

Chapter

Perspective Chapter: Biochar as a Hydroponic Substrate in *Capsicum chinense* Cultivation in the Humide Tropic

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Abstract

In Mexico, the habanero chili (*Capsicum chinense*) is one of the most economically important vegetables. The objective of this chapter was to evaluate the production of the habanero chili (*C. chinense*) crop on biochar substrate in a hydroponic system under a protected structure. The chili variety that was working with was Orange. The experiment was established with a completely randomized design with five treatments and 10 repetitions, totaling 50 experimental units. Three mixtures of biochar and tepetzil were evaluated, in addition to a treatment with 100% biochar and a control treatment (T1) with only tepetzil. The data were analyzed by analysis of variance and the Tukey test ($P \leq 0.05$) using the Statistical Analysis System statistical program. The results show no differences in terms of fruit weight; however, there was a significant effect on the yield of the habanero pepper. The results demonstrate a clear effect of biochar and hydroponics on yield, where 50% was used; the highest value was obtained with 56.30 T ha⁻¹. However, tropical agriculture usually plays a very important role in the country's economy. Therefore, the implementation of hydroponics as an alternative form of crop production helps promote environmental protection as well as sustainability.

Keywords: tropical vegetables, habanero chili, technology, tepetzil, crops

1. Introduction

Habanero peppers are predominantly grown in four main regions in Mexico at a national level: the Pacific, North-Central, Gulf of Mexico and Yucatan Peninsula. However, the states in the southeast, namely Yucatan, Tabasco, Campeche and Quintana Roo, contribute the most to production, with 39, 30, 8 and 6%, respectively. Even with Chiapas contributing 3%, the southeastern states remain the top producers [1, 2]. The cultivation of habanero chili in controlled environments has led to an increase in the use of different substrates such as tezontle, perlite, sand, rock wool, coconut fibers, tepetzil or tepojal, peat, vermiculite and pumacite. The

issue occurs when these components are hard to reach because of their distance, availability, or cost, so it is crucial to find substitutes that are nearby and make use of waste or by-products that can serve the same purpose as a commercial base [3, 4]. Several advanced and industrialized nations, such as the United States, the United Kingdom, Spain, Japan and the Netherlands, have seen a rise in the utilization of soilless indoor farming through hydroponic systems. This is performed in return for soil, inorganic materials, or utilizing organic waste to boost vegetable production and address the challenges presented by climate change [5]. Hydroponic is changing the way agricultural crops are grown globally because of its low environmental impact, enhanced pest management and increased crop output. Alternatively, hydroponics, known as soilless agriculture, is seen to mitigate soil-based agriculture's susceptibility to environmental changes [6]. Additionally, there is a growing need for food production in city settings where there is not much land available for sustainable agriculture, particularly in reducing the carbon emissions from food supply and transportation [7, 8]. Hydroponic nutrient solutions help minimize water and nutrient waste by collecting and recycling drainage, typically utilizing just 5% of the water required in traditional agriculture for the same level of production [8]. This raises the possibility of using charcoal residues as biochar to replace various substrates. Although the use of charcoal in agriculture as a soil amendment or soil improver has been known for thousands of years [9–11], its use as a substrate or soilless growing medium is relatively recent and there has been little focus on charcoal as a substrate or biochar in soilless crops [12, 13]. Fortunately, more information is now available on the subject and there is even a compilation of research on the use of charcoal and other raw materials as biochar in agriculture and as a medium for crops or substrates [14]. Biochar can be used as a substrate to partially replace the commercial substrates used today; However, the characterization of these materials is a practice that has not been given the importance it deserves, since it plays an essential role in the agronomic management of crops [15–18], allows knowing their characteristics and identifying which substrates can be more optimal according to the requirements of the crop in question. The most important quality of hydroponics is that it does not need the soil at any stage of the plant's development, neither as a support or as a source of nutrients, since the water contains dissolved nutrients from which the plant absorbs them directly, achieving greater efficiency in the regulation of nutrition and fertilizer use [4]. The objective of this work is to learn about the cultivation of habanero peppers under the hydroponic system and as substrate biochar and tepetzil (v/v) to better understand the possible effects on *Capsicum* sp.

2. Habanero chili (*C. chinense*)

In Mexico, the species within the genus *Capsicum* are referred to as “chili, a word that comes from the Nahuatl word chili (**Figure 1**) [19, 20]. This genus has about 38 species, of which 12 (including varieties) are used by man; only five species have been domesticated and cultivated (*Capsicum annuum* L., *C. chinense* Jacq., *C. pubescens* L., *C. frutescens* L. and *C. baccatum* L.), the rest are wild and semi-cultivated species [21, 22].

