UNIVERSIDAD AUTÓNOMA AGRARIA ANTONIO NARRO

SUBDIRECCIÓN DE POSTGRADO

INFLUENCIA DE LA FERTILIZACIÓN NITROGENADA ORGÁNICA EN LA PRODUCCIÓN Y CALIDAD DE TOMATE UVA EN UN SISTEMA DE CULTIVO HIDROPÓNICO

Tesis

Que presenta OSCAR GUAJARDO RÍOS

como requisito parcial para obtener el Grado de

DOCTOR EN CIENCIAS EN AGRICULTURA PROTEGIDA

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Acta Agriculturae Scandinavica, Section B - Plant Soil Science

Animal-based organic nutrition induces comparable fruit quality as that of the inorganic fertigation in soilless-grown grape tomato

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INTRODUCCIÓN

Para reducir y eliminar los efectos adversos de los fertilizantes sintéticos sobre el medio ambiente, nuevas prácticas agrícolas se han desarrollado en la agricultura orgánica, ecológica y sustentable (Chowdhury, 2004). Un cultivo orgánico estimula una mayor síntesis de compuestos fenólicos y muchos estudios sobre la calidad de vegetales orgánicos indican mayor valor nutricional y de contenido de compuestos biológicamente activos (Brandt et al., 2001; Heeb et al., 2005). La liberación de Nitrógeno (N) total en formas disponibles a la planta se relaciona con la mineralización, factores nutricionales y del suelo/sustrato como temperatura, humedad, oxígeno, acidez, etc. De forma que, los fertilizantes orgánicos son menos solubles que los inorgánicos (Bañados et al., 2012; Hirzel et al., 2012; Tamada, 2004). Las plantas pueden usar NH_4^+ y NO_3^- a través de formas poliméricas de N como las proteínas (Paungfoo-Lonhienne et al., 2008). Por lo tanto, el concepto de nutrición orgánica de plantas se basa en estudios de aminoácidos. Por otro lado, la composición de nutrientes de las plantas, incluidos los metabolitos secundarios, puede verse afectada por diferentes sistemas de producción, como orgánicos y convencionales (Daniel et al., 1999; Williams, 2002). Los polifenoles son importantes fitoquímicos bioactivos cuyo consumo puede ayudar en la prevención de enfermedades crónicas, como las cardiovasculares y la diabetes tipo II (Rothwell et al., 2013). Los fenólicos son los metabolitos secundarios más pronunciados en las plantas, y están presentes en todo el proceso metabólico. Además, contribuyen al color y las características sensoriales de las frutas y verduras (Alasalvar et al., 2001). Debido a la relevancia de este problema, y a la falta de información sobre fertilización orgánica en tomates de pequeño tamaño y su efecto sobre la organoléptica y rasgos nutricionales en condiciones de invernadero, el presente estudio tuvo como objetivo evaluar algunos fertilizantes orgánicos certificados y sus efectos sobre el crecimiento, rendimiento y calidad de fruta del tomate tipo uva.

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Animal-based organic nutrition can substitute inorganic fertigation in soilless-grown grape tomato

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Animal-based organic nutrition can substitute inorganic fertigation in soilless-grown grape tomato

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ABSTRACT

Purpose: In recent years, interest in plant nutrition research has arisen with a strong focus on organic forms. The aim of this study was to determine the effect of different organic fertilizers on growth, yield, fruit quality and polyphenol content in soilless grown grape tomatoes under greenhouse conditions.

Materials and methods: Tomato plants were subjected to three organic nutrient solutions, which consisted of different mixtures of several OMRI (Organic Materials Review Institute) certified nitrogen fertilizers of industrially processed residues: Treatment I: solid and soluble liquid fertilizers of animal raw materials, natural potassium sulphate-non-synthetic, and calcium chloride; Treatment II: solid and soluble liquid fertilizers of animal raw materials, by-product of marine raw material (soluble liquid), natural potassium sulphate-non-synthetic, and calcium chloride; and Treatment III: solid fertilizers of animal raw materials, natural potassium sulphate-non-synthetic, and calcium chloride to 100% [0-30 days after transplanting (DAT)], 125% [31-80 DAT], and 150% [>81 DAT]. The Steiner solution (SS) was used as a control (Treatment IV).

Results: Yield did not differ between organic and conventional treatments, ranging from 3.04 to 3.35 kg m^{-2} while fresh weight in organic treatments was 3.14 compared to 3.2 kg m^{-2} in plants fed with the SS. No significant differences in plant height or fruit quality were found. The application of organic fertilizers positively affected the total hydrolysable and condensed polyphenols of tomato fruits compared to the control. Twelve phenolic compounds were identified, highlighting 3-Caffeoylquinic acid, salvianolic acid and 5,6-Dihydroxy-7,8,3',4'-tetramethoxyflavone (Treatment I) and Medioresinol (Lignan) (Treatment II).

Conclusions: The results indicated that organic fertilization through animal-based fertilizer application is a feasible alternative for grape tomato production under greenhouse conditions.

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Nitrogen; organic; OMRI; polyphenols; *Solanum lycopersicum* L.

Introduction

Tomatoes (*Solanum lycopersicum* L.) are one of the most widely consumed vegetable food crops worldwide. The number of specialty tomatoes (e.g. 'grape-tomatoes') has increased in the recent years. These have become a staple of the produce section in most supermarkets in the USA and Europe. The increased demand for grape tomatoes is due to their sweet flavor, smaller size, and firm texture (Roberts et al. 2002). Organic farming techniques have gained popularity in recent years as a result of an increasing consumer preference for food with high nutritional value with better tasting and that has been grown with environmentally friendly techniques (e.g. soil conservation), compared to conventionally grown crops (Larco et al. 2013; Saba and Messina 2003). The total nitrogen (N) released in plant-available forms is related to mineralization capacity along with nutritional factors and soil/substrate factors such as temperature, moisture, oxygen, acidity, etc. In this case, organic fertilizers are usually less soluble than inorganic fertilizers (Bañados et al. 2012; Hirzel et al. 2012; Tamada 2004). Plants can convert NH_4^+ and NO_3^- [chemical N forms] to polymeric N forms such as proteins (Paungfoo-Lonhienne et al. 2008). Thus, the concept of plant organic N nutrition relies on studies of amino acids, but this issue is still a matter of intense debate. On the other hand, the nutrient composition of plants, including secondary plant metabolites, may be affected by different production systems, such as organic and conventional (Daniel et al. 1999; Williams 2002). In recent years, there has been growing

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scientific and commercial interest to identify the bioactive components of food. Polyphenols are a major class of bioactive phytochemicals whose consumption may play a role in the prevention of chronic diseases, such as cardiovascular diseases and type II diabetes (Rothwell et al. 2013). Moreover, polyphenols extracted from the peel, pulp and seeds of selected fruits, including tomatoes, have an antiproliferative effect on several cancer cell lines (Li et al. 2013). Phenolics are the most pronounced secondary metabolites found in plants, and they are distributed throughout the entire metabolic process. Furthermore, these compounds contribute to the color and sensory characteristics of fruits and vegetables (Alasalvar et al. 2001). Several studies have found that the antioxidative effect of tomato fruits is due to the presence of polyphenols (flavonoids and hydroxycinnamic acids), which are able to scavenge peroxyl radicals (García-Valverde et al. 2013). Based on the relevance of this issue, coupled with a lack of information about organic fertilization on small-sized tomatoes, and its effect on organoleptic and nutritional traits under greenhouse conditions, the present study aimed to evaluate some organic certified fertilizer sources and their effects on growth, yield and the fruit quality of grape tomatoes.

Materials and methods

Germplasm and experimental conditions

This work was conducted in 2015 in a greenhouse at the Universidad Autónoma Agraria Antonio Narro, in northern México (lat. 25° 21′ N, long. 101° 02′ W, 1759 m above sea level). The environmental conditions during the experiment were monitored with a HOBO® U12 data logger (Onset Computer Corporation®) and included a daily average temperature (18.1°C), average relative humidity (78%), and photosynthetically active radiation during the daytime (185 µmol m^{-2} s^{-1}) and solar noon (317 µmol m^{-2} s^{-1}). Grape tomato seeds (*Solanum lycopersicum* L.) cv. Luciplus (Hazera Genetics Ltd.) were sown on 2 August 2015 in trays with 200 cavities where sphagnum peat was used as the substrate. On 5 September 2015, seedlings with four developed leaves were transplanted into black polyethylene 15 L containers. The containers were filled with a substrate consisting of a blend of sphagnum peat and perlite (80:20, v:v). The conventional treatment used in the irrigation system was a nutrient solution proposed by Steiner (1984), which was used as the control (treatment IV) [KNO_3: $Ca(NO_3)_2$: $Mg(NO_3)_2$: K_2SO_4: HNO_3: H_3PO_4] and included microelements (Ultrasol®Micro) [Zn 0.399 mg L^{-1}, Fe 66 mg L^{-1}, Mn 2.46 mg L^{-1}, B 0.465 mg L^{-1}, Cu 0.199 mg L^{-1}, Mo 0.133 mg L^{-1}]. A fertigation system was used for application of the nutrient solutions, consisting of drip irrigation with four emitters per container, dispensing 1 L h^{-1} each. During the vegetative phase three 1–hour irrigations were applied per week while in the reproductive phase 2-hour irrigations were applied on a daily basis. Leaching fraction was maintained at ~25% throughout the experiment. Organically derived OMRI-approved fertilizers of horn and hoof meal, bone meal, blood (meal and soluble liquid), fish soluble liquid, calcium chloride, potassium sulphate (non-synthetic) [Us Mex Nutrition Technologies NUTRITEC], and a biostimulant complex of micronutrients chelated by GreenCorp Biorganiks de México were evaluated in different combinations (organic nutrient solutions). The EC of the nutrient solutions ranged from 2.1 to 2.3 dS/m and the pH from 5.9 to 6.2 in all of the evaluated treatments. Citric acid was used to adjust the pH of organic solutions. The applied quantities of organic material were calculated to meet equivalent levels of plant available N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) as those in treatment IV (control). The composition of the organic treatments to 100% is listed in Table 1. Each plant was cultivated with two stems. The first lateral shoot, which emerged from the first node below the first truss of the primary shoot, was not removed but was allowed to develop into a secondary stem. The plants were trained to two branches to form a 'V' trellising shape, using a rollerplast by Paskal Technologies® for each stem. Insect pests and disease pathogens were controlled by preventative organically derived and Organic Material Review Institute (OMRI)-approved compounds such as botanical and microbial pesticides by GreenCorp Biorganiks de México®, using a portable electric mist sprayer (SWISSMEX® Model W1000). The flowers were open-pollinated by bumble bees, and all additional lateral shoots were removed as they appeared; old leaves were removed every 15 days.

