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Physiological and Biochemical Responses of Tomato Plant to Amino Acids and Micronutrients Foliar Application

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SOME morphological, physiological and biochemical responses of tomato plant *cv.* 010 were determined using amino acids (Amino-Suam) and micronutrient solution include (2% Fe, 2% Zn, 2% Mn, 1% Cu and 0.5% B) individually and in combination. Two field experiments were conducted on September, 2017/2018 and 2018/2019 at the Faculty of Agriculture, Ain Shams University Farm, Shoubra El-Kheima, Cairo, Egypt. Three levels of Amino-Suam (0, 1000 and 2000ppm), micronutrients solution (0, 500 and 1000ppm) and their combinations were designed in complete randomized block design with three replications for each treatment and sprayed at 30, 45 and 60 days after transplanting. Results revealed that spraying with amino acids, micronutrients solution and their combinations stimulated vegetative growth parameters and yield components including shoot height, number of branches and leaves per plant, leaf area, leaf fresh weight, number of fruits per plant, average fruit weight, fruit diameter and total fruit yield/fed compared to control plants in both seasons. Data suggested that combination treatments achieved significant increases of most vegetative growth parameters, and some biochemical constituents such as N, Fe, Mn, Cu, photosynthetic pigments and total soluble proteins in tomato leaves at 75 days after transplanting as well as fruits yield, lycopene and ascorbic acid concentrations in fruits at harvest compared to control plants in both seasons.

Keywords: Amino acids, Foliar spray, Growth, Micronutrients, Quality, Tomato, Yield.

Introduction

The consumption of tomato (*Solanum lycopersicum* L.) as essential vegetable crop worldwide has increased due to its importance in human nutrition as fresh food and other industrial values for its nutritional factors such as K, Ca, Mg, essential amino acids, organic acids, vitamins A, C, E and K, phenolic compounds, steroids and natural pigments (chlorophylls, β-carotene, flavonoids and lycopene). Lycopene, carotene and vitamins- C and K are natural antioxidants that can prevent cancer cells and blood clotting increasing the demand on tomato fruits (Salunkhe et al., 1974; Wilcox et al., 2003; Passam et al., 2007; Iglesias et al., 2015).

Iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and boron (B) deficiencies obstruct various physiological functions, plant growth, development, biochemical constituents, crop productivity and fruit quality factors (Salunkhe et al., 1974; Taiz & Zeiger, 2002; Passam et al., 2007; Mohamed et al., 2016). Wherefore, micronutrients foliar spray on plant shoot considers more rapid availability to correction

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these nutrients deficiencies caused under the inconvenient conditions (Marschner, 1995; Fageria et al., 2009; El-Seifi et al., 2015). Therefore, Fe, B, Mn, Zn and Cu are essential micronutrients for the growth and development of all higher plants it involved in enzyme activation, chlorophyll synthesis, photosynthesis, protein metabolism and other endogenous biochemical constituents (Taiz & Zeiger, 2002; Sidhu et al., 2019). Accordingly, many studies have indicated that, micronutrients foliar spray enhances the vegetative growth characteristics, photosynthetic pigments, mineral status, fruit yield and fruit quality of vegetable crops such as tomato (Jadhav et al., 2014; Habibullah et al., 2017; Verma et al., 2018), sweet pepper (Youssif, 2014) and broad bean (Mohamed et al., 2016).

Also, amino acids can used to improve plant growth and yield productivity through biosynthesis of proteins, phytohormones, enzyme activation, nutrients uptake and assimilation, signaling processes, energy production and gene transcription (Sarojnee et al., 2009; Hildebrandt et al., 2015; Santi et al., 2017; Souri & Hatamian, 2019). Consequently, adding amino acids as foliar applications stimulated the vegetative growth, yield attributes and the biochemical constituents of vegetable crops such as common bean (Zewail, 2014), faba bean (Sadak et al., 2015), hot pepper (Aly et al., 2019) and tomato plants (Boras et al., 2011). Additionally, spraying commercial amino acids such as Amino-Mix and Amino-Vit plus at levels 500 and 1000 ppm for each compound has synergistic effects on the vegetative growth, fruit yield, biochemical changes and fruit quality of squash (Abd El-Aal et al., 2010). Likewise, Abo Sedera et al. (2010) indicated that spraying strawberry plants with peptone at 500 and 1000 ppm significantly increased the total fruits yield, N, P and K concentrations in plant shoot and fruit quality. Also, the plant length, number of leaves/ plant, fresh and dry weights of leaves, bulbs diameter, bulbs fresh and dry weights and the quality of onion plants were responded positively under superbiomine, pepton and amino-power applications (El-Abagy et al., 2014). Moreover, El-Attar & Ashour (2016) observed that, the vegetative growth and biochemical constituents of the chamomile plant increased significantly under Amino Suam foliar application.

