AGRO PRODUCTIVIDAD

Colegio de Postgraduados

Characterization of regional substrates for the production of plants in containers

Romero-Bautista, Katia Jazmín[1]; Palma-López, David Jesús[1*]; Vázquez-Navarrete, César Jesús[1]; Obrador-Olán, José Jesús[1]; Vlaminck, Winston[2]; Aldrete, Arnulfo[3]; Feintrenie, Laurène[4, 5, 6]

[1] Colegio de Postgraduados - Campus Tabasco, Periférico Carlos A. Molina S/N, H. Cárdenas, Tabasco, México, C. P. 86500.
[2] PalmElit SAS, Parc Agropolis, 2214 Bd de la Lironde, 34980 Montferrier sur Lez, France.
[3] Colegio de Postgraduados - Campus Montecillo, Km 36.5 Carretera México-Texcoco, Estado de México, México, C. P. 56264.
[4] CIRAD, TETIS, Univ.Montpellier, 34000, Montpellier, France.
[5] CATIE, Turrialba, Cartago, Costa Rica, C. P. 30501.
[6] ECOSUR, Lerma, Campeche, México, C. P. 24500.
* Correspondence: dapalma@colpos.mx

ABSTRACT
Objective: To evaluate the physical and chemical properties of waste from the oil palm industry (empty fruit bunches and palm kernel shell charcoal), from the forestry industry (*Cedrela odorata* sawdust and *Eucalyptus* spp. bark), and from the agroindustry (sugarcane bagasse, cocoa pod husk, and coconut fiber), in order to determine their potential as components of regional substrates.
Design/Methodology/Approach: A completely randomized design was used for the experiment. Seven regional substrate treatments with three replicates were used to evaluate the response variables. An analysis of variance (ANOVA) and Tukey's multiple comparison test ($p \leq 0.05$) were used to analyze the results in the InfoStat v. 2020 statistical software.
Results: Regional substrates had similar characteristics —and even a higher concentration of nutrients— than the commercial substrate, which was mainly based on sphagnum peat moss. Substrate S5 —eucalyptus (*Eucalyptus* spp.) bark:cocoa pod husk:cedar (*Cedrela odorata*) sawdust (3:1:1)— had more variables that were statistically similar to the commercial substrate, while S4 —cocoa pod husk:cedar sawdust:palm kernel shell charcoal (3:1.5:0.5)— stood out for its higher concentration of micronutrients. The results identified sustainable and accessible options that meet the recommended criteria for plant production in containers.
Study Limitations/Implications: This study only took into account the characterization of regional waste and substrates; consequently, its effects on future plant production should be evaluated.
Findings/Conclusions: The substrates were sustainable and affordable and met the recommended criteria for the plant production in containers.

Keywords: organic waste, sphagnum peat moss, physical and chemical properties, nursery, recycling.

Citation: Romero-Bautista, K. J., Palma-López, D. J., Vázquez-Navarrete, C. J., Obrador-Olán, J. J., Vlaminck, W., Aldrete, A., & Feintrenie, L. (2025). Characterization of regional substrates for the production of plants in containers. *Agro Productividad*. https://doi.org/10.32854/tsdd2q79

Academic Editor: Jorge Cadena Iñiguez
Associate Editor: Dra. Lucero del Mar Ruiz Posadas
Guest Editor: Juan Francisco Aguirre Medina

Received: March 10, 2025.
Accepted: November 6, 2025.
Published on-line: January XX, 2026.

Agro Productividad, 18(12). December. 2025. pp: 39-52.

INTRODUCTION

Peat moss is an organic, natural, and renewable material, widely used in horticulture and agriculture due to its fiber structure and porosity that favor water retention and drainage [1]. Peat moss mainly comes from peatlands in the northern hemisphere, where anaerobic

decomposition of plant material has created large deposits. However, its extraction implies the drainage of wetlands, resulting in the subsequent loss of ecosystem services [2].

A wide range of waste with the potential to become substrates can be found in southeastern Mexico. The valuation of this waste offers an alternative to mitigate environmental impacts. Waste from fishing, agricultural, forestry, poultry, and cattle-raising activities (and its resulting inputs) can be classified as special waste [3]. This type of waste comes from production processes and is not considered dangerous or part of urban solid waste, because it is not produced by large urban solid waste generators.

One of the main types of waste of the oil palm (*Elaeis guineensis* Jacq.) agroindustry is the empty fruit bunches. This fibrous and lignocellulosic material is the waste of the processing of fresh bunches and each tonne of raw palm oil causes 350 kg of dry waste [4]. The bunches are first introduced into a sterilizer, where they are subjected to high temperatures and moisture in order to facilitate the loosening of the fruits. Afterwards, a threshing machine separates the fruits from the bunches, leaving aside the empty bunches [5]. Another by-product is palm kernel shell charcoal. This hard and compact biomass is obtained from the husk that protects the kernel that contains the palm oil [6]. During this production process, the nuts are crushed to divide the kernels from the husk, which is usually used as a combustion energy source [4]. In the sugarcane (*Saccharum officinarum* L.) agroindustry, sugarcane bagasse is a fibrous waste resulting from the extraction of the juice from cane stalks. This material is mainly made up of raw fiber and neutral and acid detergent fibers [7]. Cocoa pod husk is the waste produced by the cacao (*Theobroma cacao* L.) agroindustry. It accounts for 60-70% of the dry weight of cocoa pods. It is composed of cellulose (35%), hemicellulose (11%), lignin (14.6%), and pectin (6.1%) [8, 9]. Cocoa producers usually throw this waste out in their growing areas. In time, soil microorganisms degrade cocoa pod husks, releasing organic matter back to the soil as nutrients and minerals, starting once again the production cycle [10]. Cedar (*Cedrela odorata* L.) sawdust is a by-product of the timber industry. It has abundant cellulose (45-50%), lignin (23-30%), and hemicellulose (20-30%) [11]. In Mexico, *Cedrela odorata* is the second most popular timber species, after *Eucalyptus* spp., with a 37,296 ha established area in commercial forest plantations. Cedar also classifies second in Tabasco, with 3,211 ha established areas [12]. Its importance in the forestry industry offers opportunities to add value to its waste. Eucalyptus (*Eucalyptus* spp.) has the largest established commercial plantation area in Mexico: 48,523 ha. Out of this total, 21,757 ha are located in Tabasco [12]. This tree is mainly used to produce cellulose and, to a lesser degree, lumber. One of the initial processes of eucalyptus exploitation is debarking, which produces large quantities of waste (bark). Eucalyptus bark is a valuable resource for the circular economy of the forestry industry [13]. Coconut (*Cocos nucifera* L.) fiber is another valuable resource. It is made up of the coconut external shell and an intermedium layer that surrounds the fruit. The white meat inside the coconut shell is known as copra and it has a high commercial value. The coconut fiber by-product is obtained during the copra exploitation from the mesocarp and the short fibers of the shell [14]. Tabasco has the fifth largest planting area (12,644 ha) used for the exploitation of copra [15]. Coconut fiber has favorable properties for the production of plants; however, its effects on the growth, development, yield, and quality of high value crops has not been studied in depth yet [16].

Substrates are made up of solid materials. They are different from the natural soils. They can be made up of minerals, organic matter, and synthetic or waste products. Substrates are used in containers in order to support and anchor to the plant root system. This material can be used pure or mixed. Its main purpose is to guarantee appropriate oxygen and moisture conditions, as well as to provide nutrients required to achieve an optimal plant growth. The composition of these substrates can include porous, low fertility, and lifeless materials that favor aeration and water balance in the root environment [17, 18, 19]. The quality of substrates is fundamental for plant production, because they must provide the physical, chemical, and biological conditions, as well as the essential nutrients, required to achieve the appropriate plant development [20]. In order to evaluate the suitability of the substrate formulas, the following properties were analyzed: apparent density (AD), total porosity (TP), aeration porosity (AP), water retention porosity (WRP), pH, electrical conductivity (EC), organic matter (OM), organic carbon (OC), carbon:nitrogen ratio (C:N), and total nutrient of the substrate [19, 21, 22]. These parameters determine nutrient availability and the development of seedlings, contributing to more sustainable and accessible agricultural practices for the production of plants in containers. Therefore, the objective of this study was to characterize local organic waste and the resulting regional substrates, evaluating their usefulness in the production of plants in containers.

MATERIALS AND METHODS

Study Area

Waste was collected from the Prolade S.A.P.I. de C.V. oil palm extractor and the Presidente Benito Juárez (IPBJ) – Impulsora sugar mill, located in the municipality of Huimanguillo, Tabasco. In addition, wood waste was collected from the "Maderas COCONÁ" lumberyard and cocoa waste came from the Ranchería Nicolás Bravo cocoa plantation, both located in the municipality of Teapa, Tabasco. Finally, the processing and characterization of the waste and the substrates were carried out in the Laboratorio de Ciencia Animal and the Laboratorio Central in the Área de Instrumentación Analítica of the Colegio de Postgraduados - Campus Tabasco.

Organic Waste

The waste evaluated as potential components of regional substrates were: oil palm empty fruit shells, palm kernel shell charcoal, sugarcane bagasse, cocoa pod husk, cedar sawdust, eucalyptus bark, and coconut fiber. In addition, COSMOPEAT® peat moss —the main component of the commercial control substrate— was partially and totally replaced in the regional substrate treatments. The waste was open-air dried, chopped, and sieved in a 5.0 mm mesh before it was processed.

Physical and Chemical Properties of Waste and Substrates

The physical and chemical properties chosen to characterize the waste and substrates were based on previous studies that proved their important role in the quality evaluation of substrates used in the production of plants in containers [21, 23, 24, 25]. The values of each property were determined based on the averages from the three replicates established for each type of organic waste and substrate.

The apparent density (AD) of the organic waste was determined following the NMX-FF-109-SCFI-2008 Mexican standard, which establishes the quality characteristics and specifications of vermicompost [26]. The procedure consisted of drying the sieved sample (5.0 mm mesh) in an oven, at 70±5 °C for 24 h. Five-point-cero and 10 g (W) of the samples were used. The sample was poured into a 100 mL graduated cylinder, wrapped in a dampened cloth over a firm base. The cylinder was hit twenty times on the side, at 10-20 cm height, with a frequency of one blow per second. Subsequently, the final volume (V) of the sample was measured and the following calculation was made:

$$AD = \frac{W(\mathrm{g})}{V\left(\mathrm{cm}^3\right)}$$

The process described by Landis *et al.* was used to determine the total porosity (TP), aeration porosity (AP), and water retention porosity (WRP) of the substrates [27]. The different substrates were placed in 160 mL sealed cells. Water was slowly poured into each substrate, until it was completely saturated (the surface became bright). The total water added to the substrates was recorded (total pore volume). Subsequently, the seal of each cell was removed and the freely-drained water was collected. The volume of drained water was measured (aeration pore volume). The TP, AP, and WRP were determined with the following formulas:

$$TP(\%) = \frac{total\ volume\ of\ pores(\mathrm{mL})}{container\ volume(\mathrm{mL})} * 100$$

$$AP(\%) = \frac{volume\ of\ aeration\ pores(\mathrm{mL})}{container\ volume(\mathrm{mL})} * 100$$

$$WRP(\%) = total\ porosity(\%) - aeration\ porosity(\%)$$

A Hanna® Instruments handheld potentiometer and conductivity meter was used to measure the pH and electric conductivity (EC) of organic waste and substrates, with a solution volume ratio of 1:2 (substrate:distilled water) [28, 29].

The calcination method was used to determine organic matter (OM) and organic carbon (OC) [26]. One-point-five grams of sample were weighted and placed in a previously dried and weighted porcelain crucible. Subsequently, the crucibles were placed for three hours in a muffle that had been previously warmed until it reached 550 °C. Afterwards, the crucibles were cooled in a desiccator and weighted. The ash OM, and OC percentages were calculated. The 1.724 factor proposed by Van Bemmelen was used to convert OM into OC [30].

$$Ash\% = \frac{Weight\ of\ the\ crucible\ with\ ashes(\mathrm{g}) - Weight\ of\ the\ crucible}{sample(\mathrm{g})} * 100$$

$$OM\% = 100 - Ash\%$$

$$OC\% = \frac{OM\%}{1.724}$$

Nitrogen (N) concentration was determined with the semimicro Kjeldalh method, with sulfuric-salicylic acid for the digestion [31]. Zero-point-fifteen grams of the sample were crushed and sieved with a 2.0 mm diameter sieve (mesh 10). The percentages of OC and N were divided to determine the carbon:nitrogen ratio (C:N).

The nutrient concentration of the substrates was measured by wet digestion with the perchloric acid ($HClO_4$) and nitric acid (HNO_3) digestion mix (2:1 ratio) [32]. The extracts were read in a PerkinElmer Inc. AANALYST™ 700 high-performance atomic absorption spectrometer, using the Syngistix™ for AA v. 3.0.3 software.

Substrates

Seven substrates were prepared, including a control. Control was a commercial substrate with a higher proportion of peat moss and it was used in the nursery of Prolade S.A.P.I. de C.V. This material was partially or totally replaced in the other substrates. The substrates were prepared mixing the previously open-air dried waste, sieved in a 5.0 mm mesh. Twenty L of each substrate were prepared for their characterization.

Experimental Design and Statistical Analysis

The experimental design was completely randomized and included 7 regional substrates treatments, with three replicates. They were used to evaluate the responses of the abovementioned variables. An analysis of variance (ANOVA) and Tukey's Multiple Comparison Test were used to analyze the results in the InfoStat v.2020 software [33].

Production Costs of Regional Substrates

The expenses associated with the preparation of regional substrates for the production of plants were taken into account. This analysis included two main components: local waste costs and the costs of preparing the substrates. Local waste costs included the costs of the materials available in the region. Data was gathered about the price per unit of volume of each waste, depending on its availability and transportation to the processing site and manpower. The costs associated with the activities required to prepare the substrates included the collection, cleaning, processing, and mix of waste. The parameters used for this calculation were working hours and hourly rate. The costs in local currency were estimated through the sum of these two elements. This approach resulted in a valuation of the technical feasibility for the implementation of regional substrates in the production of oil palm seedlings.

Structure of the Unit Cost of the Materials Used in the Experiment

This section briefly describes the materials and the conditioning (preparation) process that generated the various substrates used in this research.

a) **Empty fruit bunches**: Provided by the Prolade S.A.P.I. de C.V. oil palm extractor. It was delivered as dry bunches, open-air dried under a shade. It was minced with a Siemens™ meat mincer (5 HP and 220 V). A worker sieved it through a 5 cm mesh for three hours. One worker operated a mini skid steer to load the waste into the container, which was then transported 9.1 km to the nursery.
b) **Oil palm kernel shell charcoal**: Provided by the Prolade S.A.P.I. de C.V. oil palm extractor. Two working days were required to load and unload the charcoal (cost of the working day: MXN$281.00 (USD$16.72)). It was transported in a 1 tonne pick-up truck. This waste was processed with a Siemens™ meat mincer (5 HP and 220 V). One worker sieved it through a 5 cm mesh for three hours.
c) **Eucalyptus bark**: Provided by Tecnotabla by PROTEAK. It was loaded into a dump truck and transported 47.1 km to the nursery, where a worker sieved it through a 5 mm mess for three hours.
d) **Cedar sawdust**: Collected fresh, no later than 3 months after it was produced at a timber shop in Teapa, Tabasco. It was transported 121 km to the nursery, where one worker sieved it through a 5 cm mesh for 3 hours.
e) **Cocoa pod husk**: Collected from a cacao plantation harvest, located in Ranchería San Nicolás, municipality of Teapa, Tabasco. The husk was stored in sacks for six months after the harvest. It was transported 121 km to the nursery and was open-air dried under a shade, before it was sieved using a 5 cm mesh.
f) **Coconut fiber**: Bought online. It consisted of 50% coconut fiber and 50% coconut bran. The 20 L were decompressed after the package was opened. No additional processing was required and it was transported 19.7 km to the nursery.
g) **Peat moss**: Bought online. It recorded a 0.11 g cm^{-3} AD and 45-50% moisture content. It did not require additional processing and it was transported 19.7 km to the nursery.
h) **Perlite**: Bought online. It had a 34-65% porosity, 63% water retention, and 1.5-2.3 mm granules. It did not require additional processing and it was transported 19.7 km to the nursery.
i) **Vermiculite**: Bought online. Granules with fine and coarse particles. It did not require additional processing and was transported 19.7 km to the nursery.

RESULTS AND DISCUSSION

Physical and chemical properties of organic waste

Table 1 shows the physical and chemical characteristics of the diverse types of organic waste. The AD of peat moss (0.11 g cm^{-3}) is statistically similar to the AD of empty fruit bunches and eucalyptus bark. The AD of peat matches the results of Estrada-Botello *et al.* [34] (0.12 g cm^{-3}), although the value of empty fruit bunches in their study (0.24 g cm^{-3}) was higher than the value reported in this research (0.14 g cm^{-3}). Oil palm kernel shell

Table 1. AD, pH, EC, OM, and OC value of the evaluated waste.

Organic wastes	AD g cm^{-3}	pH	EC dS m^{-1}	OM	OC	N	C/N
				%			
Peat moss	0.11^{d}	5.23^{e}	0.80^{c}	69.10^{g}	40.08^{g}	0.83^{d}	48.06^{d}
Empty fruit bunches of palms	0.14^{d}	7.67^{a}	1.16^{b}	91.68^{cd}	53.18^{cd}	2.01^{b}	26.62^{e}
palm kernel shell charcoal	0.48^{a}	7.49^{a}	0.39^{d}	95.47^{b}	55.38^{b}	0.78^{d}	71.31^{c}
sugarcane bagasse	0.08^{e}	6.28^{bc}	0.38^{d}	91.10^{d}	52.84^{d}	0.42^{e}	127.82^{b}
Cocoa pod husk	0.34^{b}	5.42^{de}	1.27^{b}	75.15^{f}	43.59^{f}	2.58^{a}	16.68^{e}
Coconut fiber	0.07^{e}	6.03^{bc}	3.28^{a}	94.52^{bc}	54.82^{bc}	0.48^{e}	115.41^{b}
Eucalyptus bark	0.14^{d}	6.34^{b}	0.34^{d}	82.92^{e}	48.10^{e}	1.06^{c}	44.61^{d}
Cedar sawdust	0.17^{c}	5.83^{cd}	0.35^{d}	98.53^{a}	57.17^{a}	0.19^{f}	297.91^{a}

AD: apparent density. pH: potential of hydrogen. EC: electric conductivity. OM: organic matter. OC: organic carbon. N: nitrogen. C:N: carbon:nitrogen ratio. Means that share the same letter in the same column are not significantly different ($p>0.05$).

charcoal had the greatest AD among all the waste types (0.48 g cm^{-3}) and consequently a greater weight. For its part, cocoa pod husk had a 0.34 g cm^{-3} density, which makes it the second heaviest type of waste. These findings are different from the values reported by Sánchez-Hernández *et al.* [35] (0.676 g cm^{-3}) and Estrada-Botello *et al.* [34] (0.27 g cm^{-3}) for this type of waste in Tabasco.

Meanwhile, coconut fiber and sugarcane bagasse were the waste types with the lowest ADs, indicating that they are lighter than the other analyzed materials. Sánchez-Hernández *et al.* [35] reported a significantly higher AD (0.42 g cm^{-3}) for sugarcane bagasse, which could be attributed to differences in waste management.

The pH values of the analyzed waste have significant differences. The pH values of oil palm kernel shell charcoal (7.49) and empty fruit bunches (7.67) were close to neutrality. Cocoa pod husk and peat were the most acid waste. A clear variability can be seen in the pH results of cocoa pod husk (5.42) reported by other authors. Sánchez-Hernández *et al.* [35] recorded a 6.4 pH, suggesting a slightly acid original environment. For their part, Estrada-Botello *et al.* [34] reported a significantly higher pH (7.4), which indicates that cocoa pod husk waste was practically neutral. Likewise, Palma-López *et al.* [36] recorded a 6.9 pH a greater alkaline level than the results of this research. According to the NOM-021-SEMARNAT-2000 official Mexican standard [37], peat moss, cocoa pod husk, eucalyptus bark, coconut fiber, sugarcane bagasse, and cedar sawdust had a moderately acid pH (5.1-6.5), while empty fruit bunches and oil palm kernel shell charcoal had a moderately alkaline pH (7.4-8.5). These differences can be explained by several factors, including cultivation conditions, cocoa pod husk management, and the geographical origin of the samples. The variable pH of cocoa pod husk depends on regional agricultural practices —*e.g.*, the application of Bordeaux mixture (calcium and sulphur) as a health control measure.

Eucalyptus bark and cedar sawdust recorded the lowest EC values: 0.34 dS m^{-1} and 0.35 dS m^{-1}, respectively. Oil palm kernel shell charcoal (0.39 dS m^{-1}) and sugarcane bagasse (0.38 dS m^{-1}) had statistically similar values. For its part, coconut fiber (3.28 dS m^{-1}) stood out as the waste with the highest salt concentration. The EC of coconut fiber (3.28 dS m^{-1}) was significantly higher than the results of Gayosso-Rodríguez *et al.* [38], who recorded a 1.49 dS m^{-1} EC for this material, indicating potential differences in its origin or in the preparation of the samples.

The N concentrations of the waste recorded a clear variability (0.19-2.58%). Cocoa pod husk and empty fruit bunches had the highest N concentrations, which explains their low C:N ratio. In contrast, cedar sawdust recorded the lowest N concentration and the highest C:N ratio (297.91) among the evaluated materials. This result suggest that this type of waste has a limited mineralization capacity. Consequently, cedar sawdust is not be the best material for the application of N to the substrate. Regional waste had higher organic matter values than peat, indicating a higher carbon availability (Table 1). This high content of organic matter can improve the quality of substrates. Meanwhile, N is an essential structural constituent of all proteins and chlorophyll [39]. Its presence in substrates is key to guarantee the adequate development of plants. The C:N ratio plays a key role in the regulation of the decomposition rate of organic matter and the availability of nutrients in the substrate. The most popular waste used for composting (*i.e.*, empty fruit bunches and cocoa pod husk) recorded the lowest C:N ratio, while fresh cedar sawdust had the highest value among the evaluated waste.

Physical and Chemical Properties of Regional Substrates

Substrate formulations based on regional materials are a sustainable alternative for the production of plants in containers. Several local materials were chosen as substrate components in this study (Table 2). The ratios are connected to the substitution of the components of the commercial substrate, according to their function.

Seven substrates were formulated (control and S1-S6). The control substrate was evaluated as a commercial substrate, given its high ratio of peat moss. This commercial substrate is currently used in "La Razón" nursery of Prolade S.A.P.I. de C.V. to produce oil palm seedlings in the pre-nursery stage. A higher ratio of regional waste was used in substrates S1-S6, complemented with lower volumes of other materials, in order to improve physical and chemical properties and to favor the adequate growth and development of plants grown in containers (cells).

Table 2. Materials used in the formulation of seven substrates and their volumetric ratio.

Substrates	Peat moss	Perlite	Vermiculite	Empty fruit bunches of palms	Cedar sawdust	palm kernel shell charcoal	Cocoa pod husk	Eucalyptus bark	Coconut fiber
Control	3	0	0	0	0	0	0	2	0
S1	1	0.5	0.5	3	0	0	0	0	0
S2	0	0	0	3	1	0.5	0.5	0	0
S3	1	0	0	0	3	0.5	0.5	0	0
S4	0	0	0	0	1.5	0.5	3	0	0
S5	0	0	0	0	1	0	1	3	0
S6	0	0	0	0	1	0	1	0	3

Tables 3 and 4 show the physical and chemical characteristics of the substrates. S4 was the formulated substrate with the highest AD. Additionally, only substrates S1 and S6 recorded statistically similar AD. Abad *et al.* [17] reported that plants grown on the open air must be cultivated in substrates with 0.50-0.75 g cm^{-3} AD. Meanwhile, AD in nurseries (where wind is not a limiting factor) can be as low as 0.15 g cm^{-3}. The AD of the substrates formulated for this study are lower than the recommended density.

TP was statistically similar in the control and S4. Both substrates recorded the highest values, which complied with the recommended values (RV). Meanwhile, substrates S1, S2, S4, S5, and S6 had statistically similar AP values. S3 recorded the lowest AP, while the control had the highest value and was the only substrate to reach the RV. The PA values of the substrates were below the recommended range (20-35%). However, Bowman and Paul and Cabrera [40, 41] suggest that the optimal AP ranges from 10 to 20% although these values belong to substrates commonly used to produce ornamental plants in pots. Regarding the capacity of substrates to retain water in their pores after irrigation, all the evaluated substrates fall within the recommended WRP values (25-55%) [27]. WRP varied between formulated substrates. S4 recorded the highest WRP (49.80%), surpassing the control and the remaining substrates. All substrates complied with the RV for WRP.

Out of the seven substrates evaluated, only two (S1 and S2) had a high pH (>7), according to the classification proposed by Warnecke and Krauskopf [28]. This phenomenon could be attributed to their higher ratio of empty fruit bunches (Tables 2 and 3). The pH of the other substrates fell within the 5.0-6.5 range recommended by Warnecke and Krauskopf [28] and Landis *et al.* [27]. Meanwhile, the EC level of the waste with greater ratio in the substrate diminished when it was mixed with other materials, consequently falling within the value recommended (<1.00 dS m^{-1}) by Landis *et al.* [27]. The EC value of S6 was

Table 3. Physical and chemical characteristics of the evaluated substrates.

Substrates	AD g cm^{-3}	TP	AP	WRP	pH	EC dS m^{-1}	OM	OC	C/N
		%					%		
Control	0.11^{d}	66.46^{a}	20.6^{a}	45.86^{ab}	6.13^{d}	0.36^{c}	68.65^{e}	39.82^{e}	40.28^{b}
S1	0.13^{cd}	58.59^{b}	19.70^{ab}	38.89^{cd}	7.21^{b}	0.81^{b}	66.43^{e}	38.53^{e}	26.56^{d}
S2	0.16^{b}	50.20^{e}	16.77^{ab}	33.43^{d}	7.60^{a}	0.78^{b}	83.22^{c}	48.27^{c}	26.85^{d}
S3	0.11^{b}	53.54^{cd}	13.54^{b}	40.00^{bc}	6.59^{c}	0.25^{c}	89.31^{a}	51.81^{a}	67.61^{a}
S4	0.31^{a}	66.46^{a}	16.67^{ab}	49.80^{a}	5.49^{f}	0.72^{b}	74.58^{d}	43.26^{d}	26.73^{d}
S5	0.16^{bc}	51.41^{de}	16.77^{ab}	34.65^{cd}	5.87^{e}	0.22^{c}	85.56^{bc}	49.63^{bc}	35.26^{c}
S6	0.13^{cd}	54.95^{c}	17.07^{ab}	37.88^{cd}	5.82^{e}	1.08^{a}	87.10^{ab}	50.52^{ab}	40.66^{c}
RV		60-80	20-35	25-55	5.5-6.5	<1.0			50-70

AD: apparent density. TP: total porosity. AP: aeration porosity. WRP: water retention porosity. pH: potential of hydrogen. EC: electric conductivity. OM: organic matter. OC: organic carbon. (C/N): carbon:nitrogen ratio. Control (experimental control): peat moss:eucalyptus bark (3:2). S1: empty fruit bunches:peat moss:perlite:vermiculite (3:1:0.5:0.5). S2: empty fruit bunches:cedar sawdust:palm kernel shell charcoal:cocoa pod husk (3:1:0.5:0.5). S3: cedar sawdust:peat moss:palm kernel shell charcoal:cocoa pod husk (3:1:0.5:0.5). S4: cocoa pod husk:cedar sawdust:palm kernel shell charcoal (3:1.5:0.5). S5: eucalyptus bark:cocoa pod husk:cedar sawdust (3:1:1). S6: coconut fiber:cocoa pod husk:cedar sawdust (3:1:1). RV: recommended values for substrates used to produced forest species in trays [27, 19]. Means that share letters in the same column are not significatively different (p>0.05).

slightly higher (1.08 dS m^{-1}). However, according to Abad *et al.* [42], the acceptable content of soluble salts in substrates can reach up to 1.5 dS m^{-1}. For their part, Warnecke and Krauskopf [28] pointed out that the adequate EC range in substrates fluctuates between 1.0 and 2.0 dS m^{-1}.

OM and OC contents were similar between control and S1. However, the other substrates recorded a higher OC content. S3 recorded the highest OC content, although it also had the lowest N content (Table 4) and the highest C:N ratio among all the substrates. This situation would limit the absorption of N by the plants. All the substrates complied with the C:N ratio values included in the criteria set forth by Landis *et al.* [27]. With a balanced C:N ratio (50:70), microorganisms can efficiently mineralize organic matter, releasing essential nutrients that are then absorbed by the plants. S4 recorded a higher micronutrient and OC content than the control; among all the evaluated substrates, it had the lowest pH (5.49). For their part, S5 and S6 had statistically similar pH values (5.87 and 5.82, respectively). Additionally, these two substrates recorded a higher micronutrient content than control. Given its impact on nutrient availability (particularly micronutrients), pH is a critical factor in mineral soils. Under extreme pH conditions, certain nutrients can become hard to reach or even toxic. Organic soils have a greater availability of nutrients at a lower pH (≈5.5.) than mineral soils, which have a maximum pH availability of ≈6.5 [27]. This difference could explain the higher concentration of micronutrients and OM in S4 —whose pH is closer to the optimal level for organic soils. Controlling pH in organic crop environments is of great importance.

Substrates S1, S2, S4, S5, and S6 had a higher N and K concentration than the control. For its part, the higher acidity of S4 was likely the cause of its micronutrient concentration —the highest among all substrates.

Economic evaluation of the production of regional substrates

Table 5 shows the costs associated with organic waste. Costs were calculated based on an exchange rate of MXN$16.80 pesos per US dollar (April 2024).

Table 4. Average nutrient concentration in the evaluated substrates.

Substrates	N	P	K	Mg	Ca	Fe	Mn	Zn	Cu
	(%)					(mg kg^{-1})			
Control	1.00^{e}	0.33^{ab}	0.12^{b}	2.20^{a}	0.87^{c}	8713.64^{b}	168.04^{de}	24.42^{e}	10.32^{f}
S1	1.46^{c}	0.44^{a}	0.72^{a}	2.13^{a}	1.19^{b}	8557.40^{b}	171.88^{d}	26.88^{e}	47.65^{b}
S2	1.80^{a}	0.29^{bc}	0.76^{a}	0.32^{c}	1.32^{a}	4699.88^{c}	151.66^{ef}	35.45^{d}	49.91^{b}
S3	0.76^{f}	0.09^{d}	0.21^{b}	0.68^{b}	0.64^{d}	4399.22^{c}	140.30^{f}	23.66^{e}	17.015^{e}
S4	1.63^{b}	0.17^{cd}	0.23^{b}	0.37^{bc}	0.73^{d}	14793.21^{a}	632.29^{a}	114.17^{a}	55.82^{a}
S5	1.41^{c}	0.12^{d}	0.15^{b}	0.25^{c}	0.94^{c}	8024.80^{b}	338.15^{c}	61.13^{c}	28.83^{d}
S6	1.25^{d}	0.13^{d}	0.74^{a}	0.32^{c}	0.67^{d}	8773.42^{b}	394.99^{b}	82.96^{b}	39.70^{c}

N: nitrogen. P: phosphorous. K: potassium. Mg: magnesium. Ca: calcium. Fe: iron. Mn: manganese. Zn: zinc. Cu: copper. Control (experimental control): peat moss:eucalyptus bark (3:2). S1: empty fruit bunches:peat moss:perlite:vermiculite (3:1:0.5:0.5). S2: empty fruit bunches:cedar sawdust:palm kernel shell charcoal:cocoa pod husk (3:1:0.5:0.5). S3: cedar sawdust:peat moss:palm kernel shell charcoal:cocoa pod husk (3:1:0.5:0.5). S4: cocoa pod husk:cedar sawdust:palm kernel shell charcoal (3:1.5:0.5). S5: eucalyptus bark:cocoa pod husk:cedar sawdust (3:1:1). S6: coconut fiber:cocoa pod husk:cedar sawdust (3:1:1) Means that share letters in the same column are not significatively different ($p>0.05$).

Table 5. Costs of organic waste substrate (including costs of the waste, transportation to the nursery and preparation).

Organic wastes	Cost per liter (MXN L^{-1})	Cost per liter (USD L^{-1})
Empty fruit bunches of palm	$0.03	0.0018
Palm kernel shell charcoal	$1.39	0.0827
Eucalyptus bark	$0.71	0.0422
Cedar sawdust	$2.50	0.1488
Cocoa pod husk	$7.79	0.4636
Coconut fiber	$7.75	0.4613
Peat moss	$12.62	0.7511
Perlite	$13.55	0.8065
Vermiculite	$22.65	1.3482

Exchange rate: USD$1 = MXN$16.80 (April 2024).

Unit Cost per Liter of Regional Substrates

The study cost included the abovementioned materials and the values of the substrate mixes. This analysis recorded a variability in the prices of substrates (Table 6). With a higher empty fruit bunches ratio, S2 was the most economical substrate, at a cost of MXN$1.44 L^{-1}. In contrast, the control —which had more peat moss than S1-S6— was the most expensive substrate, at a cost of MXN$7.86 L^{-1}. The prices of substrates S1 (MXN$6.16 L^{-1}) and S6 (MXN$6.71 L^{-1}) were closer to the prices of the control substrate.

Table 6. Costs of the regional substrates used in the experiment at Huimanguillo, Tabasco.

Substrates	Control	S1	S2	S3	S4	S5	S6
Cost per liter (MXN L^{-1})	$7.86	$6.16	$1.44	$4.94	$5.56	$2.48	$6.71
Cost per liter (USD L^{-1})	$0.4678	$0.3666	$0.0857	$0.2940	$0.3309	$0.1476	$0.3994

Control: peat moss:eucalyptus bark (3:2). S1: empty fruit bunches:peat moss:perlite:vermiculite (3:1:0.5:0.5). S2: empty fruit bunches:cedar sawdust:palm kernel shell charcoal:cocoa pod husk (3:1:0.5:0.5). S3: cedar sawdust:peat moss:palm kernel shell charcoal:cocoa pod husk (3:1:0.5:0.5). S4: cocoa pod husk:cedar sawdust:palm kernel shell charcoal (3:1.5:0.5). S5: eucalyptus bark:cocoa pod husk:cedar sawdust (3:1:1). S6: coconut fiber:cocoa pod husk:cedar sawdust (3:1:1). Exchange rate: USD$1 = MXN$16.80 (April 2024).

Seedling production depends on two key factors: the cost and the availability of the materials required to formulate the substrates [43]. An ideal substrate must have characteristics that favor the species to be produced and should be easily available in the vicinity of the nursery, in order to minimize labor and costs [44]. Therefore, in the case of the regional substrates analyzed in this study, S2 had the highest ratio of empty fruit bunches and S5 had the highest ratio of eucalyptus bark. Both are the most inexpensive substrates, due to their regional availability.

CONCLUSIONS

The organic waste available in Tabasco has the potential to be used as substrate in the production of plants grown in containers. The physical and chemical properties of the substrates are closely related to the characteristics of each type of waste, which depend on its origin and handling.

Some properties of the evaluated substrates are similar to the characteristics of the commercial substrate (peat:eucalyptus bark (3:2)) that was used as control for this study. Specifically, S5 (eucalyptus bark:cocoa pod husk:cedar sawdust (3:1:1)) had the highest number of variables that where statistically similar to the commercial substrate. Additionally, S1 (empty fruit bunches:peat:perlite:vermiculite (3:1:0.5:0.5)) and S4 (cocoa pod husk:cedar sawdust:palm kernel shell charcoal (3:1.5:0.5)) recorded a higher concentration of micronutrients than the commercial substrate. Choosing to use regional substrates is mainly based on the ease with which the waste they are composed of can be acquired, as well as their physical and chemical properties, which can be applied for the production of plants in containers.

ACKNOWLEDGEMENTS

The authors would like to thank the Consejo Nacional de Humanidades, Ciencias y Tecnologías (CONAHCYT), the Colegio de Postgraduados, and CIRAD-PalmElit for the funding and support provided for this research.

This work was developed within the framework of the collaboration research projects n°2021/17 (CIRAD-PalmElit) and n°2024/15 (OptiPalMex: inclusive optimization of the production of Mexican oil palm), funded by the Fonds d'études et d'aide au secteur privé (FASEP-innovation verte) of the Agence France Trésor (FASEP AC/1301/MEXIQUE PALMELIT). Project leaders: Laurène Feintrenie (CIRAD, UMR TETIS, laurene.feintrenie@cirad.fr) and Xavier Lacan (PalmElit, xavier.lacan@palmelit.com).

The authors would also like to thank Prolade S.A.P.I. de C.V., who provided staff and materials in their "La Razón" oil palm nursery, where the experiment was established. Finally, they would like to thank Mr. Leandro Santos López (engineer) and Mr. Juan Andrés Méndez García (engineer), who shared their experience and advised the field experiment.

REFERENCES

[1] USGS. (2024). Peat Statistics and Information. Available online. https://www.usgs.gov/centers/national-minerals-information-center/peat-statistics-and-information

[2] Ponce, J.F., Coronato, A.M.J., Fernández, M., Rabassa, J.O., Roig, C. (2014). Las turberas de Tierra del Fuego y el clima del pasado. *Ciencia Hoy*; 23; 137; 2-2014; 11-17.

[3] Ley General para la Prevención y Gestión Integral de los Residuos. (2023). Diario Oficial de la Federación. Congreso de la Unión. 08 de mayo de 2023. pp. 06. https://www.diputados.gob.mx/LeyesBiblio/pdf/LGPGIR.pdf

[4] Van Dam, J. (2016). Subproductos de la palma de aceite como materias primas de biomasa. *Palmas, 37*(Especial Tomo II), pp. 149-156.

[5] Obada, D.O., Kekung, M.O., Levonyan, T., Norval, G.W. (2023). Palm oil mill derived empty palm fruit bunches as a feed stock for renewable energy applications in Nigeria: A review. *Bioresource Technology Reports*. 24, 2023, 101666, https://doi.org/10.1016/j.biteb.2023.101666

[6] Kareem, M.A., Raheem, A.A., Oriola, K.O., Abdulwahab, R. (2022). A review on application of oil palm shell as aggregate in concrete - Towards realizing a pollution-free environment and sustainable concrete. *Environmental Challenges*, Volume 8, 100531, ISSN 2667-0100, https://doi.org/10.1016/j.envc.2022.100531 .

[7] Jácome-Pilco, C., García-Culqui, R., Guevara-Narváez, L., Moreta-Guangasi, T. (2023). Revalorización del bagazo de caña de azúcar (*Saccharum officinarum*) como residuo importante para la agroindustria. *593 Digital Publisher CEIT, 8*(3), 134-148 https://doi.org/10.33386/593dp.2023.3.1661

[8] Campos-Vega, R., Nieto-Figueroa, K.H., Oomah, B.D. (2018). Cocoa (*Theobroma cacao* L.) pod husk: renewable source of bioactive compounds. *Trends in Food Science & Technology*. 81, 172-184 https://doi.org/10.1016/j.tifs.2018.09.022

[9] Soares, T.F., Oliveira, M.B.P.P. (2022). Cocoa By-Products: Characterization of bioactive compounds and beneficial health effects. *Molecules, 27*(5), 1625; https://doi.org/10.3390/molecules27051625

[10] Porto de Souza, V.L., Valladares-Diestra, K.K., Amaro, B.G., Fátima, M.A., Sarmiento, V.Z., Zwiercheczewski de, O.P., Vinícius de, M.G., Ricardo, S.C. (2022). Added-value biomolecules production from cocoa pod husks: A review. *Bioresource Technology*, 344, 126252. https://doi.org/10.1016/j.biortech.2021.126252

[11] Mallakpour, S., Sirous, F., Mustansar, H.C. (2021). Sawdust, a versatile, Inexpensive, readily available bio-waste: From mother earth to valuable materials for sustainable remediation technologies. *Advances in Colloid and Interface Science 295*(2021) 102492. https://doi.org/10.1016/j.cis.2021.102492

[12] SNIF. (2024). Producción y Productividad. Plantaciones Forestales Comerciales establecidas con apoyos de la CONAFOR. https://snif.cnf.gob.mx/produccion_y_productividad/. Fecha de consulta: Consultado 27 de diciembre de 2024.

[13] Ferrer-Villasmil, V., Fuentealba, C., Reyes-Contreras, P., Rubilar, R., Cabrera-Barjas, G., Bravo-Arrepol, G., Escobar-Avello, D. (2024). Extracted *Eucalyptus globulus* Bark Fiber as a Potential Substrate for *Pinus radiata* and *Quillaja saponaria* Germination. *Plants 2024*, 13, 789. https://doi.org/10.3390/plants13060789

[14] Mariotti, B., Martini, S., Raddi, S., Tani, A., Jacobs, D.F., Oliet, J.A., Maltoni, A. (2020). Coconut coir as a sustainable nursery growing media for seedling production of the ecologically diverse quercus species. *Forests. 11*(5), 522 https://doi.org/10.3390/f11050522

[15] SIAP. (2024). Anuario estadístico de la producción ganadera. Secretaria de Agricultura y Desarrollo Regional. https://nube.siap.gob.mx/cierre_pecuario/. Fecha de consulta: 27 diciembre de 2024.

[16] Tuckeldoe, R.B., Maluleke, M.K., Adriaanse, P. (2023). El efecto del sustrato de fibra de coco en el rendimiento y la calidad nutricional de las variedades de pimientos dulces (*Capsicum annuum*). *Sci Rep* 13, 2742. https://doi.org/10.1038/s41598-023-29914-0

[17] Abad, M., Noguera, P., Carrión, C. (2005). Sustratos para el cultivo sin suelo y fertirrigación. In: Cadahia C (Ed.) 2005. Fertirrigación. Cultivos hortícolas, frutales y ornamentales. Ed. Mundi-Prensa. Madrid. pp. 299-354.

[18] Cruz, C.E., Sandoval, V.M., Volke, H.V.H., Can, C.A., Sánchez, E.J. (2012). Efecto de mezclas de sustratos y concentración de la solución nutritiva en el crecimiento y rendimiento de tomate. *Revista mexicana de ciencias agrícolas, 3*(7), 1361-1373.

[19] Secretaría de Economía. (2016). NMX-AA-170-SCFI-2016: Norma mexicana para la certificación de operación de viveros forestales. Diario Oficial de la Federación. 07 de diciembre de 2016. México, D. F. pp. 17-28.

[20] Antunes, L.F.S., Azevedo, G., Correia, M.E.F. (2019). Produção de mudas de girassol ornamental e seu desenvolvimento em vasos utilizando como substrato o gongocomposto. *Revista Científica Rural* 21, 299–314. http://dx.doi.org/10.30945/rcr-v21i2.2698.

[21] Castro, G.S.L., Aldrete, A., López, U.J., Ordaz, C.V.M. (2019). Caracterización física y química de sustratos con base en corteza y aserrín de pino. *Madera y bosques. 25*(2), e2521520 https://doi.org/10.21829/myb/2019.2521520

[22] Aguilera-Rodríguez, M., Aldrete, A., Trejo-Téllez, L.I., Ordaz-Chaparro, V.M. (2021). Sustratos con aserrín de coníferas y latifoliadas para producir planta de *Pinus patula* Schiede ex Schltdl. *et* Cham. *Agrociencia* 55: 719-732. https://doi.org/10.47163/agrociencia.v55i8.2664

[23] Cabrera, I.R. (1999). Propiedades, uso y manejo de sustratos de cultivo para la producción de plantas en maceta. *Revista Chapingo Serie Horticultura 5*(1): 5-11. https://doi. org/10.5154/r.rchsh.1998.03.025

[24] Martínez, P.F., Roca,D. (2011). Sustratos para el cultivo sin suelo. Materiales, propiedades y manejo. En: Flórez R., V.J. (Ed.). Sustratos, manejo del clima, automatización y control en sistemas de cultivo sin suelo. Editorial Universidad Nacional de Colombia. Bogotá, Colombia. pp. 37-77.

[25] Landis, T.D., Jacobs, D.F., Wilkinson, K.M., Luna, T. (2014). Growing media. En: Wilkinson, K. M., T. D. Landis, D. L. Haase, B. F. Daley and R. K. Dumroese. (Eds.). Tropical Nursery Manual. A guide to starting and operating a nursery for native and traditional plants. Agriculture Handbook 732. United States Department of Agriculture, Forest Service. Washington, DC., USA. pp. 101-122.

[26] Secretaría de Economía. (2008). NMX-FF-109-SCFI-2008: Norma mexicana para humus de lombriz (lombricomposta)-especificaciones y métodos de prueba. Diario Oficial de la Federación. 10 de junio de 2008. México, D. F. pp. 21-22.

[27] Landis, T.D., Tinus, R.W., McDonald, S.E., Barnett, J.P. (1990). Containers and Growing Media, Vol. 2, The Container Tree Nursery Manual. Agric. Handbook. 674. U.S. Department of Agriculture, Forest Service Washington, DC: 88p.

[28] Warnecke, D.D., Krauskopf, D.M. (1983). Greenhouse growth media: Testing and nutrition guidelines, Extension Bulletin E1736. Cooperative Extension Service, Michigan State University. Michigan, USA. 7 p.

[29] Torres, A.P., Camberato, A., López, R.G., Mickelbart, M.V. (2013). Producción comercial de cultivos bajo invernadero y vivero. Departamento de Horticultura y Arquitectura de Áreas Verdes, Purdue University. Indiana, USA. 5p.

[30] Van Bemmelen, J.M. (1890). Über die Bestimmung des Wassers, des Humus, des Schwefels, der in den colloïdalen Silikaten gebundenen Kieselsäure, des Mangans u. s. w. im Ackerboden. *Die Landwirthschaftlichen Versuchs-Stationen* 37: 279-290.

[31] Bremner, J.M. (1965). Total Nitrogen. In: Norman, A.G. (ed.) Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties No. 9.2. *Am. Soc. of Agronomy*. Madison, WI, USA, pp. 1149-1178. https://doi. org/10.2134/agronmonogr9.2.c32

[32] Álvarez-Sánchez, M.E., Marín-Campos, A. (2011). Manual de procedimientos analíticos de suelo y planta Laboratorio de Química, Departamento de Suelos. Universidad Autónoma Chapingo. Chapingo, México. pp. 42-53.

[33] Di Rienzo, J.A., Casanoves, F., Balzarini, M.G., Gonzalez, L., Tablada, M., Robledo, C.W. (2020). InfoStat versión 2020. Centro de Transferencia InfoStat, FCA, Universidad Nacional de Córdoba, Argentina. URL http://www.infostat.com.ar

[34] Estrada-Botello, M.A., Gayosso-Rodríguez, S., Pérez-Cabrera, C.A., Villanueva-Couoh, E. (2024). Caracterización física y química de residuos orgánicos con uso potencial como componentes de sustratos hortícolas. *Bioagro, 36*(2), 211-222. https://doi.org/10.51372/bioagro362.9

[35] Sánchez-Hernández, R., Ordaz-Chaparro, V.M., Palma-López, D.J., Sánchez-Bolón, J. (2006). El vermicompostaje: Elemento útil en la agricultura sustentable. primera edición. Fundación Produce Tabasco A.C. Villahermosa, Tabasco. 46 p.

[36] Palma-López, D.J., Castillo-Salas, J.M., Salgado-García, S., Ortiz-Ceballos, Á.I., Aceves-Navarro, E. (2016). Caracterización química de abonos orgánicos enriquecido con guano de murciélago. *Agroproductividad 9*(12), pp: 10-15.

[37] Secretaría de Medio Ambiente y Recursos Naturales. (2002). NOM-021-SEMARNAT-2001 que establece las especificaciones de fertilidad, salinidad y clasificación de los suelos. Estudios, muestreo y análisis. Diario Oficial de la Federación. 31 de diciembre de 2002. México, D. F. 13 p.

[38] Gayosso-Rodríguez, S., Borges-Gómez, L., Villanueva-Couoh, E., Estrada-Botello, M., Garruña-Hernández, R. (2018). Caracterización física y química de materiales orgánicos para sustratos agrícolas. *Agrociencia 52*(4), 639-652.

[39] Salgado-García, S., Palma-López, D.J., Castelán-Estrada, M., Lagunes-Espinoza, L.C., Ortiz, H. (2013). Manual para el muestreo de suelos, plantas y aguas e interpretación de análisis para la producción sostenible de alimentos. Colegio de Postgraduados-Campus Tabasco. H. Cárdenas, Tabasco, México. 101 p.

[40] Bowman, D.C., Paul, J.L. (1983). Understanding of container media vital knowledge for growing successful plants. Pacific Coast Nurseryman and Garden Supply Dealer. March Issue. pp. 48-50

[41] Cabrera, I.R. (1995). Fundamentals of container media management: Part I. Physical properties. Rutgers Cooperative Extension Factsheet. 4 p. https://njaes.rutgers.edu/fs812/

[42] Abad, M., Noguera, P., Carrión, C. (2004). Los sustratos en los cultivos sin suelo. In: Urrestarazu, M. G. (ed). Tratado de Cultivo sin Suelo. MundiPrensa. Madrid, España. pp: 113-158.

[43] Meneghelli, L.A.M., Monaco, P.A.V.L., Haddade, I.R., Meneghelli, C.M., Krause, M.R., Vieira, G.H.S. (2017). Produção de mudas de café arábica em substrato composto de resíduo da secagemdos grãos. *Coffee Science*, 12, 3, p. 381-388.

[44] Escobar, R.R., Buamscha, M.G. (2012). Sustrato o medio de crecimiento. In: Buamscha MG, Contardi LT, Dumroese RK, Enricci JA, Escobar RR, Gonda HE, Jacobs DF, Landis TH, Luna T, Mexal JG, Wilkinson KM (eds) Producción de plantas en viveros forestales. Colección Nexos. Buenos Aires, Argentina pp. 8.