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Research Article

Effect of substrates formulated with organic materials on yielding, commercial and phytochemical quality, and benefit-cost ratio of tomato (*Solanum lycopersicum* L.) produced under greenhouse conditions

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Abstract

The objective of this study was to evaluate the effect of substrates formulated with different blends of sand-solarized manure and sand-vermicompost over yield, commercial and phytochemical quality of greenhouse tomatoes, and in addition to determine their benefit-cost (B/C) ratio for organic production of tomato. Six substrates were established consisting in blends of sand with 20, 30 or 40% of solarized manure (SM20, SM30 and SM40), and 20, 30 and 40% of vermicompost (VC20, VC30 and VC40), and control (TA) of sand fertilized with Steiner solution. Fruit yielding, commercial (fruit size, equatorial and longitudinal diameter, firmness, and soluble solids content), and nutraceutical quality (phenolic and lycopene content) were evaluated. In addition, cost-benefit (B/C) ratio of treatments was compared. Micro morphological analysis of the organic materials showed microscopic differences that could affect substrate functional properties. Substrate type affect yielding, and VC40 substrate had a higher yield than SM substrates, but SM20 had the highest phenolic and lycopene content in fruit, in addition to the highest cost-benefit production ratio (2.31). These results confirm that substrates formulated with blends of sand and either SM or VC can be used for organic production of tomato fruits with an adequate commercial and phytochemical quality without affecting yield, additionally to the economic advantages of such substrates for protected agriculture systems.

Keywords: lycopene; organic production; phenolics; tomato; vermicompost

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From **Volume 49, Issue 1, 2021,** Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal will use article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Introduction

Nowadays, consumers prefer fresh food products with a high nutritive quality as well as chemical-free (Wang and Wu, 2010). An alternative that meets such requirements is organic vegetable products obtained under protected agriculture systems, like either in greenhouses or in shade-net houses (Miles and Peet, 2002). In organic production is used either organic materials or organic and mineral components blends as substrates under greenhouse and shade house conditions. The use of these materials has advantages over traditional soil farming since the physical and chemical characteristics of the substrate can be manipulated in order to improve crop yield and quality (Burnett *et al.*, 2016). A substrate should have important characteristics such a high porosity, low saline content, good mechanical properties, and a low cost; in addition, that it must provide an adequate mechanical support or anchorage to plants, serve as a nutrient and water reservoir, and facilitate oxygen diffusion to roots as well as a good gas interchange (Yeager *et al.*, 2007; Suvo *et al.*, 2017). However, it is not clearly defined what an organic substrate is, since a soil is considered as organic when it presents organic materials whose organic carbon content is higher than that described for mineral soil materials, as established in the Keys to Soil Taxonomy (USDA, 2014); nevertheless, there is not a delimited classification criterion for an organic substrate. On the other side, one of the highest costs in greenhouse crop production is indeed the substrate, whose price depends on the substrate type as well as the materials used for its formulation (Cruz *et al.*, 2013). Regarding this, sand is a low-cost, easily acquired mineral material that could be used as a vegetable production substrate, but it has an important disadvantage, which is its low water retention capacity; thereby sand must be mixed with either mineral (Segura-Castruita *et al.*, 2008) or organic materials (Atiyeh *et al.*, 2000; Burnett *et al.*, 2016) in order to improve its physical-chemical characteristics. Two low-cost organic materials that can be used to formulate substrates for vegetable production under protected agriculture systems are solarized manure and vermicompost obtained from cattle manure (Fortis *et al.*, 2012; Tringovska and Dintcheva, 2012). Solarized manure is an organic material that gradually releases easily available nutrients for plants (Vázquez *et al.*, 2011). Vermicompost contains humic substances that act as growth regulators (Domínguez *et al.*, 2010), elevates cationic exchange capacity, and increases moisture retention capacity (Hashemimajd *et al.*, 2004). Hence, organic these materials could be used to formulate organic substrates for producing horticultural produce with a high nutritional and commercial quality, including tomato (*Solanum lycopersicum* L.), which is one of the most important vegetable produce worlds widely.

Tomato fruit contains mineral salts, vitamins A and C, and phytochemicals such as lycopene and phenolic compounds. Consumption of foods with these phytochemicals has been associated with prevention of chronic diseases and cardiovascular problems (Knekt *et al.*, 2002; Raffo *et al.*, 2006). Phenolic compounds and lycopene content depend on the tomato variety or type, environmental temperature, illumination, and water and nutrition supply (Dumas *et al.*, 2003), but also increase in tomato fruits as a defence response to some stress types. Thus, phenolics and lycopene content could be regulated in vegetable production systems under protected agriculture, like under greenhouse or shade net conditions, by manipulating substrate formulation. Hence, the mixture of solarized manure or vermicompost with mineral materials such as sand to formulate substrates for tomato production under protected agriculture conditions can contribute to obtain fruits with a high phytochemical content without decreasing yielding and commercial fruit quality, in addition to the increase in benefit/cost ratio compared to the use of traditional substrates under chemical fertilization.