This study aimed to improve the biochemical constituents related to the growth, yield productivity and quality factors of tomato (*S. lycopersicum* L.) using amino acids (Amino Suam), micronutrients solution (2% Fe, 2% Zn, 2% Mn, 1% Cu and 0.5% B) and their combinations as foliar applications.

Materials and Methods

Plant material and growth conditions

Tomato seedlings (*Solanum lycopersicum* L.) cv. 010 (45 days old with 4-5 mature leaves) obtained from the Agricultural Research Center, Ministry of Agriculture, Egypt were transplanted in an open field under the following soil conditions, pH 7.82, EC= 0.91ds/m, HCO_3^- 0.60meq/L, Na^+ 2.71meq/L, Ca^{+2} 3.30meq/L, Mg^{+2} 2.91meq/L, K^+ 0.19meq/L, Cl^- 5.00meq/L and SO_4^{-2} 3.40meq/L. Two winter seasons (2017/2018 and 2018/2019) were carried out at the Faculty of Agriculture, Ain Shams University, Shoubra El-Kheima, Egypt (30.114953 N, 31.247934 E) to study the effects of foliar spray with Amino Suam, micronutrients solution (Fe 2%, Zn 2%, Mn 2%, Cu 1% and B 0.5%) and their combinations on the vegetative growth, yield components and some biochemical constituents.

The chemical composition of commercial Amino Suam® registered by Ministry of Agriculture, no.1489 at 4/ 4/ 2013 and obtained from the Union for Agriculture Development Company included contains, glycine (1.64g/100mL), alanine (1.04g/100mL), valine (1.32g/100mL), isoleucine (0.61g/100mL), threonine (1.02g/100mL), serine (1.77g/100mL), lysine (0.49g/100mL), phenylalanine (0.66g/100mL), glutamic acid (2.24g/100mL), aspartic acid (1.44g/100mL), arginine (1.40g/ 100mL), proline (1.98g/100mL), leucine (0.68g/100mL), histidine (0.18g/100mL) and tyrosine (0.21g/100mL). Calcium super-phosphate (15.5% P_2O_5) 400kg, ammonium sulphate (20.6% N) 500kg and potassium sulphate (48% K_2O) 250kg/ feddan were applied using standard soil applications and other cultural practices, disease and pest control programs were recommended by the Ministry of Agriculture.

Experimental design and foliar treatments

Experimental units arranged in a complete randomized block design included nine treatments with three replicates. The experimental unit area was 10.60m consisting of four rows, each row was 3.50m long and 70cm wide and the distance was 40cm between transplants on one side. Foliar treatments included Amino Suam (0, 1000 and 2000ppm), micronutrients solution (0, 500 and 1000 ppm) and their combinations applied thrice with 15- day intervals starting at 30 days after transplanting with Tween 20 as a surfactant.

1. Control plants (spray with distilled water)

2. 1000ppm amino acids (low amino acids LAA)

3. 2000ppm amino acids (high amino acids HAA)

4. 500ppm micronutrients solution (low micronutrients LMS)

5. 1000ppm micronutrients solution (high micronutrients HMS)

6. 1000ppm amino acids plus 500ppm micronutrients solution

7. 1000ppm amino acids plus 1000ppm micronutrients solution

8. 2000ppm amino acids plus 500ppm micronutrients solution

9. 2000ppm amino acids plus 1000ppm micronutrients solution

Vegetative growth characteristics and yield components

At 75 days of growth, the shoot height, number of branches per plant, number of leaves per plant, leaf area and leaf fresh weight were determined. The leaf area of tomato plants was estimated according to Rico-García et al. (2009). The total number of fruits per plant, average fruit weight, fruit diameter (cm) and fruits yield per feddan were determined at every harvesting date starting at 90, 105, 120 and 135 days after transplantation to obtain the fruit yield per fed.

Estimation of biochemical constituents

At 75 days after transplanting, tomato leaf samples were dried at 60 °C in a forced air oven for 72h to determine N, P, K, Mg, Ca, Fe, Mn, Zn and Cu concentrations. A quarter gram of dry leaf samples was wet digested using mixture of H_2SO_4 and H_2O_2. Total N was determined using the micro-Kjeldahl method according to the method described by Horneck & Miller (1998). Total P was determined calorimetrically using ascorbic acid method (Chapman & Pratt, 1982). K concentration was determined using flame photometer as described by Horneck & Hanson (1998). Mg, Ca, Fe, Mn, Zn and Cu concentrations were determined according to Stefánsson et al. (2007).

