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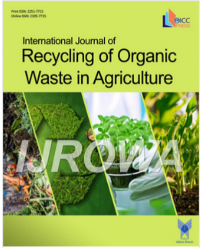

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Use of agro-industrial waste for the production of compost as a sustainable management alternative

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Original Research

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Abstract:

Purpose: The objective of this research is to evaluate the quality of the compost generated from agro-industrial storage residues composed of soybean, corn, wheat, oats, sunflower, and canola remains, as an environmental management alternative.
Method: Standardized analytical techniques were used. The samples were obtained in situ. The parameters analyzed were pH, nitrogen, phosphorus, potassium, sodium, calcium, copper, zinc, magnesium, iron, manganese, ash, and humidity. The microbial populations were quantified and the most predominant morphotypes were isolated to carry out a description and identification. The analysis of the environmental benefits of the compost production process was valued by calculating the importance of considering the positive and negative impacts.
Results: The physical-chemical characterization of the compost presented 63.8% humidity; 1.35% nitrogen; 0.86% potassium; 0.51% phosphorus; 0.04% sodium; 1.52% calcium; 0.01% copper; 0.02% zinc; 0.56% magnesium; 0.07% manganese; 8.61% iron; 63.04% ash and a pH of 8.52, which indicate a high nutritional value for plants. The genera identified were *Aspergillus spp.*, *Penicillium spp.*, and *Fusarium spp*. The analysis of the environmental benefit resulted in 4 negative moderate impacts and 11 positive severe and moderate impacts.
Conclusion: The study reveals that the transformation of this waste into compost not only contributes to reducing the amount of waste generated by the agri-food industry but also offers multiple environmental and agronomic benefits. The use of agro-industrial residues for the production of compost is a sustainable management alternative.

Keywords: Chemical composition; Agroindustrial waste; Revaluation; Circular economy

1. Introduction

Since the evolution of the economy of humanity, from hunting to agriculture, great importance has been attached to the study of various procedures for sustainable agriculture because the annual global amount of organic solid waste in agricultural activities ranges from 76 million tons, which do not receive an adequate process and final disposal treatment, which causes pollution and degradation of the environment (Álvarez-Palomino et al., 2018). It was not until the end of the last century that research strengthened the search for fertilization alternatives from the waste generated to improve soils, guarantee crop profitability, and contribute to consumer health (Chávez and Rodríguez, 2016).

Current agriculture explores alternatives that improve soil conditions, in which the organic approach stands out in some productive sectors. This strategy is aimed at improving the physical, chemical, and biological properties of the soil to regenerate its structure and promote a more efficient yield of its crops (Álvarez-Palomino et al., 2018). This is based on the use and recycling of organic waste and the application of transformation methods such as composting, not only to mitigate environmental impacts but also to give them added value and improve the economy of the regions (Rojas-González et al., 2019).

In Paraguay, the main economic activity is carried out around the primary sector, mainly agricultural production of soybeans, corn, wheat, and livestock production with bovine (Dos Santos et al., 2020). This implies the generation of a large amount of waste from the agricultural sector, therefore, options for the management of organic solid waste are proposed.

According to Nicolás et al. (2012), the external application of organic matter is an excellent promoter of biological activity, with an increase in organic carbon and nitrogen contents, as well as humic substance contents (Rosas-Calleja et al., 2016). This information suggests that the production of compost from agricultural residues is a potential alternative to generate stabilized organic matter that allows increasing soil fertility. The management of agricultural waste through composting reduces elements of environmental contamination and generates compost with added value, stable, and useful in agriculture (Hernández-Cázares et al., 2016). In the agricultural activities of several countries, waste disposal is not carried out in a sanitary landfill or suitable area, the most economical option being the uncontrolled burning of the material. However, this generates harmful effects on the environment. Biomass burning causes 40% carbon dioxide, 32% carbon monoxide, 20% particulate matter, and 50% polycyclic aromatic hydrocarbons, emitted worldwide (Chávez and Rodríguez, 2016).

