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Composting of the waste of the heart of palm agroindustry for the cultivation of edible mushrooms

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Abstract: The agribusiness of heart of palm (*Bactris gasipaes*) generates large amounts of waste, causing environmental impacts. Before this waste is returned to crop soil, it can be used in the production of carpophores of *Pleurotus* sp. in combination with other organic sources. This work characterized, at the physical-chemical level and in terms of the availability of macro- and micronutrients, compost based on the agroindustrial waste of heart of palm and chicken manure. A 2 x 2 x 2 factorial experiment (factor 1 = forms of compost; factor 2 = proportion of waste and factor 3 = harvest times) in one completely randomized design of eight treatments with six replicates was applied. The following maximum values were obtained for treatments (T): pH = 6.50 (T5), OM = 11.49% (T5), CEC = 66.77 mEq/100 g (T2); EC = 9.20 dS/m (T8), ash = 50.12% (T4), C/N = 11.71 (T4), N = 0.72% (T7),

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PUBLIC INTEREST STATEMENT

The agribusiness of heart of palm (*Bactris gasipaes*) generates large amounts of waste and currently, there is an emerging market to export edible fungus from Peru using these residues for its production. Therefore, physical-chemical characteristics and availability of macro and micro elements of composting the waste of heart of palm in combination with chicken manure in the form of strips and piling were evaluated. Our study demonstrated that the edible fungus *Pleurotus* sp. might grow from day 16 due to temperature conditions in the composting process. Additionally, nutrients, cellulose, and hemicellulose content must be supplemented in order to have an optimal compost. Finally, it is recommended to use the waste of heart of palm without chicken manure and arranged in strips including complementary needs for the oyster fungus *Pleurotus* sp.

P = 154.62 ppm (T7), K = 9590.96 ppm (T5), Ca = 25.60 mEq/100 g (T6), Mg = 17.18 mEq/100 g (T6), Na = 1.38 mEq/100 g (T8), cellulose = 23.72% (T1), hemicellulose = 12.50% (T1). Despite the significant differences between treatments, these results are insufficient for the growth and development of these mushrooms. However, T5 (with a proportion of lignin closest to that needed: 43.64%) is the best to use from day 16 of composting, as long as it is complemented with substrates that cover the needs of *Pleurotus* sp.

Subjects: Agriculture and Food; Agronomy; Environmental Issues

Keywords: chicken manure; heart of palm waste; lignin; palm industry; *Pleurotus* sp; Peru

1. Introduction

The United Nations set as one of its Sustainable Development Goals the reduction of per capita food waste by half and the reduction of food losses along production and supply chains (Philippidis et al., 2019). Food scraps generate large amounts of food waste during the manufacturing process (Garcia-Garcia et al., 2019), causing direct environmental, economic, and social impacts (Morone et al., 2019) on global food security and environmental stewardship (Dahiya et al., 2018; Stenmarck et al., 2016).

Currently, in the Peruvian jungle, the expansion of “extractive” cash crops is associated not only with deforestation but also with the reduction of agrobiodiversity and changes in access to food (Blundo-Canto et al., 2020). For example, heart of palm (i.e., palm whose terminal bud is used as food) is obtained from the palm tree *Bactris gasipaes*, locally named *pijuayo* in the Peruvian jungle. In Peru, this crop is the third most important for food purposes due to its unique flavor and aromatic properties, and it is considered rich in proteins, fiber, carbohydrates, vitamins, and minerals (Cohen et al., 2002), giving it high commercial demand (Cabral Da Silva et al., 2019). In Peru, 3,640.95 tons were exported in 2019, of which 80% (2912 tons) were produced by the Caynarachi company, followed by 509.73 tons produced by the Cooperativa Agroindustrial del Palmito APROPAL Ltda. (Koo, 2020). This company generated 178.41 tons of agroindustrial heart of palm waste in the same year.

On the other hand, the cultivation of fungi of the genus *Pleurotus* for food purposes is relatively new (Pineda-Insuasti et al., 2014) but has gained momentum throughout the world for this crop’s ability to develop in various substrates, including agricultural scraps (Sánchez & Royse, 2001). At least 58 lignocellulosic substrates from agroindustrial waste have been used to cultivate *Pleurotus* spp. (Pineda-Insuasti et al., 2014), with promising results from mixtures of cottonseed husk, wheat straw, sawdust, sugar cane, and ground limestone (Royse, 2002), which have achieved a biological efficiency of 99.8–104.3% (Melo De Carvalho et al., 2010; Pineda-Insuasti et al., 2014).