To determine the photosynthetic pigments 0.1 g fresh weight of the youngest fully expanded leaves was taken from three plants per treatment and extracted with 10 ml N, N-dimethylformamide and incubated in the dark at room temperature for 24h (Minocha et al., 2009) after measuring the absorption of the extracted pigments using a spectrophotometer (Mapada UV 1200) at 470, 647 and 664 nm. Chlorophyll a, and b and carotenoids were calculated according to Wellburn (1994). The Bradford (1976) method determined the total soluble protein concentration in tomato leaf extracts. Lycopene and ascorbic acid concentrations (mg/100g F.W.) of the fully ripe tomato fruits were determined according to Ranganna (1986).

Statistical analysis

Data of two seasons (2017/2018 and 2018/2019) were arranged and statistically analyzed using CoStat (version 6.4, CoHort Software, USA) according to the method described by Gomez & Gomez (1984). One-way analysis of variance was used to test for significant differences at $P< 0.05$, followed by Duncan's multiple range test.

Results

Vegetative growth parameters and yield

Tables 1 and 2 reveal that the number of branches per plant, leaf fresh weight, fruit number per plant, fruit fresh weight, fruit diameter and total fruit yield per fed of tomato plant increased to the highest significant values using foliar sprays with Amino Suam, micronutrients solution and their combinations compared to control plants in both seasons. The shoot height, number of leaves per plant and leaf area of tomato plants responded positively with all foliar treatments compared to control plants in both tested seasons (Table 1).

TABLE 1. Influence of foliar spray with amino acids and micronutrients solution on vegetative characteristics of tomato plants during 2017 and 2018 growing seasons

Treatments	Shoot height (cm)		Branches number/ plant		Leaves number/ plant		Leaf fresh weight (g)		Leaf area (cm²)	
	Ses 1	Ses 2	Ses 1	Ses 2	Ses 1	Ses 2	Ses 1	Ses 2	Ses 1	Ses 2
Control (distilled water)	64.00^{a}	71.33^{a}	1.67^{b}	2.67^{d}	47.33^{d}	57.67^{d}	4.72^{d}	6.33^{e}	50.61^{b}	67.89^{b}
1000ppm amino acids	74.00^{a}	76.33^{a}	4.00^{a}	4.10^{c}	72.67^{cd}	87.33^{c}	6.34^{c}	7.45^{d}	58.40^{ab}	82.49^{ab}
2000ppm amino acids	68.67^{a}	75.33^{a}	4.67^{a}	4.70^{bc}	113.33^{ab}	123.00^{ab}	6.71^{bc}	8.79^{bc}	64.23^{ab}	88.09^{ab}
500ppm micronutrients solution	68.67^{a}	75.00^{a}	4.00^{a}	4.33^{bc}	98.33^{bc}	114.67^{b}	7.60^{ab}	8.98^{a-c}	66.19^{a}	98.79^{ab}
1000ppm micronutrients solution	89.67^{a}	77.00^{a}	4.33^{a}	5.00^{a-c}	110.00^{ab}	128.67^{ab}	6.78^{bc}	9.16^{a-c}	62.29^{ab}	115.83^{a}
1000ppm amino acids* 500ppm micronutrients solution	71.00^{a}	82.33^{a}	5.00^{a}	5.33^{ab}	130.67^{ab}	139.00^{ab}	7.44^{a-c}	9.64^{ab}	70.08^{a}	111.45^{a}
1000ppm amino acids* 1000ppm micronutrients solution	64.67^{a}	72.33^{a}	4.33^{a}	5.00^{a-c}	111.33^{ab}	136.67^{ab}	7.16^{a-c}	9.87^{a}	66.19^{a}	113.88^{a}
2000ppm amino acids* 500ppm micronutrients solution	78.33^{a}	89.67^{a}	4.67^{a}	5.00^{a-c}	135.33^{a}	131.67^{ab}	7.24^{a-c}	8.23^{cd}	62.29^{ab}	109.50^{a}
2000ppm amino acids* 1000ppm micronutrients solution	73.67^{a}	77.67^{a}	4.33^{a}	6.00^{a}	105.00^{a-c}	144.00^{a}	8.08^{a}	9.70^{ab}	66.19^{a}	100.98^{ab}
LSD	16.09	10.31	2.15	1.19	33.10	23.96	1.057	0.932	13.18	37.56

Means (±SD) followed by different letters are significantly different at P< 0.05 level; Duncan's Multiple Range Test, , where LSD= Minimum significant difference.

