d	7.90cd	8.23b-d
	500 ppm	8.87b	8.97b	4.16b	4.63a	4.71ab	4.33a-d	8.63ab	8.70a-c
Met	250 ppm	7.80c	8.23d	3.47ef	3.69c	4.33bc	4.54abc	7.77cd	7.80de
	500 ppm	8.87b	8.77bc	3.94b-d	4.47ab	4.93a	4.30a-d	8.20bc	8.03c-e
Lys	250 ppm	7.83c	7.57e	3.28f	3.79c	4.55abc	3.77d	7.73cd	7.67de
	500 ppm	8.63b	8.83b	4.15bc	4.05bc	4.49a-c	4.78a	8.10b-d	8.17b-e
Combination	1	7.87c	8.37cd	3.82cd	3.76c	4.05c	4.61ab	7.83cd	8.80ab
	2	9.43a	9.53a	4.82a	4.90a	4.62abc	4.63ab	9.03a	9.07a
$LSD_{0.05}$		0.42	0.42	0.31	0.43	0.52	0.56	0.64	0.66

The same letters in the same column indicate no significant differences between treatments.

Nutritional Status

The foliar application of amino acids Glu, Try, Met, and Lys and their combinations resulted in a positive impact on improving the mineral contents of peach leaves from nitrogen, phosphorus, and potassium, compared to untreated trees (Table 8). Moreover, the spraying of 500 ppm from Try, and Met were effective in their effect in improving the leaf mineral content from N, P and K from the spraying of 250 and 500 ppm from Glu and Lys or from also 250 ppm from Try or Met in the two seasons.

Table 8. Spraying Effect of Glu, Try, Met, and Lys Amino Acids and their Combinations on the Leaf Mineral Content of Peach from Nitrogen, Phosphorous and Potassium During 2022 to 2023

Treatment		N (%)		P (%)		K (%)	
		2022	2023	2022	2023	2022	2023
Control		2.04d	2.01e	0.43e	0.45d	2.20f	2.28f
Glu	250 ppm	2.05d	2.05de	0.44de	0.46d	2.20f	2.28f
	500 ppm	2.36c	2.43b	0.50c	0.55c	2.28e	2.44bc
Try	250 ppm	2.04d	2.22cd	0.46d	0.47d	2.22f	2.42bcd
	500 ppm	2.77a	2.67a	0.57b	0.62b	2.44b	2.43bcd
Met	250 ppm	2.06d	2.11de	0.44de	0.47d	2.23f	2.35e
	500 ppm	2.64b	2.70a	0.56b	0.60b	2.39c	2.43bcd
Lys	250 ppm	2.04d	2.06de	0.45de	0.45d	2.21f	2.38cde
	500 ppm	2.54b	2.48b	0.52c	0.56c	2.35d	2.46b
Combination	1	2.28c	2.32bc	0.47d	0.54c	2.21f	2.38de
	2	2.88a	2.80a	0.61a	0.66a	2.49a	2.53a
$LSD_{0.05}$		0.11	0.16	0.03	0.04	0.04	0.05

The same letters in the same column indicate no significant differences between treatments.

Additionally, the most obvious enhancements in leaf mineral content from N (29.17 and 28.21%), P (29.51 and 31.82%) and K (11.65 and 2.88%) were observed with the application of combination 2 compared to control in the first and the second season.

DISCUSSION

The application of Glu, Met, Try, and Lys individually or in combinations through foliar spraying significantly enhanced the growth, yield, and fruit quality of peach as opposed to untreated trees. These results are in the same trend as the findings of Cao *et al.* (2011), who emphasized the importance of Glu in nitrogen metabolism, highlighting its role in nitrogen assimilation in plants and aminotransferase reactions.

The application of Glu increased photosynthetic activity and chlorophyll fluorescence measurements (Fabbrin *et al*. 2013; Lee *et al*. 2017; Röder *et al*. 2018), and this enhancement is attributed to the connection between photosynthetic capacity and leaf nitrogen concentration. Besides, Glu improved the protein and sugar content and productivity (Haghighi and Teixeira Da Silva 2013). Glu is the amino acid that most notably influences the root growth in numerous plant species (Forde 2014). In 'Flame Seedless' grapevines, the external spraying of Glu at a rate of 500 mg resulted in a 10%, 15%, and 22% increase in leaf mineral contents from N, K and P, respectively, with respect to the control treatment (Belal *et al*. 2016). Glu can organize the growth of the roots and defense responses in plants (Toyota *et al.* 2018; Goto *et al*. 2020). Glu influences the processes of pollination and fruit set and encourages the production of secondary metabolites (El-Shiekh and Umaharan 2014), as well as the activation of genes linked to stress and defence mechanisms (Li *et al*. 2019a,b). Additionally, Glu significantly improved the quality and yield of 'Thompson Seedless' grapevines, (Abou-Zaid and Eissa 2019). The application of Glu has been reported to stimulate the sprouting of both vegetative and reproductive buds, increase chlorophyll concentration, and enhance fruit quality. Improvements include increased fruit weight, size, firmness, and higher citric acid concentration (Soberanes-Pérez *et al*. 2020). Almutairi *et al.* (2022) reported that the foliar application of Glu at concentrations of 500 or 1000 ppm on guava trees resulted in increased shoot length and diameter, elevated leaf chlorophyll levels, improved fruit set, enhanced fruit yield, increased fruit firmness, and elevated content of total soluble solids, vitamin C, and total sugars. Furthermore, the leaf mineral content showed higher concentrations of N, K, and P in contrast to not sprayed trees.