Pleurotus ostreatus is the third most produced and consumed fungus in the world (Chang & Miles, 2004; Ventura-Aguilar et al., 2017). The biomass of this species is rich in proteins and vitamins and has β -glucan, which is well known for its antioxidant and antitumor activity (Stamets, 2002). The nutritional requirements for the growth of the *Pleurotus* fungus are nitrogen (4.52%), phosphorus (0.91%), potassium (1.28%), calcium (31.98 mg/100 g), magnesium (19.85 mg/100 g), iron (42.55 mg/100 g), zinc (27.65 mg/100 g), carbohydrates (42.36%) (Bhattacharjya et al., 2015), lignin (17.40%) (Ragunathan & Swaminathan, 2003), cellulose (41%) (Poppe, 2004), and hemicellulose (20%) (Tahir et al., 2019). These minimum requirements for the growth of *Pleurotus* sp. can be provided by agroindustrial residues of heart of palm (Ragunathan & Swaminathan, 2003; Temuujin et al., 2009; Tahir et al., 2019). It is estimated that the mushroom cultivation market will represent a value of USD 16.7 billion by the end of 2020 and will grow at a compound annual rate of 4.0%, reaching a value of USD 20.4 billion in 2025 (Research & Markets, 2020), making it a potential market that seeks to be exploited by jungle regions of Peru.

Due to the high amounts of agroindustrial waste of heart of palm and chicken manure (chicken manure prepared for use in industry) in the cities of Tarapoto and Yurimaguas, we aimed to characterize both materials physico-chemically and evaluate their contents of macro- and micro-nutrients using four different treatments based on two forms of composting (stacked and in strips) and two different proportions of waste (100% heart of palm and a mixture of 85% heart of palm waste and 15% chicken manure) as potential sources of nutrients in the production of carpophores of *Pleurotus* sp. before returning these residues to the crop soil.

2. Materials and methods

2.1. Description of the experimental site

The experiment was carried out at the Cooperativa Agroindustrial del Palmito APROPAL Ltda. This institution is located at km 84 in the town of Caynarachi, between the cities of Tarapoto and Yurimaguas, San Martín Region, Peru (6°07'26" S, 76°16'39" W, 162 meters above sea level). The experiment was developed during the harvests of the months of October and November 2019.

2.2. Design of the composting system and experimental treatment

Organic wastes generated at the Cooperativa Agroindustrial del Palmito APROPAL Ltda. from the agroindustrial process of heart of palm (palm husks, fibrous tips, and cassava crushed into pieces of 2 to 5 cm) were collected. The chicken manure was collected from a nearby farm. Taking into account the experimental design (eight treatments and six replicates), each experimental unit had a quantity of 50 kg of organic waste properly homogenized and distributed in two forms of compost (stacked and in strips) and in two proportions of the wastes (100% heart of palm and a mixture of 85% heart of palm waste and 15% chicken manure) and with two harvesting times (15 days and 30 days) (Table 1). The mixture proportions of the wastes consisted of 42.5 kg of chopped heart of palm waste (heart of palm shells and fibrous tips) and 7.5 kg of properly homogenized chicken manure. Turning was performed weekly to reduce heat loss during composting, and natural oxygen ventilation was used. A total of 48 solid samples (24 samples at 15 days of composting and 24 at 30 days of composting) weighing 0.5 kg were collected for physical-chemical characterization and macro- and micronutrient content analysis at the Laboratory of Soil and Water Research (LABISAG) and the Laboratory of Animal Nutrition and Food Bromatology of the Universidad Nacional Toribio Rodríguez de Mendoza (Toribio Rodríguez de Mendoza National University) of Amazonas, Peru.