TABLE 2. Influence of foliar spray with amino acids and micronutrients solution on yield characteristics of tomato plants during 2017 and 2018 growing seasons

Treatments	Fruits number/ plant		Average fruit weight (g)		Fruit diameter(cm)		Total yield/ ton fed	
	Ses 1	Ses 2	Ses 1	Ses 2	Ses 1	Ses 2	Ses 1	Ses 2
Control (distilled water)	17.17^{d}	12.60^{e}	43.67^{d}	46.00^{b}	1.81^{e}	1.95^{f}	13.76^{f}	14.82^{f}
1000ppm amino acids	36.33^{bc}	34.53^{d}	57.33^{c}	61.33^{a}	2.49^{d}	2.56^{e}	18.93^{e}	19.44^{e}
2000ppm amino acids	45.27^{ab}	45.07^{bc}	62.00^{ab}	63.00^{a}	3.29^{a-c}	3.47^{bc}	24.98^{a-d}	26.38^{bc}
500ppm micronutrients solution	40.20^{bc}	40.00^{b-d}	62.33^{ab}	63.00^{a}	2.81^{cd}	3.00^{c-e}	21.35^{c-e}	22.81^{c-e}
1000ppm micronutrients solution	32.67^{c}	33.40^{d}	63.67^{ab}	64.00^{a}	2.72^{cd}	2.94^{de}	20.64^{de}	22.32^{de}
1000ppm amino acids* 500ppm micronutrientssolution	39.20^{bc}	37.00^{cd}	64.33^{ab}	65.00^{a}	3.43^{a-c}	3.35^{b-d}	26.10^{a-c}	25.44^{b-d}
1000ppm amino acids* 1000ppm micronutrients solution	50.53^{a}	48.73^{b}	61.67^{b}	63.67^{a}	3.57^{ab}	3.66^{b}	27.12^{ab}	27.78^{b}
2000ppm amino acids* 500ppm micronutrients solution	44.33^{ab}	43.93^{bc}	62.67^{ab}	61.33^{a}	2.97^{b-d}	3.13^{cd}	22.58^{b-e}	23.80^{cd}
2000ppm amino acids*1000ppm micronutrients solution	53.33^{a}	59.27^{a}	65.33^{a}	64.33^{a}	3.94^{a}	4.88^{a}	29.97^{a}	37.10^{a}
LSD	9.414	8.207	3.315	4.252	0.6657	0.4726	4.982	3.572

Means (±SD) followed by different letters are significantly different at P< 0.05 level; Duncan's Multiple Range Test, where LSD= Minimum significant difference.

The combined treatment of Amino Suam (1000ppm) and micronutrients solution (500 and 1000ppm) significantly increased the leaf area of tomato plants compared to control plants in both seasons. However, there were no significant differences in the overall mean shoot height values with Amino Suam, micronutrients solution and their combinations compared to control. The highest significant values of the branch number per plant, leaf number per plant and leaf area in both seasons were recorded in most cases with foliar application of the combined treatment of Amino Suam (1000ppm) and micronutrients solution (500ppm). The highest values of leaf fresh weight were recorded by using the combined treatment between amino acids (2000ppm) and micronutrients (1000ppm). The highest values for the shoot height were recorded using the combined treatment of amino acids (2000ppm) using the combined treatment of micronutrients solution (500ppm).

The branch number per plant and plant leaf area (Table 1), fruits number per plant and fruit fresh weight (Table 2) increased with amino acids and/ or micronutrients solutions foliar applications increasing the final fruit yield per feddan in both seasons compared to control (Table 2). Therefore, the combined treatment of amino acids (2000ppm) and micronutrients solution (1000ppm) recorded the highest values the mean fruit number per plant, fresh weight, fruit diameter and total yield per fed of tomato plant than the other treatments and its control. Also, the same treatment increased the fresh fruit yield of tomato plants per fed by more than twofold of the corresponding control values in two seasons.

Physiological and biochemical responses

Table 3 reveals that, N, Fe, Mn and Cu concentrations in tomato leaves increased significantly with all foliar applications of Amino Suam and micronutrients solutions individually or in combination than its control. Individually foliar applications of micronutrient solutions (500 or 1000ppm) and amino acids (1000ppm) and combined foliar applications of amino acids (1000ppm) and micronutrients solution (1000ppm) and amino acids (2000ppm) and micronutrients solutions (500 or 1000ppm) recorded higher significant increases of P, K, Ca, Mg and Zn concentrations comparing with the control. Foliar application of amino acids 2000ppm led to a significant increase in K, Ca and Zn concentrations than control. However, there were no significant differences in the overall mean of P, K, Mg and Zn concentrations using the combined treatment of amino acids (1000ppm) and micronutrients solution (500ppm) compared to control (Table 3).

