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ORIGINAL RESEARCH

Peach palm residue compost as substrate for *Bactris gasipaes* self-sustaining seedlings production

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Abstract

Purpose To comply with purposes of circular economy and sustainability, as well as promoting an appropriate destination for waste from *Bactris gasipaes* agro-industry and adding value to this product, we evaluated the compost of the plant residue as substrate for seedlings production.

Methods Waste was collected, composted, dried and ground. Compost samples were characterized chemically and physically. The treatments consisted of different proportions of compost and soil (medium commonly used in *B. gasipaes* seedling nurseries), to make five growth media (v:v composted peach palm:soil): T1 - 100: 0; T2 - 75:25; T3 - 50:50; T4 - 25:75 and T5- 0: 100. After 120 days of planting the peach palm seedlings, morphological parameters were evaluated.

Results For the majority of physicochemical properties, T1 showed superior characteristics, i.e. higher water retention capacity (74.19 v/v), higher total porosity (74.78%) as well as higher concentrations of N, P, K (with 2.90 %, 3412.00 g dm^{-3} and 7120.00 g dm^{-3}, respectively) when compared to T5. Likewise, for seedling morphological parameters, the material grown in T1 presented higher height and shoot fresh and dry weight.

Conclusion *B. gasipaes* residue compost shows adequate amounts of macro and micronutrients and physical properties that enable satisfactory development of seedlings from the species, thus promoting a self-sustainable seedling production system.

Keywords Recycling in agriculture, Organic waste, Circular economy, Organic fertilizer, Soil conditioner

Introduction

Bactris gasipaes Kunth., commonly known as peach palm, is the most important domesticated palm species of the Neotropics. It is a multi-purpose native palm tree to tropical Latin America (Graefe et al. 2013) and, with economic relevance for fruits and heart-of-palm commercialization. Moreover, this species has potential for use for animal feeding as a silage component (Santos Cabral et al. 2015) and, can be used as raw material for the production of wood from pseudo-stem of peach palm (Pinheiro et al. 2017).

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Widely grown in Latin America, it is cultivated mainly by smallholders in monocultures or agroforestry systems. This cultivation system supports Sustainable Development Goals (SDGs) by conciliate environmental protection and economic development. Furthermore, it contributes with the local economy and is an important form of subsistence and source of income (Graefe et al. 2013).

Brazil is one of the world's largest producers of *B. gasipaes*, mainly for extraction of heart-of-palm. In 2017, the planted area in Brazil was of 23,110 ha and, in some Brazilian regions the cultivation of peach palm already has the second major economic relevance (e.g. Paraná coast) (IBGE 2017). The expansion of the planted area is important to reach new markets mainly in France, which is the largest importer of canned palm hearts and imported 13,000 tons of this product in 2015 (CBI 2015).

A large volume of biomass is generated after the extraction of heart-of- palm, but only an average of 400 g per plant is used as the main product (Fermino et al. 2010) and, part of stipe and sheaths become waste. A large industry can generate about 40 t of residue per day (Santos Cabral et al. 2015) and if this material does not have a sustainable destination, it has high potential to generate environmental problems (e.g. disease vector, leachate production and, consequently, water and soil contamination).

Peach palm is traditionally propagated from seeds, however, the species has dormancy, possibly caused by the immaturity of the embryos (Nazário et al. 2017). This results in germinate slowly (germination of the 38 to 133 days) and irregularly (germination capacity varies from 0% to 100%) (Bovi et al. 1994). Vegetative propagation may be an alternative to overcome the difficulties of seminal propagation. Despite the work related to this subject (Tracz et al. 2009; Steinmacher et al. 2016; Graner et al. 2018), an efficient clonal propagation protocol doesn't exist yet, therefore large part of the seedling producers of *Bactris gasipaes* in Brazil is still chosen for seminal seedling production.