The growing demand for food has established sustainable management of production systems as an alternative, promoting practices that preserve natural resources and allow efficient and adequate use of waste derived directly or indirectly from the agricultural sector, such as, for example, the practice of composting (Carrión and Franco, 2015).

Composting is a biological method that allows the transformation of organic waste into a relatively stable product (Carrión and Franco, 2015). It is a technique in which the biodegradation of organic matter is promoted by the action of microorganisms, generating its transformation into other chemical forms that form compost (Chávez and Rodríguez, 2016). Composting allows us to reduce the amount of waste and take advantage of the nutritional content of the organic fraction, generating by-products with high added value from an environmental and economic approach. It is a low-cost technology, which guarantees that organic residues link their components in the cycle of the primary production chain, also allows for improved physical-chemical conditions of the soil, and increases crop productivity (Vargas-Pineda et al., 2019).

To achieve this, it is necessary to evaluate the quality of the compost generated from agro-industrial storage residues of plant origin as an environmental management alternative.

2. Material and methods

Study area

The composting process was carried out in an agricultural establishment in the city of Yatytay, department of Itapúa, southern Paraguay.

The climate for this location is classified as Cfa, which refers to a humid subtropical climate (Köppen and Geiger, 1936). According to the Land Use Rationalization Project, the taxonomic classification of the soil in this area is ultisol of basaltic origin, whose edaphic characteristics are dark color; its tendency to be alkaline in terms of pH; its richness in minerals such as iron, calcium, phosphorus, magnesium, potassium and its high capacity to retain water (Pascua and Lucesoli, 2020).

Regarding agroecological zoning, agricultural lands suitable for intensive and extensive development of annual and perennial crops, livestock, forestry, or production activities predominate in the district (López et al., 1995). According to the origin of the soil, 100% of the district corresponds to basalt, the drainage in a greater proportion is good, it presents a null and moderate rockiness in parts, and the landscape that dominates is the hill (López et al., 1995).

The vegetable source of the compost analyzed in research was formed by agricultural silo residues composed of soybean, corn, wheat, oats, sunflower, and canola remains that go through a pre-cleaning process, in which they pass through a total of 12 sieves of different sizes, being 15 mm, 9 mm, and 3.5 mm for round grains and a 1.75 × 22 mm sieve for elongated grains. Then, these wastes are arranged in a single pile outdoors during the harvest months (generally January, February, July, and October) thus achieving thier natural decomposition.

Physicochemical characterization of the compost

Compost sub-samples were taken, 3 on the sides of the base and 1 on the tip, placed on a clean plastic canvas, divided into four equal parts, and two opposite parts separated. The procedure was repeated until a 1/2 kg sample was obtained, which was homogenized, placed in a plastic bag, and correctly identified (Salazar-Calvo et al., 2020). This procedure was carried out on site and the samples were taken at ambient temperature, considering that the average annual temperature of the area is 20.6 °C.

In the laboratory, the physicochemical parameters such as pH, nitrogen, and phosphorus were analyzed according to the Hach method; potassium, sodium, calcium, copper, zinc, magnesium, iron, and manganese according to the Perkin Elmer method; ash according to the ISO 5984:2002 method and humidity according to the method described in the ISO 6496:1999 standard.

Measurement of microbiological variables of the compost

In the Laboratory of Chemistry, Microbiology, and Bromatology of the Faculty of Sciences and Technology of the National University of Itapúa, Petri dishes were prepared with potato dextrose agar culture medium. Then, an initial suspension was prepared by weighing 10 g of compost sample that was dissolved in 90 ml of distilled water. 2 dilutions and a blank were prepared. 0.1 ml of solution was taken and placed on the surface of the plate with culture medium. This was done in duplicate for each dilution and the plates were incubated at room temperature (18-26 °C) for 5-10 days.

