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Effect of Humic Acid and Amino Acid Foliar Applications on the Growth Characteristics, Yield, and Fruit Quality of Tomato (*Solanum lycopersicom* L.)

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ABSTRACT

Foliar application of organic compounds and biofertilizers is a suitable method of optimal nutrient provision for plants. In this regard, this study aimed to investigate the effects of humic acid and amino acids as foliar applications on the quantitative and qualitative characteristics of tomato fruits under field conditions (2019-2020). The treatments included the control, three concentrations of humic acid (1, 2, and 3 g L^{-1}), three concentrations of amino acids (2, 4, and 6 g L^{-1}), and combined treatments of humic acid (3 g L^{-1}) + amino acid (3 g L^{-1}). The results showed that the effects of the treatments were significant on plant fresh and dry weight, leaf chlorophyll content, fruit number, total yield, marketability, and fruit quality, except for fruit length. The highest leaf pigment content, fruit number (30.3 per plant), yield (50.3 tons ha^{-1}), and marketable yield (43.1 tons ha^{-1}) were related to the combined treatment of humic acid + amino acids. Furthermore, the highest fruit quality characteristics such as firmness, TSS, vitamin C, anthocyanin, and potassium were observed for the humic acid at 3 g L^{-1}, which showed no significant difference with the combined treatment of humic acid + amino acid. In general, it was found that the foliar application of organic compounds improved the yield, yield components, and fruit quality of tomato plants so that the combined application of humic acid (3 g L^{-1}) + amino acids (3 g L^{-1}) had the highest effect on improving the quantitative and qualitative characteristics of tomato plants.

Introduction

Over the past few decades, excessive chemical fertilizers have had negative environmental consequences and increased production costs. This emphasizes the need for revised production and research methods for finding new and safe ways to increase productivity (Wu et al., 2016). Today, organic fertilizers are widely used for improving the quantity and quality of crops. Due to the presence of hormonal compounds, organic acids in low concentrations have significant effects on increasing agricultural crop production, without environmental hazards (Gorgini Shabankareh et al., 2017).

Humic acid is the main component of soil organic matter (humus), a natural organic polymer composition that forms as a result of decaying soil organic matter, peat, lignin, etc. This matter indirectly affects the physiological, biochemical, and biological properties of soil, and directly affects the physiological processes of plants, thereby affecting plant growth, increasing crop

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yield, and enhancing quality (Ohta et al., 2004). Humic compounds are usually composed of a large number of molecules. According to new theories, these compounds are a diverse set of relatively low molecular weight molecules that are composed of dynamic compounds stabilized by hydrophobic interactions and hydrogen bonds. Some of them are based on interconnected aromatic, phenolic, and carboxyl compounds which are connected. In principle, phenolic and carboxyl compounds as functional groups are involved in the reactivity and activation of humic acid (Canellas et al., 2015). Other benefits of humic acid include chelating nutrient elements, increasing the emergence of lateral roots, increasing the growth of shoots and nitrogen content, eliminating leaf chlorosis, improving nutrient uptake and ease of absorption of high-consumption and low-consumption elements, and increasing production and improving the quality of agricultural products (Jahan et al., 2016).

In a relevant study, the effects of humic acid were examined on the growth characteristics of pepper (*Capsicum frutesens* L.). The concentrations of 500, 1000, and 2000 mg/kg humic acid reportedly caused an increase in hypocotyl length, stem diameter and length, dry weight, nutrient content, and yield (Turkmen et al., 2005). The application of humic acid at 2000 mg L^{-1} reportedly had significant effects on yield and yield components of *Calendula officinalis* L. (Mohammadipour et al., 2012). The application of humic acid increased hypocotyl length, stem diameter, stem length, dry weight, and nutrient content in pepper plants (Tan, 2003).

In addition to humic acid, other fertilizers containing various amino acids and micronutrients have been introduced in recent years. These fertilizers are usually used for foliar application. The addition of these fertilizers to the soil improves the soil microorganisms, whose activity facilitates the absorption of some nutrients and ultimately increases growth and improves yield. Furthermore, the foliar application of these fertilizers increases nitrogen uptake efficiency and prevents nitrogen leaching (Liu et al., 2007; Cao et al., 2010).

In general, one of the most important roles of amino acids in plants is to strengthen the plant immune system, achieved by strengthening the cell wall, increasing the production of lignin (woody tissue of plants), and causing faster repair of damaged tissues. As a result, these increase the resistance of plants to pests and diseases. In addition, the application of amino acid compounds before, during, and after environmental stress such as high temperatures, extreme cold, frost, drought stress, salinity, plant movement, and transfer, mitigate the harmful effects of these stresses on plant metabolism and reduce the quantity and quality of products, while reducing the damage caused by adverse environmental conditions and increasing plant resistance (Rai, 2002).

