

Full Length Research Paper

Mixtures design of *Agave angustifolia* Haw (Asparagales: Agavaceae) residue as a growth medium for tomato seedlings

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Tomato production under greenhouse conditions needs vigorous seedlings to reduce the loss of plants after the transplant. Different local substrates such as agave bagasse, pine bark and coconut fiber complemented with peat, expanded clay, vermiculite and pure peat for tomato seedlings production were tested. The seed germination, root ball compaction, height of the seedling, stem diameter, and total dry weight were quantified. The stem diameter observed in Agave - bagasse + peat + expanded - clay + vermiculite (30:60:5:5 v/v) (BMTAEV3), Agave - bagasse + pine - bark + peat + expanded - clay + vermiculite (30:30:30:5:5) (BMCPTAEV4), Agave - bagasse + peat + expanded - clay + vermiculite (50:30:10:10) (BMTAEV5), Sphagnum peat (SUNSHINE® 3) 100% (M3SC), and Agave - bagasse + peat + expanded - clay + vermiculite (40:40:10:10) (BMTAEV6) treatments were in acceptable parameter range to commercial use, but BMTAEV3, BMTAEV5, and BMTAEV6 treatments show better germination, root ball compaction, a bigger height and diameter, getting tomato seedlings with vigor to the transplant. The local substrata overcome the commercial growth medium parameters in seedlings evaluation. It is shown that mixtures of agave-bagasse with expanded clay, and vermiculite are a substrate alternative for tomato seedlings production, reducing the use of expensive and scarce material such as peat by up to between 40 and 60% (v/v).

Key words: Agave by-product, parameters, substrate, transplant, tomato seedlings.

INTRODUCTION

The tomato crop (*Solanum lycopersicum* L.) is one of the most important vegetables worldwide. Mexico in 2018 ranked ninth worldwide with a production of 4,559,375 tons (Balcha et al., 2015; SIAP-SAGARPA, 2020; FAO, 2020), is valuable because of the flavor and beneficial health properties of its secondary compounds (Slimestad and Verheul, 2009; Shah et al., 2015; Alam et al., 2019; Bailoni, 2020). It is cultivated in open-air and greenhouse conditions, but in both cases, is necessary vigorous seedlings, that guarantee the uniformity in seeds germination, and a fast growth for an efficient production (Herrera et al., 2008; Ozer and Kandemir, 2016).

In the worldwide horticultural areas, including Mexico, some centers produce even better and sustainable seedlings to ensure they're offering for a high-quality transplant. Due to its contribution to the quality of seedling, the substratum employed is a fundamental factor for the development and growth of them (Burés, 1997; Lovarelli and Bacenetti, 2017). The employment of growing media has been one of the principal strategic in horticulture (Masaguer et al., 2005; Roehrdanz et al., 2019; Feng et al., 2020). The most utilized substratum for the development of tomato seedlings is the peat. In Mexico, the mixture of Peat Moss (fine) vermiculite, dolomitic lime, initial fertilizer load and wetting agent or the SUNSHINE® commercial product is employed, and recently FLORAVA® peat mixtures coming from the Baltic countries are introduced, its physicochemical and biological characteristics allow adequate germination and growth of the seedlings, but this material is expensive for local farmers. Peat is considered a scarce resource, expensive, and because of its unsustainable exploitation, its use has been reduced and restricted (Zárate, 2013; Ceglie et al., 2015; Chrysargyris et al., 2017; Abdel-Razzaka et al., 2019); even in some countries its exploitation has been prohibited encouraging the use of organic wastes as a substrate instead of their disposal (Moral et al., 2013; Milinkovic et al., 2019; Xue and Farrell, 2020).

Currently, seedling production is carried out taking advantage of substrates available in the region, mixed with peat and synthetic minerals such as expanded clay or vermiculite. However, different substrate mixtures differ in their characteristics and properties. The response of plants to different substrates varies according to the material with which they are mixed and the proportions used. In tomato cultivation, the substrates with the best yields are tezontle, vermicompost mixtures, bocashi, pellets and coconut fiber (Ortega-Martínez et al., 2016; Garbanzo-León and Vargas-Gutiérrez, 2017). Other

researchers report that the use of sawdust and rice husk substrates increases the yield and quality of tomato in the greenhouse, and reduces costs as a result of a cheap substrate (Dyamurshaeva et al., 2017).

