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Productive and qualitative performance of tomato plants as a function of the application of plant growth regulators and mineral nutrients

Desempeño productivo y cualitativo de plantas de tomate en relación con la aplicación de reguladores de crecimiento y nutrientes minerales

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Tomato plantation in São Manuel-SP (Brazil).
Photo: M.C. Sousa

ABSTRACT

The tomato fruit is rich in antioxidant compounds and has great nutritional and economic importance, annually promoting research on the nutritional and productive characteristics. The present study aimed to evaluate whether foliar application of commercial products based on growth regulators [auxin, cytokinin and gibberellin (Ax+CK+GA)], micronutrients [cobalt and molybdenum (Mi)] and mixtures of macro and micronutrients [nitrogen, boron, copper, molybdenum and zinc (Ma+Mi)], isolated and in combination, increase productivity and improve the post-harvest quality of tomato fruits (Predador F1). The experiment design used randomized blocks, with seven treatments and four repetitions, which were (T1) control; (T2) Ax+CK+GA; (T3) Ma+Mi; (T4) Mi; (T5) Ax+CK+GA + (Ma+Mi); (T6) Ax+CK+GA + Mi; and (T7) Ax+CK+GA + Mi + (Ma+Mi). The variables production, precocity, soluble solids content (SS), titratable acidity (TA), ratio (SS/TA), pH, total soluble sugars, ascorbic acid and weight loss were evaluated. The Ax+CK+GA application, isolated or in combination with Ma+Mi, promoted the precocity, and the use of isolated Ax+CK+GA and Mi improved the tomato plant productivity. The growth regulators, macro and micronutrients, isolated or in combination, increased the ascorbic acid content in the fruits.

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Additional key words: *Solanum lycopersicum* L., production, post-harvest, mineral nutrition, plant hormones.

Resumen

El tomate es un fruto rico en compuestos antioxidantes y tiene gran importancia nutricional y económica; anualmente se promueve investigaciones relacionadas con las características nutricionales y productivas. El objetivo de este estudio fue evaluar si la aplicación foliar de productos comerciales a base de reguladores vegetales [auxina, citocinina y giberelina (Ax+CK+GA)], micronutrientes [cobalto y molibdeno (Mi)] y mezcla de macro y micronutrientes [nitrógeno, boro, cobre, molibdeno y zinc (Ma+Mi)], de forma individual y combinada, sobre el aumento de la productividad y mejora de la calidad poscosecha de los frutos de tomate (Predador F1). El diseño experimental consistió en bloques al azar, con siete tratamientos y cuatro repeticiones, siendo (T1) control; (T2) Ax+CK+GA; (T3) Ma+Mi; (T4) Mi; (T5) Ax+CK+GA + (Ma+Mi); (T6) Ax+CK+GA + Mi; (T7) Ax+CK+GA + Mi + (Ma+Mi). Se evaluaron las variables producción, precocidad, contenido de sólidos solubles (SS), acidez titulable (AT), relación SS/AT, pH, azúcares solubles totales, ácido ascórbico y pérdida de peso. La aplicación de Ax+CK+GA de forma individual o combinada con Ma+Mi promovió la precocidad, mientras el uso de Ax+CK+GA y Mi, de forma separada, mejoró la productividad del tomate. Los reguladores de crecimiento y los macro y micronutrientes, separados o combinados, proporcionaron un aumento en el contenido de ácido ascórbico en los frutos.

Palabras clave adicionales: *Solanum lycopersicum* L., producción, poscosecha, nutrición mineral, hormonas vegetales.

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INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is the second most produced horticultural crop in the world. In Brazil, in 2016, production was 3.74 million tons, with an area of 58,600 ha and an output of 64,000 kg ha^{-1}, and the states Goiás, São Paulo and Minas Gerais were responsible for 63.7% of the production (IBGE, 2016).

In order to meet the demand of the consumer market, crop management that improves the productive and qualitative aspects of crops are needed, emphasizing the application of products, such as biostimulants, which are defined as any substance applied to plants in order to increase nutritional efficiency, tolerance to abiotic stress and/or quality characteristics, regardless of nutrient contents, including products formulated with a mixture of growth regulators (Du Jardin, 2015).

Plant growth regulators are chemical substances, not nutrients, synthetic or natural, that act like plant hormones; with an ideal balance, they can induce a positive effect on plant development (Castro and Vieira, 2001; Fagan *et al.*, 2015). Nutrients play key roles since they are involved in the regulation of many essential processes, such as enzymatic activation, photosynthesis, starch formation and proteins synthesis (Fagan *et al*., 2016).