The effects of amino acids on plants have been studied by previous researchers (Hassanpanah et al., 2008; Liu et al., 2008). Amino acids significantly improved the physiological parameters and biochemical composition of tea (Thomas et al., 2009), as well as the yield and kernel quality of pistachio (Rahdari et al., 2013). Furthermore, the application of amino acids in chamomile plants increased plant height, number of branches, chlorophyll, carotene, proline, and phenol content (Omer et al., 2013). Increasing the physiological parameters and yield, while improving the quality of tea and sweet pepper with the application of amino acids was reported by Al-Said and Kamal (2008). Honardost et al. (2012) found that amino acids increased tuber count, marketable tuber weight, and yield of potatoes.

Tomato plants (*Solanum lycopersicom* L.) are one of the most popular vegetables that have high levels of antioxidant compounds, lycopene, polyphenols, and vitamin C. The tomato plant is a perennial herbaceous that is often grown as an annual in different parts of the world. With a production of 5.24 million tons, Iran is the 7th largest tomato producer in the world (FAO, 2019). Due to their high efficiency, environment-friendly organic fertilizers are important for tomato crops. Accordingly, this study was conducted to investigate the effects of foliar application of humic acid and amino acids on the yield, yield components, and quality characteristics of tomato plants.

Materials and Methods

Plant materials

To investigate the effects of the foliar application of humic acid and amino acids on the yield, yield components, and quality characteristics of the tomato fruit (*Solanum lycopersicum*) cv. Sunseed 6189, which is an early-to-medium ripening cultivar, this study was conducted in a randomized complete block design with eight treatments in three replications under field conditions in the Kahnooj region, Kerman Province in 2019-2020 (Table 1). The Kahnooj region is located 350 km from the center of Kerman Province in the southeast of Iran with a hot and dry climate, 470 meters above sea level, longitude 57° 11′ north, and latitude 27° 58′

east. The average rainfall in this region is 140 mm and most of the precipitation is in the winter. The maximum and minimum temperatures are 48-50 °C and 4 °C, respectively, and the maximum relative humidity is 45-65%.

Table 1. Soil and irrigation water analysis of the studied site in Kahnouj region, Kerman province, Iran

Soil											
pH	**Texture**	**Organic matter (%)**	**SAR**	**Na (ppm)**	**Ca+Mg (ppm)**	**Mn (ppm)**	**Cu (ppm)**	**Fe (ppm)**	**Zn (ppm)**	**K (ppm)**	**P (ppm)**
7.8	Loamy-Sands	2	0.74	1.06	4.1	1.52	0.048	0.136	0.092	215.8	9.2

Irrigation water					
pH	SAR	EC (mS/cm)	Na (ppm)	HCO_3 (ppm)	Ca+Mg (ppm)
7.4	0.95	1112	1.92	1.3	2.3

To prepare the seedlings, tomato seeds were planted in peat moss seedling trays at the end of April and the seedlings were transferred to the farm five weeks after sowing the seeds in the nursery. The treatments were applied after the establishment of seedlings in the soil. Crop management was done according to local customs. Irrigation of all treatments was done in the same way, by a drip-tap irrigation system. The treatments included humic acid (XGreen humic, USA) at three levels (1, 2, and 3 g L^{-1}), amino acid (Aminabon, Spain) at three levels (2, 4, and 6 g L^{-1}), the combination of humic acid (3 g L^{-1}) + amino acid (3 g L^{-1}), and the control. The application of treatments started 20 days after transplanting the seedlings to the field (after the complete establishment of seedlings) and was continued (every seven days). Macro- and micro-fertilizers were used according to the results of the soil test. On this basis, macro-fertilizers, including urea, triple superphosphate, and potassium sulfate (304, 163, and 52 kg ha^{-1}) were applied before planting in the field, respectively. Furthermore, micro-fertilizers, including iron chelate, manganese sulfate, zinc sulfate, and copper sulfate were used at 7.5, 25.5, 20, and 10 kg ha^{-1}, respectively, after transplanting until the peak of fruit harvest.

