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Growth Performance of Guava Trees after the Exogenous Application of Amino Acids Glutamic Acid, Arginine, and Glycine

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Abstract: A 2020–2021 study was performed on five-year-old guava trees to examine the influence of the foliar application of three amino acids, glycine, arginine, and glutamic acid, at a concentration of 500 or 1000 ppm. Additionally, two combinations of the three mentioned amino acids were also applied: 500 glycine + 500 arginine + 500 glutamic acid (combination 1) and 1000 glycine + 1000 arginine + 1000 glutamic acid (combination 2), and compared with a control (untreated trees). The results indicated that the application of the three amino acids, solely or in combination, was effective at increasing the shoot length, shoot diameter, and leaf chlorophyll. Additionally, the applied treatments also improved markedly the fruit set percentage, fruit yield, fruit firmness, fruit content of total soluble solids (TSS %), vitamin C (VC), and total sugars as well as the leaf mineral content (nitrogen, potassium, and phosphorus) compared with untreated trees in 2020 and 2021. Moreover, the results indicated that the combinations were more effective than individual applications and that glycine had a greater influence than arginine or glutamic acid, particularly when it was applied at 1000 ppm.

Keywords: guava; amino acids; glycine; fruit quality; yield

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1. Introduction

The guava tree (*Psidium guajava* L.), cultivated widely in tropical and subtropical areas around the world, is productive and profitable, and its fruit is tasty and has great nutritional value, especially due to the vitamin C content. Recently, global demand has increased because it can be eaten fresh but also processed into pulp, juice, wines, jams, and jellies [1]. Increasing the acreage of guava farming to obtain high production and quality requires increased usage of mineral fertilizers, which are costly and can have undesirable environmental effects. Therefore, more attention has recently been given to the dependency on amino acids in sustainable production [2]. Amino acids are organic molecules that contain N, C, H, and O_2 [3]. It has been reported by some authors that the spraying of amino acids increased vegetative growth and productivity in numerous crops [4,5]. Moreover, they have a biostimulatory influence on plant growth and the absorption of nutrients [6–8] and on productivity in many plants [8]. Sadak et al. [9] mentioned that amino acids can increase a plant's resistance to the undesirable effects of abiotic stresses, such as salinity, so they positively influence plant growth and yield. Furthermore, because amino acids are effective in small quantities, they are friendly to the environment, the soil, and human health [10]. Additionally, amino acids are a good source of nitrogen for plants, affecting productivity, inducing the development of shoots and roots, and, owing to their chelating properties, improving nutrient uptake, photosynthesis efficiency, and stomata movement [11–13]. Many authors have reported that providing plants with amino acids increased the fruit content of sugars, proteins, and elements [14,15] and raised the plant's resistance to abiotic and biotic stresses [16,17]. Amino acids could boost the development of plant cells, as well as enzyme activation to decompose organic compounds, which liberates the elements, resulting in better growth averages [18–20]. Jerry and Al-Jarah [21] stated that amino acids have a pronounced role in maintaining the flowering process, transferring mineral elements to flowers.

Glutamic acid has an effect on plant development, yield, and fruit chemical characteristics [22,23]. Yaronskaya et al. [24] noted that glutamate plays a part in the synthesis of leaf chlorophyll. It has been reported by many authors that glutamate has a crucial impact on plant metabolism [25,26] and nitrogen assimilation pathways [27,28]. Nitrogen can be absorbed in the form of glutamate [29,30]. Furthermore, glutamate could be involved in the synthesis of proteins, glutamine, proline, arginine, glutamic acid, and chlorophyll [31,32]. Moreover, it can help in the transition of plants from the vegetative to the generative developing phase [33]. It has recently been demonstrated that glutamate positively affects the growth and development of roots [25,34], and it is also associated with the transportation of calcium [35] and abscisic acid in plants [36]. Haghighi and Teixeira Da Silva [37] reported that glutamic acid improved the protein and sugar content and yield.

Arginine has been identified as essential in nitrogen storage. Its weight is 174.2 g mol^{-1} and it is effective for transporting in plants because of the high nitrogen/carbon ratio [38]. Moreover, it is a source of nitrogen through the development of proteins and enzymes, involved in cell production and upregulating the production of carbohydrates and proteins, as well as stimulating physiological and biological processes and thus improving the plant's performance [39]. Additionally, its application could increase nitrogen absorption by plants [40,41] and resistance to ecological stresses [42]. Furthermore, it is the fundamental unit in the formulation of proteins and some other bioactive components of higher plants [43]. Furthermore, it encourages plants to produce proteins and hormones such as auxins by increasing the production of necessary amino acids, in particular tryptophan, which encourages the elongation of plant cells [44]. Winter et al. [45] stated that, due to raising the nitrogen-carbon ratio in arginine, it is considered a good medium for the transporting of nitrogen. Spraying strawberries with 50 ppm arginine improved the fruit size and the number of achenes [46]. Moreover, Cheng et al. [47] mentioned that arginine contributes to the storage of nitrogen and its transfer inside plants because of its high nitrogen-carbon ratio.