Growth and optical sensor parameters

The plant height and stem diameter of six selected plants per treatment were evaluated, starting from 40 days after transplant (DAT) at 15-day intervals until the end of the growing season. The plant height was measured from the substrate surface to the tip of both stems. Stem diameter was measured in the middle region of both stems at the same sampling dates as indicated previously using a digital caliper (Mitutoyo®). The relative levels of total chlorophyl (SPAD values) were estimated using a portable SPAD meter (Model SPAD-502, Minolta Co., Ltd.). The first measurement was made one week after transplanting, which was then repeated weekly until the end of the experiment. Measurements were

Table 1. Composition of organic nutrient solutions to 100% applied to grape tomatoes under greenhouse conditions.

Treatment	Description	Commercial fertilizer	Raw Material	Mineral nutrients applied (g plant^{-1} per watering) N	P	K	S
(i)	Animal solid 'A'	FON® MIX	Horn and hoof, bone and blood meal	0.461	0.124	0.048	–
ASA + AL + NK_2SO_4	Animal liquid	VIGILANTE®	Blood soluble liquid	0.211	–	–	–
	Natural K_2SO_4	FON® SUPER K	Non-synthetic insoluble solid	–	–	1.047	0.429
			Total	0.672	0.124	1.095	0.429
(ii)	Animal solid 'A'	FON® MIX	Horn and hoof, bone and blood meal	0.298	0.080	0.030	–
ASA + AL + NK_2SO_4+MO	Animal liquid	VIGILANTE®	Blood soluble liquid	0.002	–	–	–
	Natural K_2SO_4	FON® SUPER K	Non-synthetic insoluble solid	–	–	0.987	0.404
	By-products of marine origin	PHYTAFISH®	Fish soluble liquid	0.372	0.040	0.077	–
			Total	0.672	0.120	1.094	0.404
(iii)	Animal solid 'A'	FON® MIX	Horn and hoof, bone and blood meal	0.417	0.112	0.043	–
ASA + ASB + NK_2SO_4	Animal solid 'B'	FON® HCP	Horn and hoof meal	0.307	0.012	–	–
	Natural K_2SO_4	FON® SUPER K	Non-synthetic insoluble solid	–	–	1.052	0.431
			Total	0.724	0.124	1.095	0.431

made between 7:00 and 9:00 am to minimize the potential effects of light intensity on the chloroplast movement, on four plants in each replicate plot. For each plant, measurement was conducted on the most recently fully expanded and well-lit leaf. The leaf area was measured with a leaf area meter (LI-3000C, LICOR, Inc., USA) in both stems of each plant evaluated.

Determination of mineral content

Nutrient concentration [total N, P, K, Ca, Mg, and S] was determined on the shoot of plants sampled at the experiment's termination. The leaves were washed twice in distilled water and bagged prior to placement in an oven at 70°C for 48 h in a forced-air oven; once the plant tissues were dry, they were ground to pass a 20-mesh sieve (Wiley Mill), and a tissue mineral analysis was conducted, evaluating the total N concentration using Kjeldahl's procedure (Bremner 1996), whereas the P, K, Ca, Mg and S were determined with an Inductively Coupled Plasma Emission Spectrometer (ICP-AES, model Liberty, VARIAN, Santa Clara, CA) in ground tissues digested in a 2:1 mixture of H_2SO_4:$HClO_4$ with 2 ml of 30% H_2O_2 for P, K, Ca and Mg; finally, S was determined in ground tissues digested in a mixture of HNO_3:$HClO_4$ (Soltanpour et al. 1996).

Plant yield

Fruit yield per plant was determined by weighing all of the collected fruits in both stems for each replication. The total plant yield only considered the biomass from the 1st to 4th truss, expressed in kg m^{-2}.

Organoleptic fruit parameters

Tomatoes were harvested at the light-red stage (>90% red with opaque pericarp), since grape tomato flavor is best when the fruit is harvested at nearly full-red color (Roberts et al. 2002). Five representative fruits per truss in both stems were randomly selected, weighed and analyzed for their fruit-quality parameters. Following the harvest, the fruit fresh weight and longitudinal-equatorial fruit diameter were measured using an analytical scale (VELAB® VE-1000) and an electronic digital caliper (Mitutoyo®), respectively. Firmness was evaluated using a fruit hardness tester by Lutron Electronic Enterprise Co., Ltd (Model FR-5120), fitted with a 3-mm-diameter tip on the fruit equatorial perimeter. The total soluble solid content was expressed by °Brix of the fresh juice. The measurement was taken by placing a drop of fruit juice on the prism of a digital refractometer ATAGO® (PAL-1) with automatic temperature compensation.

Fruit sample preparation

Four tomato fruits, selected from each truss (1st to 4th), from each evaluated treatment were washed and cut into halves. These organs were dried in a forced-air oven at 70°C for 72 h, and the samples were pulverized and passed through a number 20 sieve (WS Tyler).

Analytical RP-HPLC-ESI-MS in fruit samples

Analyses using Reverse Phase-High Performance Liquid Chromatography were performed on a Varian HPLC system including an autosampler (Varian ProStar 410, USA), a ternary pump (Varian ProStar 230I, USA) and a PDA detector (Varian ProStar 330, USA). A liquid chromatograph ion trap mass spectrometer (Varian 500-MS IT Mass Spectrometer, USA), equipped with an electrospray ion source, was also used. The samples (5 µL) were injected onto a Denali C18 column (150 mm × 2.1 mm, 3 µm, Grace, USA). The oven temperature was maintained at 30°C. The eluents included formic acid (0.2%, v/v; solvent A) and acetonitrile (solvent B). The

following gradient was applied: initial, 3% B; 0–5 min, 9% B linear; 5–15 min, 16% B linear; and 15–45 min, 50% B linear. The column was then washed and reconditioned. The flow rate was maintained at 0.2 mL/min, and elution was monitored at 245, 280, 320 and 550 nm. The whole effluent (0.2 mL/min) was injected into the source of the mass spectrometer, without splitting. All of the MS experiments were carried out in negative mode $[M\text{-}H]^{-1}$. Nitrogen was used as the nebulizing gas and helium as the damping gas. The ion source parameters included the following: spray voltage 5.0 kV, and the capillary voltage and temperature were 90.0 V and 350°C, respectively. The data were collected and processed using MS Workstation software (V 6.9). The samples were first analysed in full scan mode acquired in the m/z range 50–2000. MS/MS analyses were performed on a series of selected precursor ions.

Determination of total hydrolyzable polyphenols (THPs) in fruit samples

The total hydrolyzable polyphenols from SNH extract were determined using Folin–Ciocalteu reagent (Ascacio-Valdés et al. 2014). The experiment was performed in triplicate, and the total hydrolyzable polyphenols content was expressed in gallic acid equivalents (GAE) (as dried weight).

Determination of total condensed polyphenols (TCPs) in fruit samples

The total condensed polyphenols from SNH extract were determined using a ferric reagent and HCl-butanol (Swain and Hillis 1959). The experiment was performed in triplicate, and the total condensed polyphenols content was expressed in catechin equivalents (CE) (as dried weight).

Experimental design and statistical analysis

The experimental design was a randomized complete block with four treatments and three blocks (replicates), with a total of six plants per replication. The plants were placed in three rows, 1.1 m apart, and the space between plants within a row was 0.40 m, at a planting density of 2.5 plants m^{-2}. The data were evaluated using a one-way analysis of variance (ANOVA) in STATISTICA Version 10 (StatSoft Inc 2013). An LSD test was applied to establish significant differences between the means, with a confidence level of 95%. A correlation matrix was conducted to show the positive and negative correlations among the researched traits included in the study.

Results and discussion

Vegetative growth and chlorophyl content

The application of organic fertilizers modified plant height at the end of the growing season; on average, organic treatments plants were 119.29 cm in length while in the control plants were 128.46 cm. Plants fed with the Steiner's nutrient solution exhibited the highest stem height (Table 2). The diameter of the secondary stem significantly increased ($p \leq 0.05$) in the control plants compared those with the organic treatments (Table 2). The increase in height and stem diameter in plants that received the organic treatments was sustained throughout experiment duration (Table 2). Significant differences ($p \leq 0.05$) were observed in leaf area between the conventional and organic treatments (Table 4). In this case, plants fed with solutions containing the organic treatments averaged 276.53 cm^2 at the end of the experiment, whereas control plants recorded 479.47 cm^2. The increased leaf area was probably associated with a higher leaf K concentration in the leaf samples (Table 3), since a major role of this nutrient is related to cell expansion and enlargement (Elumalai et al. 2002). In our study, the leaf area was higher in the inorganic treatment than in the organic treatments at the end of the growing season, indicating insufficient nutrient supply or availability of nutrients in the three organic treatments. Montagu and Goh (1990) reported that nutrients from organic material are often released more slowly and are not always easily available for plant use. However, analysis of plant nutrient status revealed that N and all the other macronutrients of the organically fertilized plants with treatment I (ASA + AL + NK_2SO_4) were similar to that of the inorganically fertilized plants (Table 3). On the other hand, SPAD exhibited no significant effects (Table 4). In this case, Bragazza and Freeman (2007) and Liu et al. (2010) reported that flavonols, a class of polyphenols, are carbon-based secondary metabolites whose content increases under lower N availability, and which is generally inversely related to chlorophyl content. In this study, all of the treatments (I, II, III, and IV) exhibited the presence of two flavonols: Quercetin 4′-*O*-glucoside and Quercetin 3-*O*-xylosyl-glucuronide, and Quercetin 3-*O*-xylosyl-rutinoside in TI (ASA + AL + NK_2SO_4) and TII (ASA + AL + NK_2SO_4+MO) (Table 6).

Fruit quality attributes

The fruit shape index, firmness and soluble solids content in tomato fruits were not affected by the treatments (Table 4). Our results are similar to those of Rinaldi

Table 2. Effect of organic and inorganic fertilization on growth parameters of grape tomatoes under greenhouse conditions.

Treatment	Mineral nutrients applied (g plant^{-1} per watering)				Sampling				
					1	2	3	4	5
	N	P	K	S	Plant height (cm)				
(I) ASA + AL + NK_2SO_4	0.672	0.124	1.095	0.429	32.08 ab	52.60 b	72.60 a*	92.84 a	116.26 a
(II) ASA + AL + NK_2SO_4+ MO	0.672	0.120	1.094	0.404	31.26 ab	55.98 a	80.20 a	101.76 a	120.20 a
(III) ASA + ASB + NK_2SO_4	0.724	0.124	1.095	0.431	30.76 b	55.80 a	78.88 a	99.60 a	121.40 a
(IV) Control	0.672	0.124	1.092	1.344	33.84 a	56.08 a	77.38 a	100.50 a	128.46 a
LSD (0.05)					3.06	3.19	9.49	16.85	17.71
					Stem diameter 1 (cm)				
(I) ASA + AL + NK_2SO_4	0.672	0.124	1.095	0.429	0.600 b	0.640 a	0.654 a	0.672 a	0.680 a
(II) ASA + AL + NK_2SO_4+ MO	0.672	0.120	1.094	0.404	0.642 ab	0.668 a	0.668 a	0.668 a	0.678 a
(III) ASA + ASB + NK_2SO_4	0.724	0.124	1.095	0.431	0.660 ab	0.682 a	0.682 a	0.688 a	0.692 a
(IV) Control	0.672	0.124	1.092	1.344	0.710 a	0.722 a	0.736 a	0.760 a	0.778 a
LSD (0.05)					0.103	0.100	0.100	0.107	0.103
					Stem diameter 2 (cm)				
(I) ASA + AL + NK_2SO_4	0.672	0.124	1.095	0.429	0.616 b	0.652 b	0.668 b	0.688 b	0.700 b
(II) ASA + AL + NK_2SO_4+ MO	0.672	0.120	1.094	0.404	0.662 ab	0.686 ab	0.686 ab	0.690 b	0.698 b
(III) ASA + ASB + NK_2SO_4	0.724	0.124	1.095	0.431	0.656 ab	0.678 ab	0.686 ab	0.690 b	0.700 b
(IV) Control	0.672	0.124	1.092	1.344	0.716 a	0.732 a	0.754 a	0.782 a	0.804 a
LSD (0.05)					0.075	0.075	0.080	0.087	0.088

Note: Description for each treatment as given in Table 1.
*Values followed by identical letters in columns indicate no statistically significant differences among treatments according to the LSD test ($p \leq 0.05$).