Other researchers have used different materials for the production of tomato seedlings and their use depend on the characteristics physical, chemical and biological properties, cost, and availability of the substratum (Andrade and Valenzuela, 2002; Utria et al., 2005; Muratalla et al., 2006; Santana et al., 2006; Berrospe, 2010; Ortega et al., 2010; Giuffrida and Consoli, 2016; Milinkovic et al., 2019; Xue and Farrell, 2020). For example, others alternative substrates to the peat are coconut coir (Noguera et al., 2003; Mariotti et al., 2020), rice hulls (Evans and Gachukia, 2007; Goodman, 2020), switchgrass (Altland and Krause, 2009; Schambach et al., 2020), mushroom compost (Medina et al., 2009; Postemskya et al., 2016), endemic seagrass species (Cocozza et al., 2011; Mininni et al., 2013), extracted sweet corn tassel (Vaughn et al., 2011), and giant reed wastes (Andreu-Rodríguez et al., 2013). For that reason, it is necessary to count on local materials. Those which are steady and of high harmlessness and quality such as the by-products of the local industry like the agave bagasse, the pine bark and coconut fiber; its use as a substrate component is an alternative of easy availability and at a low cost to diminish the environmental impact by the excessive use of peat moss (Zárate, 2013; Drzymulska, 2016).

This research aims to identify the most suitable combination of peat moss with organic materials based on pine bark, agave bagasse, and coconut fiber for tomato seedlings production as alternative substrate to reduce the peat moss pure implementation.

METHODOLOGY

Study site and substrate preparation

The research was carried out in the experimental field of the "Coloso Invernaderos" Enterprises in Ejutla de Crespo, Oaxaca (16°33'48.30" N, 96°43'32.18" O) with a temperature of 30 ± 2°C. The agave bagasse and pine bark previously composted, coconut fiber, Sphagnum peat, expanded clay, and vermiculite were the substrate used. The Sphagnum peat (SUNSHINE® 3) was used as control. Agave bags were acquired from by-products generated in the local manufacture of "Mezcal" alcoholic beverages from *Agave angustifolia* Haw. (Asparagales: Agavaceae). The mixtures used were; T1: Agave-bagasse + peat + expanded-clay + vermiculite 30:60:5:5 v/v (BMTAEV3), T2: Pine-bark + peat + expanded-clay + vermiculite 30:40:15:15 v/v (CPTAEV2), T3: Agave-bagasse + pine-bark + peat + expanded-clay + vermiculite 30:30:30:5:5 v/v (BMCPTAEV4), T4: Morelos coconut fiber + peat + expanded-clay + vermiculite 60:30:5:5 v/v (FCMTAEV), T5: Agave-bagasse + peat +

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expanded-clay + vermiculite 50:30:10:10 v/v (BMTAEV5), T6: Sphagnum peat (SUNSHINE 3) 100% (M3SC), T7: Pine-bark +uncomposted oak-chips 80:20 v/v (CPSSC), and T8: Agave-bagasse+ peat + expanded-clay + vermiculite 40:40:10:10 v/v (BMTAEV6). Sphagnum peat SUNSHINE®3 is the commercial substratum used by the seedling farmers. It is integrated with a uniform combination of Canadian Sphagnum moss and vermiculite. Then were added some carbonates to adjust the pH, a patented moistening agent and a formulation based on fertilizers. Polyethylene bowls of 200 holes (2.5×2.5×7 cm) were used sanitized with chlorine at 5% for seedlings production. The seeds were planted 5 mm deep, one seed per hole (Ozer and Kandemir, 2016).

Tomato production

The variety Ramses F1 of an undetermined habit of *S. lycopersicum*, the most cultivated in the region was used. After planting the seed (one seed per hole) the watering was done through a sprinkler pump until percolate. Then the bowls were stacked by treatment and were covered with black polyethylene for 72 h. The emergence of the seedlings was evaluated from the fourth day. The Steiner nutritive solution was applied at 14 days with a concentration of 25%, at 21 days with the 50%, and until the harvest with a 100%, considering a relation of ammonium nitrate of 30:70 (Steiner, 1961). The number of everyday irrigations with the nutritious solution varies from two to three, according to the environmental conditions, and sometimes the watering was only done with acidulated water to control the electrical conductivity in the substrate. The irrigations were given to the seedlings with a manual sprinkler. The seedlings were harvested after 27 days after sowing (Ozer and Kandemir, 2016).