The studied traits

After the application of treatments, measurements were aimed at plant fresh and dry weight, leaf count, leaf chlorophyll content, and leaf length, as well as the diameter of fruits, total yield and marketability, firmness of fruits, pH, vitamin C, total soluble solids, phosphorus, potassium, and calcium content of the fruits. The fresh and dry weight of plants and the yield per plant were measured by a digital scale. To measure the dry weight, the plants were placed in an oven at 70 °C for 48 hours. The yield and marketable yield were obtained by multiplying the total weight of fruits and marketable fruits per plant by the number of plants per hectare. Fruits with good shape, healthy state, uniform color, and with weights greater than 35 g were considered marketable (Luitel et al., 2012). The fruit length and diameter were measured with a digital caliper (Mitutoyo PK-1012 model, Japan). The method proposed by Lichtenthaler (1987) was used for calculating the levels of chlorophyll and carotenoids in the leaves. The light absorption was measured by a spectrophotometer at 647, 664, and 700 nm. Finally, the levels of chlorophyll and carotenoids were calculated based on the following formula. In the formula below, V is the volume of the supernatant solution obtained from the centrifuge and W is the fresh weight of the sample in grams.

$$Chl_a = (19.3\ A663.2 - 0.86\ A645)\ V / 100W$$
$$Chl_b = (19.3\ A645 - 3.6\ A663)\ V / 100W$$
$$Chl_T = (chla + chlb)$$
$$Carotenoid = (1000\ A470 - 1.8\ chla - 85.02\ chlb) / 198$$

The levels of pH, soluble solids, and firmness of fruits were measured using a pH meter, refractometer (SBR-32T model), and penetrometer (Penetrometer, Model FT327), respectively. The vitamin C content was measured by titration with indophenol dichlorophenol. The fruit potassium content was calculated using a flow meter. The fruit phosphorus content was calculated using a spectrophotometer and the light absorption of the sample was calculated at 420 nm. Fruit calcium content was calculated by titration with potassium permanganate (Amidi Fazli et al., 2013).

Statistical analysis

This study was conducted in a randomized complete block design with eight treatments and three replications. To assess the normality of the data, Kolmogorov-Smirnov and Shapiro-Wilk tests were used by SPSS 20.0 software, and after making sure the data were normal, the analysis of variance was performed by SAS software (ver. 9.1; SAS Institute, Inc., Cary, NC), and the mean values were compared using the least significant difference (PLSD) test ($p<0.05$) (Soltani and Torabi, 2020).

Results

Growth characteristics

Based on the results, the treatments affected vegetative traits, especially leaf pigmentation at a significant level. The maximum levels of a, b, and total chlorophyll and carotenoids were related to humic acid (3 g L^{-1}) as well as the combined use of humic acid and amino acid, while the minimum levels of leaf pigments were caused by humic acid (1 g L^{-1}) and amino acids (4 g L^{-1}) (Table 2).

Table 2. Effect of humic acid and amino acid on growth characteristics and leaf pigments of tomato (cv. Sunseed 6189)

Attribute	Plant weight (g)		Carotenoid	Chlorophyll (mg g^{-1} FW)		
Treatments	Fresh	Dry	(mg g^{-1} FW)	Chl *a*	Chl *b*	Total
Humic acid (HA) 1 g L^{-1}	700c	167b	2.54d	11.89f	2.25e	14.15f
Humic acid 2 g L^{-1}	650c	158b	3.99b	19.85b	3.50c	23.36b
Humic acid 3 g L^{-1}	650c	124cde	4.27a	27.39a	5.02a	32.47a
Amino acid (AA) 2 g L^{-1}	650c	142bcd	3.20e	14.35e	2.91d	17.26c
Amino acid 4 g L^{-1}	500d	105e	2.25f	11.98f	2.47e	14.45e
Amino acid 6 g L^{-1}	550d	118de	3.30c	17.79c	4.07b	21.87c
HA (3 g L^{-1}) + AA (3 g L^{-1})	800b	150bc	4.36a	25.30a	4.95a	30.20a
Control	1150a	200a	2.73d	16.10d	3.48c	19.58d

In each column, the treatments following the same letter are not significantly different ($P\leq0.05$)
The experiment was conducted in a randomized complete block design with 8 treatments and 3 replications.

Yield and yield components

The results showed that the foliar application of different treatments significantly affected the fruit count and yield ($P\leq0.01$), as well as fruit diameter and marketable yield ($P\leq0.05$). There was no significant difference between the studied treatments in terms of fruit length. According to the results, the maximum and the minimum number of fruits were related to the combined treatment of humic acid + amino acid (30.3 per plant) and the control (23 per plant), respectively. The use of amino acids had no significant effect on the fruit diameter. The maximum levels of yield (50.3 tons ha-1) and marketable yield (43.1 tons ha^{-1}) were related to the combined application of humic acid + amino acid. The lowest yield was related to the control (37.1 tons ha^{-1}), which had no significant difference with the effect of amino acids at 2 g L^{-1} (38.7 tons ha^{-1}) (Table 3).