2.3. Analytical methods

The temperature of the compost was recorded daily in the field with a digital thermometer (Hathen TBT-12 H, Colombia). The humidity was adjusted to 84% (Tiquia, 2005) at the beginning of all treatments. To determine the bromatological parameters, fresh laboratory samples collected at two points (15 and 30 days) were used, in which the following parameters were determined: moisture (M) using the AOAC method (Association of Official Analytical Chemists, 1984); organic matter (OM) with the Walkley and Black method (Walkley & Black, 1934); pH with the potentiometer measurement method with a 1:1 ratio (Millán et al., 2018); salinity by the measurement of electrical conductivity (EC) (Millán et al., 2018); total nitrogen (N) with the Kjeldahl method (Bradstreet, 1954); available phosphorus (P) using the modified Olsen method (Qian et al., 1994); available potassium (K) with the ammonium acetate extraction method (Qian et al., 1994); carbon/nitrogen (C/N) ratio with the Walkley and Black method (Eyherabide et al., 2014; Walkley & Black, 1934); the calcium (Ca^{+2}), magnesium (Mg^{+2}), and sodium (Na^{+}) exchangeable cations with atomic-absorption spectrophotometry (David, 1960); and the cation exchange capacity (CEC) using the ammonium acetate saturation method (Olaya et al., 2009). To measure the levels of cellulose, hemicellulose, and lignin, the ANKOM method was used (Ambavaram et al., 2011).

2.4. Statistical analysis

All statistical analyses were performed with INFOSTAT 2017 (FCa, Universidad Nacional de Córdoba, Argentina). One-way analysis of variance (ANOVA) was used to compare the data under a completely random design with a $2 \times 2 \times 2$ factorial arrangement for the composting

Table 1. Factors and treatments of the experimental design. Each treatment had 6 replicates

Treatments (T)	Form of compost (Factor 1)	Proportion of waste (Factor 2)	Moment of harvest (Factor 3)
T1	strip	100% heart of palm	after 15 days
T2	strip	mixture of 85% heart of palm and 15% manure	after 15 days
T3	stacked	100% heart of palm	after 15 days
T4	stacked	mixture of 85% heart of palm and 15% manure	after 15 days
T5	strip	100% heart of palm	after 30 days
T6	strip	mixture of 85% heart of palm and 15% manure	after 30 days
T7	stacked	100% heart of palm	after 30 days
T8	stacked	mixture of 85% heart of palm and 15% manure	after 30 days

process (factor 1: form of composting; factor 2: type of waste; factor 3: moment of harvest) with six replicates (Table 1). The data generated were tested for normality, and the Duncan multiple range test was used with a significance level of $p < 0.01$.

3. Results and discussion

3.1. Trends in composting temperature

Composting is a biochemical and heterogeneous process that involves the mineralization of organic matter in CO_2 , NH_3 , and H_2O and incomplete humification, resulting in a stabilized final product (Das et al., 2011). Composting requires special conditions of humidity and aeration to produce thermophilic temperatures (above 45°C), the main criterion for the inactivation of pathogens and the destruction of seeds (Haung, 1993). In our study, the temperature changes correspond to four phases (mesophilic 1, thermophilic, mesophilic 2, and maturation) of the composting process (Figure 2). The four mixtures used as substrates including their forms of compost went from mesophilic to thermophilic phase on day one, then to mesophilic phase 2 on day 7 and to maturation on day 15. These four phases showed temperature variations from 28°C to 61°C over the total of 30 days. Compost made from green manure can be obtained in 28 days (Zhang & Sun, 2019). Hyperventilated silos that accelerate the composting have been used with heart of palm mixtures (Yañez et al., 2007), showing similarities with our experiment in the number of days for the mesophilic and thermophilic phases (1 and 7 days, respectively) but not in the length of mesophilic phase 2. These differences were caused by the form of composting.

The mycelium of the genus *Pleurotus* grows in a wide range of temperatures (Sánchez & Royse, 2001): between 0 and 35°C , and even up to 40°C for 24 hours (but not 72 hours). Its optimal temperature is slightly lower than those for fruiting (Zadrazil, 1974). The four mixtures used as substrates in their different forms of composting of this experiment are suggested for planting after the ripening phase (day 16 onward).

3.2. Moisture content

The moisture content of the compost is important for the transport of dissolved nutrients necessary for the physiology and metabolic activities of microorganisms (Liang et al., 2003). The evaluations at 15 days showed differences ($p < 0.01$) in moisture between the treatments, with values ranging from 39.20% in P-M and 63.30% in S-Pa. At 30 days, moisture was lower (18.60–35.40%) and was different ($p < 0.01$) between the two statistical groups S-Pa/P-Pa and P-M/S-M (Figure 2). These moisture values were similar to those in a heart of palm mixture composted in hyperventilated silos (39.3–43.3% moisture) (Yañez et al., 2007).