Nowadays, the cultivation of habanero peppers is considered a traditional crop in southeastern Mexico, forming part of the regional gastronomy, representing a great opportunity for producers due to the high demand for habanero marketed both as fresh fruit and for the preparation of sauces, pastes and dehydrated products, which



Figure 1.
“Chile habanero” habanero chili in hydroponic system with protected structure.

are used to accompany our food [23–25]. In addition, the Yucatan Peninsula area (Yucatan, Quintana Roo and Campeche) has had the Denomination of Origin for habanero peppers since 2010 [26]. According to the Ministry of Economy [26], it covers the finished product or products, including their characteristics, components, form of extraction and production or elaboration processes (**Figure 2**). However, this does not minimize the importance that the state of Tabasco represents with respect to the production of habanero peppers. At the national level, habanero peppers are



Figure 2.
Habanero chili on carbon substrate in hydroponic system.

mainly produced in four regions of the country: the Pacific, north-central, Gulf of Mexico and Yucatan Peninsula; however, the states located in the southeast of Mexico are the ones that have the largest share with respect to production, which are Yucatan, Tabasco, Campeche and Quintana Roo, which contribute 39, 30, 8 and 6%, respectively [6, 27]. Of the three varieties of habanero peppers for the tropics of Mexico (Uxmal, Jaguar, Mayapán and Calakmul), it is known that the varieties Mayapán and Calakmul adapt well in the state of Tabasco [28, 29], in addition, that there are studies where Longoria [30] and Orange [31] varieties have been used in the Tabasco region.

3. Biochar and tepetzil

Biochar is a fuel resulting from the combustion at high temperatures and without oxygen (or very low concentrations) of wood for a certain time, where it undergoes a decomposition of lignin, cellulose, hemicellulose and loss of extractables, causing it to be a solid, fragile and porous material [32, 33]. This process is called pyrolysis, where to obtain charcoal, temperatures of 300–700°C can be handled according to the different processes for obtaining it: torrefaction, traditional slow pyrolysis, modern slow pyrolysis, fast pyrolysis, gasification or hydrothermal carbonization [34, 35], the parameters that intervene in the properties of charcoal are: (1) the type of organic matter used; (2) the carbonization environment (temperature and aeration) and (3) the additions during the carbonization process (**Figure 3**). Biochar made from agricultural waste is an alternative substrate for hydroponic production. The literature suggests that there is better absorption of several nutrients in the presence of biochar; However, the results seem to be dependent on the physical and structural characteristics of the carbons, so it is not possible to generalize the results [35]. As it is a recalcitrant form of carbon, it acts as a long-term reservoir of this element, delaying its return to the atmosphere as CO₂, a situation that contributes to mitigating climate change. An additional benefit is that the raw material for its production comes from

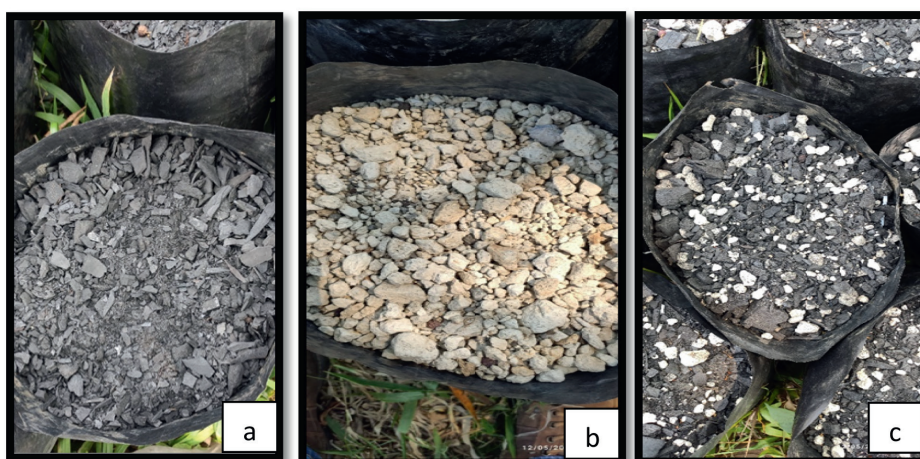


Figure 3. Substrate with (a) charcoal 100%, (b) tepetzil 100% and (c) charcoal 50 and tepetzil 50%, respectively, in the production of habanero chili for a hydroponic system.

organic waste, which often causes environmental pollution problems [36]. Nowadays, charcoal has several uses, highlighting its use as energy, caloric, for composting, in artistic and food areas [37], in addition to its use as a pigment in the food industry, in steel production, to purify water and in the medical industry. Its use is increasingly expanding to diverse areas or industries; one of these areas is agriculture, both in conventional agriculture as a soil improver or restorer, amendments and/or fertilizer [38], as in soilless crop production where it has been tested as a substrate in hydroponic systems [9, 39, 40]. Accordingly, when charcoal is used in agriculture, it is often referred to as biochar; however, this term does not refer only to charcoal. According to the International Biochar Initiative [41], biochar is a solid material obtained from the thermochemical conversion of biomass carbonization in an oxygen-limited environment, a carbonized material that has undergone a pyrolysis process with low or no oxygen conditions similar to charcoal. However, the difference lies in two particularities: (1) to produce biochar, a great variety of organic materials or feedstocks can be used [42, 43] such as plant residues, wood or tree bark [44] and biosolids [45], among others and (2) charcoal or any other carbonized material that is intended for agricultural use is referred to as biochar [46], either for agricultural soils or as a component of substrate for crops; Products similar to biochar may not be called this way if their use is directed to the energy industry, as fuel, in filtering processes, as reducers in the metallurgical industry [47].

