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Biodegradation of sugarcane bagasse and rice husk plates in tropical soils in Pucallpa, Peruvian Amazon

Biodegradación de platos de bagazo de caña de azúcar y cascarilla de arroz en suelos tropicales en Pucallpa, Amazonía Peruana

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ABSTRACT

Biodegradable food-service items are increasingly sought to reduce the environmental impact of single-use plastics. This study evaluated the biodegradation performance of plates made from sugarcane bagasse (SB) and rice husk (RH) under tropical field conditions and different soil types. Plates were produced via thermoforming using six starch and glycerol formulations and their physico-mechanical properties were characterized prior to selecting the best formulation. Biodegradation trials were conducted over 90 days in three soil environments: open soil (OS), eucalyptus-reforested soil (ER), and compost-amended soil (OC). Weight loss was measured periodically, alongside monitoring of environmental parameters and soil physicochemical and microbiological changes. Both SB and RH plates exceeded 96% biodegradation within 90 days, meeting ISO 14855-2:2018 and ASTM D5338-15 criteria. SB generally degraded faster than RH in OS and ER, while no significant differences were observed in OC. The highest degradation occurred within the first 15 days, followed by a slower phase. Biodegradation contributed to increased soil moisture, total nitrogen, and apparent density, and altered microbial populations. These findings demonstrate that agricultural-residue-based plates can serve as viable alternatives to plastics, effectively reintegrating organic matter into soils. However, limitations include low physico-mechanical performance, the restricted range of environmental conditions tested, and the absence of performance assessment under actual food-service use. Future work should address durability improvements and evaluate degradation in diverse real-world settings.

Keywords: agricultural waste, biodegradable products, biopolymer, biodegradation

RESUMEN

Los artículos biodegradables para alimentos son cada vez más buscados como estrategia para reducir el impacto ambiental de los plásticos de un solo uso. En este estudio se evaluó la biodegradación de platos fabricados con bagazo de caña de azúcar (SB) y cascarilla de arroz (RH) en condiciones tropicales de campo y diferentes tipos de suelos. Los platos se fabricaron vía termoformado. Inicialmente se utilizaron seis proporciones de almidón y glicerol, estas muestras se caracterizaron por sus propiedades físico-mecánicas, para seleccionar la mejor formulación antes de las pruebas de biodegradación. Los ensayos de biodegradación se llevaron a cabo durante 90 días en tres tipos de suelo: suelo abierto (OS), suelo reforestado con eucaliptos (ER) y suelo con compost (OC). La pérdida de peso y los parámetros ambientales se midieron periódicamente. También se midieron los cambios fisicoquímicos y microbiológicos del suelo antes y después de los ensayos. Tanto los platos de SB como los de RH superaron el 96% de biodegradación en 90 días, cumpliendo los criterios de las normas ISO 14855-2:2018 y ASTM D5338-15. Los platos de SB se degradaron más rápidamente que los de RH en los suelos OS y ER. En el suelo OC no se observaron diferencias significativas. La mayor tasa de biodegradación se produjo en los primeros 15 días, seguida de una fase más lenta. La biodegradación contribuyó al aumento de la humedad del suelo, del nitrógeno total y de la densidad aparente, y a la alteración de la actividad microbiana. Los resultados del estudio demuestran que los platos a base de residuos agrícolas pueden servir como alternativas viables al plástico, reintegrando eficazmente la materia orgánica en los suelos. Sin embargo, entre las limitaciones del estudio están la baja resistencia físico-mecánica de los platos, la cantidad de parámetros evaluados y la ausencia de evaluaciones de los platos en condiciones reales de uso. En futuros trabajos se deberá abordar la mejora de la durabilidad y la degradación en condiciones reales.

Palabras clave: residuos agrícolas, productos biodegradables, biopolímero, biodegradación

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Highlights

- Plates from sugarcane bagasse and rice husk degraded >96% in 90 days.
- Biodegradation met ISO 14855-2:2018 and ASTM D5338-15 standards.
- Initial rapid degradation phase occurred within the first 15 days.
- Degraded plates improved soil nitrogen, moisture, and microbial activity.