Variable determination

The seed germination, compaction of the root ball, height of the seedling, the diameter of the stem and total dry weight were the variables evaluated. The percentage of germinated plants per bowl was obtained after 15 days. The index of the root-ball compaction was obtained considering the following scale: (1) very hard to extract, (2) hard to extract, (3) moderately easy to extract, (4) easy to extract, and (5) very easy to extract with a compacted root ball (Díaz, 2011). After 27 days the height of the seedling by using a metallic millimeter tape was tested. The reference points were the base of the stem and the apical sprout. The width of the stem was calculated with a Vernier digital Truper® (6"/150mm). The seedlings were transferred, washed, and dried in a stove to 65°C to measure the total dry weight (Peñaloza and Durán, 2015).

Experimental design and statistical analysis

The experimental design was a randomized complete block design with eight treatments with six replicates. Each experimental sample comprised six plants per bowl and six bowls per treatment. The analysis of variance (ANOVA) was done through the statistical package SAS version 2004 (SAS Institute, 2013).

RESULTS AND DISCUSSION

Seedling germination

After 15 days, the germination of tomato seedlings was

measured. The T1=BMTAEV3, T3=BMCPAEV4, T4=FCMTAEV, T5=BMTAEV5 and T8= BMTAEV6 treatments reached the highest percentages of germination. There are statistical differences between T7=CPSSC and the other treatments, no significant differences were recorded between T1=BMTAEV3 and the T6=M3SC (common substratum employed by the producers) and T2= CPTAEV2. Fí and Cristóbal (1995) show that to get achieve good, productive results and uniformity in the seedlings, the germination must be above 90.0%. In this study, all the tested substrates are above the quoted germination values. These results are also superior to the ones found by Favaro et al. (2002) where they attained 87.0 and 72.5% of germination when peat/sawdust and peat mixture were used. Also, Ortega et al. (2010) reported 90% of germination when pure peat was used, but mentioned 12% when peanut shell was tested.

Several studies mentioned that pure peat used as substratum recorded germination and emergency data of tomato seedlings between 66 and 98% (Quesada and Méndez, 2005; Santana et al., 2006; Fernández-Bravo et al., 2006), similar results were recorded in this study with T1=BMTAEV3 and T8=BMTAEV6 treatments using 60 and 40% peat in mixture with other materials, respectively, but with the maximum values reported by these researchers (Figure 1A).

Santana et al. (2006) used compost as a substratum to germinate tomato seeds registering 83.0% of emergency; this is attributed to the material total porosity, because this physical characteristic allow the internal gas exchange, increasing the content of oxygen required by the seeds to germinate (Handreck and Black, 2002).

Rootball compaction

Treatments T1=BMTAEV3, T3=BMCPAEV4, T4=FCMTAEV, T5=BMTAEV5, T6=3M3SC, and T8= BMTAEV6 record the highest value of root ball compaction (scale=5- very easy to extract with a compacted root ball) (Figure 1B), while treatment T2= CPTAEV2 registered a scale=4 - easy to extract, and T7=CPSSC a scale=2 - hard to extract because of poor radical development. The root system has important physical and physiological functions since the beginning of seeds germination and emergence, and up to the growth and development of the seedling for transplant, the establishment in the transplant depends on adequate development of the root system, a quality seedling is identified by a vigorous stem. Root growth is limited to the volume of the container used for seedlings development, however, in roots development these grow horizontally around the growth medium which facilitates the complete extraction (substrate-root) of the mold, this benefits the establishment of the seedling in the transplant (Brutti et al., 2015).