Table 3. Effect of organic and inorganic fertilization on the mineral content of grape tomatoes under greenhouse conditions.

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Sulphur (%)
(I) ASA + AL + NK_2SO_4	3.78 a	0.19 a	0.74 a*	2.99 a	0.87 ab	0.70 a
(II) ASA + AL + NK_2SO_4+ MO	2.14 c	0.096 b	0.75 a	1.51 b	0.68 c	0.21 b
(III) ASA + ASB + NK_2SO_4	2.62 bc	0.11 b	0.64 a	1.52 b	0.70 bc	0.19 b
(IV) Control	3.26 ab	0.17 a	0.89 a	3.01 a	0.89 a	0.77 a
LSD (0.05)	0.774	0.043	0.438	0.458	0.170	0.117

Note: Description for each treatment as given in Table 1.
*Means with the same letter are not significantly different (LSD test $p \leq 0.05$).

Table 4. Effect of organic and inorganic fertilization on growth, physiological and fruit quality measurements.

Treatment	Fruit shape index	Plant yield (kg m^{-2})	Chlorophyl (SPAD)	Firmness (g)	Total soluble solids (°Brix)	Leaf area (cm^2)
(I) ASA + AL + NK_2SO_4	1.14 a*	3.04 a	50.42 a	364.17 a	12.71 a	285.88 b
(II) ASA + AL + NK_2SO_4+ MO	1.12 a	3.35 a	51.92 a	386.67 a	12.26 a	280.07 b
(III) ASA + ASB + NK_2SO_4	1.14 a	3.04 a	51.78 a	373.33 a	12.22 a	263.65 b
(IV) Control	1.14 a	3.20 a	52.12 a	378.33 a	12.22 a	479.47 a
LSD (0.05)	0.063	0.262	2.691	70.518	0.794	169.71

Note: Description for each treatment as given in Table 1.
*Values followed by identical letters in columns indicate no statistically significant differences among treatments according to the LSD test ($p \leq 0.05$).

et al. (2007) and Polat et al. (2010), who reported that treatments with organic fertilizer had no effect on the soluble solid content in tomato; however, fruits obtained from plants fertilized with treatment I (ASA + AL + NK_2SO_4) had the highest TSS (12.71 °Brix) (Table 4). Preciado-Rangel et al. (2011) found that organic tomato fruits might have more soluble solids. In our study, the total soluble solids ranged from 12.22% (control) and 12.71% (treatment I) (Table 4).

Plant yield

The total production of grape tomatoes exhibited a tendency for high yields in treatment II (ASA + AL + NK_2SO_4 + MO), compared with the other organic treatments (I and III) and the control (IV); however, the differences were not significant (Table 4); treatments I (ASA + AL + NK_2SO_4) and III (ASA + ASB + NK_2SO_4) exhibited 6.2% lower yield than treatment IV (control), and treatment II (ASA + AL + NK_2SO_4 + MO) was slightly higher than the control at 4.5%. Our results are similar to those of Zhai et al. (2009), who succeeded with the use of an organic pre-plant nutrient source, supplemented with liquid organic fertilization, in total tomato yields in the best-performing organic treatment at 80%–100% of the hydroponic control. Furthermore, De Pascale et al. (2016) observed that there were not many yield and quality parameter differences between organic and conventional farming under low N fertilization and different irrigation levels in tomatoes, while Burnett et al. (2016)

Table 5. Effect of organic and inorganic fertilization on total hydrolyzable and condensed polyphenols in grape tomato fruits under greenhouse conditions.

Treatment	Total hydrolyzable polyphenols (mg GAE/g)	Total condensed polyphenols (mg CE/g)
(I) ASA + AL + NK_2SO_4	5.62 ± 0.76 ab	170.67 ± 19.84 ab
(II) ASA + AL + NK_2SO_4 + MO	6.42 ± 0.70 ab	213.88 ± 17.66 a
(III) ASA + ASB + NK_2SO_4	8.07 ± 1.51 a	189.32 ± 16.18 ab
(IV) Control	4.16 ± 0.47 b	155.85 ± 8.88 b

Notes: Description for each treatment as given in Table 1. Identical letters indicate no statistically significant differences among the treatments using the LSD test ($p \leq 0.05$).

Table 6. RP-HPLC-ESI-MS parameters for polyphenols in grape tomatoes in response to organic and mineral fertilization.

Treatment*	Analyte	Polyphenol sub-class[a]	rt[b]	Mass
I, II, III, IV	1-Caffeoylquinic acid	Hydroxycinnamic acids	3.09	354
I	3-Caffeoylquinic acid	Hydroxycinnamic acids	4.06	354
III, IV	Delphinidin 3,5-*O*-diglucoside	Anthocyanins	7.26	626
I, II, III, IV	Quercetin 4′-*O*-glucoside	Flavonols	7.4	464
I, II, III, IV	*p*-Coumaric acid 4-*O*-glucoside	Hydroxycinnamic acids	10.51	326
I	Salvianolic acid	Other polyphenols	18.08	236
I	5,6-Dihydroxy-7,8,3′,4′-tetramethoxyflavone	Flavones	18.51	374
I, II, III, IV	Caffeic acid 4-*O*-glucoside	Hydroxycinnamic acids	20.42	341
I, II, III, IV	Sinensetin	Flavones	25.3	372
II	Medioresinol	Lignans	25.76	387
I, II	Quercetin 3-*O*-xylosyl-rutinoside	Flavonols	31.2	741
I, II, III, IV	Quercetin 3-*O*-xylosyl-glucuronide	Flavonols	32.7	609

*Description for each treatment as given in Table 1.
[a]Data from Phenol-Explorer Version 3.6 (http://phenol-explorer.eu/).
[b]rt: retention time.

found that tomato yields can match those under conventional fertilizer use, but the grower must take care to supply all of the essential plant nutrients in appropriate quantities over the course of the entire cropping cycle.

Leaf nutrient concentrations

Treatment I (ASA + AL + NK_2SO_4) had comparable N, P, K, Ca, Mg, and S concentrations as the plants grown in the control treatment (Table 3). The highest concentrations of N and P were observed in treatment I (ASA + AL + NK_2SO_4); however, the highest concentrations of K, Ca, Mg and S were detected in the control. A higher leaf K concentration may be associated with higher leaf area in the control treatment, since the leaves are largely the most K-demanding plant part. Nitrogen was the nutrient that plants accumulated the most, followed by Ca and Mg On the other hand, no significant differences were observed in K concentrations in the leaves of tomato plants between the organic and conventional treatments (Table 3). The elevated N content at the end of the experiment in organic treatment I (ASA + AL + NK_2SO_4) could be due to different rates of mineralization during the growing season compared to treatments II and III (Table 3). At the beginning, low availability of N from organic material was expected, and thus the plants had to adapt to lower N level, which was reflected in the lower leaf area in the organic treatments, compared to the control, at the end of the study (Table 4). On the other hand, plants that showed lower concentrations of N had higher polyphenol contents in their fruits (Tables 3 and 5). In this context, Oliveira et al. (2013) indicated that a N deficit causes oxidative stress in tomato, resulting in higher antioxidant capacity and phenolic content in the fruits. The level of S was similar in the organic treatment ASA + AL + NK_2SO_4 and the control (Table 3). If S availability was enough, sufficient amounts of S-containing amino acids can be synthesized and contribute to structural growth.

Polyphenol content

The total hydrolyzable and condensed polyphenols were higher in all of the organic treatments than did the control plants (Table 5). This result was concordant with data obtained by Galhardo-Borguini et al. (2013) and Toor et al. (2006), that found a higher level of total phenols in organically fertilized tomatoes compared to conventional tomatoes. Phenolic compounds are especially concentrated in the tomato pericarp, and for this reason, small-sized tomatoes, especially cherry and plum varieties versus normal-sized ones, exhibit higher levels of such compounds as a result of their higher surface or skin/volume ratio (Licciardello and Muratore 2009; Muratore et al. 2005). All of the organic treatments exhibited more hydrolyzable phenols than the control, from 5.62 to 8.07 mg, with an average of 6.7 mg of GAE/g (Table 5). Similarly, organic treatments exhibited a higher amount of condensed phenols than the control plants, from 170.6 to 213.88 mg of CE/g, with an average of 191 mg of CE/g (Table 5). Several reports indicate that a clear link exists between greater stress exposure (which induces the accumulation of antioxidants) during the growth cycle of organic crops, a lower yield and improved nutritional parameters compared to conventional crops (van Bueren et al. 2011;

Seufert et al. 2012). The most abundant phenolic compounds in all of the treatments were 1-Caffeoylquinic acid, followed by Quercetin 4′-*O*-glucoside, *p*-Coumaric acid 4-*O*-glucoside, Caffeic acid 4-*O*-glucoside, Sinensetin and Quercetin 3-*O*-xylosyl-glucuronide (Table 6). It is well-known that the biosynthesis of phenolic compounds in plants is strongly influenced by the cultivar and mode of fertilization (Macheix et al. 1990). Data on the phenolic composition of fruits and vegetables grown either organically or conventionally remain scarce in the literature as these compounds have only recently been considered to be interesting functional microconstituents due to their potential role in the prevention of cardiovascular diseases, degenerative diseases, and cancer (Medina-Remón et al. 2011). Most research that reports measurements of the total phenolic content describe a higher phenolic concentration in organically grown fruits or vegetables. Our results are in accordance with these studies because organic tomatoes showed a higher content of polyphenols (hydrolyzable and condensed) than conventional tomatoes (Table 5). On the other hand, hydroxycinnamic acids, such as *p*-coumaric acids, contribute to a varying extent of antioxidant capacity in tomatoes and tomato products. Furthermore, several flavonoids have been identified in different tomato varieties. Most of these structures belong to the flavonols, and the most predominant compound is quercetin 3 rutinoside (rutin) (Beecher 1998). Similarly, Choi et al. (2014) identified the presence of 3-caffeoylquinic acid (chlorogenic acid) and quercetin-3-rutinoside (rutin) in extracts of 12 samples of cherry tomato fruits. In our study, treatment I (ASA + AL + NK_2SO_4) showed the presence of 3-Caffeoylquinic acid and Quercetin 3-*O*-xylosyl-rutinoside in treatments I (ASA + AL + NK_2SO_4) and II (ASA + AL + NK_2SO_4+MO).