Table 3. Effect of humic acid and amino acid on yield and yield components of tomatoes (cv. Sunseed 6189)

Attribute	Fruit number per	Fruit diameter	Yield (ton ha^{-1})	
Treatments	plant	(cm)	Total	Marketable
Humic acid (HA) 1 g L^{-1}	25.00de	4.92ab	47.99ab	36.46bc
Humic acid 2 g L^{-1}	28.67abc	4.99ab	46.91ab	38.18bc
Humic acid 3 g L^{-1}	29.33ab	5.17ab	48.68ab	36.71ab
Amino acid (AA) 2 g L^{-1}	25.67cde	4.79cd	38.73cd	31.93c
Amino acid 4 g L^{-1}	24.33de	5.04c	41.59c	34.80bc
Amino acid 6 g L^{-1}	26.67bcd	5.59b	45.68b	37.56abc
HA (3 g L^{-1}) + AA (3 g L^{-1})	30.33a	4.96a	50.29a	43.07a
Control	23.00e	5.35d	37.07d	33.11bc

In each column, the treatments that are followed by the same letter are not significantly different ($P\leq0.05$).
The experiment was conducted in a randomized complete block design with 8 treatments and 3 replications.

Fruit qualitative traits

The effect of amino acid and humic acid treatments on the qualitative traits of tomato fruits showed that the foliar application of different treatments significantly affected all qualitative traits of the fruit ($P \leq 0.01$). Accordingly, the maximum and the minimum values of fruit firmness were caused by humic acid at 3 g L^{-1} (4.46 kg cm^{-2}) and control treatments (3.21 kg cm^{-2}), respectively. Similar results were obtained in the case of soluble solids and vitamin C. The highest level of fruit juice pH was related to humic acid at 1 g L^{-1} and the lowest was observed for plants treated with humic acid at 2 g L^{-1} or amino acid at 4 g L^{-1}. The application of different concentrations of humic acid as well as the combination of humic acid + amino acid resulted in the maximum amount of fruit carotenoids. However, the highest amount of fruit anthocyanin was caused by the concentrations of 2 and 6 g L^{-1} amino acids as well as humic acid at 3 g L^{-1}. By the application of humic acid at 3 g L^{-1} or amino acids at 6 and 4 g L^{-1} as well as the combined use of humic acid and amino acid, the potassium concentration of tomato fruits significantly increased. The maximum levels of the fruit calcium and phosphorus were obtained by the application of humic acid at 1 g L^{-1}. The minimum concentration of fruit calcium was observed in plants that were not treated with organic fertilizers (Table 4).

Table 4. Effect of humic acid and amino acid on fruit quality characteristics of tomato (cv. Sunseed 6189)

Attribute Treatments	Firmness (kg cm^{-2})	TSS (%)	Vitamin C (mg $100g^{-1}$)	pH	Carotenoid (mg $100g^{-1}$)	Antocyanin (µm g^{-1})	K (%)	Ca (%)	P (%)
Humic acid (HA) 1 g L^{-1}	4.43a	3.4bc	24.04c	5.92a	90.71a	3.45b	2.52b	3.53a	0.18a
Humic acid 2 g L^{-1}	3.86bc	3.3c	27.44b	5.62e	86.80ab	3.33c	2.54b	3.26de	0.15bc
Humic acid 3 g L^{-1}	4.46a	3.4a	28.53a	5.66d	88.76a	3.67a	2.84a	3.19e	0.16b
Amino acid (AA) 2 g L^{-1}	3.37cd	3.3c	28.29ab	5.79b	70.87d	3.58a	2.65b	3.33cd	0.14bcd
Amino acid 4 g L^{-1}	3.5bcd	3.2c	18.70d	5.63e	83.74bc	3.45b	2.97a	3.46ab	0.13cd
Amino acid 6 g L^{-1}	4.04ab	3.7ab	13.46f	5.81b	69.82d	3.58a	2.93a	3.46ab	0.16b
HA (3 g L^{-1}) + AA (3 g L^{-1})	3.88bc	3.2c	17.20e	5.73c	87.58ab	3.21d	2.92a	3.39bc	0.12e
Control	3.21d	3.1c	12.82f	5.79b	79.69c	3.45b	2.65b	3.06f	0.14cd

In each column, treatments that are followed by the same letter are not significantly different ($P \leq 0.05$).
The experiment was conducted in a randomized complete block design with 8 treatments and 3 replications.