Figure 1. Temperature behavior in the composting process according mixtures and forms (S-Pa = strips and 100% heart of palm; S-M = strips and a mixture of 85% heart of palm and 15% chicken manure; P-Pa = stacked and 100% heart of palm; and P-M = stacked and a mixture of 85% heart of palm and 15% manure).

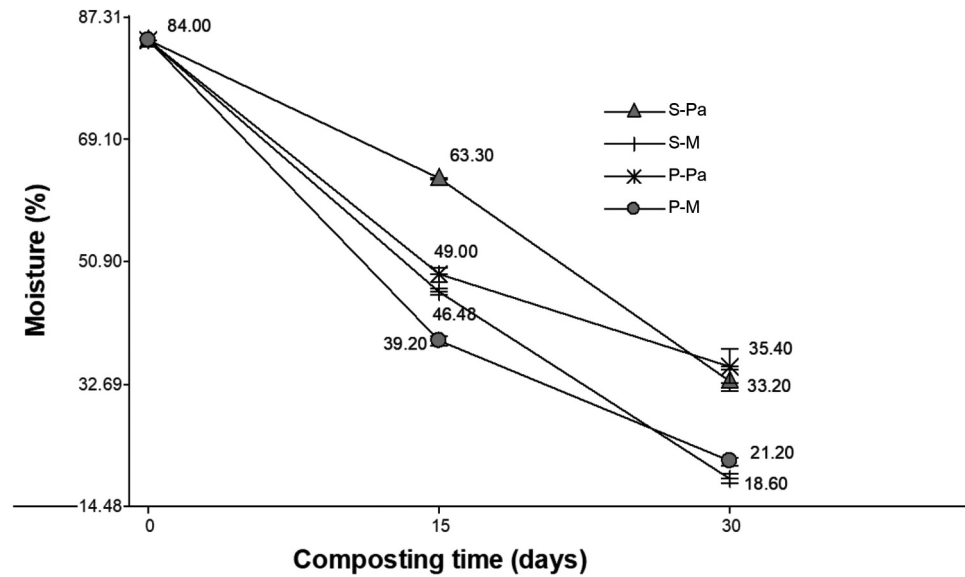
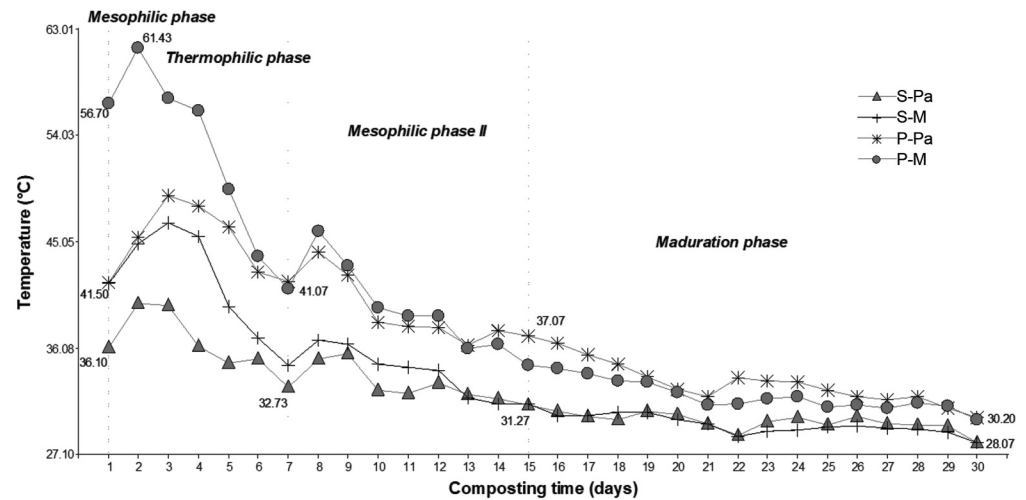


Figure 2. Moisture behavior in the composting process according mixtures and forms (S-Pa = strips and 100% heart of palm; S-M = strips and a mixture of 85% heart of palm and 15% chicken manure; P-Pa = stacked and 100% heart of palm; and P-M = stacked and a mixture of 85% heart of palm and 15% manure).



The moisture of the compost can be managed, and the water flow must be smooth, without much pressure and in the form of very small drops, to avoid damaging the surface of the substrate (Sánchez & Royse, 2001). *Pleurotus* grows in optimal substrate moisture between 50% and 60% (Chang & Miles, 1989; Zadrazil, 1978). The decision of when to water compost can only be made with experience, and no general recommendation is possible (Sánchez & Royse, 2001).