The foliar application of plant growth regulators, together with foliar fertilizers, is a very common practice in many countries, used to improve crop development, productivity and quality. In Brazil, its use has shown great potential, with studies that have proven efficiency in cultivations such as soy, corn, beans and cotton (Bertolin *et al*., 2010; Dourado Neto *et al*., 2012; Bontempo *et al*., 2016; Silva *et al*., 2016). This technique has been used for horticultural crops, but needs research verifies efficiency.

Thus, this study aimed to evaluate whether a foliar application of commercial products based on plant growth regulators (auxin, cytokinin and gibberellin), micronutrients (cobalt and molybdenum) and the mixture of macro and micronutrients (nitrogen, boron, copper, molybdenum and zinc), isolated or in combination, increases productivity and improves tomato 'Predador F1' fruit quality.

MATERIAL AND METHODS

This study was conducted in the experimental area belonging to the College of Agricultural Sciences, São Paulo State University, located in the city of São Manuel-SP, Brazil (22°46'33.72" S and 48°34'7.29" W and 768 m altitude). According to the Köppen climatic classification, the climate is a Cfa type (Temperate Rainy Climate) (Cunha and Martins, 2009).

We used an arc-shaped protected environment, 24×7 m and 3 m tall, covered with a low-density 150 μm polyethylene film, closed on the sides with 75% screen shading.

The soil was classified as dystrophic red latosol (Embrapa, 2013). In the layer between 0 and 0.20 m, the soil exhibited the following chemical characteristics: 11 g dm^{-3} of organic sample; pH 6.2; 99 mg dm^{-3} of P (resin); 3.8 $cmol_c$ dm^{-3} of K; 50 $cmol_c$ dm^{-3} of Ca; 11 $cmol_c$ dm^{-3} of Mg; 0.53 mg dm^{-3} of B; 1.7 mg dm^{-3} of Co; 11.4 mg dm^{-3} of Mn; 7.1 mg dm^{-3} of Zn; CTC = 75 $cmol_c$ dm^{-3} and V% 86. The fertilization was performed based on the chemical analysis of the soil, according to Alvarenga (2004). The fertilization at planting was performed in the furrow and the top dressing was done via fertirrigation.

The experiment design used randomized blocks with seven treatments and four repetitions. Six plants, four of them being useful, were used in each repetition. The treatments were (T1) control; (T2) 0.5 L ha^{-1} plant growth regulators (Ax+CK+GA); (T3) 3 L ha^{-1} macro and micronutrients (Ma+Mi); (T4) 1 L ha^{-1} micronutrients (Mi); (T5) 0.5 L ha^{-1} Ax+CK+GA + 3 L ha^{-1} Ma+Mi; (T6) 0.5 L ha^{-1} Ax+CK+GA + 1 L ha^{-1} Mi; and (T7) 0.5 L ha^{-1} Ax+CK+GA + 3 L ha^{-1} Ma+Mi + 1 L ha^{-1} Mi.

The experiment was conducted from March to August of 2014. The first application of the treatments was done 20 days after transplanting (dat), when the plants had emitted the first raceme, and the others were done every 20 d, for a total of five applications. The foliar applications were made using a CO_2-pressurized backpack sprayer with a constant pressure of 2.5 kgf cm^{-2}. In all of the treatments, we added vegetable oil (Natur'l oil®) at 0.5%, and the solution was acidified, maintaining the final pH of the mixture between 4.0 and 5.0 using P-51® (1% nitrogen and 51% phosphoric acid) (Stoller do Brasil, São Paulo-SP, Brazil).

Stimulate® was used as a source of plant growth regulators. This commercial product contains 0.005% indole-3-butyric acid [auxinl (Ax)], 0.009% kinetin [cytokinin (CK)] and 0.005% gibberellic acid [gibberellin (GA)]. For the mixture of macro and micronutrients, we used the commercial product Mover®, containing 5% nitrogen (N), 4.5% zinc (Zn), 4% boron (B), 0.17% copper (Cu) and 0.015% molybdenum (Mo), and, for the mixture of micronutrients, the commercial product Hold®, containing 3% molybdenum (Mo) and 2% cobalt (Co), was used. All products came from Stoller do Brasil (São Paulo-SP, Brazil). 'Predador F1' hybrid tomato plant seedlings, of the undetermined type, were transplanted 25 d after the sowing, with a spacing of 1.0×0.5 m, resulting in a density of 20,000 plants/ha. The plants were conducted with a stem during the cycle, using one plant per hole, and the tomato plants were tutored vertically until the fifth fruit bunch, when apical pruning was performed (60 and 70 dat). Diseases and plagues were controlled according to the conventional recommendations.