Discussion

In recent years, a large number of organic acids have been used for improving the quality of horticultural crops. It has been reported that these compounds are not only safe for the environment but also improve the physical and chemical properties of the soil as well as the growth and functional properties of plants (Adeleke et al., 2017). The results of this study showed that despite the fresh and dry weight, the maximum levels of yield-related traits were related to the combined application of humic acid and amino acids. It seems that in the control, carbohydrates were more allocated to the progress of vegetative growth, which led to greater fresh and dry weights. However, the application of organic compounds, especially the combination of humic acid + amino acids caused allocations of carbohydrates (carbon partitioning) to the progress of reproductive growth and better performance. Previous studies also confirmed the effect of these compounds on changes in carbohydrate allocation and biomass (biomass partitioning) (Tattini et al., 1991; Zachariakis et al., 2001).

Based on the results of this study, it was found that despite the fresh and dry weight, the use of humic acid improved the yield and yield components of tomatoes, which confirmed a previous report on grapes (Poozeshi et al., 2011) and tomatoes (Khoshmaram and Arshad, 2016). One of the most important biological effects of humic acid is the change in biomass allocation in plants (Zachariakis et al., 2001). In addition, humic acid increases photosynthetic efficiency by improving nutrient uptake and leaf chlorophyll content (Khoshmaram and Arshad, 2016). In this way, it increases the production and accumulation of carbohydrates and puts a positive effect on flowering and fruit sets. Humic acid also has a positive effect on auxin production, thereby activating various enzymes (Abdel-Mawgoud et al., 2007; Khoshmaram and Arshad, 2016). It has been reported that the foliar application of humic acid improves respiration, total protein, and photosynthesis in plants, thereby improving their yield (Neri et al., 2002). In sour tea, the foliar application of humic acid improved the motility and efficiency of nutrients, increased the leaf zinc and iron content, and thus increased the photosynthesis rate, carbohydrate content, and protein production (Heidari and Khahlil, 2014). Shahsavan and Chamani (2014) also reported the effect of humic acid on the leaf chlorophyll content and chlorophyll fluorescence of saffron, which was consistent with the results of this study. Previous studies have shown that humic acid has a wide range of organic compounds such as amino acids and improves the levels of amino acids in plants, thereby improving plant growth and yield (Soleimani Aghdam et al., 2012). Probably the synergistic effect of the combined application of humic acid and amino acids in the present study culminated in the acquisition of this role. Furthermore, the results showed that the combined application of humic acid and amino acids at a concentration of 3 g L^{-1} caused an increase of 35.6 and 3.3% in the yield of tomato cv. Sunseed 6189, compared to the control and the use of humic acid at 3 g L^{-1} alone, respectively. The combined use of humic acid and amino acids increased the yield by increasing the number and size of the fruits. Numerous reports have confirmed the positive effect of humic acid and amino acids on yield improvement and yield components in different plants (Cao et al., 2010).

Studies have shown that amino acids, directly and indirectly, affect physiological activities, growth, and plant function (Faten et al., 2010). Amino acids are involved in the construction of proteins and peptides, thereby maintaining all plant functions, including structural, enzymatic, metabolic, and metabolic ones (Al-Said and Kamal, 2008). The results of the present study showed that amino acid applications, especially with humic acid, improved the chlorophyll content and yield. Amino acids are organic substances with anti-stress properties which, either directly or indirectly, affect the physiological processes of plant growth and development and, thus, increase plant growth and yield. Amino acids affect plant growth and yield by increasing resistance to environmental stress factors, thereby increasing chlorophyll concentrations and photosynthesis. With the application of amino acid at 6 g L^{-1}, fruit diameters reached 5.59 cm, which was significantly higher than the diameter achieved by the other treatments. Furthermore, the use of amino acids, especially in combination with humic acid, increased the chlorophyll and carotenoid content in the leaves and the number of fruits and yield per unit area. Amino acids play an important role in the fertility and germination of pollen grains, water balance in plants, photosynthesis process, thereby increasing the C/N ratio, improving product quantity and quality, and interfering with the spatial structure of proteins (Geshnizjani, 2011). The effect of amino acids as growth regulators on plants has been studied by various researchers and in most cases, the positive effect of the application of amino acid on the yield has been reported (Hassanpanah et al., 2008; Liu et al., 2008). Cao et al. (2010) reported that the application of amino acids increased the yield and quality of Chinese cabbage flowers. Koukounaras et al. (2013) reported similar results on the effects of amino acids on the yield of greenhouse tomatoes. Amino acids facilitate the absorption and transport of nutrients in the vascular system by improving cell membrane permeability. The application of amino acids can increase the photosynthesis rate and, thus, increase dry matter accumulation and crop growth rate (Malakouti et al., 2008). In addition, amino acids positively affect stomatal activity, mRNA transcription, and plant protein content. Also, they improve plant growth and yield characteristics. Amino acids improve the pollination process by activating hormones that are effective in flower and fruit set, improving the germination of pollen grains, and increasing the flowering rate (Liu and Lee, 2012). The results of our study also showed that the use of amino acids, especially in combination with humic acid, had no significant effect on the fresh and dry weight of plants, although it improved leaf pigment content, caused greater biomass allocation to reproductive growth and, finally, contributed to a significant increase in the yield and yield components. Koukounaras et al. (2013) reported that growth indices, including the plant height and the number of nodes, were not affected by amino acid, but the fruit yield (average fruit weight) was affected by the application of amino acid at 0.3% (as root application) and increased by 0.9% as a result of foliar spraying.