The aims of the current study were to evaluate yielding, commercial and phytochemical fruit quality and economic advantages of tomato fruits produced using organic substrates formulated with vermicompost and/or solarized manure mixed with sand under greenhouse conditions.

Materials and Methods

Substrates formulation

The base material for substrate formulation was river sand disinfected using a 5% sodium hypochlorite solution, washed with tap water, and dried at room temperature for three days (Sánchez *et al.*, 2016). The organic materials used for the substrate formulations were solarized manure (SM), and vermicompost (VC) made from cattle manure in the Instituto Technologico de Torreón (Flores *et al.*, 2015). Manure was obtained from Holstein cattle of a local dairy stable (Torreon, Coahuila, México). Composting process consisted in covering the manure for 70 days with a transparent 30 μ-thick plastic without albedo (Vázquez Vázquez *et al.*, 2010). Vermicompost was obtained in a laboratory of the Instituto Tecnológico de Torreón using *Eisenia foetida* earthworms for digesting the manure for 90 days (Frederickson *et al.*, 2007).

The obtained organic materials (solarized manure [SM] and vermicompost [VC]) were mixed with sanitized sand at three ratios. The VC substrates were composed by sand with 20% (VC20), 30% (VC30) and 40% (VC40) of vermicompost; meanwhile the SM substrates were mixtures of sanitized sand with 20% (SM20), 30% (SM30) and 40% (SM40) of solarized manure. These six treatments were formulated according to previous studies reporting a good performance of these organic materials at such ratios (Moreno *et al.*, 2012). A control substrate of sanitized sand (TA) was included.

Plant material

The plant material used was tomato (*Solanum lycopersicum* L. *esculentum*) cv. 'Sahel' (Syngenta®), a Saladette type, since it is a variety with a short growth cycle, and it is mostly destined for fresh consumption. The study was conducted in a greenhouse at the Instituto Tecnológico de Torreón (ITT), located in Torreón, Coahuila (Mexico) between the coordinates 24°30' and 27° N, 102°00' and 104°40' W, at 1120 m above sea level. The greenhouse was a Mini-Green type with vertical columns and a surface of 120 m^2 covered with UV resistant polyethylene caliber 720 (30% diffuse shade). The greenhouse has controlled ventilation, and its windows have crystalline 25 × 25 threads/inch anti-aphid screens for protection against pests and insects. Greenhouse conditions throughout the production season were 70-75% of humidity content, and a room temperature within 22-32 °C.

Tomato seedlings were transplanted after thirty-five days from germination to 600 caliber black polyethylene bags with a capacity of 15 kg (one plant per bag). The six treatments containing organic materials were irrigated with tap water (Moreno *et al.*, 2012), while the TA was irrigated and fertilized daily with a Steiner nutrient solution (Steiner, 1984), which was prepared using inorganic salts reagent grade and distilled water, obtaining the following nutrient concentrations (in mg/L): nitrogen (168), phosphorus (31), potassium (273), calcium (80), magnesium (48), iron (2), manganese (0.7), copper (0.02), zinc (0.09), boron (0.5), and molybdenum (0.04). Applied volume of water and Steiner solution was modified depending on the crop development stage: 0.5 L per plant daily during growth and up to 1.5 L during development and harvest [10]. There were seven treatments (six organic substrate treatments plus control) in a completely randomized experimental design, and four treatment replicates were run.

Analytical tests for organic materials used for substrates formulation

The analytical tests run for the sanitized sand, solarized manure and vermicompost were: organic matter content (by calcination), pH, electric conductivity of a 1:5 (v:v) extract, nitrate content (by micro Kjeldahl), and bulk density. Besides, determination of elemental composition and a micro morphological analysis of the solarized manure and vermicompost were run. The micro morphological analyses were performed using an electronic scanning microscope (JMS-6480LV, JEOL, Celaya, Guanajuato, México) coupled with an X ray dispersive probe (INCAx-sight Oxford Instruments).

Analytical tests for organic substrates

The physical and chemical variables evaluated in the six formulated substrates were: organic matter content (by calcination), pH, electric conductivity of a 1:5 (v:v) extract, nitrate content (by micro Kjeldahl), and bulk density.

Evaluation of tomato yield and commercial fruit quality

The production variable evaluated in tomato plant was fruit yielding (kg of tomato fruit/plant), meanwhile for commercial fruit quality was evaluated polar and equatorial diameters; pericarp thickness (using a Vernier); firmness, measured with a penetrometer Extech FHT200 (Extech Instruments Corporation, Nashua, NH, USA); and total soluble solids (TSS), measured with a manual refractometer Sper Scientific 30000 (Sper Scientific Ltd, Scottsdale, AZ, USA).