Glycine is a small amino acid, hydrophilic and nonpolar, and, as a result of its chemical composition, it can react in both acidic and basic mediums. Moreover, it has a crucial effect on leaf chlorophyll and growth attributes, as well as raising the solubility of nutrients such as Mn, Zn, Cu, and Fe [48–50]. Glycine can cooperate with nutrients to raise chelates and increase nutrient uptake and translocation in plants. Its application is a sustainable way to ensure good production with respect to chemical fertilization [10]. Furthermore, the application of glycine markedly increased the total leaf chlorophyll and ascorbic acid, as well as leaf phosphorus, potassium, nitrogen, zinc, and iron [51,52]. Mosa et al. [53] found that spraying "Flame seedless" grapes with glycine at 250, 500, and 750 mg/L improved the shoot length, thickness, productivity, berry weight, cluster weight, TSS, and anthocyanin content, as well as the total chlorophyll and minerals in the leaves, such as nitrogen, potassium, and phosphorus, compared with untreated vines.

Therefore, the current study was performed to study the role of amino acids as good pathways for increasing the vegetative performance, yield, and fruit quality of guava.

2. Materials and Methods

During the 2020 and 2021 seasons, the current study was performed on a private orchard at Abou El Matamir, Beheira governorate, Egypt to examine the influence of the foliar application of three amino acids: glycine (75 g mol^{-1}), arginine (174.2 g mol^{-1}), and glutamic acid (147.13 g mol^{-1}). They were applied at 0.5 and 1 g/L, for a total of 2.5 and 5 g/L for each tree, four times: at the beginning of the vegetative growth (first week of April), the first week of May, the third week of May and mid-June. Guava trees (*Psidium guajava* L.) cv. Maamoura were five years old and were spaced at 4 × 4 m in clay soil under flood irrigation. The soil analysis is shown in Table 1 [54].

Table 1. Physicochemical analysis for the experimental orchard soil.

Depth	**pH**		**EC dS/m**	**O.M %**	**Textural Class**	**Sand %**	**Silt %**		**Clay %**	
0–60	7.4		1.94	1.72	Clay	9.12	20.78		70.1	
Nutrients (mg/kg Soil)				**Soluble Anions (meq/L)**			**Soluble Cations (meq/L)**			
N	P	K	$\mathrm{CaCo_3}$ %	$\mathrm{HCO_3}^-$	Cl^-	$\mathrm{SO_4}^{2-}$	Ca^{2+}	Mg^{2+}	Na^+	K^+
142	21	789	1.27	6.96	5.45	5.65	6.10	3.87	5.55	2.78

To perform this study, we selected 72 trees similar in growth, shape, and size, and each treatment was performed on eight trees/replicates. The trees were selected randomly and distributed in a randomized complete block design (RCBD). The following treatments were administered: control (untreated trees); glycine at 500 and 1000 ppm; arginine at 500 and 1000 ppm; glutamic acid at 500 and 1000 ppm; combination 1 (500 ppm glycine + 500 ppm arginine + 500 ppm glutamic acid); and combination 2 (1000 ppm glycine + 1000 arginine + 1000 glutamic acid).

2.1. Vegetative Growth Parameters

At the start of April (the start of vegetative growth), on every tree (replicate), five shoots on each side were chosen and numbered, and at the end of the season, the shoot length and diameter were measured, while the average leaf area (cm^2) was measured during the vegetative time (Equation (1)) [55]:

$$LA = 0.70\,(L \times W) - 1.06 \tag{1}$$

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

Total chlorophyll ($\mu\mathrm{mol/m}^2$) was measured in leaves as SPAD by a Minolta chlorophyll meter (SPAD 502; Konica Minolta, Osaka, Japan).

2.2. Fruit Set Percentage, Fruit Yield

The fruit set percentage was calculated via Equation (2):

$$\text{Fruit set }(\%) = \frac{\text{Number of fruitlets}}{\text{total number of perfect flowers}} \times 100 \tag{2}$$

In October 2020 and 2021, fruit yield was estimated in kg per tree and in ton per hectare.

2.3. Fruit Quality

Ten fruits from each tree (replicate), were picked in September (at the ripening stage) 2020 and 2021 and transferred directly to the lab for evaluation.

2.3.1. Fruit Physical Characteristics

Fruit weight (g), fruit size (cm^3), fruit length, and diameter were assessed by a Digital Vernier Caliper (Suzhou Sunrix Precision Tools Co., Ltd., Suzhou, China), and we also measured the pulp weight (g), seed weight (g), and juice weight (g). Fruit firmness (1 Lb/inch^2 = 1 psi = 6895 Pa) was assessed using a Magness and Taylor pressure tester (mod. FT 02 (0–2 lb, Alfonsine, Italy).