The effect of the studied treatments on the quality characteristics of tomato cv. Sunseed 6189 showed that the lowest levels of the characteristics of the fruit, especially tissue firmness, soluble solids content, vitamin C, carotenoid, and calcium content were related to the control treatment. However, the maximum fruit firmness, soluble solids content, vitamin C, carotenoids, anthocyanins, and fruit potassium were related to humic acid at 3 g L^{-1}. Of course, the use of amino acids alone and in combination with humic acid improved the quality characteristics of fruits. Thus, the effects of amino acids at 6 g L^{-1} as well as the combination of humic acid and amino acids were not significantly different from the treatment of humic acid at 3 g L^{-1} in terms of fruit firmness, anthocyanins, and potassium content. Probably, the role of organic acids in improving the quality characteristics of fruits resulted from their positive effects on nutrient absorption and transportation efficiency, as well as increasing the chlorophyll content and photosynthetic efficiency. It has been reported that humic acid caused an increase in the uptake and efficiency of nutrients and the uptake of potassium, nitrogen, magnesium, calcium, and phosphorus (Sabzevari et al., 2009). Nasirpour (2015) reported that the use of humic acid increased the vitamin C and calcium contents of tomato fruits cv. Zomorod under field conditions, which is consistent with the results of this study (Nasirpour, 2015). Similar results indicated the effects of humic acid on the quantitative and qualitative characteristics of three tomato cultivars (Salehi et al., 2009). The foliar application of amino acids increased the uptake of nitrogen, phosphorus, potassium, and micro-elements (Faten et al., 2010). Also, amino acids reportedly improved the transport of nutrients in the vascular system by improving cell membrane permeability (Franco et al., 1994). Investigating the effects of the foliar application of amino acids on apples (cv. Golden Delicious and Granny Smith) showed that amino acids increased the accumulation of nutrients in fruits (Arabloo et al., 2014).

Conclusion

The application of organic compounds as foliar application increased the level of leaf pigments, improved yield, yield components, and quality characteristics of tomato cv. Sunseed 6189. Furthermore, the combined application of humic acid and amino acids at a concentration of 3 g L^{-1} had the most significant effect on improving the quantitative and qualitative characteristics of tomato plants. Thus, it could be considered an effective organic fertilizer for improving tomato production.

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Conflict of interest

The authors indicate no conflict of interest for this work.

References

Abdel-Mawgoud AMR, El-GreadlyHelmy NHM, Helmy YI, Singer SM. 2007. Responses of tomato plants to different rates of humic-based fertilizer and NPK fertilization. Journal of Applied Sciences Research 3(2), 169-174.

Adeleke R, Nwangburuka C, Oboirien B. 2017. Origins, roles and fate of organic acids in soils: a review. South African Journal of Botany 108, 393-406.

Al-Said MA, Kamal AM. 2008. Effect of foliar spray with folic acid and some amino acids and some amino acids on flowering yield and quality of sweet pepper. Mansoura University Journal of Agricultural Sciences 33(10), 7403-7412.

Amidi Fazli F, Dezyani M, Ezzati R, Eivani M. 2013. Evaluation of mineral nutrition in fruits. Iranian Journal of Nutrition Sciences & Food Technology 7(5), 207-212.

Arabloo M, Imani A, Rasouli M, Shahmoradi M. 2014. Evaluation of foliar application calcium chelated and amino acid on nutritional status, chlorophyll, and leaf area surface of Golden Delicious and Granny Smith. Agroecology Journal 10(2-2), 43-52.