Nutraceutical quality of tomato fruit

In regard of nutraceutical quality of tomato fruits were evaluated the total phenolic and lycopene content. Total phenolic content was determined using the Folin-Ciocalteau method (Singleton *et al.*, 1999). A calibration curve was prepared using gallic acid as standard, having a good linearity ($r^2 > 0.999$). The results were reported in mg of gallic acid equivalent (mg GAE) per 100 g fresh weight. Lycopene content was determined following the protocol of Mayeaux *et al.* (2006) for obtaining the lycopene extract. Lycopene quantification was done using an adaptation of the method published by Anguelova and Warthersen (2000), using a high precision liquid chromatograph Agilent 2100 Series equipped with a Supelco Discovery® C18 column (5 cm x 4.6 mm x 5 μm), having a flow of 0.5 mL/min, and monitoring the eluent at 472 nm in a diode array detector. The liquid chromatograph used the Chem-Station software for LC/MSD (Agilent Technologies, Palo Alto, Calif., USA), and a lycopene (Sigma-Aldrich) calibration curve with a good linearity (r2 > 0.999) was prepared. The results were reported in μg of lycopene/g tomato solids.

Benefit/cost ratio of tomato production

An economic analysis (per square meter) was conducted, following the methodology of Perrin *et al.* (1976), using only variable costs since fixed costs are considered amortized. Input features (sand and organic materials, nutritive solution, black plastic bags, labor, organic herbicides, etc.) that make up the variable costs are shown in Table 1. Gross average yielding per square meter of each treatment was multiplied by the corresponding price of one tomato fruit kg ($0.85 American dollars for tomatoes produced using nutrient solution, and $1.19 American dollars for tomatoes produced with organic materials).

Table 1. Variable costs for greenhouse Saladette tomato production using sand-vermicompost, sand-solarized manure, and sand substrates

Material	Unit		Unitary Price ($)
Sand	kg	1	0.013
Vermicompost	kg	1	0.17
Solarized manure	kg	1	0.60
Nutritious solution (90 days)	L/m^2	210	1.80
Flower pot	piece	1	0.13

Abbreviations or symbols: $, American dollar;

The obtained result was the raw profit for the producer. The economic efficiency of the treatments was evaluated by a benefit/cost ratio (B/C) that includes production value (gross profit) per square meter, and use and management costs of the substrates (expenditures) on the same area, using the equation [a]:

$$B/C = \frac{bb - cp}{cp} \qquad [a]$$

B/C stands for the benefit/cost ratio; bb: gross benefit; cp: production cost (all costs were calculated in American dollars); where the highest B/C ratio was the best treatment determined from an economic perspective; meaning that updated benefits were higher than updated costs (Izquierdo *et al.*, 1992).

Statistical analysis

The results of the studied variables were subjected to an analysis of variance to detect significant effects of treatments ($p < 0.05$), and treatment means were compared with a Tukey test ($p < 0.05$), using the Statistical Analysis System (SAS) version 9.1 statistical software (SAS, 2009).

Results

Physical and chemical characteristics of the organic materials used for substrate formulation

Solarized manure (SM) and vermicompost (VC) had different chemical characteristics; including pH, and organic matter, potassium and nitrate content ($p < 0.05$, Table 2). Solarized manure pH was neutral (7.1), while vermicompost pH was slightly alkaline (7.9), while SM was higher than VC regarding organic matter (25.0%) and potassium content (15.1%, $p < 0.05$). However, vermicompost had a higher NO3 concentration content (48.3%, $p < 0.05$) than solarized manure. The remaining chemical characteristics were similar in both organic materials ($p > 0.05$).

Table 2. Physical and chemical properties of organic materials used for substrate formulations

Organic materials	Bd (g/cm^3)	EC (dS/m)	OM (g/kg)	CEC (cmol/kg)	PES (%)	NO_{3^-} (mg/kg)	P (mg/kg)	K^+ (mg/kg)
VC*	0.75 a	3.2 a	334.5 b	95.3 a	2.99 a	13.73 a	15.34 a	164.71 b
SM**	0.90 a	3.3 a	418.1 a	77.6 a	2.76 a	9.26 b	16.54 a	189.63 a

Means followed by different letter in columns are significantly different, according to the t-test ($p < 0.05$). Abbreviations or symbols: *VC, vermicompost; SM, solarized manure, EC, electric conductivity; OM, organic matter; CEC, cation exchange capacity; PES, percent exchangeable sodium.

Micro morphological characteristics of these two organic materials can contribute to the formulated substrate properties (Figure 1). Solarized manure consisted of isolated particles, whose size varied from <2.0 µm, like in clay granules that do not form aggregates, to 50 - 2000 µm in sand particles and woody and tissue parts (Figures 1a and 1b). On the other hand, vermicompost contains small aggregates (2-50 µm) somewhat crumbly and brittle, formed with mineral and organic particles of different size like silt and clay blended into a fine matrix (Figures 1c and 1d).

The organic materials had different elemental composition ($p < 0.05$, Table 3), since VC had a higher content of nitrogen, oxygen, sodium, magnesium, aluminium, silicon, phosphorous, calcium and iron; meanwhile solarized manure contains more carbon, chloride and potassium than vermicompost.

Physical and chemical properties of the organic substrates

The substrates formulated with organic materials were different in pH and organic matter (OM) content ($p < 0.05$, Table 4), having pH values of 7.65-8.21, and organic material content of 35.00-114.03 g/kg. Regarding organic matter SM substrates had a higher OM content than VC substrates; however bulk density and electric conductivity were similar in all six formulated substrates except VC40 substrate, with an EC of 1.06 ($p < 0.05$).