2.3.2. Fruit Chemical Characteristics

Total soluble solids (TSS %) were measured in fresh fruits by a hand refractometer (ATAGO Co., Ltd., Tokyo, Japan). Total and reducing sugars were measured by the Nelson arsenate–molybdate colorimetric method [56], and the difference between them is nonreducing sugars. The titratable acidity (%) [57], expressed as citric acid (g/100 mg) in fruit juice and then a TSS-TA ratio, was recorded. By titration with 2,6 dichloro phenol-indo-phenol [58], the Vitamin C (ascorbic acid) content in the juice was evaluated and expressed in mg/100 mL.

2.4. Nutritional Status

At the end of the season, and after the fruit picking in November 2020 and 2021, 40 leaves [59] were selected from every tree/replicate to analyze their mineral content in terms of nitrogen (N), phosphorus (P), and potassium (K). Leaf samples were washed with water and then distilled water and dried at 70 °C until a steady weight. The dried leaves were ground and digested by H_2SO_4 and H_2O_2 into a clear solution, which was used to estimate nitrogen by the micro-Kjeldahl method [60], phosphorus by the vanadomolybdate method [61], and potassium using a flame photometer (SKZ International Co., Ltd., Jinan, China) [59].

2.5. Statistical Analysis

One-way analysis of variance (ANOVA) was used to perform the statistical analysis for the obtained results [62]. The comparison of the means of the treatments was performed by a least significant difference (LSD) test at 0.05% (CoHort Software, Pacific Grove, CA, USA).

3. Results

3.1. Vegetative Growth Parameters

The application of glycine, arginine, and glutamic acid, individually or in a mix, greatly improved the vegetative growth attributes in terms of the shoot length, diameter, leaf surface area, and leaf total chlorophyll with respect to untreated trees in the 2020 and 2021 seasons (Table 2). The combination treatments had the most significant influence compared with the other treatments. Additionally, the application of 1000 ppm glycine, 1000 ppm arginine, and 1000 ppm glutamic acid, individually or in combination, was more effective than 500 ppm glycine, 500 pp arginine, and 500 ppm glutamic acid, solely or in combination, in 2020 and 2021.

Table 2. The influence of glutamic acid, arginine, and glycine amino acids on shoot thickness, shoot length, leaf area, and leaf total chlorophyll of guava during the 2020 and 2021 seasons.

Treatment		**Shoot Thickness (cm)**		**Shoot Length (cm)**		**Leaf Area (cm^2)**		**Total Chlorophyll (SPAD)**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Control	0	2.24 f	2.30 g	26.06 d	24.63 d	34.77 f	37.84 e	41.11 e	43.20 e
Glutamic acid	500 ppm	2.78 e	2.77 f	27.30 cd	24.7 d	42.3 e	46.28 d	45.05 d	45.41 d
	1000 ppm	2.96 d	3.41 d	32.08 ab	28.66 c	46.21 bcd	50.12 bc	50.39 c	51.73 c
Arginine	500 ppm	2.78 e	3.16 e	27.71 cd	27.73 c	42.66 de	46.54 d	46.32 d	45.85 d
	1000 ppm	3.58 c	3.61 c	32.33 ab	32.11 b	46.82 bc	51.96 b	51.39 bc	52.01 c
Glycine	500 ppm	2.79 e	3.26 e	30.24 bc	28.00 c	43.36 cde	47.87 cd	47.07 d	46.23 d
	1000 ppm	3.73 b	3.76 b	33.71 ab	32.33 b	47.28 b	56.70 a	52.89 abc	53.26 bc
Combination	1	3.8 ab	4.16 a	34.03 ab	36.17 a	48.89 b	57.25 a	54.29 ab	54.70 b
	2	3.58 a	4.16 a	35.91 a	37.27 a	53.78 a	58.21 a	55.03 a	57.03 a
$LSD_{0.05}$		0.11	0.13	3.69	2.68	3.50	3.03	2.84	1.84

In the same column, treatments that have the same letters have no significant differences between them.

3.2. Fruit Set and Yield

Spraying of glycine, arginine, and glutamic acid markedly improved the fruit set percentages and fruit productivity per tree or per hectare in the 2020 and 2021 seasons (Figure 1). It was noticed that the application of the three amino acids in combination was more efficient than individual application, and the highest percentages in terms of fruit set were obtained by the spraying of the combination treatments. In particular, the spraying of combination 2 enhanced the fruit yield in kg per tree and in tons per hectare in 2020 and 2021 over the other treatments. Furthermore, the same parameters were also improved with 1000 ppm glycine compared to arginine or glutamic acid.