As already mentioned, in hydroponics, it is very usual to see the use of substrates as a growing medium, the most frequent being tezontle, perlite, sand, rock wool, coconut fiber, tepetzil or tepojal, peat, vermiculite and pumacite [48]. In Mexico, coconut dust or fiber, tezontle, perlite, pumacite, tepetzil, compost, cucumber bark peat, rice husks and worm humus, among other materials, are used as substrates for various crops [49].

Tepetzil, also known as tepojal, pumita or caltete, is an inorganic material that comes from volcanic foam when lava with high water content and volatile gases is expelled from the volcano. Its use as a substrate is because it improves drainage in soils and in mixture with other substrates, presents high porosity and moisture retention, is light and has neutral pH. However, it is a component that is not recommended for use on its own [50]. Furthermore, unlike tezontle, tepetzil is even more limited in terms of its availability; in Mexico, there are two tepetzil accumulation sites: one in Calimaya, State of Mexico, near Nevado de Toluca and another in Perote, Veracruz, near the Orizaba peak volcano [3]. The same author indicates that the long-term availability of tepojal is uncertain due to the great demand by manufacturers of light blocks for construction and mentions that the tepojal from Calimaya is of lower quality and is increasingly mixed with soil particles.

3.1 Characteristics physicochemical properties of a biochar and tepetzil

The substrate should be light, hold seedlings or cuttings firmly, retain sufficient moisture, be sufficiently porous to drain excess water, allow root aeration, be free of weeds, nematodes and diseases, be suitable for sterilization without changing its properties, have sufficient nutrients for initial healthy plant development, low salinity, adequate pH, be stable and not swell or shrink excessively or form crusts in the sun [51], the substrate must have a high capacity to retain readily available water, high aeration, low bulk density, high porosity, low salinity, high buffer capacity, low decomposition speed, structural stability, reproducibility and availability, low cost and easy handling (mixing and disinfection) [52].

No matter what raw material is used as substrate, it is important that these have certain characteristics which are segmented into physical characteristics, chemical characteristics and biological characteristics (the latter in the case of organic materials); within the physical characteristics, we have the real and apparent density, granulometric distribution, porosity and aeration, water retention, permeability, pore size distribution, structural stability; chemical characteristics such as cation exchange capacity, pH, electrical conductivity, buffer capacity, nutrient content, C/N ratio; and biological characteristics such as microbial population, organic matter content, state and speed of decomposition [53, 54]. **Table 1** presents some optimal values for some of the physical and physicochemical properties in the substrates.

Since the characteristics present in biochar (and any other biochar) are dependent on the raw material and type of pyrolysis used, it is necessary to evaluate its characteristics and its incorporation as a hydroponic substrate to understand and explain the effects on the different plants produced in these soilless growing media [55–57]. However, the characterization of substrates is a process that has not been given much importance and yet plays an essential role in the agronomic management of crops [58].

The need to find partial or complete substitutes not only for tepetzil but also for any commercial substrate is important; new substrates must be found that are even considered by-products or residues from other industries to reduce their

Properties	Unit	Optimum value
Particle size	mm	0.25–2.50
Bulk density		
• In open air container	$\text{g}\cdot\text{cm}^3$	0.50–0.75
• In greenhouse		0.15
Real density		
• Organic materials	$\text{g}\cdot\text{cm}^3$	1.45
• Mineral materials		2.65
Total pore space	% vol.	>85
Aeration capacity	% vol.	10–30
Readily available water	% vol.	20–30
Reserve water	% vol.	4–10
Total available water	% vol.	24–40
Concentration		<30
pH (pH in H_2O)		
• For cultural media		5.5–6.5
• For organic materials		5.2–5.5
Electrical conductivity (1:5-v:v)	mS/cm	0.36–0.65
Cation exchange capacity		
• Permanent fertigation	meq•100 g	
• Occasional fertigation		Nil or very low >20

Table 1.
Optimum levels of physical and physicochemical properties of a biochar and tepetzil.

environmental impact by not giving them a productive use, for example, due to the hardness of the biochar pits in Tabasco, charcoal residue is produced that is not marketed due to its reduced size [59].

4. Hydroponic

Hydroponic, from the Greek “hydro” (water) and “ponos” (labor or work), is a soilless crop production technique [60] that has been practiced for centuries, although it has been used commercially for the last 50 years and has been increasing, contributing to sustainable agriculture as a new technology [61]. It is a technique that is not specific to any type of vegetable, so leaf vegetables, stem vegetables, inflorescences, roots, pods, fruits and bulbs can be grown, thus being able to cultivate from home cultivation for own consumption, to important productions for commercialization [5].