The application of exogenous Met through foliar spray is a practical approach that has a positive effect on the integrity of photosynthetic pigments, the accumulation of compatible osmolytes, the mitigation of reactive oxygen species, and the enhancement of cowpea growth and yield, as demonstrated by Merwad *et al.* (2018). The application of Met to plants can enhance the absorption of nitrogen and sulfur, as indicated by Santi *et al.* (2017), ultimately contributing to the growth and developmental processes of plants. Met plays an important role in the biosynthesis of auxins, cytokinins, and Brassinosteroids (Yong *et al*. 2014). Additionally, Met functions as a precursor for various biomolecules, including cofactors, polyamines, and vitamins, and serves as an essential component in the synthesis of antioxidants such as glutathione. These antioxidants, in turn, contribute to the production of defense compounds and participate in cellular redox homeostasis, as highlighted by Paungfoo-Lonhienne *et al.* (2008). Met plays a crucial role in regulating chlorophyll biosynthetic processes and preventing chlorophyll degradation by enhancing the scavenging system of reactive oxygen species, as suggested by Abdelhamid *et al.* (2013). The application of Met can influence the synthesis and regulation of various genes and enzymes involved in the biosynthesis and signaling of other amino acids. This, in turn, contributes to maintaining redox homeostasis, resulting in elevated amino acid contents and improved salinity tolerance in plants (Zhang *et al*. 2017). Met organizes transpiration, protein synthesis, and the process of photosynthesis, and preserves membrane firmness, and relative water content in conditions of water deficit (Merwad *et al*. 2018; Mehak *et al.* 2021). Additionally, it effectively regulates plant growth and development under conditions of water scarcity (You *et al*. 2019).

L-Try, a precursor to IAA, naturally occurs in the root exudates of plants (Quiroz-Villareal *et al*. 2012). Besides, it serves as a precursor for the production of indole-3-acetic acid, a compound with a structure similar to that of melatonin (Arnao and Hernandez-Ruiz 2019), and it markedly increases the levels of free IAA (Wójcik *et al*. 2016). Besides, the application of exogenous L-Try at concentrations of 125, 250, and 375 ppm was studied for its effects on various growth parameters of lettuce plants exposed to salt stress. The researchers observed that exogenous spraying with higher concentrations significantly influenced leaf number, salt tolerance, fresh leaf, and root weights, as well as the surface area of lettuce plants under salinity conditions at 200 mM (Hancı and Tuncer 2020). Applying L-Try to “Anna” apple trees at concentrations of 25, 50, and 100 ppm led to notable improvements in several growth and yield parameters. These enhancements included increased shoot length and diameter, expanded leaf area, higher total chlorophyll levels, greater percentages of fruit set and yield, and positive changes in both the physical and chemical advantages of the fruit. The leaf mineral composition, encompassing macronutrients such as N, P, K, and Ca, and micronutrients such as Fe, Zn, Mn, and B, also exhibited noteworthy improvements. Furthermore, the treatment resulted in a depression in the fruit drop percentages in comparison to the control trees for both seasons studied. Notably, concentrations of 50 and 100 ppm demonstrated superior effectiveness in enhancing these parameters compared to the 25 ppm concentration, as reported by Mosa *et al.* (2021).

The spraying of Lys at a concentration of 15 mM on tomatoes proved to be advantageous for the growth of the aerial part, net assimilation of CO_2, and water utilization efficiency, as highlighted by Alfosea-Simón *et al.* (2020a). Lys metabolism is implicated in various forms of plant stress responses. It is primarily catabolized through the saccharine pathway that notably raised the resistance to both abiotic and biotic stresses (Bernsdorff *et al*. 2016; Arruda and Barreto 2020). Lys serves as an essential component in the construction of proteins, playing a fundamental role in this process. Additionally, it functions as a precursor for Glu, an important signaling amino acid that plays a pivotal role in regulating plant growth and responses to environmental stimuli (Galili 2002). Applying Lys at a concentration of 100 mg/L through spray applications has been demonstrated to improve the plant height, leaf number, lateral branches, leaf area, chlorophyll content, yield, tuber length and diameter, dry matter, and the tubers-shoots ratio. Furthermore, it positively influenced the chemical composition of starch, total carbohydrates, nitrogen, phosphorus, and potassium (Hassan *et al*. 2020).

From the discussed results, the application of four amino acids has been found to be an efficient tool to improve the vegetative growth, yield, fruit quality and nutritional status of peach trees. The amino acids could be used to reduce the usage of chemical fertilizers to avoid their undesirable effects of the fruit quality characteristics of peach as well as their effective role in alleviating the environmental stresses with their high absorption rate *via* leaves.

CONCLUSIONS

1. The results showed that the application of amino acids is an effective way to improve the growth, yield, and fruit quality of peach.
2. The application of 500 ppm from Glu, Met, L-Try and Lys was more beneficial than the application of 250 ppm.
3. Notably, the most effective treatment was combination 2 (500 ppm Glu + 500 ppm Met + 500 ppm L-Try + 500 ppm Lys) in increasing the growth, yield, fruit quality characteristics, as well as nutritional content from N, P and K as opposed to not spraying the trees.
4. The surface application of amino acids could be used as an eco-friendly and environmentally friendly way to improve the growth and productivity of peach trees without any undesirable effects on the environment.

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