Correlations between variables

A Pearson correlation matrix for the 14 variables showed both high positive and negative correlations among the traits included in the analysis. Firmness and chlorophyl exhibited high correlations ($p \leq 0.01$), and total soluble solids with firmness and chlorophyl exhibited high correlations ($p \leq 0.05$). The growth and optical sensory parameters indicated no significant correlation between any of them, nor with plant yield, polyphenol content or leaf nutrient concentration. In relation to the leaf nutrient content, Ca, Mg and S concentrations exhibited high correlations with each other and positive and significant values ($p \leq 0.01$). On the other hand, P exhibited a significant correlation with N, Ca, Mg and S ($p \leq 0.05$). The polyphenol content, plant yield, growth and organoleptic parameters exhibited no significant correlation among any of them, nor with the leaf minerals, except for K, showing a high correlation, with a negative and significant value, specifically with the condensed polyphenols content ($p \leq 0.05$).

In conclusion, there were no significant differences between the inorganic and organic solutions in terms of plant yield and height or diameter at the end of the study. However, the organically produced tomatoes displayed higher phytochemical concentrations in their fruits, expressed as total polyphenols (hydrolyzable and condensed), compared to conventionally produced tomatoes. Plants fed with organic solutions containing ASA + AL + NK_2SO_4 showed comparable nutrient status as that of the control plants that received Steiner's nutrient solution, therefore, we conclude that organic fertilization, mainly using ASA, AL and NK_2SO_4, may be a potential substitute for inorganic fertilization.

Disclosure statement

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Animal-based organic nutrition induces comparable fruit quality as that of the inorganic fertigation in soilless-grown grape tomato

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Animal-based organic nutrition induces comparable fruit quality as that of the inorganic fertigation in soilless-grown grape tomato

ABSTRACT

Purpose: Digital phenotyping aims to accurately describe a trait based on analysis of electronic images. The aim of the present study was to determine the effect of animal-based organic nutrition and environmental parameters on tomato fruit quality, as well as establish relations among color and morphological values performed by Tomato Analyzer (TA) software application.

Materials and methods: Organic tomato fruits (fully red-ripe stage) produced by three organic nutrient solutions, which consisted of different mixtures of several OMRI (Organic Materials Review Institute) certified nitrogen fertilizers of industrially processed residues and one inorganic nutrien solution (Steiner solution) as the control, were evaluated for their polyphenol and carotenoid content. We used Tomato Analyzer (TA) for evaluating fruit size and shape. Moreover, we implemented a digital image analysis tool, Color Test (CT), as part of the TA software application to collect and analyze fruit color parameters.

Results: The application of organic fertilizers positively affected the total hydrolysable and condensed polyphenols of tomato fruits compared to the control. Plants fed with organic solutions containing ASA+AL+NK_2SO_4 showed comparable nutrient status as that of the control plants that received Steiner's nutrient solution. The high air temperature (>30°C), and sub-optimal light intensity negatively affected the carotene content of tomato fruits as well as their morphological and color attributes. Plants fed with organic solutions containing ASA+ASB+NK_2SO_4 showed comparable morphology and fruit color attributes as that of the control plants that received Steiner's nutrient solution.

Conclusions: The results indicated that organically produced tomatoes through animal-based fertilizer application displayed similar fruit morphology and color attributes compared to conventionally produced tomatoes, so is a feasible alternative for grape tomato quality under greenhouse conditions.

Key words: *Solanum lycopersicum* L., bioactive compounds, morphology, color, image processing, temperature.

INTRODUCTION

Today's consumers have increased their expectations for the quality of food they purchase. Tomatoes have been ranked first as a source of lycopene (71.6%), second as a source of vitamin C (12.0%), pro-vitamin A carotenoids (14.6%) and other carotenoids (17.2%), and third as a source of vitamin E (6.0%) (**Garcia-Closas et al. 2004**). Lycopene represents the predominant lipid-soluble compound and constitutes more than 80% of total tomato carotenoids in fully red-ripe fruits. Most of the lycopene is attached to the insoluble and fibrous parts of the tomato and the skin may contain about five times as much lycopene as the pulp **(Charanjit and Kapoor 2008).** β-carotene is of special interest for its provitamin A activity and constitutes nearly 7-10% of total tomato carotenoid synthesis (**Nguyen and Schwartz 1999**). Plant polyphenols have been reported to interfere with the initiation, promotion and progression of cancer **(Ramos 2008)**. In recent years, nondestructive optical methods based on image analysis have been developed for determining quality of fruits and vegetables, since it requires less sample preparation, do not disturb the product, cost effective and rapid technique (**Shao et al. 2007**). In this context, Tomato Analyzer (TA) provides objective and accurate measurements of several fruit morphological and colorimetric traits in a high-throughput and semi-automatic manner **(Rodríguez et al. 2010)**. TA has become a key tool for the objective and reliable evaluation of morphology and color variation of plant organs. The TA software automatically recognizes and outlines images of fruit, and the Color Test module (CT) records RGB values of each pixel of the selected object and translates them into average L*, a*, and b* values (**Darrigues et al. 2008**). The Color Test module implemented in TA is more precise and accurate, and less expensive than other methods to analyze fruit color. Based on the relevance of this issue, coupled with the lack of information about the animal-based organic nutrition (mineral content) and its effect on phenotypic characteristics of fruits under greenhouse conditions, the present study aimed to apply image color analysis for quantification of quality attributes of specialty tomatoes based on color and shape and their relationship with bioactive compounds and environmental parameters under greenhouse conditions. Nowadays, no reports exist of the use of phenomic tools like Tomato Analyzer to study fruit shape and color variation in organic grape tomatoes.

MATERIALS AND METHODS

Crop management and experimental conditions

This work was conducted in a greenhouse at the Universidad Autónoma Agraria Antonio Narro, in northern México (lat. 25° 21′ N, long. 101° 02′ W, 1759 m above sea level). Grape tomato seedlings (Solanum lycopersicum L.) cv. Luciplus (Hazera Genetics Ltd.) were transplanted on 25 July 2016. This work was subjected to identical experimental management according to **Guajardo-Ríos et al. (2018)**, in order to study the influence of animal-based organic nutrition and environmental parameters on morphological and fruit color attributes, as well as the content of bioactive compounds in soilless-grown grape tomato fruits.

Environmental parameters

The environmental conditions during the experiment including photosynthetically active radiation (*PAR*), air temperature (T_a) and relative humidity (*RH*) inside the greenhouse were measured using a HOBO® U12 data logger (Onset Computer Corp., USA). The daily averaged T_a and *RH* were 23.0°C and 65.0%, respectively. The photosynthetically active radiation during the daytime was 85.5 µmol m^{-2} s^{-1} and solar noon (109.7 µmol m^{-2} s^{-1}). This study was performed by sub-optimal light intensity and continuous stressing temperatures. In this context, a high number of days with maximum temperatures ≥ 30°C were recorded in this study. The daily averaged temperature of cropping cycle is shown in **Figure 1**.

Determination of mineral content

Nutrient concentration [total N, P, K, Ca, Mg, and S] was determined on the shoot of plants sampled at the experiment's termination. The leaves were washed twice in distilled water and bagged prior to placement in an oven at 70°C for 48 h in a forced-air oven; once the plant tissues were dry, they were ground to pass a 20-mesh sieve (Wiley Mill), and a tissue mineral analysis was conducted, evaluating the total N concentration using Kjeldahl's procedure **(Bremner 1996)**, whereas the P, K, Ca, Mg and S were determined with an Inductively Coupled Plasma Emission Spectrometer (ICP-AES, model Liberty, VARIAN, Santa Clara, CA) in ground tissues digested in a 2:1 mixture of H_2SO_4:$HClO_4$ with 2 ml of 30% H_2O_2 for P, K, Ca and Mg; finally, S was determined in ground tissues digested in a mixture of HNO_3:$HClO_4$ **(Soltanpour et al. 1996)**.

Fruit sample preparation for bioactive compounds quantification

Four tomato fruits, selected from each fully-red ripe truss (truss follows the order of emission in the plant, in which 1st is the first truss to appear and 8th is the last truss), from each evaluated treatment were washed and cut into halves. These organs were dried in a forced-air oven at 70°C for 72 h, and the samples were pulverized and passed through a number 20 sieve (WS Tyler).

Analytical RP-HPLC-ESI-MS in fruit samples

The content of total polyphenols was determined by Reverse Phase-High Performance Liquid Chromatography, according to **Guajardo-Ríos et al. (2018)**. In this case, the total hydrolyzable polyphenols (THPs) in fruit samples from SNH extract were determined using Folin–Ciocalteu reagent **(Ascacio-Valdés et al. 2014)**. The experiment was performed in triplicate, and the total hydrolyzable polyphenols content was expressed in gallic acid equivalents (GAE) (as dried weight). Likewise, the total condensed polyphenols (THPs) in fruit samples from SNH extract were determined using a ferric reagent and HCl-butanol **(Swain and Hillis 1959)**. The experiment was performed in triplicate, and the total condensed polyphenols content was expressed in catechin equivalents (CE) (as dried weight).

HPLC-PDA in fruit samples

Carotenoids identification was done by HPLC (Pursuit XRs 5 C18 column, 150 × 4.6 mm) described by **Hernández-Almanza et al. (2014)** with some modifications. Briefly, the analysis was determined by gradients, phase A: acetone and phase B: water (0-3 min: 75% A, 25% B; 3-6 min: 95% A, 5% B; 6-20 min: 95% A, 5% C; 20-22 min: 75% A, 25%B and 22-27 min: 75% A, 25% B), flow 1.0 mL/min and UV detector 450 nm, the elution program Varian WorkStation 6.9 was employed **(Hernández-Almanza et al. 2017)**.