The most important quality of hydroponics is that it does not need the soil at any stage of plant development, neither as a support nor as a source of nutrients, because the water contains dissolved nutrients from which the plant will take them directly, achieving greater efficiency in the regulation of nutrition and fertilizer use [62]. The hydroponics that was worked was a drop system in this method tubes are used, emitters that drip the nutrient solution directly onto the roots of the plants with the growth, development and fruiting. It is controlled by a timer. This type of technique is ideal for the cultivation of plants with a specific nutrient demand, such as Solanaceae, Curbitaceae, *Capsicum* and *Lactuca*. The substrate, which was used in this work was hydroponics using a drop system, so the biocarbon and tepetzil substrates can be used.

The nutrient solution to be used is the Steiner solution (Table 2) [62], which, before its preparation, the water must be adjusted to a pH of 6.0 using sulfuric acid and phosphoric acid, taking phosphoric acid as a source of phosphorus in the solution. The nutrient solution was applied at 50% of its concentration during the first 45 days of plant growth, and then the Steiner solution was supplied at 100% at the beginning of flowering onwards.

A drip hydroponic system was used to supply the nutrient solution (Table 3). There will be eight irrigations during the day, with an interval of 1 hour between each one, starting at 08:00 a.m. and the last one at 03:00 p.m. Each irrigation will last 1 minute for the first 30 days and then increase to 2 min each irrigation from flowering onwards. Per irrigation, 280 mL/min of the solution will be supplied on average.

Regarding micronutrients, the commercial product Haifa Micro Combi was used, which contains Fe 7.4%, Mn 3.7%, Zn 1.1%, Cu 0.8% and Mo 0.5%; Nutri-Boro 11%, was used as a source of Boron, both products were added together with the Steiner solution through the hydroponic system (Table 3).

Nutrient solution (meq/L)					
Anions			Cations		
NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻	K ⁺	Ca ²⁺	Mg ²⁺
12	1	7	7	9	4

Table 2.
Anions and cations for the nutrient solution [62].

Fertilizer	Quantities	
	meq/L	g/1000 L
Calcium nitrate	9	1060
Magnesium sulfate	4	494
Potassium sulfate	4	360
Potassium nitrate	3	303
Phosphoric acid	1	23 mL

Table 3.
Fertilizers for the nutrient solution.

4.1 Experimental

For the experiment, a completely randomized design was used with five treatments and 10 replications for a total of 50 experimental units, where three of the five treatments were the volumes of biochar mixed with tepetzil, in addition to treatment of only biochar and the control treatment which consists of only tepetzil (**Table 4**).

4.2 Fruit yield

The results were subjected to an analysis of variance (ANOVA) and a comparison of Tukey means ($P \leq 0.05$) using the statistical program Statistical Analysis System [63]. The total yield was obtained by adding the total weight of all the cuts per plant and treatment to subsequently extrapolate the yields per hectare ($T\ ha^{-1}$).

Regarding the yield with the hydroponic system, from which a total of 15 cuttings were obtained, a significant difference was found between the treatments, as shown in **Table 5**; the T3 (tepetzil 50% and biochar 50%) and T4 (tepetzil 25% and biochar 75%) treatments did not present significant differences between them, in turn, they were the treatments with the highest statistical yields with respect to the control treatment (T1), with a difference of 56.72 and 54.72 $T\ ha^{-1}$ (T3 and T4, respectively) over the T1 treatment. The T2 (tepetzil 75% and biochar 25%) and T5 (biochar 100%) treatments are not significantly different from the T3 and T4 treatments, but neither from the control treatments. The yield of the *C. chinense* pepper grown in an NFT

Treatments	Tepetzil	Biochar
	%	
T1 (control)	100	0
T2	75	25
T3	50	50
T4	25	75
T5	0	100

Table 4.
Tepetzil and biochar substrate treatments and percentages.

Treatments	Tepetzil (%)	Biochar (%)	Yield (T ha ⁻¹)
1 (control)	100	0	37.95 ^{b,‡}
2	75	25	44.35 ^{ab}
3	50	50	56.72 ^a
4	25	75	54.72 ^a
5	0	100	49.64 ^{ab}

[‡]Means with the same literal are statistically equal according to the Tukey test ($P \leq 0.05$).

Table 5.
The yield fruit habanero in response to substrate mixtures of tepetzil and biochar.

(Nutrient Film Technique) hydroponic system without salinity restriction was 2.87 kg per plant, with an estimated yield of 46.1 Mg ha⁻¹, considering the area per plant adopted of 0.6225 m² [64].