Canellas LP, Olivares FL, Aguiar NO, Jone SDL, Nebbioso A, Mazzei P, Piccolo A. 2015. Humic and fulvic acids as biostimulants in horticulture. Scientia Horticulturae 196, 15-27.

Cao JX, Peng ZP, Huang JC, Yu JH, Li WN, Yang LX, Lin ZJ. 2010. Effect of foliar application of amino acid on yield and quality of flowering Chinese cabbage. Chinese Agriculture Science Bulletin 26, 162-165.

FAO. 2019. FAOSTAT, Agricultural Database. http://www.fao.org/faostat/en/#data/QC.

Faten SA, Shaheen AM, Ahmed AA, Mahmoud AR. 2010. Effect of foliar application of amino acids as antioxidants on growth, yield, and characteristics of squash. Research Journal of Agriculture and Biological Science 6(5), 583-588.

Franco JA, Banon S, Madrid R. 1994. Effects of a protein hydrolysate applied by fertigation on the effectiveness of calcium as a corrector of blossom-end rot in tomato cultivated under saline conditions. Scientia Horticulturae 57, 283-292.

Gawronaka H. 2008. Biostimulators in modern agriculture (general aspects). Arysta Life Science, Published by the Editorial House Wies Jutra, Limited. Warsaw, 7, 25. 89.

Geshnizjani N. 2011. Investigation of the effect of foliar application of mixed amino acids on morphological and physiological characteristics of gerbera (*Gerbera jamesonni* L.). Master Thesis, Department of Horticultural Sciences, Shiraz University, Iran.

Gorgini Shabankareh H, Sabouri F, Saedi F, Fakheri B. 2017. Effects of different levels of humic acid on growth indices and essential oil of lemon balm (*Melissa officinalis* L.) under different irrigation regimes. Crop Science Research in Arid Regions 1(2), 166-176.

Hassanpanah D, Gurbanov E, Gadimov A, Shahriari R. 2008. Shortening transplantation periods of potato plantlets by use of potassium humate and kadostim and their effects on mini-tuber production. Pakistan Journal of Biological Sciences 15, 1370-1374.

Heidari M, Khahlil S. 2014. Effect of humic acid and phosphorus fertilizer on seed and flower yield, photosynthetic pigments and mineral elements concentration in sour tea (*Hisbiscus sabdariffa* L.). Iranian Journal of Field Crop Science 45(2), 191-199.

Honardoost S, Ajly J, Framarzi A, Hasanpanah D, Azizi S. 2012. Effect of different concentrations of potassium and kadostim on tuber production of savalan and agria cultivars of potato. Journal of Seed Science and Technology 2(2), 11-22.

Jahan M, Amiri M, Noorbakhsh F. 2016. Evaluation of the increased rates of water super absorbent and humic acid application under deficit irrigation condition on some agroecological characteristics of zea mays using response surface methodology. Iranian Journal of Field Crops Research 14(4), 746-764.

Khoshmaram F, Arshad M. 2016. Effect of foliar application of humic acid and zinc on yield of Early CH tomato cultivar. Proceeding of 9th Iranian Congress of Horticultural Sciences 25-28 January 2016, Shahid Chamran University Ahvaz, Iran, 1-4.

Koukounaras A, Tsouvaltzis P, Siomos AS. 2013. Effect of root and foliar application of amino acids on the growth and yield of greenhouse tomato in different fertilization levels. Journal of Food, Agriculture, and Environment 11(2), 644-648.

Lichtenthaler HK. 1987. Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. Methods in Enzymology 148, 350-382.

Liu XQ, Ko KY, Kim SH, Lee KS. 2008. Effect of amino acid fertilization on nitrate assimilation of leafy radish and soil chemical properties in high nitrate soil. Communications in Soil Science and Plant Analysis 39, 269-281.

Liu XQ, Lee KS. 2012. Effect of mixed amino acids on crop growth. Agricultural Science 1, 119-158.

Luitel BP, Adhikari PB, Yoon CS, and Kang WH. 2012. Yield and fruit quality of tomato (*Lycopersicon esculentum* Mill.) cultivars established at different planting bed sizes and growing substrates. Horticulture, Environment, and Biotechnology 53(2), 102-107.

Malakouti MJ, Bybordi A, Lotfollahi M, Shahabi AA, Siavoshi K, Vakil R, Ghaderi J, Shahabifar J, Majidi A, Jafarnajadi AR, Dehghani F, Keshavarz MH, Ghasemzadeh M, Ghanbarpouri R, Dashadi M, Babaakbari M, Zaynalifard N. 2008. Comparison of complete and sulfur-coated urea fertilizers with pre-plant urea in increasing grain yield and nitrogen use efficiency in wheat. Journal of Agricultural Science and Technology 10, 173-183.