TABLE 3. Influence of foliar spray with amino acids and micronutrients solution on some macro and micronutrients concentrations of tomato leaves during 2017 and 2018 growing seasons (main of two seasons)

Treatments	Macronutrients (%)					Micronutrients (mg/ kg DW)			
	N	P	K	Mg	Ca	Fe	Mn	Zn	Cu
Control (distilled water)	2.53^{g}	0.41^{d}	0.68^{g}	0.47^{d}	2.48^{h}	576.73^{h}	34.34^{i}	20.33^{h}	14.44^{f}
1000ppm amino acids	3.01^{e}	0.66^{a}	1.40^{d}	0.65b^{c}	3.12^{f}	998.58^{c}	83.63^{b}	70.66^{a}	15.14^{e}
2000ppm amino acids	3.14^{c}	0.45^{cd}	0.99^{e}	0.49^{d}	3.25^{e}	720.53^{g}	58.25^{g}	22.98^{f}	14.89^{e}
500ppm micronutrients solution	3.55^{a}	0.51^{c}	0.97^{e}	0.66^{bc}	6.23^{b}	722.21^{g}	51.78^{h}	24.70^{e}	16.44^{c}
1000ppm micronutrients solution	2.73^{f}	0.64^{ab}	1.88^{b}	0.93^{a}	7.05^{a}	813.50^{d}	74.84^{c}	33.14^{c}	16.80^{bc}
1000ppm amino acids* 500ppm micronutrients solution	3.39^{b}	0.45^{cd}	0.74^{fg}	0.49^{d}	2.75^{g}	1352.95^{b}	61.09^{f}	20.78^{h}	15.84^{d}
1000ppm amino acids* 1000ppm micronutrients solution	2.76^{f}	0.59^{b}	0.78^{f}	0.62^{c}	5.49^{c}	1806.72^{a}	95.66^{a}	49.53^{b}	15.21^{e}
2000ppm amino acids* 500ppm micronutrients solution	3.06^{de}	0.50^{c}	2.87^{a}	0.86^{a}	2.50^{h}	773.89^{f}	63.10^{e}	22.25^{g}	18.31^{a}
2000ppm amino acids* 1000ppm micronutrients solution	3.07^{d}	0.60^{b}	1.77^{c}	0.72^{b}	3.78^{d}	787.92^{e}	66.67^{d}	29.89^{d}	17.10^{b}
LSD	0.0595	0.0595	0.05954	0.0842	0.0842	5.087	0.9166	0.717	0.4294

Means (±SD) followed by different letters are significantly different at P< 0.05 level; Duncan's Multiple Range Test, where LSD= Minimum significant difference.

Spray Amino Suam (1000ppm) gave the highest P concentrations (0.66%) and Zn (70.66mg/kg DW) whereas, the highest N concentration (3.55%) was attained using micronutrients solution (500ppm). The foliar application of micronutrients solution (1000ppm) recorded the highest Mg (0.93%) and Ca concentrations (7.05%). Additionally, the combined treatment of Amino Suam (1000 ppm) and micronutrients solution (1000ppm) recorded the highest Fe (1806.72mg/kg DW) and Mn (95.66mg/kg DW) concentrations whereas, the highest K (2.87%) and Cu (18.31mg/kg DW) concentrations were recorded with the combined treatment of amino acids (2000ppm) and micronutrients solution 500ppm.

Photosynthetic pigments**,** chlorophyll a, b and a+ b and carotenoids in leaves of tomato plants significantly increased with foliar applications of Amino Suam, micronutrients solutions and their combinations compared to control plants in both seasons (Table 4). The more pronounced effect on these pigments was recorded by foliar application of the combined treatment of Amino Suam 2000ppm and micronutrients solution 500ppm in both seasons. The overall mean of all Amino Suam and micronutrients solutions foliar treatments indicated that the total soluble protein concentration increased to the highest significant concentrations compared to control plants in both seasons (Table 4), and the highest protein concentration was recorded in the tomato plant that received the combination of Amino Suam (1000ppm) and micronutrient solution (500ppm) compared to the lowest protein concentration in control plants.

Fruit quality characteristics (lycopene and ascorbic acid)

Spraying Amino Suam, micronutrient solution and their combinations significantly improved lycopene and ascorbic acid concentrations in tomato fruits at harvest compared to control plants in both seasons (Fig. 1). Combined Amino Suam and micronutrient solution achieved higher significant increases of ascorbic acid concentration compared to the other foliar treatments and control plants in both seasons. The highest concentrations of both lycopene and ascorbic acid were recorded in tomato plants sprayed with the combined treatment of Amino Suam (2000ppm) and micronutrients solution (1000ppm) in both seasons.

TABLE 4. Influence of foliar spray with amino acids and micronutrients solution on photosynthetic pigments (mg/g FW) and total soluble protein (µg/g FW) of tomato leaves during 2017 and 2018 growing seasons