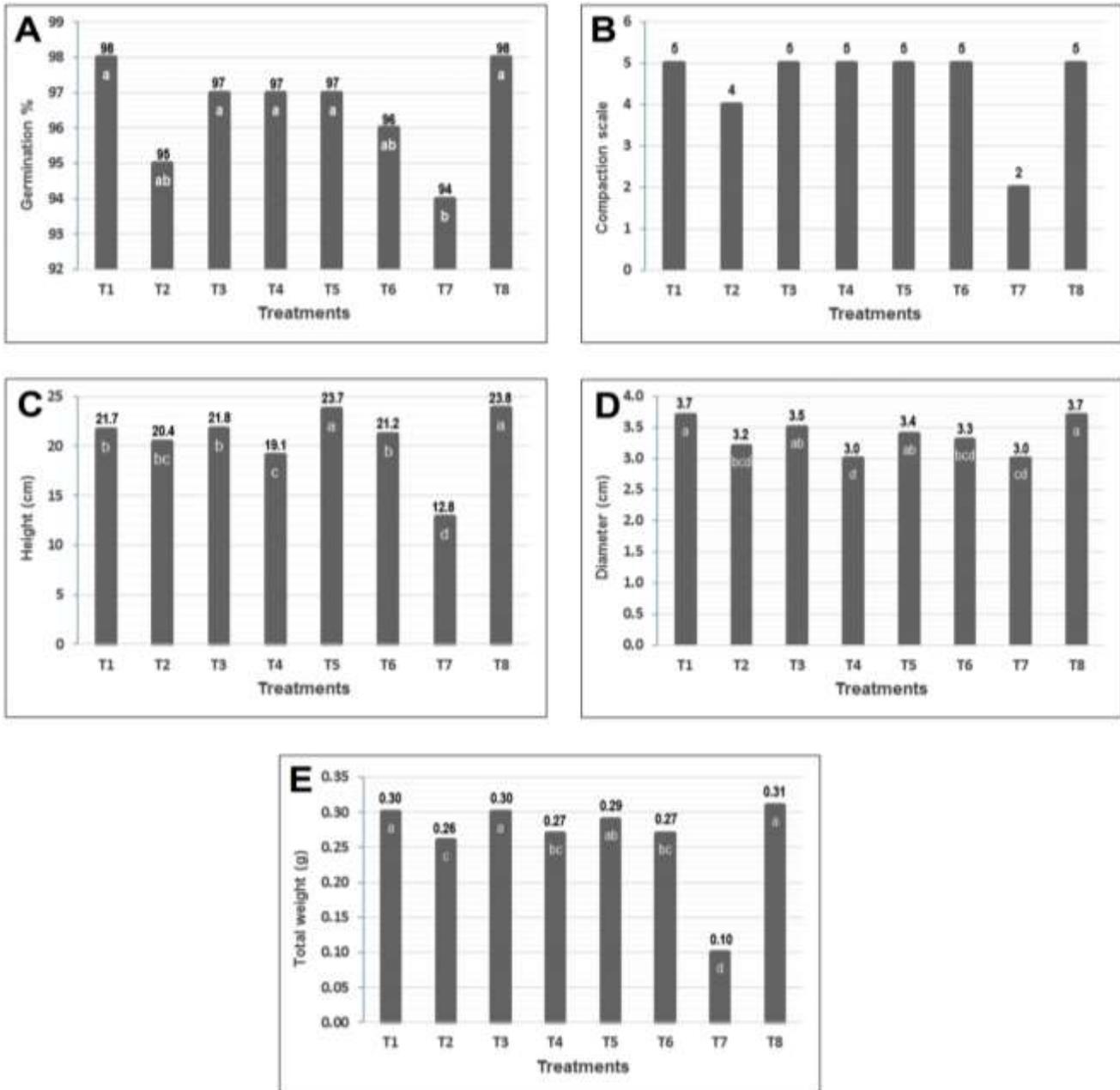


Figure 1. Tomato seedlings parameters. (A) Seed germination, (B) Compaction of the rootball, (C) Final height of the seedlings, (D) Diameter of the seedlings, (E) Total dry weight.

