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Evaluation of Pecan Nutshell (*Carya illinoensis* [Wangenh.] K. Koch) in the Production of Jalapeño Pepper (*Capsicum annuum* L.) Seedlings
Evaluación de la Cáscara de Nuez Pecanera (*Carya illinoensis* [Wangenh.] K. Koch) en la Producción de Plántulas de Chile Jalapeño (*Capsicum annuum* L.)

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SUMMARY

Due to its high salt content and phytotoxic substances, pecan nutshells (*Carya illinoensis* [Wangenh.] K. Koch) pose an environmental problem when discarded in large quantities. This study aimed to evaluate the use of pecan nutshells in the production of semicomposts for growing jalapeño pepper (*Capsicum annuum* L.) seedlings. The research consisted of three experiments: in the first, the shells from three shelling facilities were characterized based on pH, electrical conductivity, and germination index. In the second experiment, pecan shells were mixed with horse manure to produce semicompost, which was then used as a substrate for jalapeño seedlings in the third experiment. Statistical differences were observed in the salt concentrations and phytotoxic compound content among the shells studied, which were reflected in the germination index. The results showed that the semicomposts produced did not exhibit differences in the evaluated variables, indicating that the semicomposting process effectively neutralized the variations initially observed in the shells from different processing facilities. It was found that using pecan nutshell semicompost, either alone or mixed with peat, produced seedlings that were statistically comparable to the control treatment (peat) in quality parameters such as slenderness and Dickson's quality index, in three out of the six treatments studied.

Index words: *agroindustrial residues, germination, growth, phytotoxicity, semi-compost.*

RESUMEN

Por su contenido de sales y sustancias fitotóxicas, la cáscara de nuez pecanera (*Carya illinoensis* [Wangenh.] K. Koch) representa un problema ambiental al ser desechada en grandes cantidades. El objetivo fue evaluar el uso de la cáscara de nuez pecanera en la producción de semicompostas utilizadas para la producción de plántulas de chile jalapeño (*Capsicum annuum* L.). El estudio consistió en tres experimentos: en el primero se caracterizó la cáscara de tres descascaradoras utilizando las variables pH, conductividad eléctrica e índice de germinación. Posteriormente en el experimento 2, se mezclaron cáscara de nuez pecanera y estiércol de caballo para producir semicomposta, la cual se utilizó como sustrato para plántulas de chile jalapeño en el experimento 3. Se encontraron diferencias estadísticas en la concentración de sales y el contenido de compuestos fitotóxicos en la cáscara en estudio, las cuales se reflejaron en el índice de germinación. Los resultados mostraron que las semicompostas producidas no presentaron diferencias en las variables evaluadas, lo que indica que el proceso de semicompostaje permite eliminar las diferentes características observadas en la cascara proveniente de las diferentes procesadoras. Se encontró que el uso de semicomposta de cáscara de nuez pecanera, solo o mezclado con turba, produjo plántulas estadísticamente comparables con el testigo (turba) en cuanto a variables de calidad como esbeltez e índice de calidad de Dickson, con tres de los seis tratamientos en estudio.

Palabras clave: *residuos agroindustriales, germinación, crecimiento, fitotoxicidad, semicomposta.*

INTRODUCTION

Mexico ranks among the principal producers of pecan nuts (*Carya illinoinensis*) (Cervantes-Vázquez, Orona, Vázquez, Fortis, and Espinoza, 2018), with a total production of 164 651 tons, with the state of Chihuahua being the main producer, accounting for 117 114 tons (SIAP, 2022). This production generates a significant amount of waste, including the shuck, which consists of the pericarp and mesocarp of the fruit and is produced during harvesting. Another major waste is the shell or endocarp, which represents 40-50% of the nut´s weight and is generated during processing to obtain the almond and add value to the product (Prado *et al.,* 2013). Most pecan nutshells (PeNush) are not properly processed or disposed of due to their low economic value and the high costs associated with disposal (Prado *et al.,* 2013). This results in accumulation and environmental pollution (Trevizol *et al.,* 2013), since pecan shells contain acidic, water-soluble phytotoxic compounds (Massey, 1925) and salts. The concentration of these salts depends on irrigation water quality, management practices, fertilization, production cycles, and pecan nut variety (Flores-Córdova *et al.,* 2016a; Flores-Córdova and Sánchez, 2016b; Orona, Sangerman, Fortis, Vázquez, and Gallegos, 2013).

Despite this, PeNush stands out used as road filler, abrasive, thermal insulation (Parodi, 2018), a source of flavonoids and tannins (Kaksonen and Puhakka, 2007), absorbent of heavy metals such as zinc, cadmium, nickel (Aguayo-Villarreal, Bonilla, and Muñiz, 2017), and chromium (Boeykens, Saralegui, Cracciolo, and Piol, 2018), as well as an absorbent of organic compounds from wastewater (Torres-Pérez and Soria, 2015), carbon source in fermentation processes to obtain valuable enzymes such as amylases, proteases, cellulases (Orzua *et al*., 2009), obtaining fuels such as bioethanol (Hossain, Haji, and Mahlia, 2017).

PeNush has been reported to contain the necessary elements for the initial development of crops (Romero-Arenas *et al*., 2013). However, they have hardly been evaluated for developing new products or applications (Vargas-Corredor and Perez, 2018), even some that could replace existing ones (Zhang *et al*., 2020).

In this context, aerobic controlled transformation processes such as semi-composting (Semic), which is a system that does not fully meet the characteristics of composting because it does not reach the thermophilic phase (Black *et al*., 2014) and do not require specific management for temperature control. However, the mixtures were turned to homogenize the contents, reduce the formation of anaerobic zones, and promote adequate decomposition and transformation of the waste (Sánchez-Rosales *et al*., 2019). Semic is used for the transformation of organic waste into high-quality organic substrates (Sánchez-Rosales *et al*., 2017; Sánchez-Rosales *et al*., 2019) used in the propagation of vegetables (Hernández-Rodríguez *et al.,* 2017), which may be an alternative for the conversion of the PeNush.

Therefore, the main objective of this study was to evaluate the use of semi-composts obtained from PeNush (*Carya illinoensis* [Wangenh.] K. Koch) in the production of jalapeño pepper seedlings (*Capsicum annuum* L.).

MATERIALS AND METHODS

The experiment was conducted in the facilities of the Autonomous University of Chihuahua, Chihuahua, Mexico, at coordinates 28° 39′ 25.3″ N, 106° 05′ 13.5″ W, with a climatological classification of warm steppe-dry climate (Bsh), according to Köppen modified by García (1981), with an average annual temperature of 18.2 °C and annual average precipitation of 403 mm. The study consisted of three experiments:

Experiment 1: pH, electrical conductivity and phytotoxicity of the PeNush from different sources.

Experiment 2: production of semi-compost (SC) from the PeNush studied.

Experiment 3: use of the SC prepared from PeNush as the substrate for jalapeño pepper seedlings, cultivar Jalapeño M (Lujan-Favela and Chávez, 2003; Park, Luo, Zhou, Fonseca, and Stommel, 2024).

The PeNush used were collected from three processors (PROC) as of October 19th, 2019: La Nogalera (LNO) located on the Jiménez-Parral highway, which processes pecans nuts from different states in the country; Chipa Pecans Nut Company (CPN), which markets pecan almonds; and Procesadora Jimenuez (JIM), the largest pecan nut collection center in Mexico, the last two in Jiménez city in the state of Chihuahua.

pH, Electrical Conductivity and Phytotoxicity of an Aqueous Solution of Pecan Nutshells

This phase involved obtaining the aqueous solution of PeNush from each PROC separately, by soaking 100 g of the sample in 300 mL of distilled water (MAPA, 1986) in 0.5 L plastic containers. The process lasted 30 days due to the complexity of the water-soluble and moderately water-soluble phenolic compounds (De la Rosa *et al*., 2014). The following treatments were established: LNO-30d, CPN-30d, and JIM-30d, with three replicates each.

After soaking the PeNush for 30 days, the solution was filtered through a cloth, and the following variables were evaluated: pH with a portable Dr. Meter potentiometer, electrical conductivity (EC; dS m^{-1}) with a Beckman conductivity meter, and germination index (GI; %) by phytotoxicity bioassays according to the method described by Zucconi, Pera, Forte, and DeBertoli (1981) using lettuce seeds (*Lactuca sativa* L) due to its high sensitivity to phytotoxic compounds (Huerta, Cruz, Aguirre, Caballero, and Pérez, 2015) cultivar Climax.

Statistical analysis was performed by fitting the model corresponding to a completely randomized design (DCA) and comparing the means with the Tukey test ($P < 0.05$) using the SPSS version 25 statistical package (IBM SPSS Statistics, 2017).

Production of Semi-Compost from Pecan Nutshells

The preparation of a starting mixture of organic waste with a C:N ratio of 25:1 has been recommended to obtain high-quality organic fertilizers (Sánchez-Rosales *et al*., 2019). For this purpose, the characterization of total nitrogen content by Micro-Kjeldahl (Instituto Mexicano del Petróleo, 2006), total organic carbon (García and Ballesteros, 2005), and moisture content (ASTM International, 2000) of the PeNush under study and horse manure, which came from a stable located on the outskirts of the city of Chihuahua, was carried out to calculate the amount of each residue, which was achieved with 50:50 (v:v) of PeNush and horse manure, respectively.

The mixtures were placed in 58 L plastic containers, each with six 0.5 cm diameter holes at the bottom, and positioned under a galvanized sheet metal roof to protect them from rain and wind. The Semic process lasted 24 weeks, the recommended decomposition period for the Semic process in a similar environment (Sánchez-Rosales *et al*., 2019), which began on August 26th, 2020, with the moistening of the organic waste mixtures, which from then on were irrigated at their discretion every third day to maintain a moisture level between 50 and 60%, as determined by contact tests, to avoid leaching. The mixtures were manually stirred every 28 days to homogenize the contents, reduce the formation of anaerobic zones, and promote adequate decomposition and transformation of the residues (Sánchez-Rosales *et al*., 2019).

The experimental design included the treatments: LNO-Semic, CPN-Semic, and JIM-Semic, each with four replicates. The variables evaluated in the prepared SC were: pH in dilution with deionized water 1:10 (w:v) with a Fisher Scientific Accument AB15-US potentiometer, EC (dS m^{-1}) in dilution with deionized water 1:10 (w:v) using a Beckman conductivity meter, and germination index (GI; %) with the method described by Zucconi *et al*. (1981).

Statistical analysis was performed by fitting the model corresponding to a DCA. Analysis of variance of the fitted model was used to determine the significance of the effects. This analysis was performed using the SPSS version 25 statistical package (IBM SPSS Statistics, 2017).

Use of Semi-Compost Prepared from Pecan Nutshells as Substrate for Jalapeño Pepper Seedlings

Subsequently, on February 11th, 2021, in a low-tech chapel-type greenhouse, an experiment was conducted, using as substrates for germination and growth of jalapeño pepper cultivar Jalapeño M the SC obtained in the previous stage, 100% and mixed with peat sphagnum (P), packaged and distributed by Premier Tech Horticulture, under the "Premier" brand, pH 4 to 4.5 and EC < 0.25 dS m^{-1}, in a 50:50 (v:v) ratio. The experimental design consisted of a DCA with six treatments: SC-LNO, SC-CPN, SC-JIM, SC-LNO+P, SC-CPN+P, and SC-JIM+P, each with four replicates and P as a control. Seedling trays of 200 alveoli, each with a volume of 25 mL, were used, with 120 wells for each treatment and 30 for the control. One seed was deposited per cavity.

The variables evaluated 45 d after sowing were: germination (GP; %), seedling height (HEI; cm) measured with a ruler from the base of the stem to the apex of the growth, number of leaves (NL), stem diameter (SD; mm) measured in the basal part of the seedling with a Kokorox digital vernier, total dry weight (TDW; g), dry weight of leaves (LDW; g), and dry weight of roots (RDW; g) with a Rhino electronic precision balance after seedlings were dried to constant weight in a Felisa oven at 60 °C. Based on the above observations, leaf dry weight/root dry weight ratio (LDW / RDW), slenderness index (SI; HEI / SD), and Dickson quality index (DQI) were calculated using the equation (Acevedo-Alcalá, Cruz, and Taboada, 2020).

$$DQI = TDW/(\frac{HEI}{SD} + \frac{LDW}{RDW}) \quad (1)$$

The quality of the clay or root ball (QC) was evaluated by pulling on the stem to remove the seedling from the cavity of the tray and determine the stability of the substrate using the following arbitrary scale: 1) 100% of the root ball remains intact, 2) 90% of the root ball remains, 3) 75% of the root ball is removed from the tray, 4) 50% of the root ball is removed from the tray, and 5) more than 50% of the root ball is lost or the roots contain no substrate (Hernández-Rodríguez *et al*., 2017).

Statistical analysis was performed by fitting the model corresponding to a DCA and comparing the means with Tukey's test ($P < 0.05$). Dunnett's test was also performed for the comparison of the means of the treatments with the control. For the height and number of leaves variables, the analysis was performed with the split-plot model. The analysis was performed using the statistical package SPSS version 25 (IBM SPSS Statistics, 2017).

RESULTS AND DISCUSSION

pH, Electrical Conductivity, and Phytotoxicity of an Aqueous Solution of Pecan Nutshells

Table 1 shows the mean values and their standard deviation for the variables pH, EC, and GI of the aqueous solution of the PeNush about the treatments. In all cases, the pH of the PeNush aqueous solution had values lower than the original pH of the deionized water used, which was considered neutral at 7.03 (Lenntech, 1998). This decrease could be due to the dissolution of the quinone compounds present in the PeNush, which have a pH between 4.4 and 6.8 (Loredo-Carrillo, Leyva, López, Escobedo, and Navarro, 2017).

Two significance groups were found for the EC variable of PeNush soaking solution, showing a difference between the shells from the different PROC. This difference is due to the solubility of mineral salts such as sodium (Na^+), calcium (Ca^{2+}), potassium (K^+), and magnesium (Mg^{2+}). Flores-Córdova and Sánchez (2016) found content of 7 mg Na^+, 62 mg Ca^{2+}, 220 mg K^+, and 40 mg Mg^{2+} for 100 g of PeNush of the Western variety.

The effect of PROC on the variable GI, where two groups of significance emerged, showed that the solution obtained from the soaking process of the PeNush of the processor JIM had the lowest value with 27.74±8.68, showing a greater presence of hydrosoluble phytotoxic chemical compounds. According to Medic, Jakopic, Solar, Hudina, and Veberic (2021), compounds such as naphthoquinones are found in all green parts of the walnut tree, leaves, fruits, and twigs. Contained in it is the 4-glucoside of trihydroxynaphthalene, which is a nontoxic product, but when hydrolyzed and oxidized, it becomes juglone, which is a phytotoxic compound, since at a concentration of 0.002% it causes total inhibition of germination of sensitive species (Ferus, Mencik, and Konôpková, 2020).

Production of Semi-Compost from Pecan Nutshells

Table 2 shows the mean values and their standard deviation of the variables pH, GI and EC, evaluated in the SC obtained after 100 d of transformation from mixtures of horse manure and PeNush.

Analysis of variance for the response variables showed no significant effects on the treatments, which could indicate that subjecting the PeNush to the Semic process allows the elimination of the different characteristics of the PeNush of the different shelling machines, which are related to the concentration of salts and the content of acidic and phytotoxic compounds in the PeNush that could affect the germination of sensitive species (De la Rosa, Alvarez, and Shahidi, 2011).

Table 1. Variables evaluated in the pecan nutshells soaking solution.

Treatment	Processor	pH	EC	GI
			dS m^{-1}	%
LNO-30d	La Nogalera	6.25±0.09	0.43±0.01b	52.00±3.57a
CPN-30d	Chipa Pecans Nut	6.27±0.03	0.76±0.11a	41.75±11.18a
JIM-30d	Jimenuez	6.10±0.09	0.42±0.04b	27.74±8.68ab
LSD		0.1200	0.1126	13.3752
CV (%)		1.21	13.17	20.81

EC = electric conductivity; GI = germination index; LSD = least significant difference; CV = coefficient of variation. Different letters in the same column are significantly different (Tukey $P \leq 0.05$).

Table 2. Variables evaluated in the semi-composts produced from pecan nutshells and horse manure.

Treatment	Semi-compost Produced	pH	EC	GI
			dS m-1	%
LNO-Semic	SC-LNO	7.6±0.30	0.95±0.16	113.81±9.69
CPN-Semic	SC-CPN	7.9±0.07	0.92±0.45	114.09±14.52
JIM-Semic	SC-JIM	8.0±0.10	0.88±0.10	114.05±5.03
LSD		0.2397	0.2888	13.5913
CV (%)		2.36	24.22	9.19

SC-LNO = semi-compost La Nogalera; SC-CPN = semi-compost Chipa Pecans Nut Company; SC-JIM = semi-compost Jimenuez; LSD = least significant difference; CV = coefficient of variation; EC = electric conductivity; GI = germination index.

The microbiological degradation processes that occur during the Semic process, in which mainly sporigenic bacteria and actinomycetes degrade waxes, proteins, fatty acids, carbohydrates, etc., lead to the extraction of inorganic compounds with low molecular weight such as mineral salts, in addition to the degradation of nitrogen to ammonia, making the pH of the medium more alkaline, which may explain the increase in pH values in the SC obtained (Barbaro, Karlanian, Rizzo, and Riera, 2019). For the pH variable, alkaline values were found in a range between 7.6±0.30 and 8.0±0.10, suitable for use as a germination substrate because, according to Soto *et al*. (2021), the pH of a compost to be used as an agricultural substrate should be between 5.5 and 8.0, since values above or below this range affect the availability of nutrients.

In the same way, the phytotoxic compounds present in the original organic material used for the Semic process were degraded, leaving at the end of the process a safe material for use as substrate or fertilizer (Barbaro *et al.*, 2019). The values obtained for the variable GI of the SC from the mixture of PeNush and horse manure did not show phytotoxicity, indicating that they can be used as a high-quality agricultural substrate (Siles-Castellano *et al*., 2020).

Finally, for the variable EC, the obtained SC had values between 0.88±0.10 and 0.95±0.16 dS m^{-1}. The EC of a SC is determined by the nature and composition of the starting material, mainly by the concentration of salts (Sánchez-Monedero, Roig, Paredes, and Bernal, 2001), as well as by the fact that the EC tends to increase during the composting process due to the mineralization of the organic material, leading to an increase in the concentration of nutrients such as ammonium and nitrate (Sánchez-Monedero *et al*., 2001). The results obtained for this variable do not represent a problem for its use as a substrate, since they are within the optimal range mentioned by Martínez-Florián, and Roca (2011), who indicate the following EC values, expressed in dS m^{-1}: less than 0.7 without risk, 0.7 to 2.0 adequate, 2.0 to 3.5 salinization risk, and more than 3.5 excessive.

Use of Semi-Compost Produced from Pecan Nutshells as Substrate for Jalapeño Pepper Seedlings

Table 3 shows the means and standard deviations of the variables evaluated in jalapeño pepper seedlings of the cultivar Jalapeño M when the SC made from the PeNush and horse manure were used as germination substrates in this study.

No significant difference was observed between treatments for the variables GP, HEI and NL of jalapeño pepper seedlings. The average GP for treatments was 96.80±1.78%, a similar value to Hernández-Rodríguez *et al*. (2017), who reported 93.5% germination of lettuce seedlings for the treatment consisting of vermicompost + peat in a 2:1 ratio as germination substrate and 83% for tomato seedlings. These results indicate that the inhibitory substances present in PeNush were neutralized by the Semic process.

The mean values registered for the variables HEI and NL 45 d after sowing are slightly below the values indicated in the research carried out by Acevedo-Alcalá *et al*. (2020), in which different mixtures were used to prepare organic substrates for the germination of poblano pepper seedlings, in which an average of 6 leaves was recorded 52 d after sowing.

The analysis of variance performed for the results of this phase of the study showed significance for the variables SD, LDW, RDW, TDW, LDW / RDW, SI, DQI and QC (Tables 3 and 4). The results of the jalapeño pepper seedlings show that the SC made with PeNush can be used as a substrate with good results because except for the treatments SC-JIM and S-LNO+T, the values obtained for the variables SD, LDW, and RDW were statistically equal to P. These values partially coincide with the results obtained by López-Baltazar, Méndez, Pliego, Aragón, and Robles (2013), in which for the variable SD of chili seedlings of cultivar Onza, better results were found when using substrates based on maguey bagasse compost and vermicompost than with conventional peat.

Table 3. Variables evaluated in jalapeño pepper seedlings cv jalapeño M.

Treatment	GP	HEI	NL	SD	LDW	RDW
	%	cm		mm	- - - - - - - - - g	- - - - - - - - -
SC-LNO	98.33±1.92	4.6±0.3	3.9±0.5	1.40±0.06 abc	0.099±0.011 ab	0.023±0.008 bc
SC-CPN	99.17±1.67	4.8±0.3	4.0±0.2	1.41±0.04 a	0.103±0.011 a	0.025±0.008 ab
SC-JIM	97.50±3.19	4.6±0.5	3.9±0.4	1.39±0.05 bc	0.093±0.017 b	0.020±0.009 c
SC-LNO+P	95.00±6.38	4.4±0.6	3.9±0.3	1.38±0.06 c	0.094±0.019 b	0.021±0.010 c
SC-CPN+P	94.17±4.19	4.6±0.5	4.0±0.3	1.40±0.05 abc	0.102±0.015 a	0.025±0.010 ab
SC-JIM+P	96.67±4.71	4.8±0.3	4.0±0.1	1.42±0.04 a	0.105±0.009 a	0.025±0.009 ab
P	93.33	4.8±0.3	3.9±0.4	1.41±0.04 ab	0.105±0.011 a	0.027±0.010 a
LSD	11.34	0.0982	0.0719	0.0115	0.0029	0.0019
CV (%)	3.35	9.75	8.72	3.80	13.66	38.05

SC-LNO = semi-compost La Nogalera; SC-CPN = semi-compost Chipa Pecans Nut Company; SC-JIM = semi-compost Jimenuez; P = peat; LSD = least significant difference; CV = coefficient of variation; HEI = height; NL = number of leaves; SD = stem diameter; LDW = leaf dry weight; RDW = root dry weight. Different letters in the same column are significantly different (Tukey $P \leq 0.05$).

However, at LDW and RDW of jalapeño pepper seedlings in this study, the values were lower than those of Acevedo-Alcalá *et al*. (2020), who using different mixtures of vermicompost, cattle manure, sheep manure, peat, and vermiculite as a substrate for germination of poblano peppers, obtained the best values in the vermicompost and peat treatments, with values ranging from 0.45 to 1.58 g within a 52 d period, while the RDW of poblano pepper seedlings averaged 0.57 grams.

The comparison of the mean values of the quality indices is shown in Table 4. The results obtained for SI indicate that good-quality seedlings were obtained in all treatments, as values below 6 are associated with good-quality plants (Romero-Arenas *et al*., 2012), while values above eight indicated poor-quality seedlings (Sáenz, Villaseñor, Muñoz, Rueda, and Prieto, 2010).

Table 4. Quality variables in jalapeño pepper seedlings cv jalapeño M and root ball quality.

Treatment	TDW	LDW/RDW	SI	DQI	QC
	- - - - - g - - - - -				
SC-LNO	0.12±0.02 bc	4.92±1.96 ab	3.26±0.20 c	0.016±0.005 bc	2.05±0.22 b
SC-CPN	0.13±0.02 ab	4.55±1.66 ab	3.38±0.14 a	0.017±0.005 ab	2.01±0.09 b
SC-JIM	0.11±0.02 c	5.17±1.84 a	3.31±0.24 ab	0.014±0.005 c	2.01±0.09 b
SC-LNO+P	0.12±0.03 c	5.09±1.89 a	3.19±0.31 c	0.015±0.005 c	2.00±0.09 b
SC-CPN+P	0.13±0.02 ab	4.63±1.65 ab	3.28±0.23 bc	0.017±0.005 ab	2.01±0.13 b
SC-JIM+P	0.13±0.02 ab	4.57±1.62 ab	3.36±0.15 ab	0.017±0.005 ab	2.00±0.09 b
P	0.13±0.02 a	4.36±1.62 b	3.36±0.15 ab	0.018±0.005 a	1.64±0.48 a
LSD	0.0047	0.3746	0.0458	0.0010	0.0335
CV (%)	17.70	36.81	6.37	30.76	8.07

SC-LNO = semi-compost La Nogalera; SC-CPN = semi-compost Chipa Pecans Nut Company; SC-JIM = semi-compost Jimenuez; P = peat; LSD = least significant difference; CV = coefficient of variation. TDW = total dry weight; LDW/RDW = leaf dry weight/root dry weight ratio; SI = slenderness index; DQI = Dickson quality index, QC = quality of the clay or root ball. Different letters in the same column are significantly different (Tukey $P \leq 0.05$).

In the DQI, the highest values were achieved with P. However, in all cases the DQI values of the seedlings evaluated indicated poor or low quality, as the values obtained were below 0.2. For DQI, values above 0.5 indicate good seedling quality, values between 0.5 and 0.2 indicate average quality, and values below 0.2 indicate poor seedling quality (Sáenz *et al*., 2010), with the low value of DQI due to low production of root biomass. Acceptable values of SI and DQI indicate that the seedling has a balance in terms of growth of the aerial part and roots, which guarantees good development of the plant (Romero-Arenas *et al*., 2012). This type of indices can vary depending on the species, nature and proportion of the substrate, the volume of the alveolus, and above all, the time at which the variables are determined (Faria, Caldeira, Delarmelina, and Rocha, 2016). It should also be considered that these quality indices have only recently been used in horticultural crops, so more studies should be conducted on these species (Guzmán-Antonio, Borges, Pinzón, Ruiz, and Zúñiga, 2012).

The results for the QC variable showed that the substrates of SC and SC + peat were statistically lower than P, which had an average value of 1.64±0.48, with 1.0 representing the best characteristics according to the classification scale, since 100% of the root ball remains intact when the plant is pulled from the tray cavity (Hernández-Rodríguez *et al*., 2017), which means that the integrity of the seedling root is guaranteed, while the average values for the other substrates statistically ranged from 2.00±0.09 to 2.05±0.22, values that, according to the rating scale used, are substrates in which 90% of the root ball is removed from the cavity of the tray. This shows that the quality of the root balls is good, although the SC did not achieve complete integration, which could be due to the size of the piece of PeNush used in the preparation. These results differ from those obtained in the study conducted by Hernández-Rodríguez *et al*. (2017), in which when evaluating the effect of different proportions of SC of cattle manure and sawdust mixed with peat on the germination and development of lettuce and tomato seedlings in a greenhouse, it was found that the root balls of the substrates obtained better results than the control based on peat alone.

The results of this study show that PeNush and horse manure can be used in Semic processes as an organic substrate or mixed with peat in a 50:50 ratio for the germination and seedlings production of Jalapeño pepper, reducing the use of peat sphagnum, which is known to be one of the most widely used substrates for the production of seedlings due to its physical, chemical and biological properties that allow excellent germination and growth of seedlings, but its high cost and unsustainable use have begun to limit and reduce its use (Fernández-Bravo, Urdaneta, Silva, Poliszuk, and Marín, 2006). In addition, the use of PeNush as a substrate was reported by Romero-Arenas *et al*. (2013) for the initial growth of *Pinus patula* produced in a nursery, when using PeNush compost with agrolite and vermiculite, for the gradual replacement of peat, which is an alternative substrate for plant production capable of reducing production costs, in addition to contributing to productive forest management. Future studies should be carried out to evaluate the effect of the solution resulting from soaking PeNush on weed control due to its high phytotoxicity.

CONCLUSIONS

This research demonstrates distinct characteristics in the pecan nutshells from different shelling facilities. These differences were recorded in the soaking aqueous solution to which the shells were subjected, with EC values ranging from 0.42 to 0.76 dS m^{-1}, pH between 6.1 and 6.25, and GI values below 52.0%, indicating high phytotoxicity. However, subjecting pecan shells to the semicomposting process effectively reduced these adverse effects, making it a viable method for reusing the shells to produce semicomposts. The semicomposts showed mean EC values of 0.92±0.21 dS m^{-1}, pH of 7.77±0.17, and GI of 113.98±9.75%, parameters that classify them as high-quality organic fertilizers. This represents a potential solution to mitigate the environmental problems caused by the accumulation of pecan shells.

Regarding the use of semicomposts derived from pecan shells as germination substrates for growing jalapeño pepper seedlings (cultivar Jalapeño M), the seedlings exhibited stem diameter, leaf dry weight, and root dry weight comparable to those grown with commercial substrates. Additionally, the slenderness index indicated the production of high-quality seedlings across all treatments.

ETHICS STATEMENT

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF SUPPORTING DATA

Data sets used or analyzed during the current study are available from the corresponding author upon reasonable request.

COMPETING INTERESTS

The authors declare that they have no competing interests.

FINANCING

Not applicable.

AUTHORS' CONTRIBUTIONS

Conceptualization: H.A.R.S., C.R.F., A.F.M.R., A.T.G., and O.A.H.R. Methodology: H.A.R.S., C.R.F., A.F.M.R., A.T.G., and O.A.H.R. Validation: D.L.O.B., and O.A.H.R. Formal analysis: H.A.R.S., C.R.F., and O.A.H.R., Research: H.A.R.S., A.F.M.R., A.T.G., and O.A.H.R. Writing: preparing the original draft, H.A.R.S., C.R.F., A.F.M.R., A.T.G., and O.A.H.R. Writing: review and editing, H.A.R.S., D.L.O.B., C.R.F., A.F.M.R., and O.A.H.R. Monitoring: O.A.H.R. Project management: O.A.H.R.

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