Treatments	Chlorophyll a		Chlorophyll b		Chlorophyll a+ b		Carotenoids		Total soluble protein	
	Ses 1	Ses 2	Ses 1	Ses 2	Ses 1	Ses 2	Ses 1	Ses 2	Ses 1	Ses 2
Control (distilled water)	4.11^{h}	4.07^{h}	3.79^{g}	3.84^{f}	7.90^{h}	7.90^{h}	1.53^{f}	1.15^{d}	56.53^{f}	55.56^{f}
1000ppmamino acids	6.18^{f}	6.23^{f}	5.57^{c}	5.58^{c}	11.75^{d}	11.81^{d}	2.61^{b}	1.73^{b}	77.14^{d}	81.59^{b}
2000ppm amino acids	6.21^{f}	6.24^{f}	3.94^{f}	3.97^{e}	10.15^{f}	10.21^{f}	2.06^{e}	1.32^{c}	84.52^{b}	88.55^{a}
500ppm micronutrients solution	6.37^{e}	6.44^{e}	5.36^{d}	5.42^{d}	11.73^{d}	11.86^{d}	2.35^{d}	1.76^{b}	67.39^{e}	70.87^{cd}
1000ppm micronutrients solution	7.15^{c}	7.18^{c}	5.54^{c}	5.55^{c}	12.69^{c}	12.72^{c}	2.62^{b}	1.72^{b}	66.14^{e}	65.44^{e}
1000 ppm amino acids* 500 ppm micronutrients solution	5.65^{g}	5.69^{g}	4.06^{e}	4.07^{e}	9.71^{g}	9.77^{g}	2.01^{e}	1.30^{c}	87.3^{a}	88.69^{a}
1000ppm amino acids* 1000ppm micronutrients solution	8.02^{b}	8.05^{b}	5.90^{b}	5.97^{b}	13.92^{b}	14.02^{b}	2.38^{d}	2.13^{a}	80.2^{c}	83.26^{b}
2000ppm amino acids* 500ppm micronutrients solution	9.04^{a}	9.08^{a}	6.47^{a}	6.54^{a}	15.51^{a}	15.62^{a}	3.63^{a}	2.08^{a}	65.86^{e}	67.39^{de}
2000ppm amino acids* 1000ppm micronutrients solution	6.59^{d}	6.63^{d}	3.67^{h}	3.70^{g}	10.26^{e}	10.33^{e}	2.53^{c}	1.30^{c}	77.97^{d}	74.07^{c}
LSD	0.0595	0.1331	0.0595	0.1191	0.0842	0.0842	0.0595	0.05954	2.130	3.572

Means (±SD) followed by different letters are significantly different at $P< 0.05$ level; Duncan's Multiple Range Test, where LSD= Minimum significant difference.

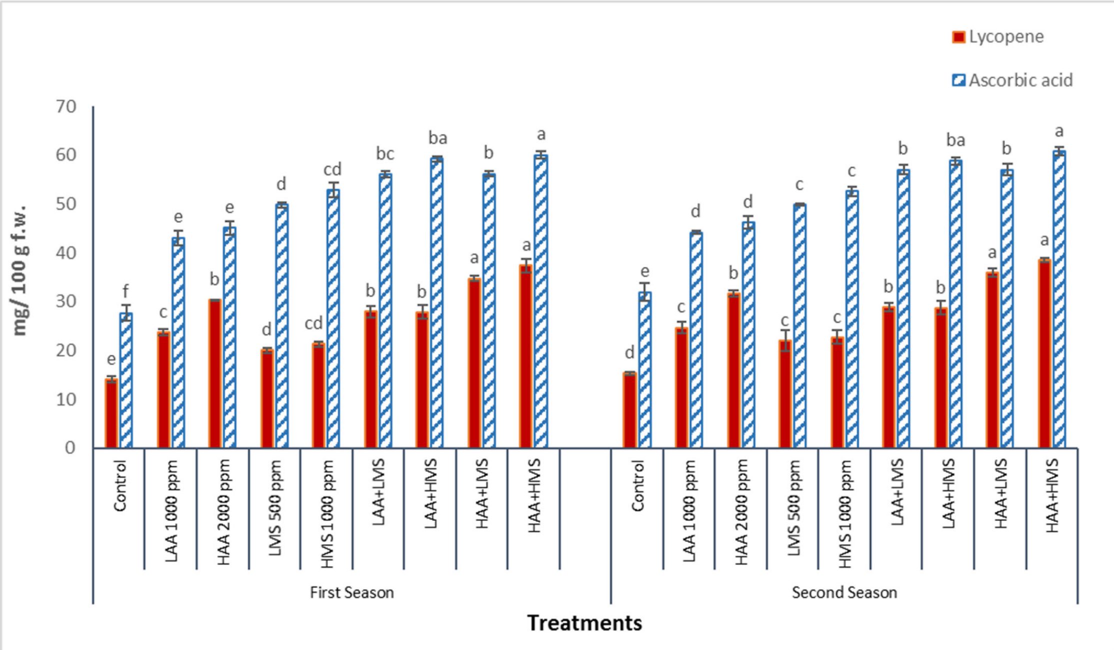

Fig. 1. Influence of foliar spray with amino acids and micronutrients solution on lycopene and ascorbic acid concentrations (mg/100g FW) of tomato fruits during 2017 and 2018 growing seasons [Means (±SD) followed by different letters are significantly different at P< 0.05 level; Duncan's Multiple Range Test, where LSD= Minimum significant difference. LAA= 1000ppm amino acids, HAA= 2000ppm amino acids, LMS= 500ppm micronutrients solution, HMS= 1000ppm micronutrients solution]

Discussion

Foliar application of the natural biostimulants such as Amino Suam and micronutrients is a promising aspect in stimulating the growth, physiological processes, flowering, yield productivity and the quality of various crops (Abo Sedera et al., 2010; Mohamed et al., 2016; El-Attar & Ashour, 2016; Sidhu et al., 2019).