Fruit shape characterization

A step-by-step protocol was used for digitalization of grape tomato fruit and subsequent semi-automatic analysis of morphology and color atributes using the Tomato Analyzer (TA) software package version 2.2.0.0 **(Rodríguez et al. 2010).** Fruit scanning, as well as the manual adjustments and morphological analyses by TA, was previously reported **(Brewer et al. 2006).** For each truss, five fruits were harvested at

fully-red ripe stage in each evaluated treatment. Previous maturity stages were not considered in the sampling plan because of their negligible lycopene content (**Davies and Hobson 1981**). Fruits were brought to the laboratory and washed immediately after the harvesting. Subsequently, fruits were cut longitudinally through the center, placed cut-side down on a HP Scanjet G3110 (Hewlett-Packard, Palo Alto, CA, USA) at a resolution of 300 dpi, which was covered with a cardboard box to minimize the effect of shadow and provide a black background, and subsequently subjected to phenotypic analyses of fruit shape traits with Tomato Analyzer version 2.2.0.0 software. A total of 28 fruit shape traits organized in eight categories within the software: Basic Measurement (6), Fruit Shape Index (2), Blockiness (3), Homogeneity (3), Proximal Fruit End Shape (4), Distal Fruit End Shape (2), Asymmetry (4), and Internal Eccentricity (4), were evaluated **(Table 1, Figure 2).**

Color Test

For obtaining color standards and scanning, was used a standard 24-color rendition chart (ColorChecker, X-Rite, Grand Rapids, MI). Each of the 24 patches was considered an individual object and was analyzed for color. We collected RGB data and converted it to estimates of L*, a*, and b* measurements for each patch using TACT (Tomato Analyzer-Color Test) (**Darrigues et al. 2008**). The color test module "Tomato Analyzer Color Test" is designed to quantify the color parameters inside the boundaries recognized by the software. The color measurements are based on the RGB color space: R (red), G (green), and B (Blue). The average RGB values for each pixel is taken by Color test module and then translated to the CIELAB color space which uses L*, a*, b* to describe color in a way that approximates human visual perception. The Color test module calculates Hue and Chroma color descriptors based on a* and b* **(Rodriguez et al. 2010)**. The chromaticity was expressed in L*, a*, b* colour space coordinates (CIELAB). The L* coordinate indicated the darkness or lightness of the colour and ranged from black (0) to white (100). Coordinates a* and b* indicated colour directions: + a* was the red direction, – a* the green direction, + b* the yellow direction, and – b* the blue direction **(Darrigues et al. 2008)**.

Data analysis

The data were evaluated using a one-way analysis of variance (ANOVA) in STATISTICA Version 10 **(StatSoft Inc. 2013)**. An LSD test was applied to establish significant differences between means, with a confidence level of 95%. Also, it was performed a correlation matrix to show the positive and negative correlations among the evaluated traits included in the study.

RESULTS AND DISCUSSION

Leaf nutrient concentrations

Treatment I (ASA+AL+NK2SO4) had comparable N, P, K, Ca, Mg, and S concentrations as the plants grown in the control treatment **(Table 2)**. Similar behavior was observed by **Guajardo-Ríos et al. (2018)**. The highest concentrations of N, K, Mg and S were observed in treatment I (ASA+AL+NK_2SO_4); however, the highest concentrations of P and Ca were detected in the control. Nitrogen was the nutrient that plants accumulated the most, followed by Ca, K and Mg. On the other hand, no significant differences were observed in K and Mg concentrations in the leaves of tomato plants between the conventonal and organic treatments **(Table 2)**. The elevated N content at the end of the experiment in organic treatment I (ASA+AL+NK_2SO_4) could be due to different rates of mineralization during the growing season compared to treatments II and III **(Table 2)**. On the other hand, plants that showed lower concentrations of N had higher polyphenol contents in their fruits **(Tables 2 and 3)**. **Oliveira et al. (2013),** suggested that the higher concentrations of polyphenols that they found under organic production would be related to stressing conditions resulting in oxidative stress. In this context, ASA+AL+NK_2SO_4 and ASA+AL+NK_2SO_4+MO showed 40.2% and 46.1% higher hydrolyzable and condensed polyphenols, respectively, in relation to control treatment (IV) **(Table 3)**. The level of S was similar in the organic treatment ASA+AL+NK_2SO_4 and the control **(Table 2)**. **Montagu and Goh (1990)** reported that nutrients from organic material are often released more slowly and are not always easily available for plant use. However, analysis of plant nutrient status revealed that N and all the other macronutrients of the organically fertilized plants with treatment I (ASA+AL+NK_2SO_4) were similar to that of the inorganically fertilized plants **(Table 2)**.

Polyphenol content

The total hydrolyzable and condensed polyphenols were higher in all of the organic treatments than did the control plants ($p \leq 0.05$) **(Table 3)**. All of the organic treatments exhibited more hydrolyzable polyphenols than the control, from 5.37 to 6.65 mg, with an average of 6.2 mg of GAE/g **(Table 3)**. Similarly, organic treatments exhibited a higher amount of condensed polyphenols than the control treatment, from 150.85 to 218.54 mg of CE/g, with an average of 175.51 mg of CE/g **(Table 3)**. In this context, **Guajardo-Ríos et al. (2018)**, reported an similar average of 6.7 mg of GAE/g, and 191 mg of CE/g. It is well-known that the biosynthesis of phenolic compounds in plants is strongly influenced by the cultivar and mode of fertilization **(Macheix et al. 1990)**. Most research that reports measurements of the total phenolic content describe a higher phenolic concentration in organically grown fruits or vegetables. Our results are in accordance with these studies because organic tomatoes showed a higher content of polyphenols (THP and TCP) than conventional tomatoes **(Table 3)**. This result was concordant with data obtained by **Guajardo-Ríos et al. (2018)**, that found a higher level of total phenols in organically fertilized tomatoes compared to conventional tomatoes. On the other hand, the higher was air temperature, the higher was TCP content. In this study, the maximum biosynthesis of condensed polyphenols occurred at 38.4°C **(Table 4)**.

Carotenoid content

Significant differences ($p \leq 0.05$) were observed in lycopene and β-carotene content in tomato fruits between the organic and conventional treatments. Plants fed with the Steiners nutrient solution exhibited the highest carotenoid content in tomato fruits **(Table 5)**. In this case, plants fed with solutions containing the organic treatments averaged 44.71 and 47.94 mg/100 g of lycopene and β-carotene content, respectively, whereas control plants recorded 76.71 and 100.81 mg/100 g for each bioactive compound at the end of the experiment, which represents an increase of 41.72% and 52.45%, respectively. All of the evaluated treatments showed higher β-carotene content in their fruits, except for treatment I (ASA+AL+NK_2SO_4), which presented higher lycopene biosynthesis **(Table 5)**. Plants fed with ASA+AL+NK_2SO_4+MO, showed lower lycopene and β-carotene fruit content versus treatment I (ASA+AL+NK_2SO_4). On the contrary, carotenoid fruit content significantly increased ($p \leq 0.05$) in the

treatment III (ASA+ASB+NK_2SO_4) compared with the organic treatment ASA+AL+NK_2SO_4+MO **(Table 5)**. The lycopene and β-carotene content in tomato fruits was not significantly affected among the harvesting dates; however, harvested fruits from plants on third truss had the highest lycopene and β-carotene content (77.53 and 93.20 mg/100 g^{-1} dry weight, respectively) (data not presented). Before third truss harvesting, the daily averaged temperature ranged from 18.8°C to 21.0 °C. In this context, **Dumas et al. (2003)** indicated that the optimal temperature for lycopene synthesis is 16°C to 22°C, whereas the ceiling temperature is 30°C to 32°C, but within the above mentioned range, optimum levels vary with variety, cultivar and other environmental and growth conditions of tomato plants. **Kuti and Konuru (2005)** evaluated 40 tomato varieties under greenhouse and field conditions; lower lycopene content was reported for cherry tomatoes grown in the greenhouse because of temperatures over 32°C in most cases. β-carotene tended to increase with increasing lycopene content, but not to the same degree. In this study, the maximum biosynthesis of β-carotene occurred at 34°C. In this case, the daily maximum air temperature (T_a) preceding the first harvest was the highest (40.7°C), and during cropping cycle ranged between 31.9°C and 40.7°C. This prolonged, extremely high temperature may have led to the diminishing of the lycopene content among the harvesting dates. There was a linear relationship between β-carotene and b*, as well as lycopene and a* in fruits. In this context, lycopene content, which causes red coloration of fruits, is characterized well by a* parameter **(Sacks and Francis 2001)**.

Morphological fruit descriptors

Significant differences ($p \leq 0.05$) were observed in *ell*, *pan*, *piar*, *hob*, *e*, and *pe* attributes between the conventional and organic treatments **(Table 6)**. On the other hand, *fl II*, *fd I*, *fs I*, *fs II*, *pblk*, *dblk*, *tri*, *cir*, *rec*, *psh*, *pan*, *dan I*, *dan II*, *ovo*, *ver*, *wwp*, *de*, and *fsi*, exhibited no significant effects between all of the evaluated treatments. All of the fruit shape descriptors were highly influenced by air temperature throughout the entire harvesting period **(Table 7)**. For the attributes included in the fruit shape category, the most significant differences were found for basic fruit shape measurements. Highly significant differences ($p \leq 0.001$) were found among the four nutrition solutions evaluated for four out of the 28 fruit shape traits studied (*per*, *ar*, *fd II*, and *fl I*) **(Table 6)**. Treatments I (ASA+ASB+NK_2SO_4) and IV

(Control) showed similar basic morphological features (*per*, *ar*, *fd II*, *fl I*) **(Table 6)**. Furthermore, highly significant differences ($p \leq 0.001$) were observed among all of the harvested fruits for *per*, *ar*, *fl II*, *fd I*, *fd II*, and *fl I* **(Table 7).** No significant differences in *fs I* and *fs II* were found. However, for these fruit shape descriptors, organic treatments and control showed values greater than 1, which indicates an elongated fruit. Plants fed with organic solutions containing ASA+ASB+NK_2SO_4 showed comparable fruit shape index (*fs I* and *fs II*) as that of the control plants that received Steiner's nutrient solution. The highest *fs I* and *fs II* values were found in the seventh truss, followed by the sixth truss with the smallest index found in the fourth truss **(Table 7)**. For *pblk*, *dblk*, and *tri* no significant effects among the evaluated treatments were detected. However, the seventh truss was the least blocky (i.e. more tapered) whereas the second truss was the most blocky (*dblk*). A fruit shape triangle (*tri*) value greater than 1 indicates that the proximal end of the fruit is wider than the distal end of the fruit, while a value less than 1 indicates that the distal end of the fruit is wider **(Brewer et al. 2006)**. In this context, all of the harvested fruits tended to be wider at proximal end of the fruit than the distal one. Furthermore, fruits from the seventh truss tended to be more triangular **(Table 7)**. Significant differences ($p \leq 0.05$) were found among the four nutrition solutions evaluated for *ell* descriptor. Treatment III (ASA+ASB+NK_2SO_4) had the highest ellipsoid-shaped fruit value compared to the control ($p \leq 0.05$). Furthermore, fruits from the seventh and fourth truss were the most ellipsoid and circular, respectively. The *sun* and *ovate* loci both have a large effect on fruit elongation, and the underlying genes are known. The *ovate* allele canbe found in many obovoid and ellipsoid varieties such as grape tomato **(Wu et al. 2015)**. On the other hand, fruit shape rectangular (*rec*) exhibited no significant differences. For *pan* and *piar* descriptors, significant differences among the evaluated treatments were found although at a lower level of significance ($p \leq 0.05$). Treatment II (ASA+AL+NK_2SO_4+MO) showed fruits more tapered (<180°) than treatment IV (control). On the contrary, ASA+AL+NK_2SO_4 had fruits more flat (almost 180°) ($p \leq 0.05$). Furthermore, the eighth truss presented the more tapered fruits (<180°) ($p \leq 0.05$). For shoulder height (*psh*) no significant differences were detected neither among treatments nor harvesting dates. The angle of the distal fruit end was measured at the point where the lines intersected and was expressed in degrees (where 180° is flat, >180°