The substrate commonly used for seedlings production of peach palm is soil. This element is a non-renewable resource (FAO 2015; Lal 2015), as the formation of a 30-cm-thick soil layer requires 1,000 to 10,000 years to be completed (Haberli et al. 1991) and excessive exploitation can cause damages to the environment. Thus, the use of new materials from renewable sources for seedlings production is relevant, providing a more sustainable character to the production system.

The composted residue of peach palm industry is among the materials with potential to be used as substrates instead of soil. Composting is an aerobic process which relies on high temperatures and bacteria to sanitize, detoxify and stabilize organic wastes (Mendoza-Hernández et al. 2014). Composting of plant residues can be a source of organic matter which contributes to increasing the fertility of the substrate (Eksi et al. 2015). In an effort to recycle waste from agriculture, composting is a low cost alternative and a sustainable means to reduce environmental liabilities (Qdais and Al-Widyan 2016), and being successfully used as substrate for plant seedling production (Jayasinghe 2012; Zhang et al. 2012; Meng et al. 2018; Vukobratovic et al. 2018). Composting of organic waste provides nutrients, growth regulators and physical and chemical properties suitable for plant growth (Hossain et al. 2017).

As a way to provide an application for this environmental liability residue of the peach palm industry, besides to attend the premises of circular economy through re-use of a product from the production system itself and, aggregate value to this waste, this study assessed the feasibility of the use of peach palm residue compost as substrate for *Bactris gasipaes* seedlings production.

Materials and methods

Composting pile establishment

Peach palm residues were collected at the agroindustry in the city of Morretes/PR, Brazil, forwarded to Embrapa Florestas (Colombo-PR) to be triturated with a fodder crusher (Trapp) and dumped in wooden boxes (2 x 2 x 1.3 m) (Fig. 1) coated internally with plastic. To promote aerobic conditions through natural convection during composting, we used a set of 4 horizontal soil pipes and 3 vertical soil pipes, arranged at 40 cm from the bottom of the box (Ferreira et al. 2005). Urea (24 g kg^{-1} residue) was added to ensure optimum C:N ratio, to improve microbial activity. The temperature was measured in the center of the compost mass by a thermometer every 3–5 days. Composting was carried out for 45 days until the temperature stability and then the material was triturated to reduce the particle size using sieve of 50 mm in diameter.

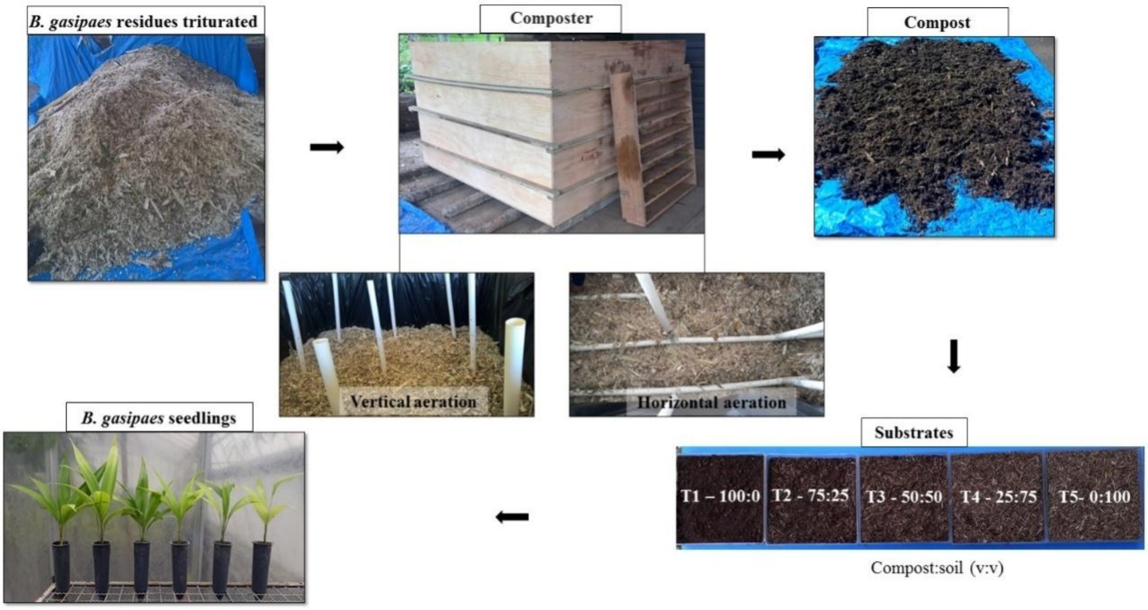

Fig. 1 Flowchart of substrate elaboration for production of *B. gasipaes* seedlings from heart-of-palm agroindustry residues