5. Conclusions

The results show that the hydroponic system using the drip technique with the substrate mixed with 50% biochar and tepetzil showed a higher yield, obtaining 56.30 T ha⁻¹. Therefore, tropical vegetables often play a very important role in the Mexican economy. Therefore, the implementation of hydroponics as an innovative alternative form of crop production helps promote environmental protection as well as sustainability. Hydroponics, if this technology is applied to the production of tropical vegetables, does not require soil directly, but a substrate, in this case, biochar and tepetzil with the hydroponic system, mineral nutrients dissolved in water are provided, which is called nutrient solution, and the nutritional needs of habanero chili crops are covered.

Acknowledgements

The author would like to thank the Academic Division of Agricultural Sciences of the Juarez Autonomous University of Tabasco and the Academic Body of Sustainable Tropical Agriculture.

Conflict of interest

The authors declare no conflict of interest.

Notes/thanks/other declarations

Thanks, and no declarations.

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References

- [1] Tucuch-Haas CJ, Alcantar-Gonzalez G, Ordaz-Chaparro VM, Santizo-Rincon JA, Larque-Saavedra A. Production and quality of habanero peppers (*Capsicum chinense* Jacq.) with different NH_4^+ + NO_3^- + substrate particle size ratios. Terra Latinoamericana. 2012;**30**(1):9-15
- [2] Ramirez M, Arcos G, Mendez R, Meneses I. Chilli bell pepper varieties and hybrids for the tropics of Mexico. In: Meza VM, Chay AJ, Ramírez AR, Palacios RE, Valenzuela N, Alcantara JP, Kido MT, editors. Production Agriculture: An Approach Integrated. Mexico: University of Papaloapan; 2019. pp. 29-37. Available from: https://www.researchgate.net/publication/358749135_Produccion_Agropecuaria_Un_enfoque_integrado
- [3] Castellanos JZ. Tomato Production Manual in Greenhouse. 1st ed. Intagri; 2009. pp. 456. Available from: https://www.intagri.com/public_files/Manual-de-produccion-de-tomate-bajo-invernadero.pdf
- [4] Villa M, Catalan EA, Inzunza MA, Roman A, Macias H, Cabrera D. Hydroponic Production of Habanero Chilli in Greenhouses. Mexico: INIFAP; 2014. Available from: <http://cenid-raspa.inifap.gob.mx/demo/modulo/Folletos%20tecnicos/2014/>
- [5] Hernandez-Hernandez M, Palma-Lopez DJ, Salgado-Garcia S, Palma-Cancino DJ, Rincon-Ramirez JA, Hidalgo-Moreno CI, et al. Charcoal as an improver of an acrisol cultivated with sugar cane (*Saccharum* spp.). Agro Productivity. 2020;**13**(5):35-41. DOI: 10.32854/agrop.vi.1607
- [6] Ramirez FL. Forest charcoal as substrate, plus nitrogen, phosphorus and potassium (NPK), in the cultivation of *Raphanus sativa* radish [thesis]. Iquitos: National University of the Peruvian Amazon; 2014. Available from: <https://repositorio.unapiquitos.edu.pe/handle/20.500.12737/3359>
- [7] Man JK, Yunho H, Juyeon L, Baknoon H, Arifur R, Hossain A, et al. Waste nutrient solutions from full-scale open hydroponic cultivation: Dynamics of effluent quality and removal of nitrogen and phosphorus using a pilot -scale sequencing batch reactor. Journal of Environmental Management. 2021;**281**:111893. DOI: 10.1016/j.jenvman.2020.111893
- [8] Al SA. Hydroponics, aeroponic and aquaponic as compared with conventional farming. American Scientific Research Journal for Engineering, Technology, and Sciences. 2017;**27**(1):247-255. Available from: https://www.researchgate.net/profile/Ali-Shrouf-2/publication/318307802_Hydroponics_Aeroponic_and_Aquaponic_as_Compared_with_Conventional_Farming/links/658a78403c472d2e8e8d1d35/Hydroponics-Aeroponic-and-Aquaponic-as-Compared-with-Conventional-Farming.pdf
- [9] Nemati MR, Simard F, Fortin JP, Beaudoin J. Potential use of biochar in growing media. Vadose Zone Journal. 2015;**14**(6):1-8. DOI: 10.2136/vzj2014.06.0074
- [10] Huang L, Gu M. Effects of biochar on container substrate properties and growth of plants-a review. Horticulture. 2019;**5**(1):14
- [11] Poma WA. Bibliographic review of the use of hydroponic systems in the cultivation of vegetables [thesis]. Peru:

- César Vallejo University; 2020. Available from: <https://repositorio.ucv.edu.pe/handle/20.500.12692/54960>
- [12] Perez-Cabrera CA, Juarez-Lopez P, Anzaldo-Hernandez J, Alia-Tejaca I, Gayosso-Rodriguez S, Salcedo-Perez E, et al. Rice husk biochar as a substrate for cucumber seedling growth. *Journal Chapingo Horticulture Series*. 2021;27(3):171-183. DOI: 10.5154/r.rchsh.2021.01.002
- [13] Vargas-Tapia P, Castellanos-Ramos JZ, Sánchez-García P, Tijerina-Chávez L, López-Romero RMa, Ojodeagua-Arredondo JL. Physical, chemical and biological characterization of coconut dust substrates. *Journal Phytotecnia Mexicana*. 2008;31(4):375-381. DOI: 10.35196/rfm.2008.4.375
- [14] Bu X, Ji H, Ma W, Mu C, Xian T, Zhou Z, et al. Effects of biochar as a peat-based substrate component on morphological, photosynthetic and biochemical characteristics of rhododendron delavayi Franch. *Scientia Horticulturae*. 2022;302:111148. DOI: 10.1016/j.scienta.2022.111148
- [15] Guo Y, Niu G, Starman T, Volder A, Gu M. Poinsettia growth and development response to container root substrate with biochar. *Horticulture*. 2014;8(1):14. DOI: 10.3390/horticolae4010001
- [16] Awad YM, Lee SE, Ahmed MBM, Vu NT, Farooq M, Kim IS, et al. Biochar, a potential hydroponic growth substrate, enhances the nutritional status and growth of leafy vegetables. *Journal of Cleaner Production*. 2017;156:581-588. DOI: 10.1016/j.jclepro.2017.04.070
- [17] Blok C, Van der Salm C, Hofland-Zijlstra J, Streminska M, Eveleens B, Regelink I, et al. Biochar for horticultural rooting media improvement: Evaluation of biochar from gasification and slow pyrolysis. *Agronomy*. 2017;7(1):6. DOI: 10.3390/agronomy7010006
- [18] Kaudal BB, Chen D, Madhavan DB, Downie A, Weatherley A. An examination of physical and chemical properties of urban biochar for use as growing media substrate. *Biomass and Bioenergy*. 2016;84:49-58. DOI: 10.1016/j.biombioe.2015.11.012
- [19] Lopez R, Mirafuentes HF, Aviles WI, Jimenez JA, Meneses I. Production of Habanero Chilli with Irrigation by Drip. Mexico: INIFAP; 2015
- [20] Servicio Nacional de Inspección y Certificación de Semillas. Chile (*Capsicum* spp.). National Seed Inspection and Certification Service. Gobierno de México; 2017. Available from: <https://www.gob.mx/snics/acciones-y-programas/chile-capsicum-spp>
- [21] Muñoz LS. Selection of varieties of habanero chilli (*Capsicum chinense* Jacq.) for industrial purposes [thesis]. Yucatan: Centro de Investigación Científica de Yucatan A.C; 2020. pp. 146. https://cicy.repositorioinstitucional.mx/jspui/bitstream/1003/1827/1/PCB_D_Tesis_2020_Liliana_Sarai_Mu%C3%B1oz_Ram%C3%ADrez.pdf
- [22] Shared RT. Havana Chile, with Designation of Origin. 2017. Available from: <http://www.gob.mx/firco/articulos/chile-habanero-con-denominacion-de-origen?idiom=es>
- [23] Hernandez J. It Is Consolidated he Habanero Chilli Looking for Exceed a Thousand Hectares of Sowing. SIT/ Diario Presente; 2018. Available from: <https://www.diariopresente.mx/tabasco/se-consolida-el-chile-habanero-buscan-superar-mil-hectareas-de-siembra/207960>