is indented and <180° is pointed). No significant differences in *dan l* and *dan* II were found among the treatments evaluated. However, *dan l* from the tip of the fruit clearly differentiated the seventh truss from the other ones, that is, it was higher pointed **(Table 7)**. Horizontal asymmetry (*hob*) and vertical asymmetry (*ver*) describe how asymmetric a fruit is when divided along a horizontal or vertical axis, respectively. The horizontal or vertical axes that divide the fruit are termed n and m, respectively **(Figure 2)**. Vertical and horizontal asymmetry values of 0 signify a perfectly symmetric shape. Horizontal asymmetry ovoid is defined by the general formula for horizontal asymmetry if there is more area above the horizontal axis n than below it; otherwise, horizontal asymmetry ovoid equals 0 **(Brewer et al. 2006)**. In this study, the horizontal assymetry ovoid descriptor exhibited a value equals 0 in all of the treatments, that is, there was more area above the horizontal axis n than below it in all of the harvest fruits, thus we only considered horizontal asymmetry obovoid (*hob*) fruit descriptor in fruit phenotypic characterization. In this case, *hob* is defined by the general formula for horizontal asymmetry if there is more area below the horizontal axis n than below it; otherwise, horizontal asymmetry obovoid equals 0 **(Brewer et al. 2006).** In this case, significant differences ($p \leq 0.05$) were found among the four nutrition solutions evaluated for *hob* descriptor. Furthermore, treatment II (ASA+AL+NK_2SO_4+MO) had the lowest *hob* value whereas the highest *hob* value was displayed by the control treatment. Likewise, the second truss had the lowest *hob* value whereas the highest *hob* value was displayed by the seventh truss ($p \leq 0.05$). Thus, obovoid values indicated that the largest width of the fruit was well below the midpoint of the fruits. That is, the area below the midpoint must be larger than the area above the midpoint. If this is not the case, the value is 0 **(Gonzalo et al. 2009)**. For *ovo*, *ver*, and *wwp* no significant effects among the evaluated treatments were detected. Furthermore, the seventh truss had the lowest *ver* value whereas the highest *ver* value was displayed by the third truss ($p \leq 0.05$). For fruit asymmetry (*ovo*), the seventh truss presented more fruit area above mid height **(Table 7)**. For *e* and *pe* descriptors, significant differences among the evaluated treatments were found ($p \leq 0.05$) **(Table 6)**. The seventh truss had the highest *fsi* value (higher ratio of the ellipse area over total fruit area), whereas the lowest *fsi* value was displayed by the fourth truss

($p \leq 0.05$) **(Table 7)**. No significant differences for *de* and *fsi* descriptors were found among the treatments evaluated.

Fruit Color attributes

No significant differences for L*, a*, b*, Hue and chroma values were found among the treatments evaluated; however, significant differences ($p \leq 0.05$) were observed among all of the harvested fruits **(Table 8)**. The increase in the a* value is known to be directly associated with lycopene synthesis, contrary to L* values, which decrease at full-ripe stage. The pigmentation characteristics of tomato fruits are attributed to the transformation of chloroplasts to chromoplasts due to the synthesis of carotenoids, mainly lycopene and β-carotene **(Pek et al. 2010)**. Our results exhibited averaged L*, a*, and b* values from 47.18 to 47.24, 18.63 to 19.23, and 28.74 to 29.46 (organic treatments versus inorganic one, respectively). In this context, treatment III (ASA+ASB+NK_2SO_4) had higher a* and b* and lower L* values (data not presented). On the other hand, the a* value was significantly higher in the sixth and seventh truss ($p \leq 0.05$); which indicates more red coloration intensity **(Table 8)**. The hue parameter, the most usable color index of the CIELab color system, is closely correlated to the lycopene content of tomato fruits **(Hertog et al. 2007)**. The hue value of tomato fruits was significantly lower (more red color) in the fifth truss, than of those harvested in the second truss. Color index a* (redness) significantly varied ($p \leq 0.05$) from 16.63 (third truss) to 20.68 (sixth truss) as a consequence of the lycopene synthesis, color index b* (yellowness) from 26.6 (third truss) to 31.68 (seventh truss), and chroma (C*) from 32.38 (third truss) to 37.65 (seventh truss) at $p \leq 0.001$. The hue, significantly varied from 54.7° (fifth truss) to 60.6° (third truss) at $p \leq 0.05$. A hue of 180° represents pure green and a hue of 0°, pure red **(Shewfelt 1988)**. Significant differences ($p \leq 0.05$) were observed in lightness value (L^*), among the harvesting dates **(Table 8)**. The L^* value on full-ripe truss stage reflects the darkening of the tomatoes with carotenoid synthesis and the loss of greenness.

Correlations between variables

A Pearson correlation matrix for the 37 variables showed both high positive and negative correlations among the traits included in the analysis. In this case, strong correlation was observed for THP content

and color attribute a* (r = −0.97). A negative significant correlation was found among THP with β-carotene content, *per*, *ar*, *fd II*, and *fl I*. On the other hand, TCP content exhibited high correlation with lycopene content, *piar* and *hob*, with a negative and significant value ($p \leq 0.05$). In contrast, we found a strong positive correlation between TCP with *dan II* and *e* (r= 0.98 and 0.98, respectively) at $p \leq 0.05$. Lycopene and β-carotene exhibited high positive correlations with *per* ($p \leq 0.05$). A significant negative correlation (r = −0.89, p = ≤ 0.0000) was found between lycopene and β-carotene content among harvesting dates. The higher was air temperature, the higher was the β-carotene content. In this context, only β-carotene might be synthesized above 30°C, which has a ceiling temperature of 38°C **(Brandt et al. 2006)**. A significant negative correlation (r= −0.996) was found between lycopene content and *e* ($p \leq$ 0.05), indicating that higher eccentricity values were related to lower lycopene content. β-carotene, *per*, *fd II*, *fl I*, *fs I* and *fs II*, exhibited high correlations with each other and positive and significant values ($p \leq$ 0.05). The fruit area (*ar*) showed a significant correlation with *fd II*, *fl I*, a*, b* and chroma ($p \leq 0.05$). Fruit perimeter exhibited strong correlations with *ar*, *fd II* and *fl I* (r = 0.98, 0.99, and 0.99, respectively). A positive correlation (r= 0.736) was found between lycopene content and a* color trait. The increase in the a* value is known to be directly associated with lycopene synthesis (red coloration of fruits), contrary to L* values, which decrease at full-ripe stage. β-carotene is an orange colorant of fruits, in which the parameter is measurable by b* in the CIELab color system **(Sacks and Francis 2001)**. In this case, β-carotene exhibited a significant positive and negative correlation with b* (r = 0.83) and L* (r = −0.26). A statistically significant stronger correlation was found between chroma, a* and b* color traits (r= 0.95 and 0.99, respectively). β-carotene exhibited a strong negative and positive correlation (r= −0.97 and 0.98, respectively) with two internal eccentricity descriptors (*de* and *fsi*). *Fd I* exhibited a strong positive correlation with b* (r= 0.96) and chroma (r= 0.98). Width at Mid-height (*fl II*) exhibited high positive correlations with a* and chroma (r= 0.96 and 0.98, respectively). β-carotene, *per*, *fd II*, *fl I*, *fs I* and *fs II*, exhibited high correlations with each other and positive and significant values ($p \leq 0.05$). Height at Mid-width *(fd II)* exhibited a strong positive correlation with *fl I*, *fsi*, *fs I* and *fs II* (r= 0.99, 0.97, 0.96, and 0.97, respectively). On the contrary, *fd II* showed a strong negative correlation with *cir* and *rec* (r= −0.98 and

−0.97, respectively). Fruit shape index was negatively correlated with *cir* (r = -0.98), but positively correlated with *fsi* (r = 0.99). On the other hand, *piar* (representing proximal fruit end shape) and *ell* (representing the TA category, homogeneity) were negatively correlated (r = -0.75). The air temperature (T_a) exhibited a significant positive correlation with the basic fruit shape traits studied (*per*, *ar*, *fl II*, *fd I*, *fd II*, and *fl I*) throughout the entire harvesting period.

As a final conclusion of this study, we can state that organically produced tomatoes exhibited higher levels of polyphenols compared to conventionally produced tomatoes, which may offer potential health benefits. Treatment III (ASA+ASB+NK_2SO_4) displayed higher lycopene and β-carotene content among the organic nutrient solutions. As the contents of bioactive compounds in tomatoes were affected by both nutrition and air temperature, morphological and fruit color were also affected. Color Test (CT), revealed no significant differences between the inorganic and organic solutions in terms of fruit color. Plants fed with organic solutions containing ASA+ASB+NK_2SO_4 showed comparable morphology and fruit color attributes as that of the control plants that received Steiner's nutrient solution, therefore, we conclude that organic fertilization, mainly using ASA+ASB+NK_2SO_4, may be a potential substitute for inorganic fertilization in terms of fruit quality. However, this work strongly points to the need for additional studies to define the effect of organic fertilization and environmental parameters on morphological and fruit color traits of grape tomato and its possible beneficial role on bioactive compounds synthesis.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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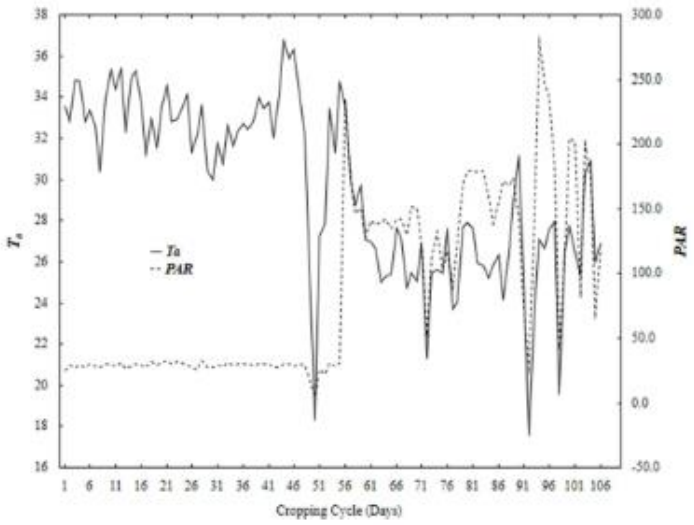
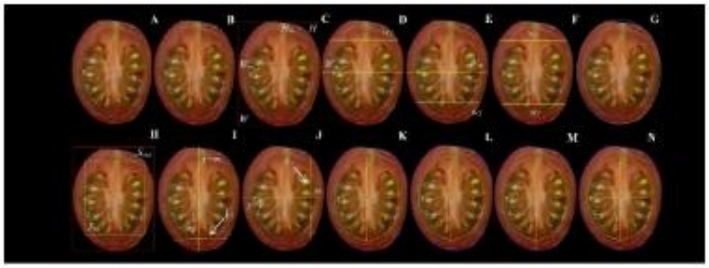


Figure 1. Seasonal variations of mean daily light intensity-PAR (µmol m−2 s−1), and air temperature-Ta (°C) inside the greenhouse

165x123mm (96 x 96 DPI)



Fruit shape traits by the Tomato Analyzer software in organic grape tomato. Basic measurements: A, Width at Mid-height [fl II]. B, Height at Mid-Width [fd II]. Fruit shape index: C, Fruit Shape Index I and II [fs I and fs II]. Blockiness: D, Proximal Fruit Blockiness [pblk]. E, Distal Fruit Blockiness [dblk]. F, Fruit Shape Triangle [tri]. Homogeneity: G, Fruit Shape Ellipsoid [ell]. H, Fruit Shape Rectangular [rec]. Asymmetry: I, V. Asymmetry [ver]. J, H. Asymmetry (Obovoid) [hob]. Internal eccentricity: K, Eccentricity [e]. L, Proximal eccentricity [pe]. M, Distal Eccentricity [de]. N, Internal Fruit Shape Index [fsi].