Seedling height

The treatments T5=BMTAEV5 and T8=BMTAEV6 produced higher height of 23.9 and 23.8 cm, and presented significant differences with the rest of the treatments. The treatments with the highest seedlings also presented a higher percentage of emergences, which may be attributed to a good emergence in the first days of cultivation. These results differ from that of previous studies, although measurements are made over similar period of time (27-30 day), for example, Ortega et

al. (2010) tested pure peat, composted sawdust, composting, arable land and peanut shell getting 15.0, 12.0, 17.0, 7.0 and 8.0 cm seedling height. Muratalla et al. (2006) used corn straw and "tezontle" (volcanic rock) and registered 7.57 and 8.18 cm, while Berrospe (2010) implemented cachaza (filter mud) as a substrate getting 5.8, 5.0, and 4.5 cm as the highest values with this material. Jacobo and Uexkül (1973) mention that it is favorable to use mixed or unmixed compost as a substratum owing to its capacity of activating the microbiological processes by its structure, increasing

airing and capacity of humidity retention, it also acts as a temperature regulator; it delays mineral phosphoric acid fixation by making the phosphorus more absorbable, favoring a more suitable growth of the seedling (Figure 1C).

Seedlings weight and total dry weight

Treatments T8= BMTAEV6 and T1=BMTAEV3 obtained the best values with 3.67 and 3.66 mm, where there are significant differences among the treatments, favoring a bigger development of the stem related to the other substrate (Figure 1D). These treatments exhibit significant differences among the others, favoring a bigger development of the stem. The suitable physical properties offered by these substrata (proper airing capacity and water-air curve and good porosity) offer the best conditions for the plant development, generating vigorous seedlings with strength and resistance for transplant. Muratalla et al. (2006) reported diameter tomato seedlings of 2.09 to 3.21 mm (small) when corn straw was used as a substrate, while Ortega et al. (2010) obtained diameters of 5.0, 4.0, 6.0, 1.0, and 1.0 mm with substrata based on pure peat, composted sawdust, composting, agricultural land and peanut shell. Berrospe (2010) mentioned a 4.5 and 1.2 mm as a maximum and minimum rate for seedlings width when cachaza (filter mud) was used as a substrate. Other studies show a width of stem between 1.3 and 3.3 mm at the end of seedbed production; but when peat moss is used, the seedling growing between 1.3 and 2.1 mm (Quesada and Méndez, 2005; Santana et al., 2006; Fernández-Bravo et al., 2006; Shibuya et al., 2006; Herrera et al., 2008).

In the study, the diameter observed in T1=BMTAEV3, T3=BMCPAEV4, T5=BMTAEV5, T6=M3SC, and T8=BMTAEV6, is according to the commercial recommendable parameters, but in T1=BMTAEV3, T5=BMTAEV5, and T8=BMTAEV6 it is registered better germination, suitable compaction of the root ball, a bigger height, and diameter, getting seedlings with proper vigor for transplant. The best results were achieved with treatment T5=BMTAEV5, T1=BMTAEV3, T3=BMCPAEV4, and T8=BMTAEV6 with 0.29, 0.30, 0.30, and 0.31 g (Figure 1E). Different effects in the growing dynamic of the seedlings and accumulation of dry matter were presented with the tested substrate, being the best-performing treatments the compounds by Agave-bagasse/peat/expanded clay/vermiculite (T1, T5 and T8) in proportions of 30:60:5:5, 50:30:10:10, and 40:40:10:10 v/v.

Conclusion

It is shown that mixtures of agave-bagasse with expanded clay, and vermiculite are a substrate alternative for tomato seedlings production, reducing the use of

expensive and scarce material such as peat by up to 40 and 60% (v/v). It is recommended to continue testing different organic residues alone or in mixtures that have potential characteristics to a substrate for crop production, and to produce from these value-added products that compete with commercial products.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