Weekly, the fruits were harvested when presenting a red base. Afterwards, they were evaluated according to the production, precocity, soluble solids content (SS), titratable acidity (TA), ratio (SS/TA), pH, total soluble sugars, ascorbic acid and weight loss.

For the production evaluation, the fruits were weighed after being selected as "non-commercial" or "commercial" according to the methodology proposed by CQH/Ceagesp (2003).

The harvests were performed eight times, calculating the relative proportion of each harvest in the total fruit productivity, aiming to determine the harvest precocity. The treatments that, with four harvests, produced values close to 50% of total productivity, according to the method adapted from Martins *et al*. (2017) were considered more precocious.

Post-harvest chemical analyses were performed at 110 dat. The fruit pulp was homogenized in a domestic grinder (mixer) and evaluated according to the titratable acidity, expressed in grams of citric acid per 100 g of pulp, obtained with titration of 5 g of diluted pulp per 100 mL of distilled water (Instituto Adolfo Lutz, 2008).

The total soluble solids was determined with a digital refractometer (Atago, Tokyo, Japan). The results were expressed in °Brix, and the ratio between the SS content and TA (SS/TA) was calculated (AOAC, 2005). The pH was determined using a potentiometer on a solution of homogenized pulp (Analyser – model pH 300) (Ministério da Saúde, 2005). The ascorbic acid content (AA) was determined using 10 g of tomato pulp mixed with 0.5% oxalic acid. This solution was titrated with a 0.1 mol L^{-1} 2.6-dichloro-phenol-indophenol solution. The results were expressed in mg of ascorbic acid 100 g^{-1} of pulp (MAPA, 2006).

The total soluble sugars (TSS) was determined with the method described by Somogy, adapted by Nelson (1944), and the results were expressed as a percentage.

In the analysis of weight loss, tomato samples (10 fruits) were selected from each repetition, placed on five expanded polystyrene commercial foam trays and weighed every two days while the fruits presented a weight loss lower than 10%. These fruits were kept on the laboratory bench at room temperature, between 17.2 and 22.4°C, with a relative humidity between 10 and 70%. The difference between the initial and final fruit weights in each time interval was calculated as a percentage (Chitarra and Chitarra, 2005).

The results were submitted to variance analysis (test F) and the means were compared with the Tukey test, at 5% probability, using the SAS 9.2 statistical package (SAS, 2002).

RESULTS AND DISCUSSION

The plants that received an application of micronutrient (Mi) and the mixture of plant growth regulators + micronutrients [Ax+CK+GA + (Mi)] presented the highest average of total fruit number and total productivity, differing from the control treatment (Tab. 1). According to Matos *et al.* (2017), the application of plant growth regulators and micronutrients allows plants to express their greatest genetic productive potential because they are important metabolic activators.

For the average total fruit weight, the treatment with Ax+CK+GA and the control presented higher values in relation to the treatment with an application of Mi and [Ax+CK+GA + (Mi)]. Amaro (2014), working with the application of the same products on vines, observed that the use of the Ax+CK+GA product induced a higher total weight of tomato bunchs per plant, besides increasing the values of length and height. In addition, the application of these plant growth regulators and the product based on Mi¸ isolated or combination, increased the average weight of bunches in relation to the control. The author attributed this effect to the influence of the products used on the efficiency of gas exchanges.

Souza (2014), working with the same products on vines, observed that the combination of the mixtures of growth regulators and of mineral nutrients promoted alterations in plant metabolism, increasing production.

In this experiment, the application of Mi and [(Ax+CK+GA + (Mi)] had positive results as a result of the mechanism of action of these compounds that improved growth and plant development. This occurs because growth regulators, such as auxin, gibberellin and cytokinins, when applied in synthetic forms, can induce a hormonal balance.

The application of some micronutrients, used with physiological appeal, can also promote similar results. In the Peruvian carrot (*Arracacia xanthorrhiza*), for example, the effect of the application of Upper® (Ax+Ck+GA+Mo) was evaluated on the pre-rooting of seedlings, where the authors observed a significant increase in the number and length of the roots, indicating that the product can act as a rooting stimulator (Reghin *et al*., 2000).