1195x441mm (120 x 120 DPI)

Table 1. Grape tomato fruit shape descriptors studied and their description.

Basic measurements	Code	Units/description
Perimeter	*per*	Perimeter length (cm)
Area	*ar*	Fruit area (cm^2)
Width at Mid-height	*fl II*	The width measured at ½ of the fruit's height (cm)
Widest Width [Maximum Width]	*fd I*	The maximum horizontal distance of the fruit (cm)
Height at Mid-width	*fd II*	The height measured at ½ of the fruit's width (cm)
Highest Height [Maximum Height]	*fl I*	The maximum vertical distance of the fruit (cm)
Fruit shape index		
Fruit Shape Index I	*fs I*	The ratio of the maximum height to maximum width (H/W)
Fruit Shape Index II	*fs II*	The ratio of mid height to mid width (H_m/W_m)
Blockiness		
Proximal Fruit Blockiness	*pblk*	Ratio of fruit width at the proximal end to mid width, (w_1/W_m).
Distal Fruit Blockiness	*dblk*	Ratio of fruit width at the distal end to mid width, (w_2/W_m)
Fruit Shape Triangle	*tri*	The ratio of proximal width to distal width (w_1/w_2).
Homogeneity		
Fruit shape circular	*cir*	Fitting precision (R^2) of the actual shape to a circle; larger values indicate that the fruit is more circular.
Fruit shape ellipsoid	*ell*	Fitting precision (R^2) of the actual shape to an ellipse; larger values indicate that the fruit is more ellipsoid

Fruit shape rectangular	*rec*	The ratio of maximum area inscribing the rectangle to the minimum area of the enclosing rectangle, (S_{in}/S_{out}).
Proximal fruit end shape		
Shoulder height	*psh*	The ratio of the average height of the shoulder points above the proximal end point to Maximum Height
Proximal end angle at 2% and 20%	*pan*	The angle from the shoulder points to the site of pedicel attachment or the proximal end, where 180° is flat, greater than 180° indented, and less than 180 is tapered.
Proximal fruit end indentation: area	*piar*	The ratio of the indentation area to the total fruit area.
Distal Fruit End Shape		
Distal Angle Micro	*dan I*	Determines where the proximal angle is measured, ranging from 2% to 10% from the tip of the fruit
Distal Angle Macro	*dan II*	Determines the percentage of the perimeter from the bottom where the angle will be measured, ranging from 5% to 50%.
Asymmetry		
Ovoid	*ovo*	Calculated according to the formula provided in the tomato Analyzer Manual (Rodríguez et al. 2010). The higher the value, the greater is the area of the fruit above mid height
V. Asymmetry	*ver*	Fruit shape eccentric vertical asymmetry, $(\Sigma\|m - m_i\|)$/number of rows L
H. Asymmetry (obovoid)	*hob*	Fruit shape eccentric horizontal asymmetry, $(\Sigma\|n - n_i\|)$/number of columns L
Width Widest Pos	*wwp*	The ratio of the height at which the maximum width occurs to the maximum height
Internal eccentricity		
Eccentricity	*e*	The ratio of the height of the internal ellipse to the Maximum Height
Proximal Eccentricity	*pe*	The ratio of the area of the height of the internal ellipse to the distance between the bottom of the ellipse and the top of the fruit

Distal Eccentricity	*de*	The ratio of the area of the height of the internal ellipse to the distance between the bottom of the ellipse and the bottom of the fruit
Internal Fruit Shape Index	*fsi*	The ratio of the internal ellipse's height to its width

All traits, were measured with Tomato Analyzer software version 2.2.0.0. Further details for the measurement of fruit shape traits with Tomato Analyzer can be obtained from Brewer et al. (2006), Gonzalo and van der Knaap (2008), and Rodríguez et al. (2010).

Table 2. Effect of organic and inorganic fertilization on the mineral content of grape tomatoes under greenhouse conditions

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Sulphur (%)
(I) ASA+AL+NK_2SO_4	3.19 ± 0.24 a	0.19 ± 0.03 a	0.98 ± 0.37 a*	3.01 ± 0.37 a	0.91 ± 0.21 a	0.80 ± 0.16 a
(II) ASA+AL+NK_2SO_4+ MO	2.65 ± 0.63 ab	0.11 ± 0.05 b	0.76 ± 0.20 a	1.55 ± 0.62 b	0.70 ± 0.20 a	0.24 ± 0.11 b
(III) ASA+ASB+NK_2SO_4	2.28 ± 0.10 b	0.10 ± 0.02 b	0.84 ± 0.19 a	1.49 ± 0.25 b	0.68 ± 0.19 a	0.20 ± 0.04 b
(IV) Control	3.19 ± 0.78 a	0.21 ± 0.03 a	0.89 ± 0.41 a	3.02 ± 0.32 a	0.76 ± 0.15 a	0.71 ± 0.13 a
LSD (0.05)	0.763	0.048	0.385	0.597	0.260	0.162

Note: Description for each treatment (composition of nutrient solutions) according to Guajardo-Rios et al. (2018).

*Means with the same letter letters indicate no statistically significant differences among treatments using the LSD test ($p \leq 0.05$).

Table 3. Effect of organic and inorganic fertilization on total hydrolyzable and condensed polyphenols in grape tomato fruits under greenhouse conditions

Treatment	Total hydrolyzable polyphenols (mg GAE/g)	Total condensed polyphenols (mg CE/g)
(I) ASA+AL+NK_2SO_4	6.65 ± 0.82 a *	157.15 ± 12.24 b
(II) ASA+AL+NK_2SO_4+ MO	6.58 ± 0.66 a	218.54 ± 22.04 a
(III) ASA+ASB+NK_2SO_4	5.37 ± 2.61 b	150.85 ± 23.08 b
(IV) Control	3.98 ± 1.18 c	117.19 ± 10.21 c
LSD (0.05)	1.15	15.89

Note: Description for each treatment (composition of nutrient solutions) according to Guajardo-Ríos et al. (2018).

*Means with the same letter letters indicate no statistically significant differences among treatments using the LSD test ($p \leq 0.05$).

Table 4. Effect of organic and inorganic fertilization on polyphenols content in relation to harvest date for each fully-red ripe truss under greenhouse conditions.

	Tomato fruit harvesting/Air temperature (*max-min*)							
	1st truss	2nd truss	3rd truss	4th truss	5th truss	6th truss	7th truss	8th truss
Bioactive	Sept 16	Sept 24	Sept 30	Oct 08	Oct 16	Oct 23	Oct 30	Nov 07
compound	[40.7°C–13.9°C]	[38.4°C–14.3°C]	[34.0°C–11.4°C]	[31.9°C–12.6°C]	[35.0°C–12.6°C]	[36.2°C–10.5°C]	[32.0°C–10.6°C]	[34.9°C–11.0°C]
THP	5.71 ± 1.23 b*	8.35 ± 2.01 a	5.37 ± 1.47 b	6.09 ± 1.15 b	4.81 ± 1.56 b	4.99 ± 1.52 b	4.66 ± 2.28 b	5.18 ± 1.46 b
TCP	161.52 ± 42.13 bc	184.94 ± 43.09 a	160.28 ± 35.41 bc	154.32 ± 41.46 bc	169.03 ± 53.63 ab	156.15 ± 59.35 bc	144.38 ± 32.31 c	156.83 ± 43.01 bc

Notes: THP = Total hydrolyzable polyphenols (mg GAE/g), TCP = Total condensed polyphenols (mg CE/g). The daily averaged temperature (*max-min*), was calculated between each harvest period. For the first truss was only considered the daily average temperature beginning with fruit setting period.

*Means with the same letter letters within rows indicate no statistically significant differences using the LSD test ($p \leq 0.05$).

Table 5. Lycopene and β-carotene content in grape tomato fruits under greenhouse conditions.

Treatment	Lycopene (mg/100 g)	β–carotene (mg/100 g)
(I) ASA+AL+NK_2SO_4	49.66 ± 17.80 ab	34.01 ± 26.28 bc
(II) ASA+AL+NK_2SO_4+ MO	24.88 ± 3.67 b	28.00 ± 31.20 c
(III) ASA+ASB+NK_2SO_4	59.60 ± 11.71 a	81.81 ± 31.93 ab
(IV) Control	76.71 ± 45.90 a	100.81 ± 78.34 a
LSD (0.05)	27.47	50.28

Note: Description for each treatment (composition of nutrient solutions) according to Guajardo-Rios et al. (2018).

*Means with the same letter letters indicate no statistically significant differences among the treatments using the LSD test ($p \leq 0.05$).

Table 6. Effect of organic and inorganic fertilization on tomato fruit morphology attributes under greenhouse conditions

Fruit shape descriptors	Treatment			
Basic measurements	(I) $ASA+AL+NK_2SO_4$	(II) $ASA+AL+NK_2SO_4$+ MO	(III) $ASA+ASB+NK_2SO_4$	(IV) Control
per	9.49 ± 0.94 ab*	9.39 ± 0.87 b	9.69 ± 0.61 ab	9.86 ± 0.87 a
ar	6.24 ± 1.05 ab	6.18 ± 1.01 b	6.42 ± 0.63 ab	6.74 ± 1.12 a
fd II	3.07 ± 0.29 ab	3.05 ± 0.27 b	3.17 ± 0.23 ab	3.24 ± 0.28 a
fl I	3.12 ± 0.29 b	3.09 ± 0.27 b	3.22 ± 0.23 ab	3.29 ± 0.28 a
Homogeneity				
ell	0.79 ± 0.004 ab	0.79 ± 0.01 a	0.79 ± 0.005 ab	0.78 ± 0.004 b
Proximal fruit end shape				
pan	179.63 ± 6.58 a	172.94 ± 6.98 b	177.33 ± 5.11 ab	179.85 ± 5.38 a
piar	0.004 ± 0.004 ab	0.001 ± 0.002 b	0.003 ± 0.002 ab	0.006 ± 0.01 a
Asymmetry				
hob	10.02 ± 3.52 ab	8.12 ± 1.52 b	9.76 ± 1.94 ab	10.59 ± 1.67 a
Internal eccentricity				
e	0.79 ± 0.004 ab	0.79 ± 0.01 a	0.79 ± 0.005 ab	0.78 ± 0.004 b
pe	0.89 ± 0.001 a	0.89 ± 0.001 ab	0.89 ± 0.001 ab	0.89 ± 0.001 b

Notes: Description for each fruit shape atributes as given in Table 1. Description for each treatment (composition of nutrient solutions) according to Guajardo-Rios et al. (2018).