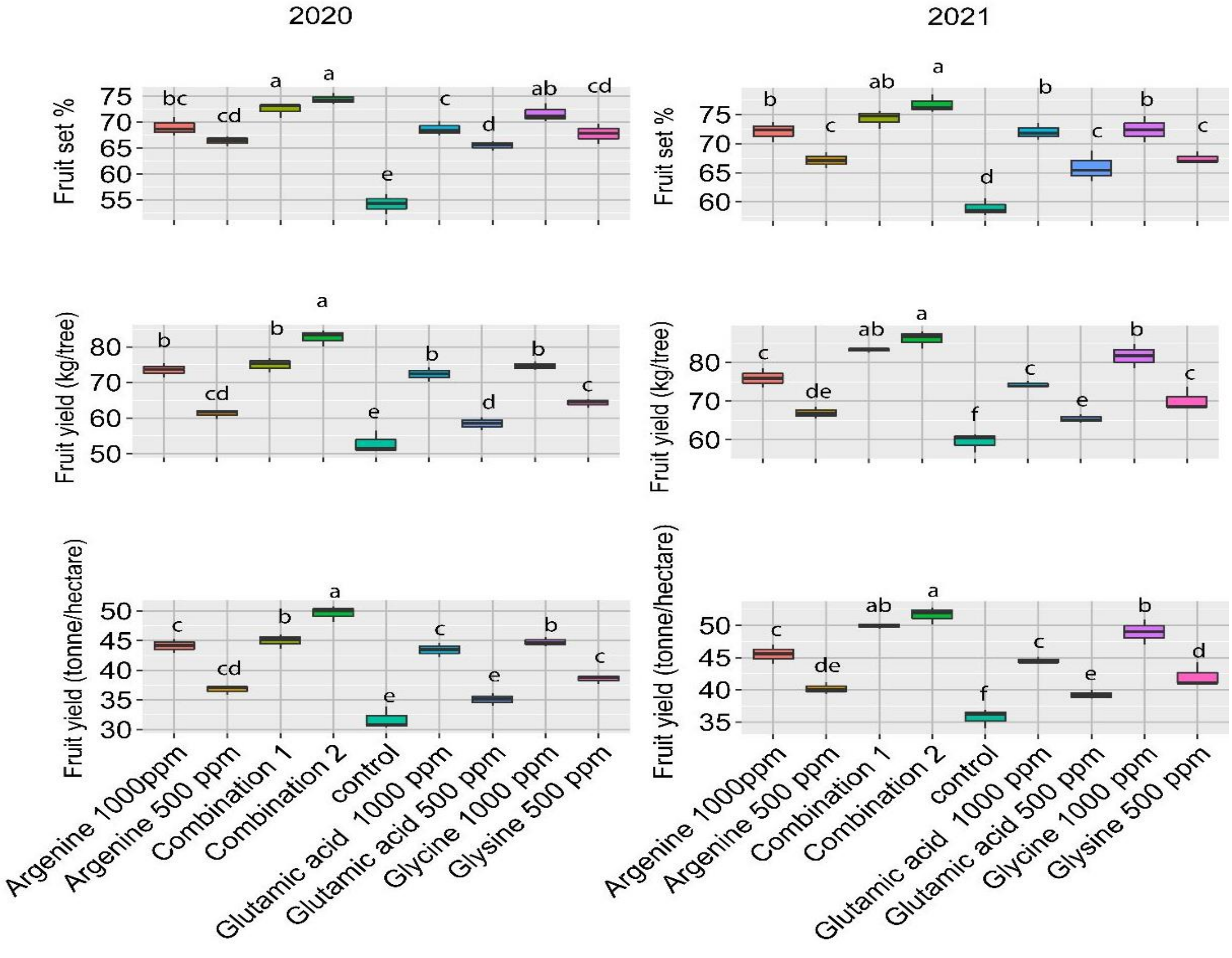

Figure 1. The influence of glutamic acid, arginine, and glycine amino acids on fruit set percentages and fruit yield in kg per tree and ton per hectare of guava during the 2020 and 2021 seasons. Treatments that have the same letters have no significant differences between them.

3.3. Fruit Quality

3.3.1. Fruit Physical Quality Characteristics

Fruit weight, size, length, and diameter were greatly enhanced by the spraying of glycine, glutamic acid, and arginine, individually or in combinations over untreated trees (Table 3). Additionally, the highest increases in fruit weight (in kg per tree) in the 2020 and 2021 seasons were obtained by the application of combinations compared with untreated trees. Additionally, the fruit size, length, and diameter were statistically improved by the spraying of combinations over untreated trees. Moreover, the higher concentration (1000 ppm) of the three applied amino acids was better than the lower concentration

(500 ppm) at improving fruit weight, size, length, and diameter in the 2020 and 2021 study seasons.