3.3. Cellulose, hemicellulose, and lignin

Agricultural activities generate many scraps of plant origin, which have approximately 70% cellulose and lignin. These agroindustrial scraps with a high lignocellulosic content are difficult to degrade; however, many microorganisms use these compounds as a source of nutrition, and some of them are used as an alternative food source across the world (Fernández, 2014; cited by Guzmán, 2018). The scraps from the palm oil industry used in the experiment had values of 35.58% cellulose in their natural state, and due to the effect of degradation, the percentage cellulose dropped at 15 and 30 days under all treatments.

Cellulose evaluations revealed significance ($p < 0.01$) clustered in five statistical groups (a–e). The highest (group a and T1) and lowest (group e and T4, T8) values are explained by the interaction effects of the type of residue, reinforcing the idea that there is a lower level of cellulose degradation in 100% palm heart compost (Table 2).

- (1) Significance at 15 days. 2) Significance at 30 days. (* = significance $p < 0.05$; ** = significance $p < 0.01$; ns = no statistical significance). Different superscript letters correspond to different statistical groups within each row.

The different species of *Pleurotus* act mainly as saprophytes by naturally growing and fruiting directly on wood logs. They carry out this function through the oxidative and hydrolytic capacity conferred by the secretion of a broad spectrum of enzymes, which act with high specificity on lignocellulosic structures (Rajaratnam et al., 1987). Oyster fungi such as *Pleurotus* consume significant amounts of cellulose and hemicelluloses as their main food source (Temuujin et al., 2010; World, 2004). Materials based on stems of *Zea mays*, *Pisum* sp., *Oryza sativa*, and *Triticum aestivum* straw, with 48%, 43%, 41%, and 40% cellulose, respectively, can be added to heart of palm compost (Poppe, 2004). Cluster composting based on empty oil palm fruits has shown no significant effect on cellulose content (50–60%) for up to 20 weeks (Tahir et al., 2019), so this plant deserves to be part of that list.

The hemicellulose values showed differences ($p < 0.01$) between five statistical groups. Values between 8.35% and 12% were recorded in the entire experiment, which are low compared to reports of substrates used for the cultivation of heart of palm, of 20% in clusters of empty fruits of oil palm (Tahir et al., 2019), 40% in *Avena sativa* straw, and 39% in *Triticum aestivum* (Poppe, 2004).

Oyster fungi need abundant substrates in the form of polysaccharides (cellulose and hemicelluloses) and lignin for their growth. *Pleurotus* can grow in lignocellulosic materials because it has the enzymes necessary to break lignin, namely ligninase (LPI) and extracellular manganese peroxidase (Kirk and Farrel, 1987). Lignin concentrations between 43.64% and 26.22%, with a decreasing tendency, were recorded in the entire experiment under the eight treatments ($p < 0.01$). This decrease in lignin over time could be predicted from the increase in organic matter *per se* (Silanikove et al., 1988). The values in all treatments allowed the growth of *Pleurotus*, as it is possible to obtain about a kilogram of fresh fungi from each kilogram of a dry base of substrate with cellulose and lignin (Poppe & Hofte, 1995). The amounts of lignin in our study exceeded the maximum amounts reported in the composition of carpophores of *Pleurotus* spp. when planted on cotton stalk (21.6 ± 0.2), coconut fiber (18.3 ± 0.05), or sorghum residues 17.40 ± 0.10 (Ragunathan & Swaminathan, 2003).

3.4. pH, organic matter, electrical conductivity, cation exchange capacity, and ash

pH is an important factor that deserves evaluation because it affects microbial activity during composting. It affects the ionic character of the medium and directly influences membrane proteins and the activities of enzymes linked to the cell wall (Sánchez & Royse, 2001). Growth records of *Pleurotus* show optimal growth ranges between pH 4 and 7 (Sánchez & Royse, 2001), and the variations depend on the strain and the species (Rajaratnam et al., 1989; Srivastava & Bano, 1970). In our experiment, there were no significant differences in pH between the treatments, and the pH values were between 4.8 and 6.8, within the optimal range (Table 3). However, alkaline management should be considered optimal, i.e., pH higher than those found, since most of the contaminants found during the cultivation process are more sensitive to high pH values than *Pleurotus* species (Sánchez & Royse, 2001). pH tended to increase at 15 (T1–T4) and 30 (T5–T8) days of composting because of the increase in ash contained in the substrates (Silanikove et al., 1988).