- Abdel-Razzaka H, Alkokaik F, Rashwan M, Fulleros R, Ibrahim M (2019). Tomato waste compost as an alternative substrate to peat moss for the production of vegetable seedlings. *Journal of Plant Nutrition* 42(3):287-295.
- Alam P, Raka MA, Khan S, Sarker J, Ahmed N, Nath PD, Hasan N, Mohib M, Tisha A, Sagor AT (2019). A clinical review of the effectiveness of tomato (*Solanum lycopersicum*) against cardiovascular dysfunction and related metabolic syndrome. *Journal of Herbal Medicine* 16:100235.
- Altland JE, Krause C (2009). Use of switchgrass as a nursery container substrate. *Horticultural Science* 44(7):1861-1865.
- Andrade N, Valenzuela E (2002). Aserrín de pino pretratado con cepas fúngicas como sustrato para la producción de la plántulas de tomate (*Lycopersicon esculentum* Mill). *Revista Agrosur* 30(2):28-34.
- Andreu-Rodríguez J, Medina E, Ferrandez-García MT, Ferrandez-Villena M, Ferrandez-García CE, Paredes C, Bustamante MA, Moreno-Caselles J (2013). Agricultural and industrial valorization of *Arundo donax* L. *Communications in soil science and plant analysis* 44(1-4):598-609.
- Bailoni ER (2020). Antioxidant and free radical scavenging properties of tomato seed wastes and potential use as a functional food. *Theses and Dissertations*. University of Maryland, United State of America. <https://doi.org/10.13016/4pxx-3qrf>
- Balcha K, Belew D, Nego J (2015). Evaluation of tomato (*Lycopersicon esculentum* Mill.) varieties for seed yield and yield components under Jimma condition, South Western Ethiopia. *Journal of Agronomy* 14(4):292-297.
- Berrospe EA (2010). Sustratos alternativos a base de cachaza para la producción de plántulas de tomate (*Lycopersicon esculentum* Mill). Master Degree Thesis. Colegio de Posgraduados, Montecillo, Texcoco, Edo de México, Mexico 90 p.
- Brutti L, Alvarado P, Rojas T, Martensson A (2015). Tomato seedling development is improved by a substrate inoculated with a combination of rhizobacteria and fungi. *Acta Agriculturae Scandinavica, Section B - Soil and Plant Science* 65(2):170-176.
- Burés S (1997). Sustratos. Ediciones Agrotécnicas, Madrid, España. 342 p.
- Ceglie FG, Bustamante MA, Amara MB, Tittarelli F (2015). The challenge of peat substitution in organic seedling production: Optimization of growing media formulation through mixture design and response surface analysis. *PLoS ONE* 10(6):1-14.
- Chrysargyris A, Stamatakis A, Prasad M, Tzortzakakis N (2017). Evaluation of municipal solid waste compost and/or fertigation as peat substituent for pepper seedlings production. *Waste and Biomass Valorization*. doi:10.1007/s12649-017-0124-6.