Table 3. The influence of glutamic acid, arginine, and glycine amino acids on fruit weight, size, length and diameter of guava during the 2020 and 2021 seasons.

Treatment		**Fruit Weight (g)**		**Fruit Size (cm^3)**		**Fruit Length (cm)**		**Fruit Diameter (cm)**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Control	0	148.24 e	152.81 g	159.24 d	165.28 f	7.42 g	7.65 e	4.40 e	4.43 f
Glutamic acid	500 ppm	155.43 d	156.82 ef	167.67 c	170.28 de	8.18 f	8.20 d	5.09 d	5.10 e
	1000 ppm	162.58 c	164.34 d	173.25 b	178.14 c	8.62 cd	8.65 bc	5.54 b	5.60 bc
Arginine	500 ppm	156.33 d	155.04 f	167.09 c	168.51 ef	8.41 e	8.54 c	5.22 c	5.35 d
	1000 ppm	164.22 bc	165.06 cd	175.55 b	178.53 c	8.63 c	8.68 bc	5.55 b	5.63 bc
Glycine	500 ppm	158.01 d	158.37 e	167.68 c	172.83 d	8.53 d	8.57 bc	5.50 b	5.52 c
	1000 ppm	165.56 bc	166.63 bc	175.56 b	179.43 bc	8.69 c	8.71 b	5.58 b	5.66 b
Combination	1	167.46 b	168.37 b	176.46 b	182.51 b	8.84 b	8.95 a	5.81 a	6.18 a
	2	172.73 a	176.17 a	183.73 a	189.30 a	8.95 a	8.97 a	5.89 a	6.21 a
LSD$_{0.05}$		3.15	2.15	3.04	3.34	0.09	0.14	0.08	0.10

In the same column, treatments with the same letters have no significant differences between them.

The results of Table 4 show that the pulp weight, juice content, and fruit firmness were obviously increased by the foliar addition of glycine, arginine, and glutamic acid amino acids in both study seasons. Moreover, more obvious results were noticed with the application of combinations compared to the other treatments applied during our study. In contrast, they reduced the seed weight compared with untreated trees. The results also showed that the influence of glycine, particularly at 1000 ppm, was higher than that of glutamic acid or arginine.

Table 4. The influence of glutamic acid, arginine and glycine amino acids on seed weight, pulp weight, fruit juice content, and fruit firmness of guava during the 2020 and 2021 seasons.

Treatment		**Seed Weight (g)**		**Pulp Weight (g)**		**Juice (g)**		**Fruit Firmness (Ib/inch^2)**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Control	0	21.70 a	21.76 a	126.54 g	131.06 g	86.29 f	86.65 e	5.29 e	5.30 f
Glutamic acid	500 ppm	20.08 b	21.10 ab	135.35 f	135.72 ef	88.62 ef	89.55 de	6.01 d	5.96 e
	1000 ppm	18.79 bcd	19.89 cd	143.79 d	144.45 d	91.61 cde	93.09 bc	6.33 c	6.14 de
Arginine	500 ppm	19.74 bc	20.49 bc	136.60 ef	134.55 f	89.15 def	90.62 cd	5.94 d	6.08 e
	1000 ppm	18.63 cd	19.51 cde	145.58 cd	145.55 cd	92.30 bc	93.30 bc	6.47 c	6.38 cd
Glycine	500 ppm	18.99 bc	20.10 bcd	139.02 e	138.26 e	90.46 de	90.81 cd	5.99 d	6.13 de
	1000 ppm	17.62 d	19.02 def	147.95 bc	147.61 bc	94.59 bcd	95.05 b	6.45 c	6.60 c
Combination	1	17.52 d	18.51 ef	149.94 b	149.87 b	94.85 ab	95.58 b	7.47 b	7.60 b
	2	17.45 d	18.22 f	155.28 a	157.95 a	97.01 a	103.88 a	8.00 a	8.17a
LSD$_{0.05}$		1.09	1.09	3.28	2.91	2.93	2.91	0.25	0.27

In the same column, treatments with the same letter have no significant differences between them.

3.3.2. Fruit Chemical Quality Characteristics

The TSS %, VC, and TSS-acidity ratio were clearly affected by the application of amino acids in the two seasons compared to untreated trees (Table 5). The highest increases in TSS, Vitamin C, and TSS-acidity ratio were noticed with the application of combination treatments in 2020 and 2021. On the contrary, the combination treatments markedly decreased fruit acidity in 2020 and 2021 as compared to untreated trees. Moreover, TSS, Vitamin C, and the TSS-acidity ratio in fruits were higher with the spraying of 1000 ppm glycine rather than arginine or glutamic acid at the same dose.

Table 5. The influence of glutamic acid, arginine, and glycine amino acids on the fruit content from TSS, total acidity, TSS-acidity ratio, and VC of guava during the 2020 and 2021 seasons.