This factor becomes more evident when observing the functions of molybdenum, a cofactor of aldehyde oxidase, which is involved in auxin biosynthesis, catalyzing the oxidation of indole-3-acetaldehyde to indole-3-acetic acid during initial plant development (Broadley *et al.*, 2012). Thus, micronutrient applications can increase auxin levels in plants, which are responsible for regulating different stages of development, such as cell expansion and division, as well as vascular tissue differentiation (Di *et al*., 2016). Molybdenum is also a cofactor of nitrate reductase in the metabolic pathway of nitrogen assimilation (Broadley *et al.*, 2012).

Cobalt, another micronutrient present in the Mi treatment, plays a role in the development of lateral roots (Xu *et al.*, 2011), where the treatment with

$CoCl_2$ induced the regulation of genes involved in the formation of lateral roots in tomato plants. These structures perform a considerable function in the increase of the water absorption capacity and mineral nutrients, anchorage of plants in soil and cytokinin synthesis.

This affirmation can explain the data presented in table 1, where the application of micronutrients, isolated (Mi) or in mixture [Ax+CK+GA + (Mi)], increased the production of a higher number of fruit, as compared to the control treatment. For the total commercial production, the application of Ax+CK+-GA and Mi also provided an increase in productivity.

In the average total weight characteristic of commercial fruit (Tab. 1), the application of (Mi), isolated or in mixture [Ax+CK+GA + (Mi)], provided a lower value, as compared to the control treatment. Higher averages were observed in the control and with the application of (Ax+CK+GA); however, it is worth pointing out that they did not differ significantly from the treatments (Ma+Mi), [Ax+CK+GA + (Ma+Mi)] and [Ax+CK+GA + (Mi) + (Ma+Mi)].

Tavares *et al.* (2014) observed that the application of Stimulate® in tomato decreased the number of fruits with a diameter lower than 40 mm (considered non-commercial), improving the quality of the produced fruits.

It was also possible to notice that the treatments with the application of Mi and [Ax+CK+GA + (Mi)] produced a higher number of fruits with a less than average weight as a result of the application of molybdenum, which might have contributed to flower fixation and, consequently, increasing the number of produced fruits.

The increased fruit production can also be explained by the fact that the Ax+CK+GA mixture had gibberellins. This growth regulator regulates almost all plant processes, including fruit fixation and development (Wang *et al*., 2009). Gibberellins are considered the second group of phytohormons that present essential function in the coordination of fruit and seeds growth. Type GA_1 and GA_3 active gibberellins are capable of inducing fruit setting and effective fructification in many plant species, such as the tomato (Dorcey *et al*., 2009).

Cato *et al.* (2013), studying the effect of combined and isolated applications of plant growth regulators on the development of tomato plants cv. Micro-Tom, concluded that the combined application of gibberellic acid, indolbutyric acid and kinetin or of the commercial product Stimulate® induced an increase in the accumulation of dry matter in roots and in the fresh and dry matter of fruits, as compared to the control. Ramos (2013) verified that the application of Stimulate® on tomato plants presented efficiency in the gas exchanges and in the maintenance of leaf coloration, which can translate to higher fruit production.

Figure 1 shows the average percentage of the obtained fruits in each harvest and treatment. In this figure,

Table 1. Average total fruit (ATF) number per area, total productivity (TP), average total fruit weight (AWTF), number of commercial fruits (NFC), commercial production (CP) and average weight of commercial fruits (AWCF) of the tomato plants treated with plant growth regulators and nutrients. São Manuel-SP, Brazil, 2014.

Treatment	ATF	TP	AWTF	NCF	CP	AWCF
	(m^{-2})	(kg m^{-2})	(g/fruit)	(m^{-2})	(kg m^{-2})	(g/fruit)
Control	18 b	3,70 b	199,76 a	17 c	3,58 b	211,53 a
Ax+CK+GA	26 ab	5,37 a	204,47 a	24 abc	4,95 a	207,30 a
(Ma+Mi)	24 ab	4,3 ab	183,07 ab	21 abc	4,09 ab	194,06 ab
Mi	32 a	4,99 a	157,09 b	30 a	4,82 a	162,03 b
Ax+CK+GA + (Ma+Mi)	24 ab	4,47 ab	188,32 ab	23 abc	4,28 ab	192,91 ab
Ax+CK+GA + (Mi)	30 a	4,61 ab	159,88 b	25 ab	4,26 ab	171,23 b
Ax+CK+GA + (Mi) + (Ma+Mi)	26 ab	4,61 ab	178,37 ab	23 abc	4,29 ab	188,39 ab
CV(%)	15,58	11,2	9,21	14,26	11,97	7,33