Introduction

Since the 20th century, plastics have become widely used due to their versatility and durability, with global production estimated between 7.8 and 8.3 billion tons. However, only 9% of this plastic has been recycled, while 79% has accumulated in landfills and open dumps, causing significant environmental impacts [1-2].

The main cause of these impacts is the non-biodegradability of plastic [3], which can take 100 to 500 years to fully degrade under environmental conditions [4]. Given this persistence, numerous studies have explored alternatives to conventional plastic [5]. Biopolymer-based materials represent one promising biodegradable alternative, particularly those derived from waste biomass [6]. For example, corn starch products can fully degrade in approximately 90 days [7]. Liu *et al*. [8] reported that sugarcane pulp and bamboo tableware exhibited fungal growth within 20 days, loss of structural integrity by days 30–45, and gradual disappearance after day 60. Similarly, Buxoo and Jeetah [9] developed biodegradable disposable cups from pineapple peels, orange peels, and Mauritian hemp leaves coated with beeswax, which completely disintegrated in active soil within five weeks. Oberlintner *et al*. [10] assessed chitosan biopolymer films enriched with *Quercus* polyphenol extract and observed significant weight loss during soil burial tests across different soil types. These findings highlight the growing potential of biodegradable materials from diverse waste sources as viable replacements for conventional plastics.

The use of waste-derived biopolymers offers multiple benefits: (i) they are generated in large quantities year-round [11-12], (ii) they promote resource recovery, and (iii) they reduce final disposal costs. These advantages make them an attractive option for sustainable material production, particularly in regions seeking low-cost, circular economy solutions. Using residues available within the production region not only ensures cost-effectiveness but also strengthens local value chains. However, despite increasing research on waste-based biopolymers [13-15], few studies have evaluated biodegradable plates produced from locally sourced agricultural residues, such as sugarcane bagasse (SB) and rice husk (RH), under Amazonian or tropical conditions.

Sugarcane bagasse and rice husk are abundant in Peru, particularly in Amazonian regions [16], making them promising feedstocks for biodegradable products. In 2024, sugarcane was the most cultivated crop in Peru (10 087 748 metric tons), while rice ranked fourth (3 367 614 metric tons) [17]. From this production, approximately 30% of processed sugarcane becomes bagasse waste, while rice milling generates about 57% husk waste. This represents a considerable amount of waste rich in cellulose, suitable for transformation into biodegradable plates [16].

Given the abundance of these cellulose-rich residues, this study investigated their suitability for producing biodegradable plates. The objective of this study was to assess the biodegradation rate of sugarcane bagasse and rice husk plates under different soil treatments. Plates were prepared using five glycerol and starch formulations, and their physico-mechanical properties were first characterized to identify the most suitable compositions. The selected formulations were then evaluated in terms of biodegradation performance under specific environmental and soil conditions.

Additionally, the nutritional contribution of the plates was quantified to explore their potential as soil amendments after disposal. By integrating physico-mechanical assessment, biodegradation analysis, and nutrient content evaluation, this study addresses multiple sustainability dimensions and demonstrates the potential of locally sourced agricultural residues to reduce single-use plastic dependency in Amazonian contexts.

Materials and Methods

All experiments were conducted at the National University of Ucayali, located in the district of Callería, province of Coronel Portillo, Ucayali region in Peru in 2023. The study was carried out in two stages. First, SB and RH biodegradable plates were prepared using different glycerol and starch ratios to select the best formulation.

Second, field tests were conducted to assess the biodegradation rate of the SB and RH plates under different soil treatments, while monitoring environmental conditions.

Plates

Plates Elaboration: RH was sourced from a local rice milling company, and rice bran was obtained from grocery stores located in the port area of the study site. SB was collected from sugarcane juice vendors in the study area. Starch was sourced from local producers in the port area, and glycerol (99.8%) was purchased from *Químicos Perú SAC*. RH and SB were air-dried for two days before being stored in plastic bags. Both SB and RH were characterized for cellulose (ASTM D1695-77), hemicellulose (indirect holocellulose method, ASTM D1104), and lignin (TAPPI T222 os-74).