Treatment		**TSS %**		**Total acidity %**		**TSS-Acidity Ratio**		**VC (mg/100 mL)**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Control	0	8.63 f	9.27 e	0.50 a	0.53 a	17.30 f	17.49 f	176.53 d	176.58 d
Glutamic acid	500 ppm 1000 ppm	9.80 e 12.50 b	10.30 d 12.53 b	0.49 a 0.36 cd	0.50 a 0.37 c	20.50 ef 35.07 c	20.54 f 34.21 d	178.22 cd 187.20 b	181.33 cd 185.90 c
Arginine	500 ppm 1000 ppm	10.50 d 12.57 b	11.60 c 12.87 b	0.44 ab 0.35 cd	0.44 b 0.33 cd	24.01 de 36.35 c	26.09 e 39.45 c	183.77 bcd 191.80 b	181.84 cd 197.00 b
Glycine	500 ppm 1000 ppm	11.30 c 12.63 b	11.19 c 13.77 a	0.40 bc 0.34 cd	0.41 b 0.32 de	28.57 d 37.54 c	27.43 e 43.49 b	184.88 bc 199.87 a	183.80 c 197.33 b
Combination	1 2	13.63 a 14.06 a	14.10 a 14.20 a	0.32 d 0.29 d	0.31 de 0.28 e	42.76 b 47.97 a	46.27 b 51.58 a	200.09 a 207.63 a	205.00 a 208.11 a
$LSD_{0.05}$		0.49	0.64	0.06	0.04	5.18	3.78	7.64	5.38

In the same column, treatments with the same letter have no significant differences between them.

Spraying of glycine, arginine, and glutamic acid amino acids enhanced the total, reduced, and nonreduced sugars compared to the untreated trees (Figure 2). The total sugar and reduced sugar content were increased by the foliar application of combination 2 in 2020 and 2021. The nonreduced sugar percentages were greatly improved by the spraying of arginine, glutamic acid, and glycine at 1000 ppm in 2020 and by combination 1 in 2021. Additionally, the high concentrations of glycine, arginine, and glutamic acid were more effective at increasing the fruit content from total sugars and reduced sugars than the low ones.