The quantification of microbial populations was made by the plate count method using a colony counter. The most predominant morphotypes were isolated, microscopic mounts were prepared, and the description of morphological char-

acteristics and identification was carried out.
The macroscopic characteristics of the colony-forming units (CFU) were described 8 days after incubation, on the front and back in a Petri dish. This brief period can provide a preliminary view of the diversity and development of microbial colonies, but it is important to note that this period can limit the observation of slower-growing organisms. This cautious approach underlines the importance of considering time as a key factor in the complete and accurate identification of microbial diversity in the compost under study.
For the preliminary observations of fungi under the microscope, the adhesive tape method was used, which consists of extracting fragments of the colony by gently pressing the sticky side of the tape on the aerial mycelium of the fungus, placing the tape on an object holder with a drop of lactophenol blue and observe under the microscope the morphological characteristics of the mycelium and reproductive organs (Pacasa-Quisbert et al., 2017). The possible taxonomic identification of the genus was made by comparing with the literature of (Samson et al., 2014) and (Pacasa-Quisbert et al., 2017).

Analysis of the environmental benefit of compost production

To carry out the analysis of the environmental benefits of the compost elaboration process, the positive and negative impacts that may arise from this activity were considered. The evaluation of the impacts was carried out through the Conesa method, which is an analytical method, by which the importance (I) can be assigned to each possible environmental impact of the execution of the project, applying Equation 1 (Arboleda, 2008):

$$I = \pm(3IN + 2EX + MO + PE + RV + SI + AC + EF + PR + MC) \quad (1)$$

Where:
±: Nature of the impact, being + for positive impact or - for negative impact.
IN: Probable intensity or degree of destruction, being 1 for low intensity; 2 for medium intensity; 4 for high intensity, or 8 for very high intensity.
EX: Extension or area of influence of the impact, being 1 for a specific area of influence; 2 for a partial extension; 4 for a large area of influence, or 8 for full extensión.
MO: Moment or time between the action and the appearance of the impact, being 1 for long term; 2 for medium term, or 4 for immediate.
PE: Persistence or permanence of the effect caused by the impact, being 1 for fleeting; 2 for temporary, or 4 for permanent.
RV: Reversibility, being 1 for short term; 2 for medium term, or 4 for irreversible.
SI: Synergy or reinforcement of two or more simple effects, being 1 for no synergism; 2 for synergistic, or 4 for very synergistic.
AC: Accumulation or effect of progressive increase, being 1 for simple, or 4 for cumulative.
EF: Effect, being 1 for indirect, or 4 for direct.
PR: Periodicity, being 1 for discontinuous; 2 for periodically, or 4 for continuous.
MC: Recoverability or possible degree of reconstruction by human, being 1 for immediate recoverable; 2 for medium-term recoverable; 4 for mitigable, or 8 for irrecoverable.
According to the values assigned to each criterion, the importance of the impact can vary between 13 and 100 units which, according to the method, establishes the following significance: less than 25 are irrelevant or compatible with the environment; between 25 and 50 are moderate impacts; between 50 and 75 are severe; above 75 are critical.

3. Results and discussion

Physicochemical characterization of the compost

The physical-chemical characterization of the compost under study was carried out. Table 1 presents the characteristics of the analyzed sample expressed in percentages.
The laboratory results indicate that it is a material with a humidity greater than 50% which is ideal because the presence of water is essential for the physiological needs of microorganisms since it is the means of transport of the soluble substances that serve as food to the cells and the waste products of the reactions that take place during this process.
It presents significant amounts of macronutrients such as nitrogen, which is essential for plant cell reproduction and the quality of compost as a fertilizer is directly related to its nitrogen content; potassium, which helps plants develop strong stems, fight diseases, and allow fast growth; phosphorus, which has a fundamental role in the formation of energy-rich cellular compounds being necessary for microbial metabolism. Similarities are observed regarding the 0.37% potassium reported by Rivas-Nichorzon and Silva-Acuña (2020).
It also has significant amounts of micronutrients such as calcium, copper, iron, magnesium, manganese, sodium, and zinc that contribute to enzymatic synthesis, microorganism

Table 1. Physicochemical characterization of the compost.