Means followed by the same letter in the columns do not differ significantly from each other according to the Tukey test ($P \leq 0.05$). Ax+CK+GA: plant growth regulators; Ma+Mi: mixture of macro and micronutrients; Mi: mixture of micronutrients.

it is possible to determine the proportion of fruit in relation to the total produced for each treatment; in other words, it serves as a tool to determine whether there was precocity.

The cultivation provided eight harvests, and the first and eighth were the less productive ones. For precocity, two treatments stood out: Ax+CK+GA and [Ax+CK+GA + (Ma+Mi)]. The plants treated with Ax+CK+GA showed 47.45% of the total, and treatment [Ax+CK+GA + (Ma+Mi)] had 51.67%. This represents, in kg m^{-2}, that, with four harvests, Ax+CK+GA produced 254.82, [Ax+CK+GA + (Ma+Mi)] produced 230.98, and the control group produced 41.08% of the total, with 152.02 kg m^{-2} (Fig. 1).

Even though the application of Mi was the second most productive (total production: 4.99 kg m^{-2}), it did not promote precocity. With four harvests, 38.78% of the total fruit weight was obtained. Between harvest three and seven, this treatment had a good distribution of weight of the harvested fruits, between 15.22 and 21.94%, which is an important factor for production uniformity, making it useful as a for weekly harvest prediction. However, it was not effective for precocity, but, if these results were reached from the second harvest, the Mi treatment would possibly reach precocity results similarly to Ax+CK+GA and [Ax+CK+GA + (Ma+Mi)].

For the post-harvest quality characteristics, there was no difference between the treatments for weight loss (Fig. 2). The literature reports that weight loss between 3 and 6% can cause a decline in fruit quality, a value that is normally reached in around six days. It is important to emphasize that fruits with up to 10% weight loss are not commercialized (Chitarra and Chitarra, 2005).

We observed differences between the treatments during the chemical analyses in the pH and ascorbic acid evaluations. However, there were no differences in the percentage of total soluble sugars, soluble solids, titratable acidity or ratio (Tab. 2).

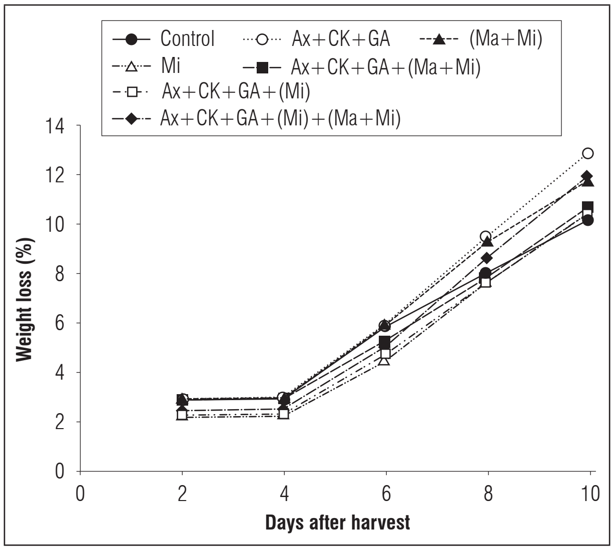

Figure 2. Weight loss for 10 d in tomato plant fruits treated with plant growth regulators and nutrients. São Manuel-SP, Brazil, 2014. Ax+CK+GA: plant growth regulators; Ma+Mi: mixture of macro and micronutrients; Mi: mixture of micronutrientes.