The benefits of spraying tomato plants with Amino Suam (1000 and 2000ppm) stimulated the vegetative growth and yield components compared to control plants (Tables 1 and 2) and showed improvements in nutrients, photosynthetic pigments and total soluble proteins (Tables 3 and 4). These results agreed with Abd El-Aal et al. (2010) on squash, Abo Sedera et al. (2010) on strawberry, El-Abagy et al. (2014) on onion, Shalaby & El-Ramady (2014) on garlic, Zewail (2014) on common bean, Sadak et al. (2015) on faba bean, Salama & Yousef (2015) on basil and Aly et al. (2019) on hot pepper.

The vegetative growth characteristics and fruit yield of tomatoes were enhanced using foliar applications of commercial amino acids (Amino Suam) probably due to the many physiological processes of amino acids, such as nutrient uptake and photosynthesis (Sarojnee et al., 2009). Additionally, Hildebrandt et al. (2015) suggested other useful functions of amino acids in plant cells, such as protein biosynthesis, signaling processes, energy producers, auxin biosynthesis and enzyme regulation influencing physiological processes, plant growth and development. Therefore, amino acid application increased nutrient translocation recorded higher free cytokinin content and regulated the growth and development of *Zea mays* L. by affecting gene transcription (Santi et al., 2017).

Maximizing the endogenous biochemical constituents of tomato plants by Amino Suam treatments compared to control in this study agreed with the works obtained on common bean and faba bean plants respectively by Zewail (2014) and Sadak et al. (2015) who indicated that the concentration of photosynthetic pigments, total protein and minerals i.e. N, P, K, Mg and Ca increased with amino acids foliar applications. Also, El- Attar & Ashour (2016) found that spraying chamomile plants with Amino Suam enhanced chlorophylls synthesis and nutrients uptake. In addition, spraying amino acids (2 g l^{-1}) produced higher lycopene and ascorbic acid concentrations in hot pepper fruits compared to control plants (Aly et al., 2019). The synergistic effect of using amino acids in foliar applications on N, P, K, Ca, Mg, Fe, Mn, Zn and Cu concentrations of tomato leaves in Table 3 may be attributed to the fact amino acids facilitate the nutrients uptake, translocation and assimilation in plant cells (Marschner, 1995; Sarojnee et al., 2009; Santi et al., 2017).

This study revealed that spraying micronutrients solution (500 and 1000ppm) had strong positive impacts on the vegetative growth parameters and fruit yield of tomato compared to control. These findings agreed with Youssif (2014) who produced the best values of plant height, number of branches, shoot fresh weight, leaf area, number of fruits per plant, diameter, weight and total fruits yield of pepper plants sprayed with 100ppm Fe-EDTA plus 50 or 100ppm Zn-EDTA. Likewise, many studies reported that, micronutrients mixtures as foliar applications improve the vegetative growth characteristics and yield traits of fennel plants El-Seifi et al. (2015) and tomato plants (Jadhav et al., 2014; Habibullah et al., 2017; Verma et al., 2018).

Increases in the vegetative growth parameters and yield components of tomato plants (Tables 1 and 2) using micronutrients foliar applications may be because micronutrients such as Fe, Mn, Zn, Cu and B have favorable essential roles to influence physiological functions including development, flowering, nutrients uptake, chlorophylls synthesis, photosynthesis, metabolism and enzyme activation resulting in higher vegetative growth and yield of vegetable crops (Sakya & Sulandjari, 2019; Sidhu et al., 2019; Salim et al., 2019). Therefore, micronutrients such as Fe, Zn and B are requirements for auxin (indole-3-acetic acid) and cytokinin biosynthesis (Taiz & Zeiger, 2002; Abou EL-Yazied & Mady, 2012; Sakya & Sulandjari, 2019). Additionally, B has fundamental roles in cell wall structure, cell membrane functions, cell elongation, DNA and RNA metabolism and several metabolic pathways in plant cells (Uchida, 2000; Taiz & Zeiger, 2002; Bubarai et al., 2017). Also, micronutrients have tonic effects on the photosynthetic rate producing higher carbohydrate accumulation and its translocation from leaves (source) to fruits (sink) increasing the total yield (Marschner, 1995; Uchida, 2000; Jadhav et al., 2014; Sidhu et al., 2019).