- Cocozza C, Parente A, Zaccone C, Mininni C, Santamaria P, Miano T (2011). Chemical, physical and spectroscopic characterization of Posidonia oceanica (L.) Del. residues and their possible recycle. *Biomass Bioenergy* 35(2):799-807.
- Díaz SFR (2011). Paja de trigo como sustrato en el crecimiento de plántulas de brócoli. Doctoral Thesis. Colegio de Posgraduados, Montecillo, Texcoco, Edo de México, Mexico 268 p.
- Dzrymulska D (2016). Peat decomposition – shaping factors, significance in environmental studies and methods of determination; a literature review. *Geologos* 22:61-69.
- Dyamurshaeva EB, Kudiyarov RI, Urazbaev NZ, Dyamurshaeva GE (2017). Efficiency of use of the rice peel and wood sawdust as the substratum for cultivation of tomatoes. *Agriculture* 2:56.
- Evans MR, Gachukia MM (2007). Physical properties of sphagnum peat-based root substrates amended with perlite or parboiled fresh rice hulls. *HortTechnology* 17:312-315.
- Food and Agriculture Organization of the United Nations (FAO) (2020). http://faostat3.fao.org/browse/Q*/S. Fecha de consulta septiembre de 2020.
- Favaro J, Buyatti M, Acosta M (2002). Evaluación de sustratos a base de serrín de Salicáceas ("Salix sp.") compostados para la producción de plantones. *Investigación agraria. Producción y Protección Vegetales* 17(3):367-374.
- Feng J, Zhi Y, Zhang D, Chi CP, Chu S, Hayat K, Zhou P (2020). Rice straw as renewable components of horticultural growing media for purple cabbage. *Science of the Total Environment* 747:141274.
- Fernández-Bravo C, Urdaneta N, Silva W, Poliszuk H, Marín M (2006). Germinación de semillas de tomate (*Lycopersicon esculentum* Mill.) cv `Río Grande sembradas en bandejas plásticas, utilizando distintos sustratos. *Revista de la Facultad de Agronomía* 23(2):188-196.
- Fí J, Cristóbal R (1995). Método de producción de posturas para el cultivo sin suelo por la técnica de cepellón. Informe final de etapa. 04. P.C.T. Viandas y Hortalizas. INIFAT. La Habana, Cuba.
- Garbanzo-León G, Vargas-Gutiérrez M (2017). Actividad microbiana en sustratos y análisis de crecimiento en almáxicos de tomate en Guanacaste, Costa Rica. *Revista Colombiana de Ciencias Hortícolas* 11(1):159-169.
- Giuffrida F, Consoli S (2016). Reusing Perlite Substrates in Soilless Cultivation: Analysis of Particle Size, Hydraulic Properties, and Solarization Effects. *Journal of Irrigation and Drainage Engineering* 142:04015047.
- Goodman BA (2020). Utilization of waste straw and husks from rice production: A review. *Journal of Bioresources and Bioproducts* 5(3):143-162.
- Handreck KA, Black ND (2002). *Growing Media for Ornamental Plants and Turf*. 3rd ed. UNSW Press. Australia. 542 p.
- Herrera F, Castillo JE, Chica F, López L (2008). Use of municipal solid waste compost (MSWC) as a growing medium in the nursery production of tomato plants. *Bioresource Technology* 99(2):287-296.
- Jacobo A, Uexküll H (1973). *Nutrición y abono de los cultivos tropicales y subtropicales*. Cuarta edición. México: Ediciones Ecoamericanas 626 p.
- Lovarelli D, Bacenetti J (2017). Seedbed preparation for arable crops: environmental impact of alternative mechanical solutions. *Soil and Tillage Research* 174:156-168.
- Mariotti B, Martini S, Raddi S, Tani A, Jacobs DF, Oliet JA, Maltoni A (2020). Coconut Coir as a Sustainable Nursery Growing Media for Seedling Production of the Ecologically Diverse Quercus Species. *Forests* 11:522.
- Masaguer A, Navas M, López MC (2005). Sustratos de cultivo nueva alternativa eco-compatible. *Phytoma* (169):26-32.
- Medina E, Paredes C, Pérez-Murcia MD, Bustamante MA, Moral R (2009). Spent mushroom substrates as a component of growing media for germination and growth of horticultural plants. *Bioresource Technology* 100(18):4227-4232.
- Milinkovic M, Lalevic B, Jovicic-Petrovic J, Golubovic-Curguz V, Klijuev I, Raicevic V (2019). Biopotential of compost and compost products derived from horticultural waste-Effect on plant growth and plant pathogens' suppression. *Process Safety and Environmental Protection* 121:299-306.
- Mininni C, Bustamante MA, Medina E, Montesano F, Paredes C, Pérez-Espinosa A, Moral R, Santamaria P (2013). Evaluation of posidonia seaweed-based compost as a substrate for melon and tomato seedling production. *Journal of Horticultural Science and Biotechnology* 88(3):345-351.