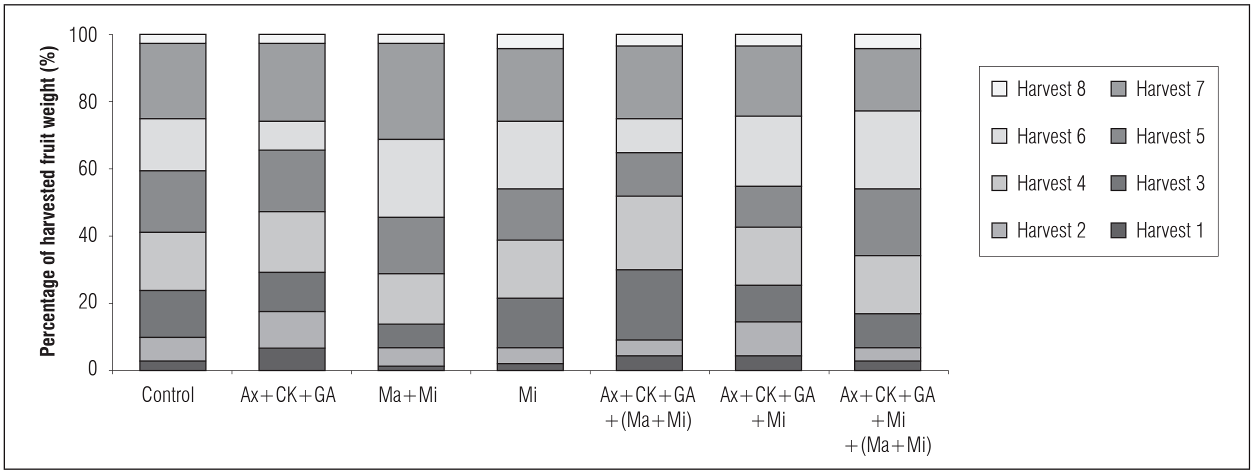

Figure 1. Percentage of harvested fruit weight depending on the harvest, of tomato plants treated with plant growth regulators and mineral nutrients. São Manuel-SP, Brazil, 2014. Ax+CK+GA: plant growth regulators; Ma+Mi: mixture of macro and micronutrients; Mi: mixture of micronutrientes.

Table 2. Soluble solids content (SS), titratable acidity (TA), ratio (SS/TA), pH, total soluble sugars (TSS), and ascorbic acid (AA) in tomato plant fruits treated with plant growth regulators and nutrients. São Manuel-SP, Brazil. 2014.

Treatment	SS	TA	SS/TA	pH	TSS	AA
	(°Brix)	(% citric acid)	(ratio)		(%)	(mg 100 g^{-1})
Control	3,5	0,27	13,1	4,37 a	1,9	7,8 b
Ax+CK+GA	3,6	0,29	12,3	4,33 ab	2,0	13,5 a
(Ma + Mi)	3,4	0,28	12,2	4,29 b	1,9	13,1 a
Mi	3,5	0,29	12,2	4,31 ab	2,0	13,7 a
Ax+CK+GA + (Ma+Mi)	3,6	0,27	13,1	4,34 ab	1,8	13,1 a
Ax+CK+GA +(Mi)	3,6	0,28	12,7	4,29 b	1,9	15,1 a
Ax+CK+GA + (Mi) + (Ma+Mi)	3,6	0,28	13,2	4,31 ab	1,8	14,6 a
CV (%)	5,86	7,53	9,26	0,66	9,72	9,58

Means followed by the same letter in the columns do not differ significantly from each other according to the Tukey test ($P \leq 0.05$). Ax+CK+GA: plant growth regulators; Ma+Mi: mixture of macro and micronutrients; Mi: mixture of micronutrientes.

The average pH values of the fruit varied from 4.30 to 4.37. For all of the treatments, the averages remained within the variation range considered ideal for quality tomatoes, where the desirable pH interval is 3.7 to 4.5 (Giordano *et al*., 2000). We observed a higher value in the control treatment and a lower one in the plants that were treated with (Ma+Mi) and [Ax+CK+GA + (Mi)]. However, there were only significant differences between these and the other treatments.

The ascorbic acid content (AA) was higher for all treatments, as compared to the control. Thus, we inferred that the increase of the AA content was related to the action of the mineral products and growth regulators used in this study in the metabolism, demonstrating that their application increases some antioxidant compounds in fruits.

Good quality tomato fruits should have a ratio lower than 10. In this study, this ratio varied between 12.20 and 13.21, indicating it is a great product for processing, as well as for *in natura* consumption.

CONCLUSION

The application of commercial products based on plant growth regulators, isolated or in combination with mixtures of macro and micronutrients, promoted the precocity of the harvest. The use of growth regulators and isolated micronutrients improved the tomato plant productivity. The plant growth regulators, macro and micronutrients, isolated or in combination, increased the ascorbic acid content in the tomato fruits.

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