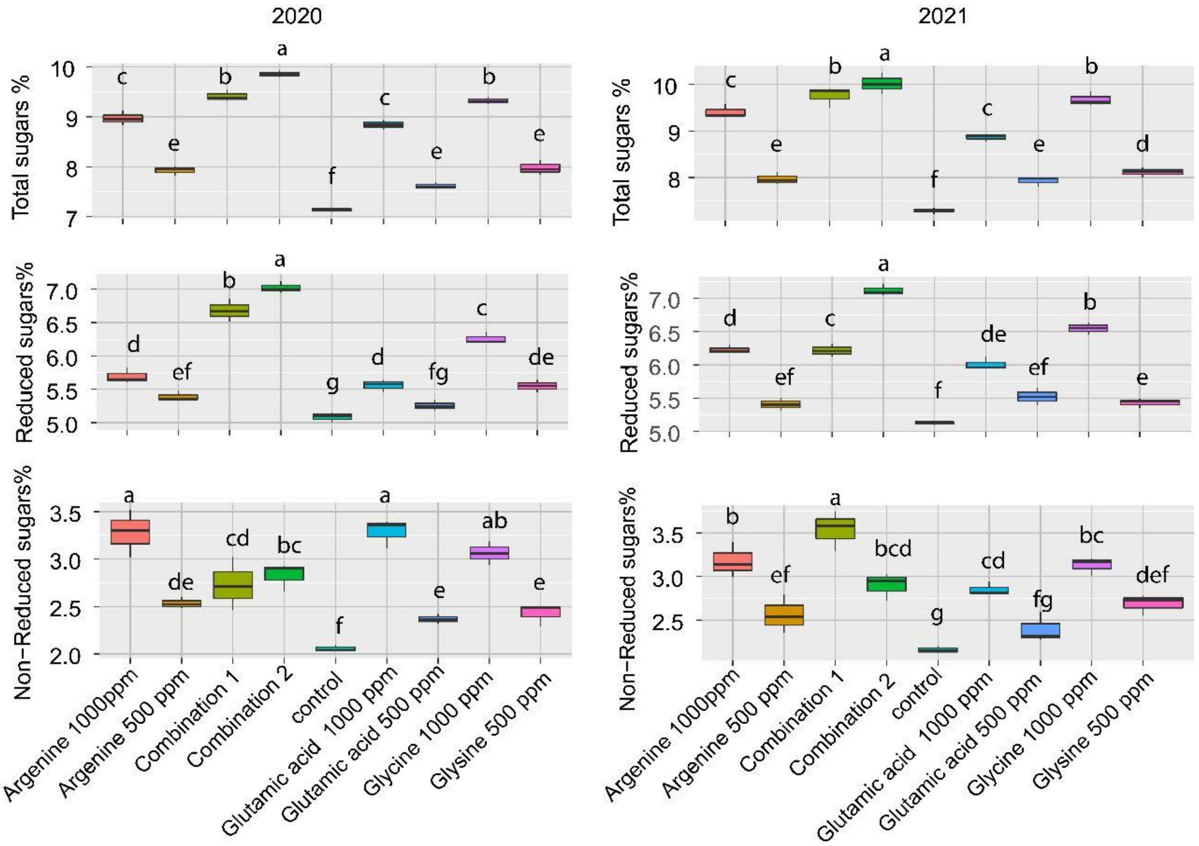

Figure 2. The influence of glutamic acid, arginine, and glycine amino acids on the fruit content from total, reduced and non-reduced sugars percentages of guava during the 2020 and 2021 seasons. Treatments with the same letter have no significant differences between them.

3.4. Nutritional Status

Spraying guava trees with glutamic acid, arginine, and glycine amino acids greatly improved the leaf mineral content of nitrogen, potassium, and phosphorus compared to untreated trees in the 2020 and 2021 seasons (Table 6). The highest increases were noticed after the spraying of combination 2, followed by combination 1, during 2020 and 2021. Moreover, the application of glycine at 1000 ppm was more effective at increasing the leaf mineral content from the same nutrients than arginine or glutamic acid.

Table 6. The influence of glutamic acid, arginine, and glycine amino acids on the leaf content from N, P, and K of guava during the 2020 and 2021 seasons.

Treatment		**N %**		**P %**		**K %**	
		2020	**2021**	**2020**	**2021**	**2020**	**2021**
Control	0	2.06 e	2.11 d	0.32 d	0.36 d	2.32 f	2.51 f
Glutamic acid	500 ppm	2.12 e	2.19 d	0.34 cd	0.36 d	2.52 e	2.72 e
	1000 ppm	2.72 c	2.79 b	0.44 ab	0.45 abc	3.53 c	3.97 b
Arginine	500 ppm	2.25 d	2.29 c	0.35 cd	0.38 cd	2.71 d	2.82 de
	1000 ppm	2.68 c	2.72 b	0.40 bc	0.45 abc	3.48 c	3.58 c
Glycine	500 ppm	2.26 d	2.34 c	0.38 bcd	0.40 bcd	2.72 d	3.00 d
	1000 ppm	2.86 b	2.80 b	0.45 ab	0.47 ab	3.88 b	3.99 b
Combination	1	2.94 ab	2.81 b	0.45 ab	0.49 a	3.99 ab	4.12 ab
	2	3.04 a	3.11 a	0.49 a	0.53 a	4.14 a	4.20 a
$LSD_{0.05}$		0.12	0.10	0.06	0.07	0.17	0.19

In the same column, treatments with the same letter have no significant differences between them.

4. Discussion

The results of the current study demonstrate that foliar spraying of glutamic acid, arginine, and glycine has an obvious effect in terms of improving the vegetative growth attributes, fruit set, fruit yield, fruit quality, and nutritional status of guava under the conditions of the study. These results were explained previously by Lv et al. [63], who reported that spraying with 500 ppm glutamic acid increased the leaf chlorophyll content. Additionally, glutamate could induce chlorophyll synthesis [64,65], and consequently plant growth, with photosynthesis process products used in the production of new organs [66]. Moreover, spraying 50, 100, and 200 mg.L^{-1} glutamine remarkably enhanced the plant growth attributes, yield, and quality [27]. The foliar application of glutamic acid markedly improved the photosynthetic rate and stomatal conductance [67]. Additionally, the application of glutamic acid raised the yield, bunch weight, fruit height, thickness, and volume, as well as the TSS content, of dates [68]. Glutamic acid has a beneficial effect on plants' productivity and quality [69–71]. As glutamic acid is involved in the synthesis of proline, it is one of the most necessary amino acids for plants [72]. Moreover, it has a pronounced influence on the photosynthetic rate [73,74]. Yang et al. [75] reported that glutamate could ameliorate plant development by increasing the resistance of plants to undesirable environments. Furthermore, Noroozlo et al. [8] reported that the foliar application of glutamine at 250, 500, and 1000 mg/L on lettuce significantly increased the total leaf chlorophyll content, leaf Fe content, leaf vitamin C, plant height, root dry weight, N, K, Ca, Mg, and Zn, yield, and vitamin C. Our results are in line with the findings of Abou-Zaid and Eissa [76], who reported that spraying grapevines with glutamic acid at 1000 mg/L greatly improved the total chlorophyll, leaf area, fruit yield, and vine content of N, P, and K. Glutamic acid improved the protein and sugar content, and yield, in the Hongyangl tomato cultivar [37].