- (1) Significance at 15 days. 2) Significance at 30 days. (* = significance $p < 0.05$; ** = significance $p < 0.01$; ns = no statistical significance). Different superscript letters correspond to different statistical groups within each row.

Table 2. Effect of composting with different substrates based on waste from the pijuayo (*B. gasipraes*) agroindustry on the concentrations of cellulose, hemicellulose, and lignin

Raw material/ content	T1	T2	T3	T4	T5	T6	T7	T8	CV %
Cellulose (%) ¹⁾ ^{**2)}	23.72 ± 0.25 ^a	23.01 ± 0.27 ^b	19.02 ± 0.25 ^d	17.17 ± 0.42 ^e	21.83 ± 0.44 ^c	17.66 ± 0.14 ^c	19.02 ± 0.25 ^d	16.98 ± 0.26 ^e	1.82
Hemicellulose (%) ¹⁾ ^{**2)}	12.00 ± 0.40 ^b	10.68 ± 0.29 ^c	11.05 ± 0.08 ^{bc}	8.35 ± 0.39 ^d	12.50 ± 0.48 ^a	11.03 ± 0.09 ^{bc}	11.05 ± 0.08 ^{bc}	11.80 ± 1.07 ^{ab}	4.13
Lignin (%) ¹⁾ ^{**2)}	43.64 ± 0.36 ^a	32.51 ± 0.02 ^d	36.90 ± 0.34 ^c	43.30 ± 0.03 ^a	39.56 ± 0.44 ^b	32.25 ± 0.05 ^d	36.90 ± 0.34 ^c	26.22 ± 0.04 ^c	0.72

There were three statistical groups in organic matter ($p < 0.01$), however, the average ranges found in the entire experiment (7.36% in T3 and 11.49% in T5) were very low compared to those in other common agroindustrial byproducts used in the planting of *Pleurotus*, such as sugarcane bagasse (97.5%) (Stamets & Chilton, 1983), cocoa husk (92.2%) (Piccioni, 1970), and rice husk (82.5%) (González et al., 1987), so new evaluations are suggested that require complementary substrates such as those mentioned.

CEC showed six statistical groups ($p < 0.01$), the T7 presented the highest average CEC of 66.77 ± 0.23 (mEq/100 g). Compost with green forage of fallen leaves and branch cuttings, bamboo vinegar, and a microbial inoculum of *Trichoderma* spp. and *Phanerochaete chrysosporium* (Zhang & Sun, 2019) has reached values between 37.23 and 121.44 (mEq/100 g) due to the effects of β -cyclodextrin.

The differences between treatments ($p < 0.01$) in EC showed four statistical groups in both evaluations (Table 3). Between groups a (T8) y b (T2, T4, and T5), the time had a positive effect on EC because the stabilization process in the maturation stage increases the concentration of salts, a phenomenon caused by the greater decomposition and mineralization of the material (Kimura (2005) cited by Miyashiro (2014)). Therefore, the higher the content of chicken manure in composting, the higher the EC concentration (Guizado, 2018).

Likewise, ash was different at 15 and 30 days ($p < 0.01$), forming four statistical groups (Table 3). All values are high with respect to ash values reported in cotton residues (13%) and rice husk (17.1%) (González et al., 1987), which are used as substrates for planting *Pleurotus*.

Despite some numerical differences, there were no significant differences in the C/N ratio among treatments (Table 3). However, neither the maximum values presented in the experiment (T4 and T2) reached the range of values (between 30 and 300) suggested for substrates used in the planting of *Pleurotus* (Sánchez & Royse, 2001). One study on a mixture with 40% heart of palm waste reported average C/N values of up to 27.9 The C/N ratio was so high either because much of the organic carbon was in the form of lignin and cellulose that were not immediately available for microbial use or because of the loss of nitrogen (Yañez et al., 2007).

3.5. Macro- and micronutrients

The nutrient content of the compost is related to the quality of the original organic substrate. However, most compost is too low in nutrients to be classified as fertilizer. Its main use is as a soil conditioner, mulch, dressing, or organic base with fertilizer amendments (Haug, 1993). Since *Pleurotus* grows and fructifies using the same elements (macro- and micronutrients) required by any other cultivated plant (Molena, 1986; Sales-Campos et al., 2009), it is necessary to know the quantities that the compost can offer.