Mohammadipour E, Golchin A, Mohammadi J, Negahdar N, Zarchini M. 2012. Effect of humic acid on yield and quality of marigold (*Calendula officinalis* L.). Annals of Biological Research 3, 5095-5098.

Nasirpour M. 2015. The effect of humic acid, calcium, and boron application on yield and physicochemical properties of *Lycopersicon esculentum* Mill. M.Sc Thesis, Department of Horticultural Science, Shahroud University, Semnan, Iran.

Neri D, Lodolini EM, Luciano M, Sabbatini P, Savini G. 2002. The persistence of humic acid droplets on leaf surface. Acta Horticulturae 594, 303-314.

Ohta K, Morishita S, Suda K, Kobayashi N, Hosoki T. 2004. Effects of chitosan soil mixture treatment in the seedling stage on the growth and flowering of several ornamental plants. Journal of the Japanese Society for Horticultural Science 73(1), 66-68.

Omer EA, Said-Al-Ahl HAH, El-Gendy AG, Shaban KA, Hussein MS. 2013. Effect of amino acids application on production, volatile oil and chemical composition of chamomile cultivated in saline soil at Sinai. Journal of Applied Sciences Research 9(4), 3006-3021.

Poozeshi R, Zabihi H, Ramazani Moghadam M, Rajabzadeh M, Mokhtari A. 2011. Yield and yield components of grape (*Vitis vinefera* cv. Peykani) as affected by foliar application of zinc, humic acid, and acetic acid. Journal of Horticultural Science 25(3), 351-360.

Rahdari P, Mozafari A, Panahi B. 2013. Evaluation of foliar treatment of free amino acids effect on some of the quantitive and qualitative parameters in pistachio (*Pistacia vera* L.) Ohadi (Fandoghi) cultivar. Iranian Journal of Biology 25(4), 606-617. (In Persian).

Rai VK. 2002. Role of amino acids in plant responses to stresses. Biologia Plantarum 45(4), 481-487.

Sabzevari S, Khazaei H, Kay M. 2009. Effect of humic acid on root and shoot growth of two wheat cultivars (*Triticum aestivum*. L). Water and Soil 23(2), 53-63. (In Persian).

Salehi B, Bagherzadeh A, Ghasemi M. 2010. Impact of humic acid on growth properties and yield components of three tomato varieties (*Lycopersicon esculentum* L.). Journal of Agroecology 2(4), 640-647. (In Persian).

Shahsavan M, Chamani A. 2014. The effect of concentration and time of application of humic acid on quantitative and qualitative characteristics of cut flowers Matthiola incana “Hanza”. Journal of Science and Technology of Greenhouse Culture 5(19), 157-

170.

Soleimani Aghdam M, Hassanpouraghdam M, Paliyat G, Farmani B. 2012. The language of calcium in postharvest life of fruits, vegetables, and flowers. Scientia Horticulturae 144, 102-115.

Soltani A, Torabi B. 2020. Designing the analysis of agricultural experiments (with SAS programs). The second edition, Mashhad Jehad-Daneshgahi Publication, 431.

Tan KH. 2003. Chemical composition of humic matter. In: Humic matter in soil and the environment. Principles and controversies. Marceland Dekker, New York. USA.

Tattini M, Bertoni P, Landi A, Traversi ML. 1991. Effect of humic acids on growth and biomass partitioning of container-grown olive plants. Acta Horticulturae 294, 75-80.

Thomas J, Mandal AKA, Raj Kumar R, Chordia A. 2009. Role of biologically active amino acid formulations on quality and crop productivity of Tea (*Camellia* sp.). International Journal of Agricultural Research 4, 228-236.

Turkmen O, Demir S, Sensoy S, Dursun A. 2005. Effect of arbuscular mycorrhizal fungus and humic acid on the seedling development and nutrient content of pepper grown under saline soil conditions. Journal of Biological Sciences 5, 565-574.

Wu S, Lu M, Wang S. 2016. Effect of oligosaccharides derived from Laminaria japonica-incorporated pullulan coatings on the preservation of cherry tomatoes. Food Chemistry 199, 296-300.

Zachariakis M, Tzorakakis E, Kritsotakis I, Siminis CI, Manios V. 2001. Humic substances stimulate plant growth and nutrient accumulation in grapevine rootstocks. Acta Horticulturae 549, 131-136.