*Means with the same letter letters within rows indicate no statistically significant differences using the LSD test ($p \leq 0.05$).

Table 7. Effect of organic and inorganic fertilization on grape tomato fruit descriptors in relation to harvest date for each fully-red ripe truss under greenhouse conditions

	Tomato fruit harvesting/Air temperature (*max-min*)							
	1st truss	2nd truss	3rd truss	4th truss	5th truss	6th truss	7th truss	8th truss
Fruit shape descriptors	Sept 16 [40.7°C–13.9°C]	Sept 24 [38.4°C–14.3°C]	Sept 30 [34.0°C–11.4°C]	Oct 08 [31.9°C–12.6°C]	Oct 16 [35.0°C–12.6°C]	Oct 23 [36.2°C–10.5°C]	Oct 30 [32.0°C–10.6°C]	Nov 07 [34.9°C–11.0°C]
per	10.51 ± 0.49 a*	10.48 ± 0.47 a	9.54 ± 0.41 c	10.15 ± 0.32 ab	9.22 ± 0.55 c	9.71 ± 0.29 bc	8.62 ± 0.14 e	8.63 ± 0.62 de
ar	7.49 ± 0.67 a	7.50 ± 0.74 a	6.07 ± 0.46 c	6.91 ± 0.43 ab	5.88 ± 0.64 bc	6.40 ± 0.36 ab	5.08 ± 0.24 d	5.83 ± 0.74 cd
fl II	2.68 ± 0.12 a	2.70 ± 0.14 a	2.46 ± 0.05 b	2.64 ± 0.06 a	2.39 ± 0.13 b	2.45 ± 0.07 b	2.19 ± 0.11 c	2.16 ± 0.11 c
fd I	2.71 ± 0.12 a	2.73 ± 0.14 a	2.50 ± 0.06 b	2.68 ± 0.07 a	2.42 ± 0.13 b	2.49 ± 0.08 b	2.22 ± 0.11 c	2.19 ± 0.10 c
fd II	3.42 ± 0.21 a	3.40 ± 0.17 a	3.06 ± 0.23 bc	3.24 ± 0.16 ab	3.03 ± 0.17 bcd	3.21 ± 0.16 ab	2.89 ± 0.04 cd	2.80 ± 0.22 d
fl I	3.49 ± 0.20 a	3.44 ± 0.18 a	3.11 ± 0.24 bc	3.28 ± 0.17 ab	3.06 ± 0.19 bcd	3.26 ± 0.14 ab	2.94 ± 0.04 cd	2.86 ± 0.22 d
fs I	1.29 ± 0.08 ab	1.26 ± 0.04 ab	1.25 ± 0.09 ab	1.23 ± 0.05 b	1.26 ± 0.02 ab	1.31 ± 0.06 ab	1.33 ± 0.08 a	1.31 ± 0.04 ab
fs II	1.28 ± 0.09 ab	1.26 ± 0.04 ab	1.25 ± 0.09 ab	1.23 ± 0.05 b	1.26 ± 0.02 ab	1.31 ± 0.06 ab	1.33 ± 0.08 a	1.30 ± 0.04 ab
dblk	0.55 ± 0.02 ab	0.58 ± 0.02 a	0.54 ± 0.04 ab	0.54 ± 0.03 ab	0.52 ± 0.02 bc	0.52 ± 0.04 bc	0.48 ± 0.04 c	0.53 ± 0.03 ab
tri	1.28 ± 0.06 bc	1.22 ± 0.05 c	1.33 ± 0.10 bc	1.29 ± 0.11 bc	1.39 ± 0.03 ab	1.41 ± 0.15 ab	1.52 ± 0.14 a	1.34 ± 0.09 bc
cir	0.93 ± 0.018 ab	0.94 ± 0.008 ab	0.94 ± 0.02 ab	0.95 ± 0.01 a	0.94 ± 0.002 ab	0.93 ± 0.01 b	0.93 ± 0.02 b	0.93 ± 0.01 ab
ell	0.78 ± 0.001 bc	0.79 ± 0.002 a	0.79 ± 0.003 abc	0.79 ± 0.003 a	0.79 ± 0.01 a	0.79 ± 0.01 ab	0.79 ± 0.004 ab	0.78 ± 0.004 c
pan (2%)	179.91 ± 2.99 ab	181.6 0 ± 3.41 a	179.64 ± 7.15 ab	178.98 ± 4.91 ab	179.13 ± 10.15 ab	176.94 ± 8.42 abc	172.56 ± 3.37 bc	170.74 ± 2.76 c

dan1	148.30 ± 8.82 ab	152.65 ± 4.95 a	133.89 ± 15.90 ab	145.20 ± 10.15 ab	144.17 ± 5.24 ab	150.81 ± 31.32 a	129.17 ± 7.61 b	138.91 ± 6.19 ab
ovo	0.17 ± 0.02 b	0.17 ± 0.01 b	0.19 ± 0.02 ab	0.19 ± 0.02 ab	0.20 ± 0.01 ab	0.19 ± 0.04 ab	0.21 ± 0.02 a	0.17 ± 0.02 b
ver	4.60 ± 1.31 a	4.21 ± 1.02 ab	3.18 ± 1.08 bc	2.72 ± 0.55 c	2.49 ± 0.78 c	2.84 ± 0.68 c	2.43 ± 0.75 c	3.12 ± 0.63 bc
hob	9.42 ± 1.89 ab	7.98 ± 0.84 ab	9.77 ± 2.45 ab	9.48 ± 3.50 ab	10.22 ± 1.04 ab	11.07 ± 3.53 ab	11.21 ± 1.62 a	7.84 ± 2.30 b
wwp	0.44 ± 0.01 ab	0.44 ± 0.01 ab	0.43 ± 0.01 b	0.43 ± 0.01 ab	0.42 ± 0.01 b	0.44 ± 0.03 ab	0.43 ± 0.02 b	0.45 ± 0.01 a
e	0.78 ± 0.001 bc	0.79 ± 0.002 a	0.79 ± 0.003 abc	0.79 ± 0.003 a	0.79 ± 0.01 a	0.79 ± 0.01 ab	0.79 ± 0.004 ab	0.78 ± 0.004 c
pe	0.89 ± 0.001 ab	0.89 ± 0.001 b	0.89 ± 0.000 ab	0.89 ± 0.001 ab	0.89 ± 0.001 ab	0.89 ± 0.001 a	0.89 ± 0.001 a	0.89 ± 0.000 ab
de	0.89 ± 0.002 ab	0.89 ± 0.001 a	0.89 ± 0.001 a	0.88 ± 0.003 b	0.89 ± 0.001 ab	0.89 ± 0.001 ab	0.89 ± 0.001 a	0.89 ± 0.001 ab
fsi	1.28 ± 0.08 ab	1.26 ± 0.04 ab	1.25 ± 0.09 ab	1.23 ± 0.04 b	1.27 ± 0.02 ab	1.31 ± 0.06 ab	1.33 ± 0.08 a	1.30 ± 0.04 ab

Notes: Description for each fruit shape atributes as given in Table 1. The daily averaged temperature (*max-min*), was calculated between each harvest period. For the first truss was only considered the daily average temperature beginning with fruit setting period.

*Means with the same letter letters within rows indicate no statistically significant differences using the LSD test ($p \leq 0.05$).

Table 8. Effect of organic and inorganic fertilization on fruit color atributes in relation to harvest date for each fully-red ripe truss under greenhouse conditions

	Tomato fruit harvesting/Air temperature (*max-min*)							
	1st truss	2nd truss	3rd truss	4th truss	5th truss	6th truss	7th truss	8th truss
Fruit color atributes	Sept 16 [40.7°C–13.9°C]	Sept 24 [38.4°C–14.3°C]	Sept 30 [34.0°C–11.4°C]	Oct 08 [31.9°C–12.6°C]	Oct 16 [35.0°C–12.6°C]	Oct 23 [36.2°C–10.5°C]	Oct 30 [32.0°C–10.6°C]	Nov 07 [34.9°C–11.0°C]
L*	47.20 ± 1.40 b	49.20 ± 0.63 a*	45.86 ± 0.38 bc	47.51 ± 0.52 ab	44.54 ± 0.60 c	46.91 ± 1.90 b	49.16 ± 1.87 a	47.19 ± 1.28 b
a*	18.77 ± 1.01 ab	18.68 ± 2.70 b	16.63 ± 0.58 c	18.44 ± 0.73 bc	18.78 ± 0.67 ab	20.68 ± 0.36 a	19.41 ± 1.59 ab	18.87 ± 0.76 ab
b*	28.91 ± 1.61 bc	29.36 ± 0.77 bc	26.60 ± 0.37 e	28.40 ± 1.32 cd	27.05 ± 0.39 de	30.41 ± 0.92 ab	31.68 ± 1.37 a	28.98 ± 1.53 bc
Hue	58.37 ± 2.09 ab	60.49 ± 2.11 a	60.64 ± 0.83 a	58.23 ± 0.44 ab	54.71 ± 1.38 c	57.28 ± 0.87 bc	58.84 ± 3.20 ab	58.26 ± 1.96 ab
Chroma	35.25 ± 1.64 cd	35.85 ± 2.03 bc	32.38 ± 0.64 e	34.61 ± 0.62 cd	33.65 ± 0.50 de	37.38 ± 0.99 ab	37.65 ± 0.30 a	35.34 ± 1.43 cd

Note: The daily averaged temperature (*max-min*), was calculated between each harvest period. For the first truss was only considered the daily average temperature beginning with first fruit setting period.

*Means with the same letter letters within rows indicate no statistically significant differences using the LSD test ($p \leq 0.05$).

CONCLUSIÓN GENERAL

En conclusión, no hubo diferencias significativas entre las soluciones orgánica e inorgánica en términos de rendimiento de la planta y la altura o el diámetro de tallo al final del estudio. Sin embargo, los tomates producidos orgánicamente mostraron mayores concentraciones fitoquímicas en su frutos, expresadas como polifenoles totales (hidrolizables y condensados), comparadas a los tomates producidos convencionalmente Las plantas alimentadas con soluciones orgánicas que contenían ASA + AL + NK_2SO_4 (tratamiento I) mostraron un estado nutricional comparable al de las plantas control que recibieron la solución nutritiva Steiner. Así mismo, la fertilización orgánica, principalmente utilizando ASA + ASB + NK_2SO_4 (tratamiento III), puede ser un posible sustituto de la fertilización inorgánica en términos de calidad de fruto. Es importante señalar que con este trabajo se genera la necesidad de estudios adicionales para definir el efecto de fertilización orgánica y de parámetros ambientales sobre características de morfología y color del fruto de tomate uva y su posible papel benéfico en la síntesis de compuestos bioactivos.