- [24] Marcial L. Growth and production of habanero chilli (*Capsicum chinense* Jacq.) under three sowing dates in the Comarca Lagunera [thesis]. Mexico: Autonomous University Antonio Narro Agrarian; 2016
- [25] Lopez-Lopez R, Inzunza-Ibarra MA, Fierro-Alvarez A, Palma-Lopez DJ. Transplant dates and productivity of habanero chilli under irrigation by drip. Mexican Journal of Sciences Agricole. 2018;9(1):51-64. DOI: 10.29312/remexca.v9i1.847
- [26] Fideicomiso de Riesgo Compartido. Chile Habanero, con Denominación de Origen. Gobierno de México; 2016. Available from: <https://www.gob.mx/firco/articulos/chile-habanero-con-denominacion-de-origen?idiom=es>
- [27] National Research Institute Forestry, Agriculture and Livestock. Products and Services. Chile. 2017. National Research Institute. Forestry, Agriculture and Livestock. International Biochar Initiative. FAQs; 2013. Available from: <https://biochar-international.org/resources/ibi-publications/>
- [28] Ramirez GS. Analysis of the production of habanero chilli (*Capsicum chinense* Jacq.) in the main states producers in Mexico during 2006-2015 [thesis]. Mexico: Autonomous University Agrarian Antonio Narro; 2017. Available from: <http://repositorio.uaaan.mx:8080/xmlui/handle/123456789/42753>
- [29] Lopez M, Poot JE, Cortez MA. Response of habanero chilli (*Capsicum chinense* L. Jacq) to fertilizer supply organic in Tabasco, Mexico. Magazine UDO Agricole Scientist. 2012;12(2):307-312 <http://repositorio.uaaan.mx:8080/xmlui/handle/123456789/42383>
- [30] Guillen RI. Fabricación de Carbón Vegetal Aprovechando los Raleos en Bosques Energéticos. Project Profile. Sistema De La Integracion Centroamericana. Alianza Energía Ambiente. San Salvador, El Salvador; 2008. p. 30. Available from: https://www.sica.int/busqueda/busqueda_archivo.aspx?Archivo=dpro_86588_1_30052014.pdf
- [31] Diaz M, Gonzales A, Sifuentes D, Gonzales E. The charcoal: Alternative energy and chemical products. Xylem. 2010;23(1):95-103
- [32] Cox J, Downie A, Hickey M, Jenkins A, Lines-Kelly R, McClintock A, et al. Biochar in Horticulture: Prospects for the Use of Biochar in Australian Horticulture. NSW Trade and Investment. Departments of Primaty Industries; 2012. p. 104. Available from: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/447857/DPI-BioChar-in-Horticulture.pdf
- [33] Trelles WL, Gonzalez JL. Response of strawberry (*Fragaria vesca*) crop to different charcoal granulometries and soil moisture tension ranges under greenhouse conditions, at la Argelia experimental station [thesis]. Ecuador: National University of Loja; 2014. Available from: <https://dspace.unl.edu.ec/handle/123456789/11795>
- [34] Valverde JC, Arias D, Campos R, Guevara M. Characterization physical and chemical characterization of charcoal from three stem segments and branches of *Eucalyptus camadulensis* from dendroenergy plantations. Mesoamerican Forestry Journal Kurú. 2018;15:16-24. DOI: 10.18845/rfmk.v15i1.3774
- [35] Fiallos-Ortega LR, Flores-Mancheno LG, Duchi-Duchi N, Flores-Mancheno CI, Baño-Ayala D, Estrada-Orozco L. Ecological soil restoration using biochar (charcoal), and its effect on *Medicago sativa* production. Science

in Agriculture. 2015;**12**(2):13-20. DOI: 10.19053/01228420.4349

[36] CABI, Authors Info & Affiliations. *Capsicum annuum* (Bell Pepper). CABI Compendium; 2019. DOI: 10.1079/cabicompendium.15784

[37] Pinedo JJ. Charcoal application in four treatments for nutrient recovery in agricultural soils [thesis]. Peru: Cesar Vallejo University; 2017. Available from: <https://repositorio.ucv.edu.pe/handle/20.500.12692/33170>

[38] Rios CL. Application of *Mespilus germanica* L. and *Mangifera indica* L. biochar in contaminated soils to reduce lead in the area of La Huaca-Huaral. Peru: Cesar Vallejo University; 2018. Available from: <https://repositorio.ucv.edu.pe/handle/20.500.12692/18276>

[39] Sanchez-Reinoso AD, Avila-Pedraza EA, Restrepo-Diaz H. Use of biochar in agriculture. Acta Biologica Colombiana. 2020;**25**(2):327-338. DOI: 10.15446/abc.v25n2.79466

[40] Dispenza V, De Pasquale C, Fascella G, Mammano MM, Alonzo G. Use of biochar as peat substitute for growing substrates of euphorbia × lomi potted plants. Spanish Journal of Agricultural Research. 2016;**14**(4):11. DOI: 10.5424/sjar/2016144-9082

[41] Escalante A, Perez G, Hidalgo C, Lopez J, Campo J, Valtierra E, et al. Biochar I: Nature, history, manufacture and use in the soil. Terra Latinoamericana. 2016;**34**(3):367-382

[42] Schahczenski J. Biochar and Sustainable Agriculture. ATTRA Sustainable Agriculture; The National Center for Appropriate Technology. 2018. pp. 12. Available from: <https://attra.ncat.org/publication/biochar-and-sustainable-agriculture/>

[43] Lampel P. Biochar from Garden Waste as a Potential Hydroponic Growing Substrate. Digitala Vetenskapliga Arkivet; Linköping University, Department of Management and Engineering Master's thesis. 2022. pp. 65. Available from: <https://www.diva-portal.org/smash/get/diva2:1683930/FULLTEXT01.pdf>

[44] Sarauer JL, Coleman MD. Biochar as a growing media component for containerized production of douglas-fir. Canadian Journal of Forest Research. 2018;**48**(5):581-588. DOI: 10.1139/cjfr-2017-0415

[45] Diaz-Perez M, Camacho-Ferre F. Effect of composts in substrates on the growth of tomato transplants. HortTechnology. 2010;**20**(2):361-367. DOI: 10.21273/HORTTECH.20.2.361

[46] Zarate MA. Hydroponics Manual. 2014. Available from: https://www.gob.mx/cms/uploads/attachment/file/232367/Manual_de_hidpononia.pdf