The concentration of nitrogen did not represent significant differences, despite the numerical differences, which reached ranges between $0.37 \pm 0.02\%$ in T3 to $0.88 \pm 0.15\%$ in T7 (Table 4). The study that used a mixture with 40% heart of palm waste showed approximately 1% nitrogen, with losses over time explained by high pH values, leading to losses of ammonia, suggesting that adding alkaline material to the cells of compost can be more harmful than beneficial if not well controlled (Yañez et al., 2007). However, in our experiment, under all treatments, nitrogen increased from day 15 to day 30 with the addition of 150 grams of lime to each experimental unit.

Phosphorus showed differences ($p < 0.01$), with six statistical groups, the product of the interaction between the form of composting and the waste mixture (Table 4), the major values in the treatments T6 and T7 behaved statistically similarly. Phosphorus in soil increases its ability to solubilize in the presence of decomposing lignocellulose, and only biologically active

Table 3. Effect of composting with different substrates based on waste from the pijuayo agroindustry (*B. gasipaes*) on physicochemical properties

Raw material/ content	T1	T2	T3	T4	T5	T6	T7	T8	CV %
pH _(1, ns,2) ns	5.20 ± 0.10	4.80 ± 0.10	5.50 ± 0.10	5.00 ± 0.10	6.50 ± 0.10	5.00 ± 0.10	5.30 ± 0.10	5.30 ± 0.10	5.38
OM (%) _{(1, **,2) **}	9.19 ± 0.21 ^c	9.65 ± 0.07 ^b	7.36 ± 0.19 ^d	10.30 ± 0.32 ^a	11.49 ± 0.23 ^a	10.57 ± 0.24 ^c	11.03 ± 0.13 ^b	11.03 ± 0.13 ^b	2.01
CEC (mEq/100 g) _{(1, **,2) **}	27.62 ± 0.49 ^f	30.85 ± 0.08 ^e	19.93 ± 0.09 ^d	35.21 ± 0.23 ^d	53.88 ± 0.13 ^c	66.77 ± 0.23 ^a	63.80 ± 0.25 ^b	63.80 ± 0.25 ^b	0.55
EC (dS/m) _{(1, **,2) **}	3.46 ± 0.11 ^c	6.30 ± 0.15 ^b	2.70 ± 0.32 ^d	6.60 ± 0.37 ^b	6.60 ± 0.13 ^b	9.00 ± 0.10 ^a	9.20 ± 0.21 ^a	9.20 ± 0.21 ^a	3.34
Ash (%) _{(1, **,2) **}	38.06 ± 3.06 ^c	44.29 ± 1.96 ^b	33.50 ± 0.50 ^d	50.12 ± 2.12 ^a	20.83 ± 0.93 ^e	38.81 ± 0.96 ^c	46.28 ± 1.28 ^b	46.28 ± 1.28 ^b	4.53
C/N ratio _{(1, ns,2) ns}	10.25 ± 3.25	11.67 ± 1.34	11.54 ± 0.29	11.71 ± 4.72	7.58 ± 1.99	11.57 ± 5.81	11.03 ± 3.64	11.03 ± 3.64	30.35

Table 4. Effect of composting with different substrates based on waste from the pijuayo agroindustry (*B. gasipaes*) on the levels of macro- and micronutrients

Raw material/ content	T1	T2	T3	T4	T5	T6	T7	T8	CV %
N (%) _{1) ns,2) ns}	0.52 ± 0.06	0.48 ± 0.37	0.37 ± 0.02	0.51 ± 0.21	0.88 ± 0.15 a	0.53 ± 0.28 a	0.72 ± 0.18 a	0.58 ± 0.14 a	46.20
P (ppm) _{1) **,2) *}	59.97 ± 0.63 e	112.20 ± 2.99 c	60.64 ± 0.08 e	89.31 ± 2.81 d	134.42 ± 0.34 b	155.29 ± 10.0 a	154.62 ± 0.34 a	143.94 ± 0.11 db	5.67
K (ppm) _{1) **,2) **}	4374.38 ± 0.86 e	3825.98 ± 0.72 f	3700.25 ± 0.59 g	4347.19 ± 0.25 e	9590.96 ± 0.5 a	8039.27 ± 0.55 c	6909.54 ± 0.80 d	9114.50 ± 0.6 b	0.84
Ca (mEq/100 g) _{1) **,2) **}	9.23 ± 0.06 f	12.61 ± 0.40 e	8.20 ± 0.24 g	13.44 ± 0.32 d	21.04 ± 0.26 b	25.60 ± 0.27 a	21.02 ± 0.33 b	20.21 ± 0.16 c	1.67
Mg _a (mEq/100 g) _{1) **,2) **}	5.36 ± 0.08 f	8.08 ± 0.19 e	3.74 ± 0.03 g	7.76 ± 0.24 d	9.12 ± 0.15 c	17.18 ± 0.34 a	8.71 ± 0.29 c	16.52 ± 0.32 b	2.41
Na (mEq/100 g) _{1) **,2) *}	0.48 ± 0.10 d	1.07 ± 0.10 c	0.19 ± 0.10 e	1.56 ± 0.10 a	0.72 ± 0.30 b	1.23 ± 0.10 bc	0.40 ± 0.08 de	1.38 ± 0.10 ab	14.47