Table 3. Elemental composition of organic materials used for substrate formulation

Chemical element	Solarized manure	Vermicompost
Carbon	39.86 a	18.47 b
Nitrogen	1.97 b	2.24 a
Oxygen	39.83 b	45.91 a
Sodium	0.56 b	0.83 a
Magnesium	0.50 b	1.24 a
Aluminium	1.25 b	3.15 a
Silicon	7.81 b	15.62 a
Phosphorus	0.25 b	0.79 a
Sulphur	0.62 a	0.53 a
Chlorine	1.13 a	0.29 b
Potassium	5.12 a	3.46 b
Calcium	2.17 b	7.75 a
Iron	0.52 b	1.76 a

Results in % dry weight basis. Values in rows followed by different letters are significantly different, according to the t-test ($p < 0.05$).

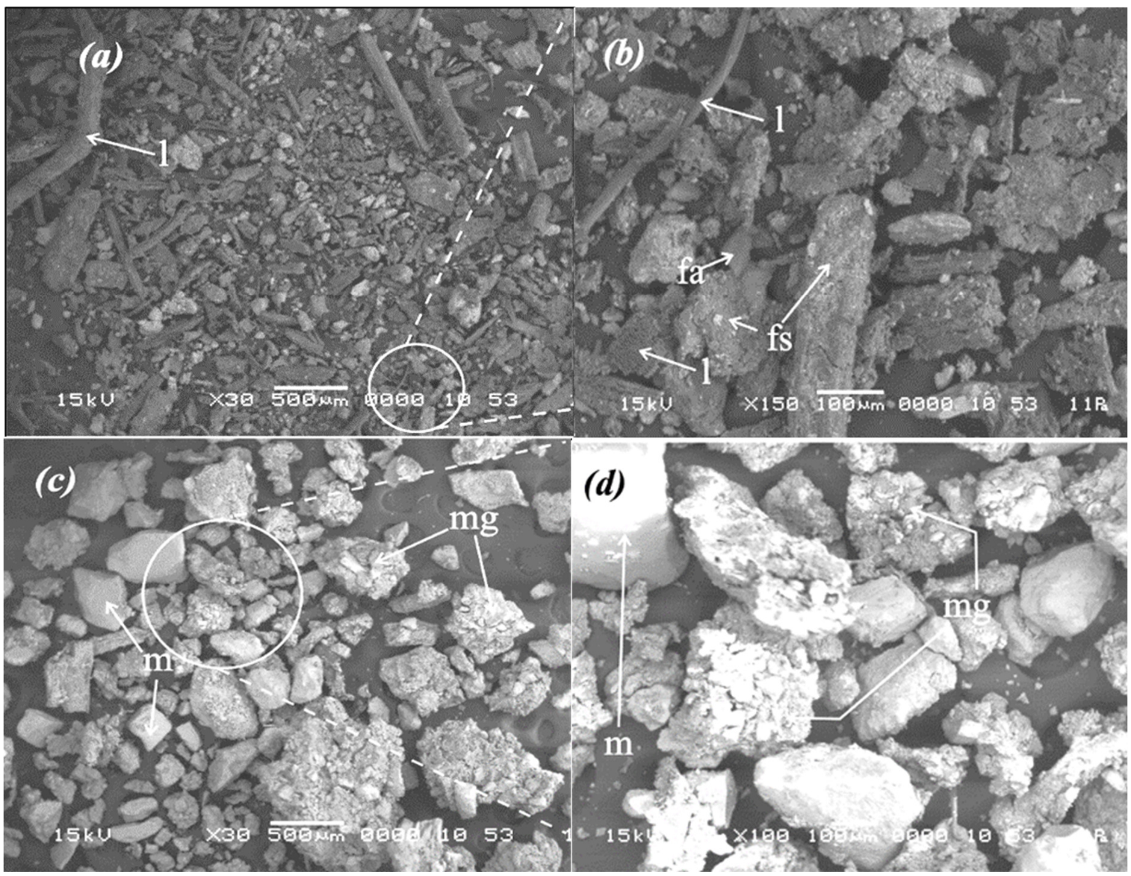

Figure 1. Micro photographs of solarized manure and vermicompost

(a) Solarized manure at 30X (1:500 µm); (b) Solarized manure at 150X (1:100 µm); Vermicompost at 30X (1:500 µm); (d) Vermicompost at 100X (1:100 µm). Abbreviations: fa = angular blocks, fs = subangular blocks, l = woody parts, m = minerals, mg = crumb structure.