Plates were prepared as shown in Fig. 1. First, SB and RH were milled and pulverized using a knife-and-hammer mill, producing particles smaller than 8 mm. Glycerol (6.92%) was selected based on previous studies [18] and to reduce production costs. Glycerol (6.92%) and starch solutions were prepared according to each treatment condition (Table 1), followed by mixing and molding. The mold used had a diameter of 20 cm.

Thermopressing was performed at 180°C using a thermoforming machine with a 20-ton capacity and mild steel molds coated with non-stick Teflon. The effective pressure applied to the mold was 73.4 MPa. Pressing time was adjusted according to the starch content of each formulation (Table 1). When starch is exposed to high temperatures, it undergoes gelatinization, followed by cooling and drying. Because thermopressing conditions affect brittleness, pressing time was controlled to minimize these effects and preserve plate integrity.

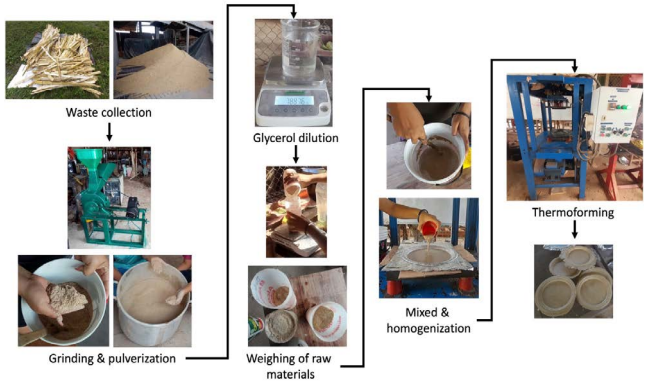

Figure 1. Process for manufacturing biodegradable plates from sugarcane bagasse and rice husk.
Source: Author

Starch and glycerol treatments: To identify the most suitable conditions, three treatments were tested for each plate type (Table 1). Residues alone were not evaluated because they lack sufficient natural binding capacity for successful thermoforming. The results of each treatment were compared based on physico-mechanical parameters determined using ASTM methods. Young's modulus (YM), tensile strength (TS), and elongation (EL) were measured using a universal testing machine according to ASTM D5035-11.

Elasticity modulus (EM) and breakage modulus (BM) were determined using the same universal testing machine following ASTM D143-94, while hardness (HR) was measured using a Shore hardness tester according to ASTM D1037. Statistically significant differences between plates and treatments were assessed using the Kruskal–Wallis test.

Table 1. Experimental design for the production of biodegradable plates

DESCRIPTION	Time (min)	Code
10% rice bran + 10% sugarcane bagasse + 10% starch + 70% glycerol at 6.92%	10 and 12	SB1
10% rice bran + 10% sugarcane bagasse + 20% starch + 60% glycerol at 6.92%	10 and 12	SB2
10% rice bran + 10% sugarcane bagasse + 30% starch + 50% glycerol at 6.92%	8	SB3
18% rice bran + 12% rice husk + 10% starch + 60% glycerol at 6.92%	15	RH1
18% rice bran + 12% rice husk + 20% starch + 50% glycerol at 6.92%	7 and 10	RH2
18% rice bran + 12% rice husk + 30% starch + 40% glycerol at 6.92%	3	RH3

Source: Authors. Percentages are based on a total formulation weight of 1200 g for all treatments. Two times indicate different pressing times among replicates.

Biodegradation tests

Biodegradation was evaluated using a 2 × 3 factorial design, testing SB3 and RH3 plates under three soil treatments: open soil (OS), eucalyptus (*Eucalyptus urograndis*) reforestation soil (ER), and compost from organic waste (OC). Each treatment was performed in triplicate. The experimental area measured 6 m² and was subdivided into 1 m² plots. In each plot, holes 15 cm deep were dug following the burial method described by Yap *et al*. [19] and Liu *et al*. [8].

Weight loss was recorded every 15 days until day 90. