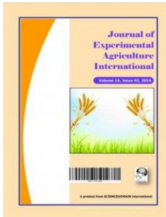

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Addition of Charcoal Waste to Earthworm Humus Promotes Better Results in the Production of Papaya Seedlings

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Authors' contributions

This work was carried out in collaboration between all authors. Authors MMS and EFO designed the study, conducted the experiment in the field and managed the writing of the manuscript. Authors CMM and LP managed the writing of the manuscript. Authors MZM and PAB performed the evaluations of the parameters analyzed in the study. The author JLFJ managed the bibliographic searches. All authors read and approved the final manuscript.

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ABSTRACT

Aimed at improving the physical and chemical attributes of the substrates for seedling production, several agro-industrial wastes have been used. One of the waste with a potential of substrate incorporation is the charcoal waste. The objective of this study was to evaluate the effect of increasing doses of charcoal waste (CW) on the production of papaya seedlings (*Carica papaya* L.). The experimental design was a randomized block design, as an experimental model. The

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treatments were composed of 5 (five) concentrations of CW added to earthworm humus based on volume, and the following treatments were evaluated: T1: 100% earthworm humus + 0% CW (control); T2: 97.5% humus + 2.5% CW; T3: 92.5% humus + 7.5% CW; T4: 85% humus + 15% CW and T5: 70% humus + 30% CW. Each of the 5 (five) treatments had 4 (four) replicates (blocks). The evaluations consisted of plant height measurement, collection diameter, root length, dry mass of leaves and roots, and Dickson quality index. Regression models were adjusted (P <0.05) to treatments with increasing levels of CW. CW doses around 10% promoted better results of collection diameter, root length and root dry mass. For the other variables, CW doses around 13% promoted the best results. It is believed that the addition of CW promoted significant improvements in earthworm humus; however, high doses promoted an elevation of pH at levels considered critical for the availability of some nutrients for the crop. In general, the best values obtained for the analysed variables were those in which about 9.25% to 14.25% of the CW addition to the humus used.

Keywords: Carica papaya L.; charcoal; humus; alternative substrate.

1. INTRODUCTION

Papaya (*Carica papaya* L.) is one of the most consumed fruits in the world [1]. Brazil ranks second place as a world fruit producer with a production of 1,517.696 to per year^{-1}, ranking among the main exporting countries [2].

One of the problems related to the production of papaya fruit in Brazil is the culture establishment in the field because of the hard time to obtain quality seedlings within desirable phytosanitary characteristics [3]. The productivity and quality of the papaya fruits are directly related to the cultural practices, which have begun since the formation and implantation of the seedlings in the field [4].

Several factors can contribute to the production of seedlings with quality, among them, the substrate has great relevance. To be considered a good substrate, the material must have attributes such as aeration, porosity, nutrient availability and water retention, being these attributes essential for the good development of the plants [5]. In addition, the use of the substrate is due to its availability, cost and obtaining easiness and handling [6].

One of the substrates commonly used by farmers in the production of seedlings, mainly those working in an organic scheme, is earthworm humus or vermicompost. The humus can be considered a plant growth biostimulator, moreover, it also stimulates the present microbiota in the substrate, improving plant health [7]. However, the same author defends that the humus concentration in the substrate, to produce forest seedlings, it should not exceed 80%, and it is necessary to incorporate some other element with good availability and low cost so that it acts as a good substrate.

To improve the physical and chemical attributes of the substrates for seedlings production, several agro-industrial waste has been used, so their accumulation in the industrial yards is reduced, and they have a more sustainable disposal [8]. One of the waste with potential for incorporation into substrate to produce papaya seedlings is the charcoal waste. The carbonised biomass (charcoal) has some physico-chemical characteristics, such as basically aromatic molecular structure, high specific surface area and hydrophobicity [9] and, depending on the active sites, gives greater protection to soil microorganisms [10]. Thus, coal waste can act as a substrate conditioner [11].

According to the scientific literature, there are promising results of the use of charcoal waste for crops such as lettuce [12], rice [12]. soybean and rice [13], eucalyptus [14], among others. Although it is used in the production of seedlings of some crops, little is known about the use of charcoal waste in the production of papaya seedlings. The objective of this work was to evaluate the effect of the addition of increasing doses of charcoal waste on earthworm humus in the production of papaya seedlings (*Carica papaya* L.).

2. MATERIALS AND METHODS

The experiment was installed and conducted in the Fruticulture Sector of the Federal Institute of Education, Science and Technology of Espírito Santo (Ifes), Santa Teresa campus, from November 2016 to January 2017, in a seedling nursery covered with polyolefin screen with 50%

of shading, located in the municipality of Santa Teresa, state of Espírito Santo, with altitude of 155 m, latitude of 18° 48'South and longitude of 40° 40' West. The climate of the region, according to the Köppen climate classification of, fits in the Cwb type (temperate maritime climate/altitude tropical climate), with an average annual temperature of 24.6°C and annual precipitation ranging from 700 to 1200 mm.

During the seedling production, were used Solo Gropu's papaya seeds from healthy and ripe fruits, as propagative material. The fruits of this group present the fruit size, with a weight varying from 300 g to 650 g. In addition, the shape of the well rounded fruits contribute to make them one of the most requested for export. Another characteristic is the precocity in the production, the orange-red pulp, which attracts the consumers, and with excellent taste [1]. The fruits were cut in half, separating pulp and seed. The seeds were washed in running water on fine mesh sieve to eliminate mucilage and pulp and bark waste. The selection was made through manual harvesting for the small and damaged seeds disposal. The drying was held in an airy and shaded place, during 6 (six) days.

The materials used in the formulation of the alternative substrate to produce papaya seedlings were earthworm humus and charcoal waste (CW). The earthworm humus was used in the experimental area of the Nucleus of Studies in Agroecology of the same Campus, from the digestion of cattle manure tanned by the intestinal tract of the rural Californian earthworms (*Eisenia foetida*) in, following the specifications of the EMBRAPA model, adapted by [15]. The charcoal waste (CW) used, originating from eucalyptus wood (*Eucalyptus* spp.), came from charcoal farms around the region. The CW was ground and sieved until a fine powder was obtained.

A randomized complete block design was used as the experimental model. The treatments were composed of 5 (five) CW concentrations added to the earthworm humus based on the volume, and the following treatments were evaluated: T1: 100% earthworm humus + 0% of CW (control); T2: 97.5% humus + 2.5% CW; T3: 92.5% of humus + 7.5% of CW; T4: 85% of humus + 15% of CW and T5: 70% of humus + 30% of CW. Each one of the 5 (five) treatments had 4 (four) replicates (blocks), considering 25 seedlings each, resulting in 500 seedlings throughout the experiment. Six central plants of each experimental unit were considered useful.

The humus physico-chemical analysis and charcoal waste consisted of the determination of the electrical conductivity (EC) through bench conductivity meter. The chemical analyses consisted of the determination of the pH by means of a bench potentiometer and the quantification of total organic carbon (TOC), organic matter (OM), total nitrogen (TN), phosphorus (P), potassium (K) and calcium (Ca), performed at the Soil and Solid Waste Laboratory of the Department of Agricultural Engineering of the Federal University of Viçosa (Table 1).

Table 1 presents the physical-chemical and chemical characteristics of the materials used in the formulation of the substrates.

For the papaya seedlings production was used suspended trays, allocated in masonry benches, containing 500 mL tubes suitable for germination. The mixture of CW to the humus happened manually until obtaining a homogeneous material, being held 7 (seven) days before sowing. According to nursery routine, the irrigation was performed manually. No pesticides types were applied, nor was any other correction process performed on the substrates.

Evaluations occurred at 60 (sixty) days after sowing (DAS). The seedlings were removed from the core and were carefully washed. The evaluation of seedling development was held by the following parameters: plant height (PH), collection diameter (CD), root length (RL), dry leaf mass (DLM) and root (DRM) and determination of the Dickson quality index (DQI).

Table 1. Physical-chemical (EC) and chemical characteristics of humus and charcoal waste (CW) used in the experiment

Materials	**pH**	**EC**	**TOC**	**OM**	**TN**	**P**	**K**	**CA**
		dS m^{-1}	**--------------------------------dag kg^{-1}--------------------------------**					
Humus	6.67	280	74.1	46.79	0.75	1.64	0.83	1.40
CW	7.77	283	76.95	-*	0,41	0.023	0.66	0.330

CW: charcoal waste pH: potential of hydrogen; EC: electrical conductivity; TOC: total organic carbon; OM: organic matter; TN: total nitrogen; P: phosphorus; K: potassium; Ca: calcium.
** Organic matter: Charcoal waste is considered organic matter.*

To obtain the height of the aerial part was used a ruler millimeter, measuring from the stem base to the apical bud that gave rise to the last leaf. The sample diameter was measured by 0.01 mm precision digital caliper. To calculate the aerial part dry mass, it was considered only leaves. These leaves were extracted during the insertion of the petiole of the plants period. To obtain the root dry mass, the roots were carefully washed in running water, on a 5-mm sieve. The roots were measured from the collecting region of the root with the aid of a millimeter ruler. Subsequently, both plant materials were packed in paper bags, properly identified and dried in a greenhouse with forced air circulation at 65°C until reaching constant weight. Soon afterwards, the materials were weighed in a precision electronic scale of 0.01 g. To determine the DQI, the method proposed by Dickson et al. (1960), (Equation 1).

$$DQI = \frac{TDM\ (g)}{(PH(cm)/CD(mm)) + (DLM\ (g)/DRM\ (g))} \quad (1)$$

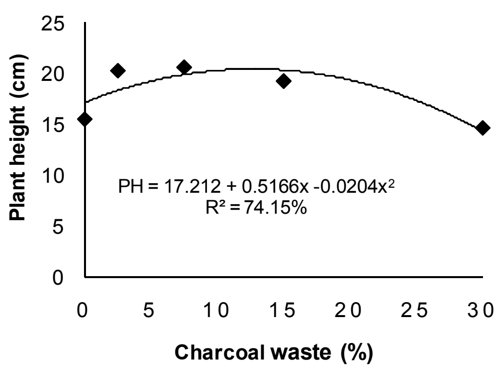
where: DQI = Dickson quality index; TDM = Total dry matter mass (g); PH = Plant height (cm); CD = Collection diameter (mm); DLM = Dry leaf mass (g), and DRM = Dry root mass (g).

All the evaluated variables were submitted to the normality tests (Lilliefors) and homoskedasticity (Barttlet) tests, which are the assumptions for the analysis of variance, using adjustments in regression models for the orthogonal polynomials method. A "α" of 0.05 was used for all procedures.

3. RESULTS AND DISCUSSION

The Fig. 1 (A, B, C, D, E and F) shows the plant height values (PH), root length (RL), collection diameter (CD), dry leaf mass (DLM), dry root mass (DRM) and Dickson quality index (DQI) of papaya seedlings respectively, in response to the addition of increasing doses of charcoal waste on the substrate.

A



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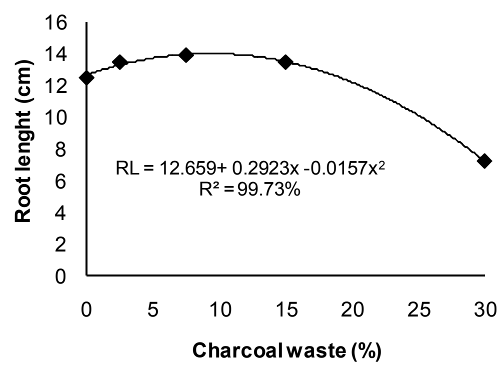

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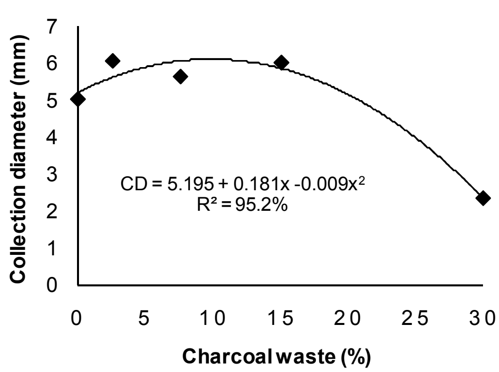

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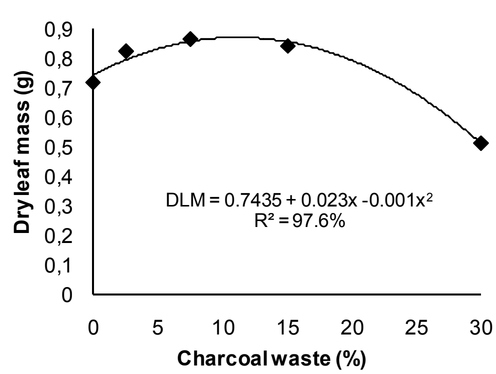

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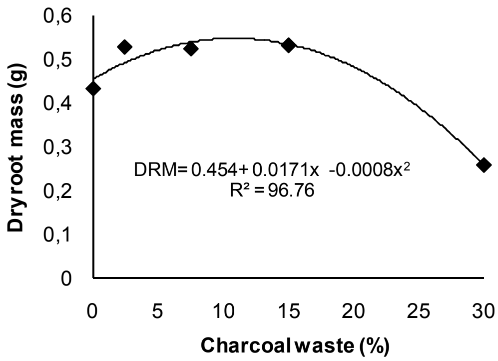

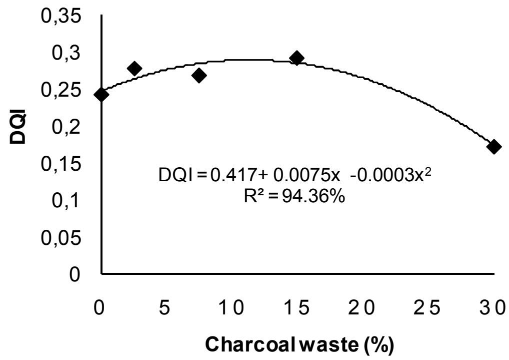

Fig. 1. Plant height (A), root length (B), collection diameter (C), dry leaf mass (D), dry root mass (E) and Dickson quality index (F) of papaya seedlings respectively, in response to the addition of increasing doses of charcoal waste in the substrate.

The plant height variable showed an increase with the CW increasement of to the humus to a concentration of 12.75%, providing a maximum height of 20.48 cm (Fig. 1 (A)). Lower results of this study were found by [16], which evaluated different substrates to produce papaya seedlings. It was found greater growth, about 7 cm, with substrate composed by a mixture of Plantmax + humus + cattle manure (1: 2: 1); however, the evaluation took 37 DAS. Similarly, to the variable plant height, the variables root length and collection diameter presented the best results of 13.57 cm and 6.08 mm with the additions of CW to humus of 9% and 9.75%, respectively.

Other authors such as [17] concluded in the experiment that the substrate containing corral + charcoal + soil and sand in the proportion of 2: 1: 1: 1 v / v, were the ones that presented the best results in the production of seedlings for variables length of shoot, root and number of leaves, this association being a good alternative in the production of papaya seedlings. As well as the data found in this work.

Regarding the collection diameter, lower results were found by [18] evaluating the quality of papaya seedlings grown on different commercial and organic substrates, the results for this variable were 5.68 in the treatment composed of Plantmax + Sand washed . [18] found superior results when evaluating the treatment composed by Plantmax + worm humus, finding and 7.36 mm in diameter. Making it clear that the substrate in which it composed humus was the one that presented better development, as well as the results found in this work.

According to [19], in tropical fruit researches, the good development of papaya trees stands out, stating that the papaya will develop well as long as the substrate or soil in question presents characteristics such as good drainage capacity and water retention capacity by period of time.

For the variables dry leaf mass and root dry mass (Fig. 1 (D) and (E)) it is observed that the increase of CW to humus promoted significant results similar to the other variables, with the best concentrations of CW to humus at 11.25% and 10.75%, respectively, promoting a dry biomass gain of leaves and roots of 0.87 g and 0.55 g, respectively. [20], studying different substrates in the formation of papaya seedlings of the soil group, found better results for plant height of 31.45 cm with substrates containing bovine manure, soil, sand and vermiculite (2: 1: 1: 1 v / v) and Plantmax, corral dung, soil and sand (1: 1: 1: 1 v / v). In the same experiment, [20], found average values of 1.64 g evaluating the whole aerial part of the plants at 90 DAP and not only leaves at 60 DAP herein. These authors attribute the best constitution results of substrates rich in macronutrients such as P and K, these are of foremost importance in the development of papaya cultures. Moreover, the physical subtrates characteristics are mentioned by [20] as indicative of satisfactory results because they present higher water retention capacity, aeration and nutrients, thus producing better quality seedlings.

The P element is very important in papaya crops, positively influencing the increase of the aerial and root system of the plants, mainly in the initial phase of plant growth [21]. According to Table 1, this element presents in good amount of earthworm humus, but an incipient amount in CW. Thus, whereas the addition of CW increased to the humus, it means a reduction in the proportion of this and other nutrients in the total volume of the substrate was promoted, which may have contributed to the reduction of the response in higher CW concentrations. At lower concentrations, the addition of CW to humus may have promoted conditioning action of the substrate, making it more suitable for production of papaya seedlings, contributing to greater retention of nutrients and water, and reducing physical barriers, which favors better plant development [11].

Some studies report positive effects of the addition of charcoal on the production of various seedlings, however [22] states that all this success with the use of charcoal residues, may be directly associated with the species tested, and this result may vary. [23] evaluating the effect of growing doses of charcoal in the production of *carvoeiro* (*Tachigali vulgaris*) seedlings found increasing dry shoot and root biomass growing doses of up to 50%of charcoal. [24], when evaluating the effect of charcoal application on different substrates, they observed a major increase of dry shoot biomass and roots in *crajiru* seedlings (*Arrabidaea chica* Verlot.). These results corroborate with the results obtained herein, evidencing that the addition of CW promotes physical-chemical improvements of the substrate, leading to greater retention of moisture and nutrient availability.

For DQI, a variable includes several correlated elements to the quality of formed seedlings and the addition of CW in 11% to humus promoted the best result (0.2896). On contrary, higher doses promoted the reduction of this index (Fig. 1 (F)). The value of DQI found herein points out that the CW addition at 11% to the earthworm humus that provides better papaya seedlings. [25] evaluating different substrates in the production of papaya seedlings, except for the treatment containing vermiculite, (IQD = 0,334), the other treatments presented lower IQD than those found in this study. However, in [21], organic and mineral fertilisation were used to enrich the substrate. It is worth to point out that no nutritional correction or addition was used to the substrate in this study and, therefore, it is believed that the superiority of the DQI result found in this work in relation to those found by [25], is mainly a result of the interaction of the CW with the worm humus, indicating the combination of earthworm humus and CW may be an alternative in the substitution of commercial substrates.

In general, the addition of CW to the humus is between 9.25% and 14.25% promoted better results in the evaluated variables. [19] state that the addition of coal fines or charcoal waste can promote major improvements in the physical and chemical properties of the soil, correcting its acidity, increasing the levels of exchangeable Ca, extractable P, CTC, besides soil aggregation capacity. Although CW is considered an inert material, its structure has sites capable of performing ionic exchanges, thus promoting the better availability of nutrients present in the substrate [26]. Thus, the addition of CW up to certain concentrations to earthworm humus may have provided greater stability of the substrate as well as favouring the absorption of nutrients by plants.

Fig. 2 shows the plot of substrate pH values as a function of the various levels of charcoal waste insertion incorporated into the humus in the production of papaya sludge.

The CW addition promoted a linear pH increase of the substrate solution (Fig. 2). According to [27] the ideal pH range is between 6.0 and 6.5 but there may be a behavioural variation of each plant species in relation to pH and its effects on the substrate. This alteration (acidity/alkalinity) in the substrate solution may promote the unavailability of some nutrients, such as P, N, S and B, which remain with high availability up to a pH range of 7.3 [28]. Thus, higher ratios than 11%promoted elevations of soil alkalinity (Fig. 2) at indexes that may promote precipitation, especially P, making it unavailable to plants [29]. P is one of the main elements in initial plant growth, acting in storage, energy transfer and absorption of other nutrients [30]. Therefore, its lack can severely compromise the development of plants. [31], evaluating papaya seedlings observed an increase in the dry matter of plant roots due to the positive effect of P, which increased the capacity of nutrient absorption due to the greater root development.

According to the data obtained in this research, the CW addition can make earthworm humus more suitable to produce papaya seedlings. It is therefore believed that such fact is due to the increase of porosity and greater retention of water, besides the reduction of the physical barriers in the substrate that are propitiated by

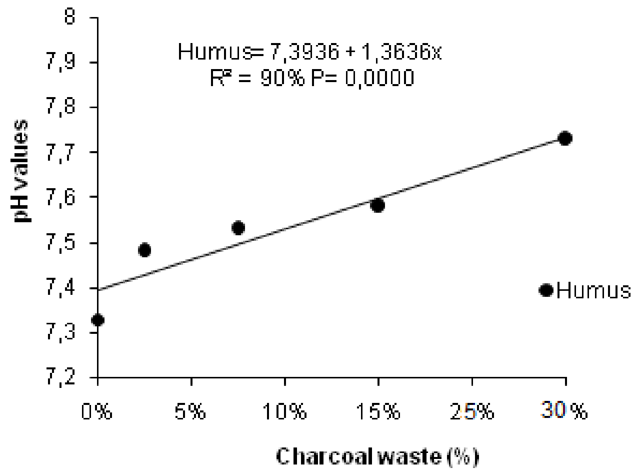

Fig. 2. pH values of the substrate as a function of the various levels of charcoal waste incorporated into the humus in the production of papaya seedlings.

the incorporation of CW to the humus. Thus, the CW addition can promote significant improvements in earthworm humus, making it an important substrate for production of papaya seedlings, minimising the production costs, increasing the profitability of the productive chain of seedlings production.

In addition to the quality and sanity with which the seedlings are formed, the addition of CW to the substrate can promote the sustainability of the coal sector, being an option for the final waste destination waste, also contributing to the carbon storage in the soil, reducing the harmful gas emission to the greenhouse effect [32], considering that [33] state that a great part of the C emitted by anthropic activities (12%) could be eliminated by applying C in soil in the form of carbonised biomass.

4. CONCLUSION

The insertion of CW to the humus around 9% promoted better results in the variables collection diameter and root length in papaya plants.

For the variables plant height, dry mass of leaf and root, and DQI the insertion of CW to humus around 14% promoted better results in papaya plants.

The addition of CW to the earthworm humus promoted elevation of the substrate pH.

The best values obtained from the analysed variables of papaya plants were 9% to 14% of the insertion of charcoal waste to the humus.

The use of charcoal added to the humus can be an alternative to cost reduction in the production of seedlings, minimising the impacts generated by the disposal of this residue and increasing the use of alternative sources within the property by the use of earthworm humus in the crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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