Table 4. Physical and chemical characteristics of sand and organic substrates used for tomato production under greenhouse conditions

Organic material	pH	EC (dS/m1)	Bd (g/cm^3)	OM (g/kg)
Vermicompost (VC)	7.91 ab	3.21 a	0.75 c	334.45 b
Solarized manure (SM)	7.01 c	3.26 a	0.90 c	418.10 a
Substrate				
TA (Control with chemical fertilization*)	6.50 c	2.50 b	1.40 a	0.00 f
VC 20 (80% Sand + 20% Vermicompost)	7.92 ab	0.44 d	1.23 ab	35.00 ef
VC 30 (70% Sand + 30% Vermicompost)	7.89 ab	0.51 d	1.16 b	56.08 de
VC 40 (60% Sand + 40% Vermicompost)	7.65 b	1.06 c	1.08 b	79.64 cd
SM 20 (80% Sand + 20% Solarized manure)	8.03 ab	0.55 d	1.25 ab	51.54 de
SM 30 (70% Sand + 30% Solarized manure)	8.06 ab	0.59 d	1.19 b	81.12 cd
SM 40 (60% Sand + 40% Solarized manure)	8.21 a	0.60 d	1.13 b	114.03 c

* Chemical fertilization consisted in application of Steiner solution. Means followed by different letters in the same column are significantly different, according to the Tukey test ($p < 0.05$). Abbreviations or symbols: EC, electric conductivity; Bd, bulk density; OM, organic matter.

Tomato yielding

Tomato yielding was different among treatments, with TA substrate having the highest yield (17.20 kg/m^2, Figure 2), followed by the VC40 substrate (14.72 kg/m^2), meanwhile the SM 20 obtained the lowest yield (11.52 kg/m^2).

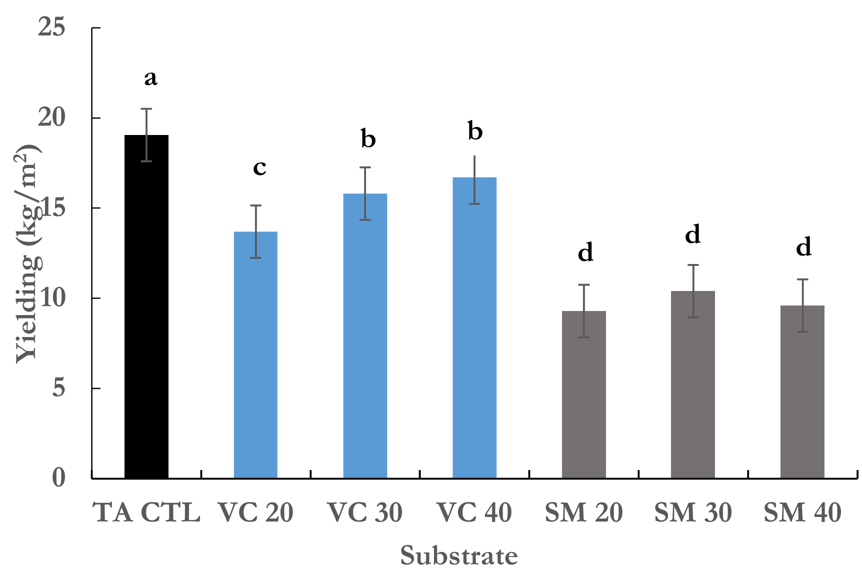

Figure 2. Yielding of Saladette tomato fruit produced in organic substrates formulated with sand-vermicompost and sand-solarized manure

Results (n = 4) reported in kg/m^2. TA: Control with chemical fertilization; VC 20: 80% Sand + 20% Vermicompost; VC 30: 70% Sand + 30% Vermicompost; VC 40: 60% Sand + 40% Vermicompost; SM 20: 80% Sand + 20% Solarized manure; SM 20: 80% Sand + 20% Solarized manure; SM 20: 80% Sand + 20% Solarized manure. Bars with a different letter are significantly statistical different, according to the Tukey test ($p < 0.05$).

Commercial quality of tomato fruit

The tomato fruit quality parameters were different among all treatments ($p < 0.05$), except in polar diameter (Table 5). Tomato fruits produced in the control substrate (fertilized chemically) had the highest values of equatorial diameter, pericarp thickness, texture firmness and soluble solids content followed by VC substrates and SM substrates ($p < 0.05$). Nevertheless, tomato fruits of all treatment substrates had firmness values above 6.00 N (Figure 3), which could be considered as a firm texture in this produce; in addition to that tomato fruits produced in VC treatments had adequate soluble solids content for tomato processing (Figure 4).

Table 5. Results* of the quality variables of Saladette tomato fruit produced in organic substrates formulated with sand-vermicompost and sand-solarized manure

Treatment substrate	Polar diameter	Equatorial diameter	Pericarp thickness
TA (Control with chemical fertilization**)	63.6 a	51.8 a	9.1 a
VC 20 (80% Sand + 20% Vermicompost)	62.5 a	48.6 a	8.6 a
VC 30 (70% Sand + 30% Vermicompost)	62.4 a	48.8 a	7.6 b
VC 40 (60% Sand + 40% Vermicompost)	63.5 a	48.8 a	9.7 a
SM 20 (80% Sand + 20% Solarized manure)	62.8 a	45.6 b	6.0 c
SM 30 (70% Sand + 30% Solarized manure)	62.2 a	46.9 b	6.3 b
SM 40 (60% Sand + 40% Solarized manure)	62.1 a	43.1 b	6.5 b

*Result means (n = 4), reported in mm. ** Treatment fertilized with Steiner solution. Values followed by different letters in the same column are significantly different, according to the Tukey test ($p < 0.05$).