Photosynthetic pigments, total soluble proteins, nutrients concentrations and fruit quality (Tables 3 and 4; Fig. 1) are more pronounced in tomato plants sprayed with micronutrients solution than control in good agreement with Youssif (2014), El-Seifi et al. (2015) and Mohamed et al. (2016) on sweet pepper, fennel and faba bean plants, respectively. Additionally, combined micronutrient foliar treatment improved lycopene and ascorbic acid concentrations in tomato fruits (Habibullah et al., 2017; Verma et al., 2018). Increments in the endogenous biochemical constituents of tomato plant with micronutrients treatments may be related to Fe, Mn, Zn, Cu and B involved in biosynthesis and/ or keeping these constituents in plant cells, and maintaining cell membrane functions and various enzymatic systems in plants (Uchida, 2000; Taiz & Zeiger, 2002; Salim et al., 2019).

The combined treatments of amino acids and micronutrients solution recorded higher increases in the vegetative growth parameters and yield components of tomato plants in both seasons compared to control which may be linked to increases in the endogenous concentrations of N, P, K, Ca, Mg, Fe, Mn, Zn, Cu, photosynthetic pigments and total soluble proteins with the combination treatments. These results were supported by Iancu et al. (2017) who reported that, physiological responses such as chlorophyll and photosynthesis rate of the tomato plant influenced the foliar application of macronutrients and micronutrients with amino acids. Therefore, the mineral status, yield productivity and quality factors were higher with the combined applications of various amino acids and single or multiple nutrients rather than the individual supply of these nutrients (Souri & Hatamian, 2019). Finally, Niu et al. (2021) reported that, using chelated foliar fertilizers enhanced nutrients use efficiency, crop yield and quality.

Conclusion

This study concluded that amino acids (Amino Suam) and micronutrients solution (2% Fe, 2% Mn, 2% Zn, 1% Cu and 0.5% B) foliar applications alone or in combination have positive impacts on vegetative growth, leaf mineral status, photosynthetic pigments and total soluble protein concentrations increasing the total fruit yield and fruit quality of tomato. Especially at the combination treatments achieved highly significant increases in most of these characteristics compared to control plants.

Conflict of interests: The authors declare that they have no conflict of interest.

Authors contribution: All authors did equally in conceptualization, methodology design, the laboratory work, morphological and biochemical measurements, interpretation of the results and preparing the manuscript.

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إستجابة نبات الطماطم للرش الورقي بالأحماض الأمينيه ومخلوط العناصر الغذائيه الصغرى

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أنجزت تجربه حقليه خلال سبتمبر لموسمين متتاليين 2017 & 2018 بمزرعة كلية الزراعه جامعة عين شمس - القاهرة - مصر لدراسة إستجابة نبات الطماطم صنف 010 للرش الورقي بالأحماض الأمينيه بثلاث تركيزات هي 0، 1000 و2000 جزء في المليون ومخلوط العناصر الغذائيه الصغرى المكون من الحديد، المنجنيز، الزنك، النحاس والبورون بتركيزات 0، 500 و1000 جزء في المليون منفرده ومخلوطاتها رشاً على المجموع الخضري عند 30، 45 و60 يوم من الشتل.

الرش الورقي بالأحماض الأمينيه ومخلوط العناصر الغذائيه الصغرى منفرده ومخلوطاتها سبب تنشيط لخصائص النمو الخضري ومحصول نبات الطماطم (إرتفاع النبات – عدد الأفرع/ نبات – عدد الأوراق/ نبات – الوزن الرطب للورقه – مساحة الأوراق – عدد الثمار/ نبات – متوسط وزن الثمره – قطر الثمره – محصول الثمار الطازج/ فدان) في كلا الموسمين مقارنة بنباتات الكنترول (المقارنه). كما أعطى الرش الورقي بمعاملات الأحماض الأمينيه ومخلوطات العناصر الغذائيه الصغرى منفرده ومخلوطاتها زيادة معنويه في تركيزات بعض المكونات البيوكيميائيه (النيتروجين، الحديد، المنجنيز، الزنك، صبغات البناء الضوئي والبروتين الكلي الذائب) في أوراق نبات الطماطم عند عمر 75 يوم من الشتل مقارنة بنباتات الكنترول وتركيزات صبغة الليكوبين وحمض الأسكوربيك في ثمار الطماطم الناضجه عند الحصاد مقارنة بنباتات الكنترول. كما سجل الرش الورقي بمعاملات الخليط بين الأحماض الأمينيه والعناصر العذائيه الصغرى زياده معنويه قويه لمعظم خصائص النمو الخضري والمحصول والمكونات البيوكيميائيه لنبات الطماطم.