- Moral R, Paredes C, Pérez-Murcia MD, Pérez-Espinosa A, Bustamante MA (2013). Challenges of composting for growing media purposes in Spain and the Mediterranean area. *Acta Horticulturae* 1013:25-39.
- Muratalla S, Rodríguez MA, Sánchez P, Tijerina L, Santizo JA, López A (2006). Paja de maíz como sustrato en el crecimiento de plántula de jitomate. *Revista TERRA Latinoamericana* 24(3):319-325.
- Noguera P, Abad M, Puchades R, Maquieira A, Noguera V (2003). Influence of particle size on the physical and chemical properties of coconut coir dust as a container medium. *Communications in Soil Science and Plant Analysis* 34:593-605.
- Ortega LD, Sánchez J, Díaz R, Ocampo J (2010). Efecto de diferentes sustratos en el crecimiento de plántulas de tomate (*Lycopersicon esculentum* Mill.). *Ra Ximhai* 6:365-372.
- Ortega-Martínez LD, Martínez-Valenzuela C, Ocampo-Mendoza J, Sandoval-Castro E, Pérez-Armendáriz B (2016). Eficiencia de sustratos en el sistema hidropónico y de suelo para la producción de tomate en invernadero. *Revista Mexicana de Ciencias Agrícolas* 7(3):643-653.
- Ozer H, Kandemir D (2016). Evaluation of the performance of greenhouse tomato seedlings grown with different cultivation techniques. *Bangladesh Journal of Botany* 45(1):203-209.
- Peñaloza P, Durán JM (2015). Association between biometric characteristics of tomato seeds and seedling growth and development. *Electronic Journal of Biotechnology* 18(4):267-272.
- Postemskya PD, Marinangeli PA, Curvetto NR (2016). Recycling of residual substrate from *Ganoderma lucidum* mushroom cultivation as biodegradable containers for horticultural seedlings. *Scientia Horticulturae* 201:329-337.
- Quesada RG, Méndez SC (2005). Evaluación de sustratos para almáxicos en hortalizas. *Agronomía Mesoamericana (Costa Rica)* 16(2):171-183.
- Roehrdanz M, Greve T, Jager M, Buchwald R, Wark M (2019). Co-composted hydrochar substrates as growing media for horticultural crops. *Scientia Horticulturae* 252:96-103.
- Santana Y, Aguilar I, León LE, Del Busto A, Cruz R (2006). Comportamiento de las plántulas de tomate en sustratos elaborados de humus, turba y cascarilla de arroz. *Universidad de Pinar del Rio Hermanos Saiz Montes de Oca, Pinar del Rio, Cuba* 17 p.
- SAS Institute Inc (2013). *SAS® 9.4 guide to software Updates*. Cary: SAS Institute Inc.
- Schambach JY, Finck AM, Kitin P, Hunt CG, Hanschen ER, Vogler B, Starkenburg SR, Barry AN (2020). Growth, total lipid, and omega-3 fatty acid production by *Nannochloropsis* spp. cultivated with raw plant substrate. *Algal Research* 51:102041.
- Shah K, Singh M, Chandra R (2015). Bioactive compounds of tomato fruits from transgenic plants tolerant to drought. *Food Science and Technology* 61(2):609-614.
- Shibuya T, Tsuruyama J, Kitaya Y, Kiyota M (2006). Enhancement of photosynthesis and growth of tomato seedling by force ventilation within the canopy. *Scientia Horticulturae* 109(3):218-222.
- SIAP-SAGARPA (Servicio De Información Agroalimentaria Y Pesquera - Secretaría De Agricultura, Ganadería, Desarrollo Rural, Pesca Y Alimentación) (2020). <http://www.siap.gob.mx/cierre-de-la-produccion-agricola-por-estado>. Consulted September 2020.
- Slimestad R, Verheul M (2009). Review of flavonoids and other phenolics from fruits of different tomato (*Lycopersicon esculentum* Mill.) cultivars. *Journal of the Science of Food and Agriculture* 89(8):1255-1270.
- Steiner A (1961) A Universal Method for Preparing Nutrient Solutions of a Certain Desired Composition. *Plant Soil* 15(2):134-154.
- Utría E, Reinaldo I, Cabrera A, Morales D, Lores A (2005). Crecimiento de plántulas de tomate (*Lycopersicon esculentum* Mill) cultivadas en diferentes sustratos y niveles de abastecimiento hídrico. *Revista Cultivos Tropicales* 26(3):31-38.
- Vaughn SF, Deppe NA, Palmquist DE, Berhow MA (2011). Extracted sweet corn tassels as a renewable alternative to peat in greenhouse substrates. *Industrial Crops and Products* 33(2):514-517.
- Xue M, Farrell C (2020). Use of organic wastes to create lightweight green roof substrates with increased plant-available water. *Urban*

Forestry and Urban Greening 48:126569.

Zárate B (2013). Valoración de subproductos agrícolas y forestales como sustratos de cultivo en el estado de Oaxaca (México). Doctoral thesis. Escuela Técnica Superior de Ingenieros Agrónomos. Universidad Politécnica de Madrid, Madrid España 407 p.