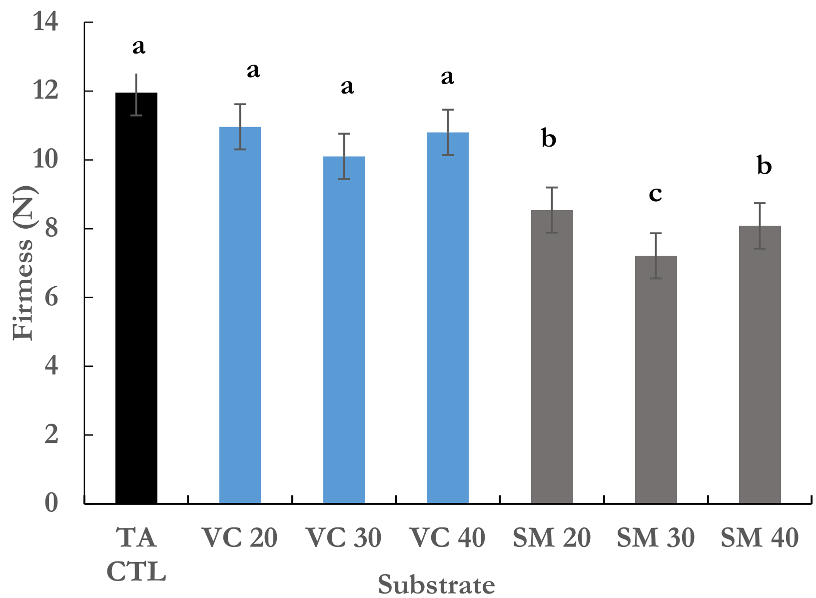

Figure 3. Firmness of tomato of Saladette tomato fruit produced in organic substrates formulated with sand-vermicompost and sand-solarized manure

Results (n = 4) reported in kg/m^2. TA: Control with chemical fertilization; VC 20: 80% Sand + 20% Vermicompost; VC 30: 70% Sand + 30% Vermicompost; VC 40: 60% Sand + 40% Vermicompost; SM 20: 80% Sand + 20% Solarized manure; SM 20: 80% Sand + 20% Solarized manure; SM 20: 80% Sand + 20% Solarized manure. Bars with a different letter are significantly statistical different, according to the Tukey test ($p < 0.05$).

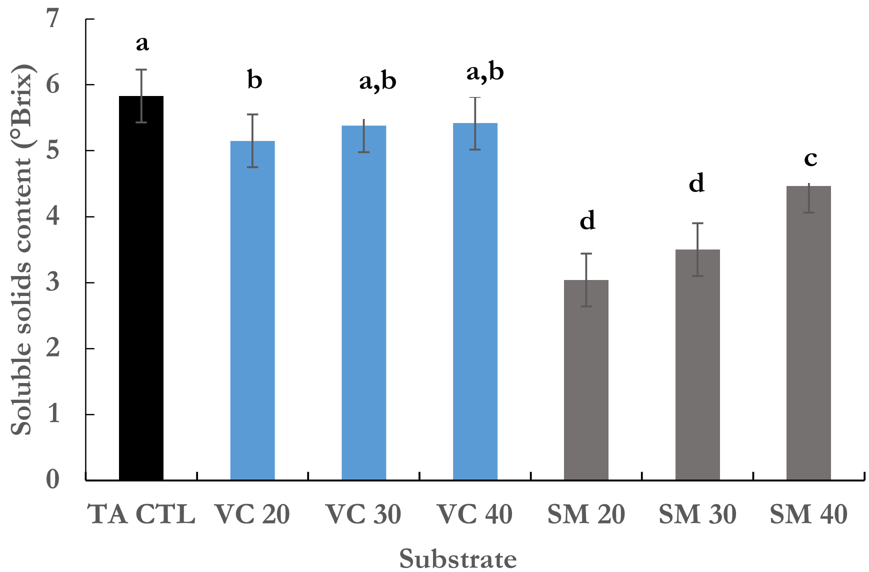

Figure 4. Soluble solids content of Saladette tomato fruit produced in organic substrates formulated with sand-vermicompost and sand-solarized manure

Results (n = 4) reported in °Brix. TA: Control with chemical fertilization; VC 20: 80% Sand + 20% Vermicompost; VC 30: 70% Sand + 30% Vermicompost; VC 40: 60% Sand + 40% Vermicompost; SM 20: 80% Sand + 20% Solarized manure; SM 20: 80% Sand + 20% Solarized manure; SM 20: 80% Sand + 20% Solarized manure. Bars with a different letter are significantly statistical different, according to the Tukey test ($p < 0.05$).

Phytochemical quality of tomato fruit

Phenolic compound content of tomato fruits was different among the treatments ($p < 0.05$) within a range of 19.7-28.5 mg GAE/100 g fresh weight of fruit, having the SM30 the highest value, meanwhile fruits obtained in the VC20 substrate had the lowest phenolic content (Table 6). Lycopene content was within a range of 20.4-33.7 µg of lycopene/g dry weight, and it was affected by the substrate formulation ($p < 0.05$, Table 6), resulting in a decrease of lycopene content as the % of solarized manure in the substrates increased, whilst the three VC substrates had similar lycopene content.