Seedling assay

B. gasipaes seeds from Porto Velho, state of Rondônia, Brazil, treated with fungicide Carbendazim (100 mL 100 kg^{-1} of seeds) were sown in plastic boxes with perforations in the bottom (filled with medium texture vermiculite), wet to field capacity and maintained in a Mangelsdorf germinator at 25°C for 120 days (Brasil 2013). After this period, only normal seedlings were selected (one bifid leaf and adventitious roots) to the transplant (Yuyama and Mesquita 2000).

The soil belonging to the class Haplic Cambisol with a clayey texture was collected in the municipality of Colombo (Paraná state, Brazil). The compost was mixed in different proportions with soil, to make five growth media (v:v composted *B. gasipaes*:soil): T1 – 100:0; T2 - 75:25; T3 - 50:50; T4 - 25:75 and T5- 0:100. *B. gasipaes* seedlings were transplanted to plastic tubes (110 cm^3) containing different substrates. The plants were grown in a greenhouse until they reach the ideal standard for field planting (30 to 40 cm high and at least 3 leaflets). Greenhouse environmental with sprinkling (1 min, 3 times per day) and temperature 20±18ºC.

The experiment was carried out using a completely randomized design with five treatments with four replications and ten plants per treatment. In all treatments the following fertilization was added:1.5 Kg m^{-3} of the granular fertilizer Super Simple Phosphate and 0.7 Kg m^{-3} of micronutrients cocktail –Fritted Trace Elements (FTE BR12®) (boron 1.8%; cupper 0.8%; iron 3.0%; manganese 2.0%; molybdenum 0.1%; zinc, 9.0%).

The substrates were physically and chemically characterized, using triplicate samples per treatment, for the following parameters: density, water holding capacity (WHC), pH, electric conductivity (EC), total porosity, bulk density according to the methods of Normative Instruction N°17 (MAPA 2007) and macro and micronutrients.

For chemical characterization of composted residue, samples were collected in triplicate and digested in nitro-perchloric acid. Total chemical elements (N, Ca and Mg) and micronutrients were determined by atomic absorption spectrophotometer. Total K was quantified by flame photometry and P by the method of ammonium molybdate (colorimetric determination).

The morphological parameters of the seedlings were evaluated at 210 days after the test installation. Plant-growing characteristics such as height (from the plant's neck to the last two leaf fork), stem diameter, number of leaflets (bifid leaves), steam and leaf fresh and dry weight. To measure the dry weight, we used five seedlings of each replicate, randomly chosen and dried in an oven at 70°C for 24 hours.

The Dickson quality index (DQI) was calculated according to the equation (Dickson et al. 1960) DQI = TFM/(H/D + SDW/RDM), in which: TFM is the total fresh biomass (g); SDW, shoot dry weight (g); RDW, root dry weight (g); H, height (cm); and D, stem diameter (mm). The data were analyzed in the SISVAR software and means were statistically compared using Tukey's multiple-range test.

Results and discussion

During the initial phase of composting, for five days, the temperature of the compound remained higher than 50 °C, the maximum pile temperature (peak) was 57 °C, which reduce the risk of diseases transmission, because temperatures above 55 °C maximize sanitization (Wichuk et al. 2011). In order to use a safe product in a circular economy and self-sustaining production of *B. gasipaes* seedlings, temperature variation in the compost pile should be rigorous monitored to ensure sterilization of any phytopathogens such as *Fusarium* sp., a major disease which affects this crop (Jarek et al. 2018). Further studies can evaluate the presence of pathogens in the compost and investigate whether the use of biological agents (e.g. *Trichoderma*) mixed with the compost can control any pathogens. The chemical composition of composted residue is shown in Table 1.