Arginine is largely used for enhancing the resistance of plants to stress by encouraging the synthesis of polyamine [77]. It can affect the seed germination rate and phloem and xylem transport [23], and is necessary for root development and elongation [78]. Moreover, it is vital for nitrogen metabolism, in particular urea production and ammonia transformation in plants [45]. Petridis et al. [79] reported that arginine-induced photosynthesis increased the carbohydrate content, SS%, and sugars; therefore, it might be responsible for improving fruit yield and quality. Furthermore, the application of arginine increases fruit quality [80,81] and supplies plants with nitrogen in the form of organic nitrogen, which influences the chloroplast structure and chlorophyll synthesis, and consequently, the photosynthesis process in plants [28,40]. In the same way, it has been found that the exogenous application of arginine at 50 and 100 ppm on pistachios, one week before full bloom and five weeks after full bloom, greatly increased the growth and physiological parameters of shoots. Additionally, it had a positive influence on the fruit and inflorescence bud abscission, and on the number of nuts [82]. Many authors reported that VC and total sugar were remarkably raised by the spraying of arginine [81,83]. Moreover, the foliar spraying of arginine led to a remarkable increase in VC, nutrients, total sugar, TA, and TSS % [84,85]. Additionally, our results are consistent with those of Pakkish and Mohammadrezakhani [86], who found that spraying mango trees with 35 and 70 ppm arginine increased the fruit weight, anthocyanin, carotenoids, phenols, and TSS, with 70 ppm having more significant effects. Yagi and Al-Abdulkareem [87] also noticed that arginine increased the synthesis of chlorophyll and thus improved photosynthesis. Treating guava and pomegranates with arginine minimized weight loss by protecting the integrity of the cell membrane [80,88]. Furthermore, arginine increased the fruit weight, anthocyanin, and TSS in strawberries [46], and reduced postharvest decay when sprayed on pistachios [82], strawberries [81], and pomegranates [80].

Our results were confirmed by many authors who found that spraying glycine increased leaf protein by raising the availability, uptake, translocation, and distribution of the nutrients from the soil to inside the plants [7,89,90], and consequently increased the leaf mineral nutrients [91]. Moreover, it increased the leaf water content and photosynthesis [90,92]. Additionally, glycine is a reduced form of nitrogen, which could be assimilated in the leaves to hasten the biosynthesis of protein [90,93–95], and has a pronounced influence on plant yield and quality [11]. It has been observed by Forsum et al. [96] that the spraying of glycine increased productivity in *Arabidopsis* plants. Furthermore, glycine plays a vital role in improving chlorophyll content and growth attributes and also in terms of the increased availability of zinc, manganese, copper, and iron [97,98], and is a signal-transducing molecule that can increase the availability and uptake of nutrients by plants [29]. Moreover, glycine ameliorated the photosynthetic process by increasing the usage efficiency of nitrogen [90]; its effect is similar to that of hormones [99], and sometimes it is considered a plant growth regulator [100]. Souri and Hatamian [10] found that the application of glycine is helpful for safe production and improving the leaf mineral composition of N, K, Mg, and Zn with respect to untreated plants. Additionally, the application of glycine at concentrations of 5 and 10 mg/L^{-1} increased plant growth [5]. In the same vein, Souri et al. [101] stated that the foliar addition of glycine to sweet basil greatly improved the plant height, leaf chlorophyll content, shoot and root fresh weights, and VC as well as the N, Ca, K, P, Fe, and Zn content in the leaves compared with unfertilized plants. Our results are also consistent with the findings of Mosa et al. [102], who found that treating apples with 25, 50, and 100 ppm glycine markedly increased the shoot length and diameter, leaf area, and leaf chlorophyll compared to untreated trees. Furthermore, the authors added that the same treatments also enhanced the fruit set, productivity, and fruit physical and chemical quality, as well as the N, P, K, Ca, Fe, Zn, Mn, and B mineral content, whereas it lowered fruit drop with respect to untreated trees.

5. Conclusions

The results of the current study demonstrate that the application of glycine, arginine, and glutamic acid improved guava's vegetative growth performance, fruit set, yield, and quality, as well as the leaf mineral composition from NPK, compared with untreated trees in 2020 and 2021. Moreover, the application of a 1000 glycine + 1000 arginine + 1000 glutamic acid combination and also a 500 glycine + 500 arginine + 500 glutamic acid combination was more efficient than the usage of glycine, arginine, or glutamic acid alone in the two seasons. Additionally, the concentration of 1000 ppm of glycine, arginine, or glutamic acid was more effective than 500 ppm in the two seasons. Combination 2 (1000 glycine + 1000 arginine + 1000 glutamic acid) had more significant effects than 500 glycine + 500 arginine + 500 glutamic acid in terms of fruit yield in kg and in tons per hectare in the first season, as well as on fruit weight, size, length, diameter, and firmness in the two seasons.

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