[47] Rajaseger G, Chan LK, Tan YK, Ramasamy S, Khin CM, Amaladoss A, et al. Hydroponics: Current trends in sustainable crop production. Bioinformation. 2023;**19**(9):925-938. DOI: 10.6026/97320630019925

[48] Rajendran S, Domalachenpa T, Arora H, Li P, Sharma A, Rajauria G. Hydroponics: Exploring innovative sustainable technologies and applications across crop production, with emphasis on potato mini-tuber cultivation. Heliyon. 2024;**10**(5):e26823. DOI: 10.1016/j.heliyon.2024.e26823

[49] Eden Green Technology. Hydroponics vs. Traditional Farming: A Comprehensive Comparison. Ministry of Agriculture and Rural Development; 2019. Available from: <https://www.edengreen.com/blog-collection/hydroponics-vs-traditional-farming>

- [50] AgriTech Tomorrow. Water Management in Hydroponics: Techniques, Challenges, Solutions. Indoor & Vertical Farming, Precision Farming Grow Director Ltd.; 2024. Available from: <https://www.agritechtomorrow.com/news/2024/03/31/water-management-in-hydroponics-techniques-challenges-solutions/15419/>
- [51] GMC C. Determination and study of substrates and fertigation in the production of certified citrus plants [thesis]. Mexico: Colegio de Postgraduados; 2012. Available from: <http://colposdigital.colpos.mx:8080/xmlui/handle/10521/1833>
- [52] Service Mexican Geological Survey. Tepojal Monograph. SGM. Mexico: Service Mexican Geological Survey; 2016
- [53] Osuna Fde J, Garcia F, Ramirez S, Canul J, Moreno MF. Substrate Management for Biological Control of Root Rot in Indoor Poinsettia with *Trichoderma* Spp. Mexico: INIFAP; 2011. Available from: <https://www.compucampo.com/tecnicos/manejosustratos-nochebuenainterior.pdf>
- [54] Jaenicke H. Section 3: Substrate. In Good Tree Nursery Practices: Practical Guidelines for Research Nurseries. World Agroforestry Centre; 1999. pp. 30-44. Available from: https://apps.worldagroforestry.org/Units/Library/Books/PDFs/17_Good_tree_nursery_practices.pdf?n=44
- [55] Pastor JN. Use of substrates in nurseries. Terra Latinoamericana. 1999;17(3):231-235. Available from: <https://www.redalyc.org/pdf/573/57317307.pdf>
- [56] Burés S, Gago MC, Morales O, Marfà O, Xavier MF. Water characterization in granular materials. Acta Horticulturae. 1997;450:389-396. DOI: 10.17660/ActaHortic.1997.450.48
- [57] Gayosso-Rodriguez S, Borges-Gomez L, Villanueva-Couoh E, Estrada-Botello MA, Garruña-Hernandez R. Substrates for growing flowers. Agrociencia. 2016;50(5):617-631. Available from: <https://www.scielo.org.mx/pdf/agro/v50n5/1405-3195-agro-50-05-617.pdf>
- [58] Perez-Cabrera CA, Juarez-Lopez P, Anzaldo-Hernandez J, Alia-Tejagal I, Salcedo-Pérez E, Balois-Morales R. Potential benefits of biochar on agricultural crop productivity. Mexican Journal of Agricultural Sciences Agricultural. 2021;12(4):713-725. DOI: 10.29312/remexca.v12i4.2542
- [59] Wiggins Z, Akaeze O, Nandwani D, Witcher A. Substrate properties and fertilizer rates on yield responses of lettuce in a vertical growth system. Sustainability. 2020;12(16):6465. DOI: 10.3390/su12166465
- [60] Schafer G, Lerner B. Physical and chemical characteristics and analysis of plant substrate. Ornamental Horticulture. 2022;28(2):181-192. DOI: 10.1590/2447-536x.v28i2.2496
- [61] Mixquititla-Casbis G, Villegas-Torres OG, Andrade-Rodriguez M, Sotelo-Nava H. Physical and chemical properties of substrates as a function of their particle size and organic-mineral component. Agricultural and Livestock Act. 2022;8(1):e0081007. DOI: 10.30973/aap/2022.8.0081007
- [62] Steiner AA. The universal nutrient solution, proceedings of IWOSC. In: 6th International. Wageningen, The Netherlands: Congress on Soilless Culture; 1984. pp. 633-650. Available from: <https://www.scirp.org/reference/referencespapers?referenceid=1833796>

[63] University of North Carolina. Statistical Analysis System (SAS for Windows). University of North Carolina. Institute Inc., SAS Institute Inc.; 2023. Available from: https://www.sas.com/es_mx/learn/academic-programs/software.html

[64] Amorim BMA, Miler ST, Watanabe CAM, da Silva PVP, Raj GH, Severo RMR, et al. Hydroponic production of ‘ Biquinho’ pepper with brackish water. *Agricultural Water Management*. 2021;**245**:106607. DOI: 10.1016/j.agwat.2020.106607