Table 1 Phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), boron (B), nitrogen (N), carbon (C), hydrogen (H) and sulfur (S) of composted residue of peach palm industry

P	K	Ca	Mg	Cu	Fe	Mn	Zn	B	N	C	H	S
($g\ kg^{-1}$)				($mg\ kg^{-1}$)					(%)			
3.41	7.12	6.12	1.85	18.00	432.67	52.33	14.67	20.93	2.90	45.45	7398.00	0.27

Physicochemical parameters

The physicochemical characteristics of the compost-soil substrates (before nutrient addition) are shown in Table 2. The increased proportion of composted *B. gasipaes* residue led to an increased in nutrients, C/N ratio, bulk density and water holding capacity.

Table 2 Total nitrogen (N), phosphorus (P) and potassium (K) concentrations, C/N ratio, bulk density (BD), total porosity (TP), water holding capacity (WHC), pH and electrical conductivity (EC) of substrates used as treatments for *Bactris gasipaes* seedlings production

Treatment	N (%)	P ($g\ dm^{-3}$)	K ($g\ dm^{-3}$)	C/N Ratio	BD ($g\ dm^{-3}$)	TP %	WHC ($v\ v^{-1}$)	pH	EC $dS\ m^{-1}$
T1	2.90a	3412.00a	7120.00a	15.68a	246.52a	74.79a	74.19a	6.16a	1.56[a]
T2	2.23b	3398.78a	5496.58b	14.90ab	525.32b	67.36b	57.13b	5.17b	0.70c
T3	1.56c	3385.56a	3873.16c	14.11bc	701.60c	64.00bc	46.11c	4.00d	0.73b
T4	0.89d	3372.34a	2249.73d	13.33cd	982.09d	60.60bc	37.78d	3.56e	0.60d
T5	0.22e	3359.12a	626.31e	12.55d	1116.82e	59.85c	33.45d	4.60c	0.15e

T1 – 100:0 ; T2 – 75:25; T3 – 50:50; T4 – 25:75; T5 – 0:100 (v:v composted peach palm : soil);. Means values followed by the same letter in columns are not statistically different according to the Tukey test at $p < 0.05$

The C/N ratio ranged from 15.7 to 12.6 in T1 and T5, respectively. The relationship between carbon/ nitrogen is one that indicates the compost maturity (Dores-Silva et al. 2013). The most common problems in the use of compost as substrate includes immature compost (Meng et al. 2018) which can negatively affect plant development due to the presence of phytotoxic compounds and/or to reduced N availability (Huang et al. 2004), as it happened with the addition of peach palm residue (dry and crushed material) to the soil to produce lettuce seedlings (Belletini et al. 2017). However, a C/N ratio lower or equal to 15 can be considered satisfactory (Kumar et al. 2010) and indicates mature compost. Then, the composting of the peach palm used in this study was suitable and can be considered mature.

The total pore space values of all treatments were within the range (50-80%) recommended by Pascual et al. (2018). Increasing proportion of compost promoted the increase of porosity, T1 showed the highest value (74.79%) differing statistically from the other treatments. The porosity of a substrate is responsible for suitable gas exchange capacity for root system (Pascual et al. 2018) and is related to the amount of macropore and micropore. In general, substrates formed from organic residues have a predominance of micropores in detriment of macropores, consequently accumulate a larger volume of water (Guerrini and Trigueiro 2004), this fact corroborates the results of WHC.