organic matter improves the availability of P in the soil (Iyamuremye & Dick, 1996). This could explain why, in our experiment, higher values of available phosphorus showed in treatments with interactions at 15 days than 30 days. The highest phosphorus value was 155.29 ± 10.0 ppm (T2), well below the 13,000 ppm recorded in evaluations using heart of palm (40% of the mixture) in hyperventilated silos (Yañez et al., 2007). *Pleurotus* has shown up to 9100 ppm of phosphorus absorbed in sawdust mixture, which suggests that new substrates need to be added to the base mixture studied in this work to complement the needs of the fungus.

Significance at 15 days. 2) Significance at 30 days. (* = significance $p < 0.05$; ** = significance $p < 0.01$; ns = no statistical significance). Different superscript letters correspond to different statistical groups within each row.

Potassium was different ($p < 0.01$, with seven treatment groups (Table 4). In all treatments, there was a trend towards greater availability of potassium as time passed, with a maximum value of 9590.96 ± 0.5 ppm (T5). However, phosphorus was lower than the 9770 ppm obtained in ground stems of *Bactris gasipaes* (Sales-Campos et al., 2009) and the 16,000 ppm of total potassium product obtained from composting heart of palm (40% of the mixture) in hyperventilated silos (Yañez et al., 2007).

Minerals such as NaCl, $MgCl_2$, and $CaCl_2$ stimulate the growth of the mycelium, as well as the beginning of the formation of the fruiting body (Zadrazil & Kurtzman, 1989). Calcium showed differences ($p < 0.01$), and each treatment was represented as one statistical group (Table 4). The highest value reported were T2 (25.60 ± 0.27 mEq/100 g). All the calcium values of this experiment are lower that required for *Pleurotus* culture, according to a study that evaluated the effects of substrates that allowed harvesting *Pleurotus*, which found that calcium of 31.98 mg/100 g was needed (based on sawdust of mahogany trees) (Bhattacharjya et al., 2015).

Magnesium showed differences ($p < 0.01$) (Table 4). The highest values are within the range of magnesium values in *Pleurotus* when planted in sawdust-based substrates: 13.31 mEq/100 g (fig) and 17.26 mEq/100 g (eucalyptus) (Bhattacharjya et al., 2015).

When evaluating sodium concentrations, seven statistical groups were founded ($p < 0.01$). The T8 had the greatest concentration of sodium (1.38 ± 0.10) (mEq/100 g) (Table 4). However, all the values of this experiment are lower than those found with substrates based on heart of palm strips (40% of the mixture), which reached 66.58 ± 0.27 mEq/100 g (Sales-Campos et al., 2009).

The interactions of all treatments showed increases in the concentrations of macronutrients and microelements with the passage of time until the end of composting. Therefore, it is expected that the nutrients produced by this compost can function as fertilizers (Zhang et al., 2013; Zhang & Sun, 2016).

4. Conclusion

Due to the temperature conditions in the composting process, it is possible to plant *Pleurotus* from day 16 onward (i.e., T5- T8). To achieve an optimal compost according to the needs of the fungus, it is necessary to complement the quantities of organic matter and macro- and micronutrients and to regulate the values of pH, CEC, and EC in all treatments. The closest values for the growth and development of the fungus were those in treatment 5 (strip type and 100% heart of palm at 16 days of composting). Therefore, to use agroindustrial residues of heart of palm (i.e., *B. gasipaes*), it is recommended to use treatment 5 over the other treatments evaluated here, as long as this waste is only a complementary material to the needs of the oyster fungi of the genus *Pleurotus*.

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Competing interests

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