Variable	Result
Humidity	63.8%
Nitrogen	1.35%
Potassium	0.86%
Phosphorus	0.51%
Sodium	0.04%
Calcium	1.52%
Copper	0.01%
Zinc	0.02%
Magnesium	0.56%
Manganese	0.07%
Iron	8.61%
pH	8.52[a]
ash	63.04%

[a]-: Is dimensionless

metabolism, and intracellular and extracellular transport mechanisms. The values reported by Rivas-Nichorzon and Silva-Acuña (2020) are similar for magnesium (0.65%), but not for calcium (0.68%), zinc (0.003%), and iron (0.0008%), which are below the found in this work. It is important to highlight the elevated iron value, which could be due to the characteristics of the soil where the starting materials were grown since ultisols tend to have a high iron adsorption capacity due to the presence of clay minerals, iron oxides, and other characteristic components of these soils (López et al., 1995).

The pH has a direct influence on the microbial composting process. According to literature, the optimal range for the composting process is between 5.50 and 8.0. Compared to what was recently expressed, the result obtained is above the optimal range. In a study carried out by Barbaro et al. (2019), it was established that compost is alkaline because it contains a lower proportion of exchangeable hydrogen ions and a higher proportion of calcium and magnesium. Coincidentally, the compost analyzed in this work contains a high concentration of these micronutrients.

Measurement of microbiological variables of the compost

After 3 days of incubation of the sample, the plate colonies were counted. For the 10^{-1} concentration plates, on average, 65 CFU were counted, for the 10^{-2} plates 58 CFU, and for the 10^{-3} dilution plates 21 CFU.

After 8 days of incubation of the plates, the macroscopic and microscopic descriptions of the fast-growing fungal colonies were made, the possible genera identified were *Aspergillus spp.* and *Penicillium spp.* from the *Trichocomaceae* family; *Fusarium spp.* of the *Nectriaceae* family. In Table 2 characteristics and the corresponding identification are described, according to the morphology observed at the macro and micro scale.

The most frequent organisms in the composting process are bacteria, fungi, and actinomycetes. The ratio of fungal to prokaryotic biomass in compost is approximately 2:1. In addition, the fungi existing in the compost use many carbon sources, mainly lignocellulosic polymers, which can survive in extreme conditions and are responsible for the maturation of the compost. The fungi most commonly found in compost materials are *Aspergillus*, *Penicillium*, *Fusarium*, *Trichoderma*, *Chaetomonium*, *Acremonium*, and *Cladosporium* (Dehghani et al., 2012; Rivas-Nichorzon and Silva-Acuña, 2020).

Aspergillus, *Penicillium*, and *Fusarium* fungi found in the analysis are important in the composting process due to their role in the decomposition of the most difficult and resistant components of organic matter; these fungi are known as primary degraders (Barrios and Sandoval, 2018).

Fungi of the *Aspergillus* genus have the ability to degrade cellulose, hemicellulose, and lignin, and also produce enzymes such as cellulases and ligninases, which help break down these complex compounds into simpler molecules.

Fungi of the genus *Penicillium* are also capable of breaking down a variety of organic substrates, including cellulose, starch, and protein. Some species produce enzymes such as amylases and proteases, which facilitate the breakdown of

Table 2. Macroscopic and microscopic characteristics of observed fungal colonies and possible identification.

Macroscopic characteristics	Microscopic characteristics	Identification
Circular-shaped colony, white in color with a defined dark green dotted center; cottony. On the re-verse, the colony is circular, white, with a dull green center.	It presents hyaline, branched mycelium, with long, coenocytic conidiophores. Near the vesicle a rough part is formed, the vesicles are spherical, covered in 360°, and contain 1 or 2 series of phialides.	*Aspergillus flavus*
Fast-growing colony, matured in 3 days; white with abundant black dots; cottony texture. The reverse is white and circular.	Septate, hyaline mycelium, presents sub-spherical aspergilate heads, with two series of phialides, at an angle of 360°, with round equinulate and black conidia.	*Aspergillus niger*
Fast-growing colony as it matured in 3 days; brown; cottony, with a ye-llowish-brown underside.	Septate mycelium, hyaline, with coenocytic conidiophores and subspherical vesicles. Aspergilar, biseriate heads are observed, with abundant free, spherical, hyaline conidia.	*Aspergillus terreus*
Light pink colony and darker center; cottony texture.	The conidiogenous cells are mo-nophialid, long, and septate. The macroconidia have 3 to 5 septa and present a curved dorsal area and a more straight ventral area.	*Fusarium sp.*[a]
Initially white; cottony surface. A greenish-blue center is observed. It presents exudates on the surface and pigmentation on the back.	It has septate hyaline hyphae. The conidiophores have cylindrical se-condary branches, with smooth walls carrying phialides from which long unbranched chains of spores emerge, forming the characteristic brush of the genus.	*Penicillium sp.*[a]

[a] sp.: Unidentified species.

Table 3. Effect of seed dormancy breaking treatment on Bunium luristanicum germination and seedling growth.

Impact	±[a]	**IN**[b]	**EX**[c]	**MO**[d]	**PE**[e]	**RV**[f]	**SI**[g]	**AC**[h]	**EF**[i]	**PR**[j]	**MC**[k]	**Importance**	**Impact**
Reduced dependency on chemical fertilizers	(+)	12	1	2	2	1	1	1	4	4	2	55	Severe
Recovery of soil fertility	(+)	12	1	1	2	1	2	1	4	4	2	55	Severe
Improves water retention in the soil	(+)	8	1	2	2	1	1	1	4	4	2	43	Moderate
Improves the arrival of nutrients to plants	(+)	4	1	1	2	1	1	1	4	4	2	30	Moderate
Avoids the collection of waste and its transport to the treatment plant	(+)	12	1	4	2	1	1	1	4	4	1	56	Severe
Reduction of infrastructure investment spending	(+)	4	1	4	2	1	1	1	4	4	1	32	Moderate
Reduction of the cost of waste treatment	(+)	12	2	4	2	1	1	1	4	4	1	58	Severe
Improves the physical-chemical properties of the soil	(+)	8	1	1	2	1	2	1	4	4	2	43	Moderate
Reduction of erosive processes	(+)	4	1	1	2	1	2	1	4	4	2	31	Moderate
Increase in productive land uses	(+)	4	1	2	2	1	2	1	4	4	2	32	Moderate
Increase in soil biodiversity	(+)	8	1	1	2	1	2	1	4	4	2	43	Moderate
Generation of atmospheric emissions (gases from decomposition of organic matter)	(-)	4	2	4	2	1	2	1	4	4	1	35	Moderate
Accident risk	(-)	4	1	4	2	1	1	1	1	4	1	29	Moderate
Landscape alteration	(-)	4	1	4	2	1	1	1	4	4	1	32	Moderate
Deterioration of air quality	(-)	4	2	1	2	2	2	1	1	4	2	31	Moderate

[a] ±: Nature of the impact.
[b] IN: Probable intensity or degree of destruction.
[c] EX: Extension or area of influence of the impact.
[d] MO: Moment or time between the action and the appearance of the impact.
[e] PE: Persistence or permanence of the effect caused by the impact.
[f] RV: Reversibility.
[g] SI: Synergy or reinforcement of two or more simple effects.
[h] AC: Accumulation or effect of progressive increase.
[i] EF: Effect.
[j] PR: Periodicity.
[k] MC: Recoverability or possible degree of reconstruction by human.