Table 6. Results* of phenolic and lycopene content of Saladette tomato fruit produced in organic substrates formulated with sand-vermicompost and sand-solarized manure

Treatment substrate	Phenolic content**	Lycopene content***
TA (Control with chemical fertilization**)	27.7 a	25.0 bc
VC 20 (80% Sand + 20% Vermicompost)	19.7 b	27.2 b
VC 30 (70% Sand + 30% Vermicompost)	22.5 b	24.0 bc
VC 40 (60% Sand + 40% Vermicompost)	21.1 b	24.5 bc
SM 20 (80% Sand + 20% Solarized manure)	27.6 a	33.7 a
SM 30 (70% Sand + 30% Solarized manure)	29.2 a	28.1 b
SM 40 (60% Sand + 40% Solarized manure)	20.1 b	20.4 c

*Result means (n = 4), reported in mm. **Results reported in mg GAE/100 g fresh weight. ***Results reported in µg of lycopene/g dry weight. Values in columns followed by different letters in the same column are significantly different, according to the Tukey test ($p < 0.05$).

Benefit/cost ratio of the organic substrates

Cost analysis (per square meter) of the organic materials used in this study for substrate formulation showed that SM20 substrate was the cheapest ($1.59 dollars), while VC40 and VC30 had the highest costs

(Table 7). The highest B/C ratio for tomato production per square meter was obtained in the substrate SM 20 (8.16), followed by SM30>VC20>SM40>VC30. The sand substrate had the lowest B/C ratio (3.72).

Table 7. Benefit-cost ratio of Saladette tomato fruit produced in organic substrates formulated with sand-vermicompost and sand-solarized manure

Substrate	Substrate costs			CTs (S+AO+CB)	Yielding	Price	Bb	Bb/CT
	S	OMat	VCos					
	------------ ($/m2) --------------				(kg/m2)	($/kg)	($/m2)	
TA	1.60	1.80 *	0.52	3.92 a	18.97 a	0.85	16.12 b	4.11 d
VC20	0.62	1.36	0.52	2.50 c	13.25 c	1.19	15.76 b	6.30 bc
VC30	0.55	2.04	0.52	3.11 bc	15.58 b	1.19	18.55 a	5.96 c
VC40	0.47	2.55	0.52	3.54 b	16.50 b	1.19	19.64 a	5.55 c
ES20	0.62	0.45	0.52	1.59 d	9.38 d	1.19	11.17 c	7.03 ab
ES30	0.55	0.67	0.52	1.74 d	10.49 d	1.19	12.48 c	7.17 a
ES40	0.47	0.90	0.52	1.84 d	9.52 d	1.19	11.33 c	6.16 bc

Values in columns followed by different letters are significantly different according to the Tukey test ($P \leq 0.05$). TA: Control with chemical fertilization; VC 20: 80% Sand + 20% Vermicompost; VC 30: 70% Sand + 30% Vermicompost; VC 40: 60% Sand + 40% Vermicompost; SM 20: 80% Sand + 20% Solarized manure; SM 20: 80% Sand + 20% Solarized manure; SM 20: 80% Sand + 20% Solarized manure; S: sand; OMat: organic material; Vcos, variable cost; Bb: gross profit; B/C = cost benefit ratio; * Cost of the nutrient solution per square meter during 90 days.

Discussion

Physical and chemical characteristics of the organic materials used for substrate formulation

The physical and chemical characteristics of solarized manure and vermicompost used in this study for substrate formulation were similar to those reported by Beltrán *et al.* (2016), who mentioned that these organic materials provide an adequate nutrient supply for plants and contribute to improve the substrate physical properties. Micro morphological characteristics of both organic materials could be attributed to their specific preparation processing, since solarized manure is obtained by heating manure under sunlight in order to eliminate pathogens, without additional processing (Flores *et al.*, 2015), thereby woody fragments, tissues, and angular forms were observed (Figures 1a and 1b). On the other hand, vermicompost results from organic matter (in our case of cattle manure) digestion by specific worms (Hu *et al.*, 2004) and microorganisms during the composting stage and maturation (Lazcano *et al.*, 2008), forming crumb structures (Tringovska and Dintcheva, 2012) (Figures 1c and 1d).

Physical and chemical characteristics of the organic substrates

Bulk density of the formulated substrates represented no risk for plant development (Acosta *et al.*, 2014; Garbanzo and Vargas, 2014), and their electric conductivity (EC) ranged from 0.44 – 1.06 dS/m, which could be considered below the EC levels recommended by Abad *et al.* (2004) for vegetable production. On the other hand, in regard of substrates pH Urrestarazu (2004) indicates that the optimum pH value for soilless crops is between 5.5 and 6.8 (moderately acid), since this is the pH range where nutrient assimilation occurs at maximum rate. This slight pH reduction could be related to the higher quantity of hydrogen ions as a result of ionization of the radicals present in vermicompost (Durán and Henríquez, 2010), whilst in solarized manure it may be due to acid production resulting from mineralization and organic matter nitrification (Azarmi *et al.*, 2008). Regarding to organic matter (OM) content, there is not an established minimum OM content (for substrates), although the Mexican Technical Committee of National Standardization of Agricultural and Animal Products (CTNNPAP, 2007) establishes an OM content of 200-500 g/kg vermicompost, while Urrestarazu and Salas (2004) indicates an OM content of 56.1 – 62.7% in compost. However, as aforementioned it has not been established a minimum OM content for mineral substrates added with organic materials.