The highest WHC was obtained for T1 (78.19%), where content was compost and, lowest WHC was obtained for T4 (37.7%) and T5 (33.4%). There was no significant difference between them. Increasing the proportion of the compost provided an increase in water retention capacity possibly related to a greater predominance of micropores present in the compost (Guerrini and Trigueiro 2004). This is another advantage of the use of the compost, in relation to soil, because with higher WHC, there is less demand for water application in each irrigation, unlike the soil in which it requires an increase of irrigation frequency given its lower WHC.

pH value of the growth media varied significantly from 6.2 (T1) to 3.6 (T4). The addition of soil tended to reduce the pH of substrates. The pH of T1 and T2 (with higher proportions of compost) showed values considered at acceptable levels (between 5.2 and 6.5) (Abad et al. 2001). Among the chemical characteristics, the pH value is very important, and low values can increase the availability of some micronutrients and cause phytotoxicity for some plants (Bailey 2000).

Electrical conductivity (EC) was significantly different among the substrates. EC values ranged from 0.15 to 1.56 dS m^{-1}, and the highest EC was observed in substrate containing only compost. The EC decreased as increasing the proportion of soil because this characteristic is related to the total soluble salts of the substrate (Guerrini and Trigueiro 2004). High EC causes poor shoot and root growth (Pascual et al. 2018) but all substrates used in this study showed suitable EC values.

An increasing trend of N and K was seen when the compost was gradually added to soil. The content of N and K of T1 was from 2.90% and 7,120 g dm^{-3}, respectively, values higher than T5. The results in Table 2 showed that increasing the proportion of composted peach palm residue led to an increased content of N and K when compared to the soil. The highest content was reached with 100% compost, because these elements are accumulated in the largest amount by the species (Fernandes et al. 2013), indicating potential use of this treatment to supply the initial development of the seedlings. Compost increases the availability of macro and micronutrients (Wang et al. 2016), increasing the root surface area per unit of soil volume, water-use efficiency and photosynthetic activity, which directly affects the physiological processes and utilization of carbohydrates (Abdelaziz et al. 2007; Morales-Corts et al. 2014; Ali et al. 2007); therefore, composts tend to contribute to plant growth.

Highlighting some micronutrients present in the evaluated compost, as mg kg^{-1} of compost: copper (18.00); iron (432.67); manganese (52.33); zinc (14.67); boron (20.93) (Table 1). This high concentration of micronutrients remains high even in peach palm residues grown in other regions (Carvalho et al. 2018). It is important to point out that boron is deficient in Brazilian soils, being indispensable for the development of palm trees fertilization (Moldolo et al. 2018), and the use of compost is the most appropriate for this.

The physical and chemical characteristics identified in the peach palm compost indicates a promising application of the product on the market, as compared to commercial substrates based on agricultural residues of similar origin, like coconut fiber. Further studies are suggested to evaluate potential application in other species to help add value to the product.

The addition of the compost to the soil decreased the bulk density (BD). The BD of T1 was significantly smaller than other substrates and the substrate with only soil was denser. This substrate characteristic can interfere in seedlings root development because it is strictly linked to the degree of particle compaction (Pascual et al. 2018) and the availability of air to the roots, also changing the total porosity (TP) of the substrates (Guerrini and Trigueiro 2004).

Morphological parameters

An overall ANOVA revealed that the incorporation of compost to the substrate significantly altered ($p < 0.05$) the plant height and, shoot fresh and dry weight. The seedlings height ranged from 22.3 to 35.6 cm (Fig. 2).