these compounds. These fungi also help control the growth of pathogenic microorganisms during the composting process, as do some members of the *Aspergillus* genus.
The *Fusarium* genus is known for its ability to degrade lignin, a key component of plant cell walls. Additionally, some members of this genus can also break down other organic components, such as cellulose and hemicellulose. However, some *Fusarium* species can also be pathogenic to plants, so it is important to maintain a proper balance of their presence in the compost.
Taken together, the presence of *Aspergillus spp.*, *Penicillium spp.*, and *Fusarium spp.* in the compost is essential for the decomposition process of organic matter. These fungi break down the more complex components of organic materials and release nutrients and simpler compounds that are beneficial to plant growth. In addition, its activity contributes to the stabilization of the compost and the control of the proliferation of undesirable microorganisms.

Analysis of the environmental benefit of compost production

The presence of agro-industrial waste generates negative and positive impacts on the environment since every production process generates waste at different levels according to its characteristics. When these residues are not properly disposed of or adequately managed, they cause adverse changes in the environment that are detrimental and negatively affect the development of living beings. However, well-used agro-industrial residues prevent the contamination of various ecosystems and could recover the environmental conditions altered by human activities (Aguiar et al., 2022).
Table 3 presents the results of the analysis of the environmental benefit of compost production, where the impacts, the variables with the numerical values assigned to them, and the product are presented.
100% (4) of the negative impacts belong to the moderate category, which means that they are not in a state of alert and therefore measures are required to minimize the impacts that occur.
Regarding the positive impacts, 64% (7) belong to the category of moderate and 36% (4) to the category of severe. These are manifested in the environment and the socio-economic environment with the reduction of dependence on chemical fertilizers, erosive processes, investment costs in infrastructure, cost of waste treatment; with the improvement of the physical-chemical properties of the soil and the arrival of nutrients to the plants. Also, it allows the increase of soil biodiversity, the recovery of soil fertility, and the improvement of water retention in the soil. It avoids the collection of waste and its transport to the treatment plant. That is why these positive impacts must be strengthened.
A study conducted by Islam et al. (2019), in which the influence of the addition of banana peel biochar in the soil was analyzed, shows that it is positive for plant growth and suggests an alternative to overcome the use of chemical fertilizers. In this way, they also highlight the positive impacts of the use of agricultural waste through recycling.

4. Conclusion

The results obtained in this research demonstrate the potential of using agro-industrial residues for the production of compost as a sustainable management alternative. The study reveals that the transformation of this waste into compost not only contributes to reducing the amount of waste generated by the agri-food industry but also offers multiple environmental and agronomic benefits.
The use of agro-industrial residues for compost production is presented as an effective and sustainable solution for the proper management of this waste. The compost obtained offers a valuable contribution of nutrients to improve soil quality, reduce dependence on synthetic chemical fertilizers, and promote healthy crop growth.
Disposing of agro-industrial waste in landfills or sanitary landfills, at other times, was perhaps the only possible solution. However, it is currently possible to reintegrate them into a circular economy, with other alternatives such as compost production. According to Aguiar et al. (2022), this is the most economical alternative, with less risk that maximizes its positive environmental impact.
The composting technique promotes the proper management of waste, the improvement of soil health, and the reduction of the environmental footprint of the agri-food industry (Pacasa-Quisbert et al., 2017). This approach presents great opportunities to move towards a circular and environmentally friendly agricultural system while promoting the production of quality and sustainable food.

Authors Contributions
The authors confirm the study conception and design: Tatiana Wieczorko Barán, Estelvina Rodríguez Portillo; data collection: Tatiana Wieczorko Barán, Claudia González Britos; analysis and interpretation of results: Tatiana Wieczorko Barán, Estelvina Rodríguez Portillo, Claudia González Britos; draft manuscript preparation: Tatiana Wieczorko Barán. The results were evaluated by all authors, and the final version of the manuscript was approved.

Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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