Tomato yielding

Substrates fertilized using synthetic nutrient solutions contribute to obtain higher yielding than in organic based substrates (Díaz *et al.*, 2014). Yielding of VC substrates and control were in the range of 12.0-15.0 kg/m^2. These results could be considered as acceptable since are similar to those reported in commercial operations of tomato production under protected agriculture systems, such as under shade net (De la Cruz *et al.*, 2009; Godoy *et al.*, 2009). This suggests that tomato production using substrates formulated with vermicompost from solarized manure can assure acceptable produce yielding.

Commercial quality of tomato fruit

Three of the most important quality parameters of tomato fruits are soluble solids content, which implies whether a tomato could be used either for processing or fresh consumption, fruit firmness, and pericarp thickness, which stands for the fruit resistance during postharvest stages such as storage and delivery (Taylor, 2002). Tomato fruits produced in vermicompost substrates of this study had an adequate firmness according to the established commercial quality standards (between 5.0 and 8.0 N) (Edan *et al.*, 1997). Besides, pericarp thickness values were higher than those reported in previous studies (Márquez *et al.*, 2014). Tomato peeling and pericarp should be thick and firm in order to avoid produce breakage which could result in fruit juice leakage, as well as fermentation and microbial contamination during postharvest stages like shipping, storage and delivery (Gaona and Juárez, 2005). Hence, the use of organic substrates formulated with vermicompost obtained from solarized manure is a feasible alternative for production of good quality tomato fruits destined to either processing or fresh consumption. The tomato fruits produced in the vermicompost substrates had quality parameters below official commercial requirements, such as the Supreme Quality Mexican Official Norm (NOM, 1997). However, TSS content of the fruits produced with VC substrates were higher than 5 °Bx, while those produced in SM were not. Total soluble solids content of tomato fruits destined for fresh market or industrial processing should be between 4.50 and 5.50 °Bx (Macua *et al.*, 2006). The TSS results obtained in the current study indicate that an increase of organic materials concentration in a substrate formulation caused a slight increase in electric conductivity, which is known that affects the soluble solids content of produce. Nevertheless, the EC of the formulated substrates does not imply there was osmotic stress for the tomato plants, since EC of the formulated substrates can be considered as low (0.43-2.50 dS/m). Saline compounds contained either in substrates or soil alter water uptake in roots, thereby activating plant metabolic mechanisms that alleviate this stress through accumulation of organic solutes in fruits, diminishing osmotic potential (Goykovic and Saavedra, 2007). Thus, TSS of tomatoes in our study could result from a specific rhizosphere response, in addition to reactions of root exudates with several organic substrates compounds (Cheng, 2009).

Phytochemical quality of tomato fruit

Plant response to stressful environmental conditions triggers defensive mechanisms including antioxidants production (Winter and Davis, 2006). The tomato phenolic and lycopene content in our study were higher than those reported in other previous studies (Zapata *et al.*, 2007; Omar *et al.*, 2012). It has been reported that lycopene content mostly depends on the plant nutritional status, harvest time and variety (Waliszewski and Blasco, 2010). It is possible that the nutritional supply of the organic substrates was not sufficient in the early growth stages due to the mineralization and nutrient solubilization occurring at a slow rate during such stages, thereby increasing production of the carotenoid lycopene as a response to such stress factor. These results show that organic substrates formulated with vermicompost can be used for obtaining fruit tomato that meet good yielding (Grijalva *et al.*, 2011) and commercial quality requirements (Gónzalez *et al.*, 2004; IPGRI, 1996), as well as an adequate nutraceutical content (Sereme *et al.*, 2016).

Benefit-cost ratio of the organic substrates

Two of the most important features to select a substrate for protected agriculture use are optimum plant development and economic profitability for producers (Cruz *et al.*, 2013). Preliminary results of the economic analyses state the substrate formulated using solarized manure ES20 have the highest benefits. Besides, the vermicompost substrate VC20 is a good alternative due to its positive effect over tomato yielding (Jagadeesh *et al.*, 2018). Hence, it was determined that these two organic substrates could be used to obtain organic vegetables with a high commercial and nutraceutical quality, in addition to the economic advantages of using such substrates containing either solarized manure or vermicompost.

Conclusions

Organic substrates formulated with blends of sand and either solarized manure or vermicompost contribute to obtain tomato fruits with a high nutraceutical quality without affecting either yielding or commercial fruit quality. Besides, the use of such substrates increases the profit-cost ratio in organic tomato production under greenhouse conditions.

Authors' Contributions

Conceptualization: MAGR; Data analysis: CVV and ARG; Formal analysis, MFH, EAO and PPR; Methodology: MFH, PPR and ARG; Project administration: MAGR and JRE; Writing – original draft: MFH and EAO; Writing – review & editing: PPR and JRE. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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