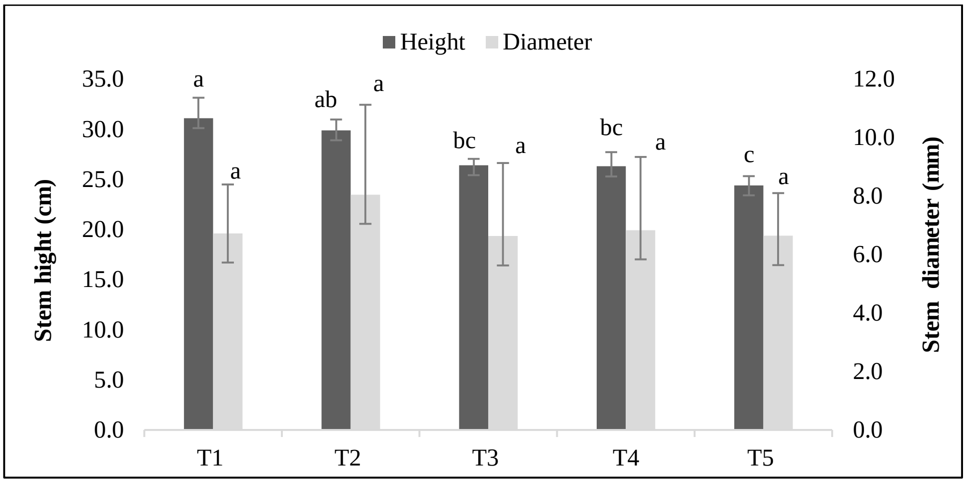

Fig. 2 Stem height (cm) and stem diameter (mm) of *B. gasipaes* seedlings in different substrates
T1 – 100:0 (v:v composted peach palm : soil); T2 – 75:25; T3 – 50:50; T4 – 25:75; T5 – 0:100. Error bars represent the standard deviations. *means values followed by the same letter do not differ by Tukey test at $p < 0.05$

The compost contributed with growth of peach palm seedlings, the bigger plants were grown on the growing media with higher proportion of compost (T1) and the lowest heights were observed in plants developed in substrate with only soil (T5) (Fig. 3). The standard height of the peach palm seedlings established for expedition is 30 cm (Garcia et al. 2011), so the only treatment that made it possible to obtain seedlings with adequate height was T1.

Fig. 3 *B. gasipaes* seedlings cultivated in T1 (substrate formed with 100% compost) and T5 (substrate with only soil)

This result could be attributed to the physical and chemical characteristic of substrates, mainly the input of N and K provided by the compost, nutrients directly responsible for plant growth. The nitrogen is one macronutrient with a vital role in the formation of active photosynthetic pigments which influence on net photosynthesis and, consequently, production of plant biomass and growth (Razaq et al. 2017). Potassium (K) is a nutrient required in major amount for plant growth and development (Pyo et al. 2010). Height is one of the most commonly used parameters to assess the quality of seedling in a non-destructive and easily measurable manner, besides its positively correlation with growth and survival in the field after planting (Melo et al. 2018; Santos et al. 2019). However, stem diameter and dry matter are also commonly considered to indicate seedling quality.

Regarding the stem diameter, we found no significant difference for different substrates, with diameters ranging from 6.6 to 8.1 mm (Fig. 2). These values are according with established standard for seedlings of other species of the Arecaceae family at 6 to 8 months (Martins Filho et al. 2007; Garcia et al. 2011; Silva et al. 2015).

The use of compost resulted in higher accumulation of biomass in seedlings of *B. gasipaes*. The highest shoot dry weight (11 and 10 g) pertained to T1 and T2 which contained higher compost proportion, differing statistically from T4 and T5 with 7.0 g of dry matter in both treatments (Fig. 4). The dry matter of *B. gasipaes* seedlings was most limiting by N, P and K (Fernandes et al. 2013). The chemical properties of the compost can have contributed to this result. The higher nutrient availability (NPK) provided by the compost may have favored the greater dry weight gain of the shoot. Several studies indicate that compost use provides the highest dry matter gain (Gómez-Merino et al. 2010; Morales-Corts et al. 2014) largely due to the nutritional composition of this media.

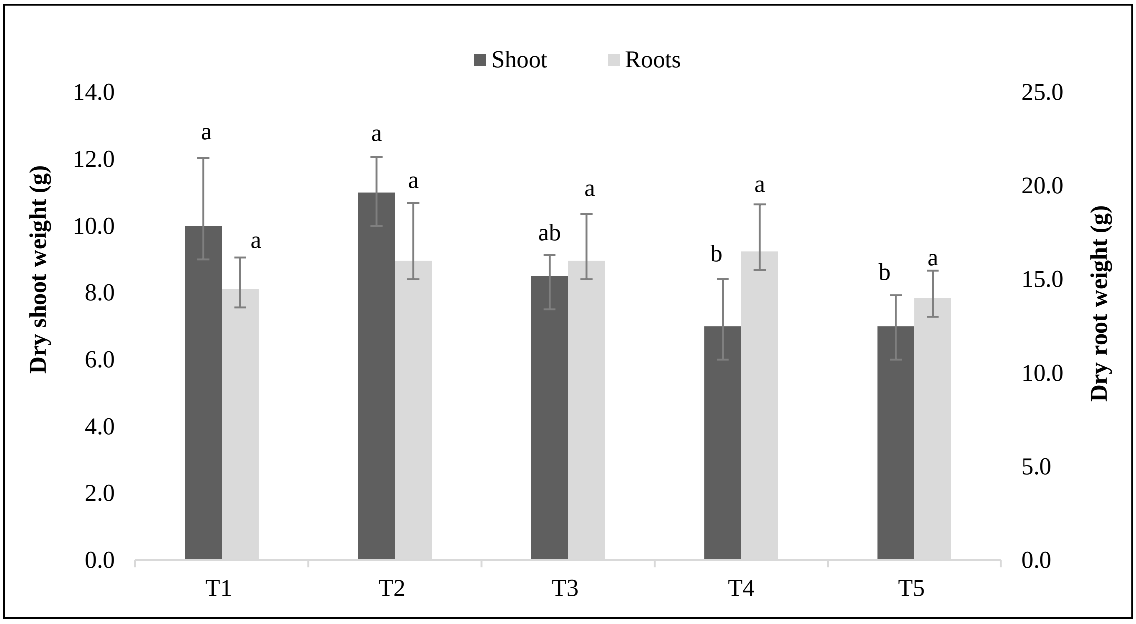

Fig. 4 Dry weight of shoot and root measures of peach palm seedlings in different compositions of substrates T1 – 100:0 (v:v composted peach palm : soil); T2 – 75:25; T3 – 50:50; T4 – 25:75; T5 – 0:100. Error bars represent the standard deviations. *means values followed by the same letter do not differ by Tukey test at 5% level of probability

In an experiment with peach palm seedlings, P deficiency reduced root dry matter production (Fernandes et al. 2013). As there was no significant difference in the concentration of this element in the evaluated treatments (Table 2), this indifference was reflected in the dry weight of the roots (Fig. 4), indicating an appropriate P level for the initial development of the species. In addition, peach palm is a species associated with mycorrhizal fungi (Hurtado et al. 2013) and the use of substrates with more organic matter such as compost (T1) may further lead to colonization, and consequently the absorption of P by the plant and stimulating the production sustainability.

The Dickson quality index (DQI) ranged from despite the contributions of the presence of compost in biomass growth and production, this did not significantly affect the index of seedling quality which varied from 0.52 to 0.71. However, this difference could be significant as the seedlings develop over a longer period. This is one of the most important parameters because analyzes the robustness and balance of biomass distribution, considering morphological characteristics such as total dry matter, shoot and root, height of shoot and diameter and, the larger the value obtained, the better the quality of the seedlings (Reis et al. 2011). In any case, the use of the compost as substrate has relevance in the production of peach palm seedlings, constituting as a substitute for soil use and a way to add value to a product considered as waste, and development a circular economy.

The lower growth of seedlings on substrate with higher proportion of soil may be related to the higher substrate density and lower porosity. During the seedling evaluation, we verified the accumulation of water on the surface of the plastic tubes in the seedlings grown on the substrate that contained only soil Garcia et al. (2011) also noted this in peach palm seedlings grown on substrates with density greater than 900g dm^{-3}. Thus, the lower density and higher porosity of the composted residue may have promoted better drainage of irrigation water, allowing greater aeration in the root system and, consequently, greater seedling development.

Conclusion

A compost containing 100% heart-of-palm agroindustrial residue has chemical characteristics suitable for use as a growth medium for *Bactris gasipaes* seedling production, replacing the substrate commonly used in nurseries, i.e., soil, promoting self-sustaining seedlings production and transforming the environmental liability on a valuable product.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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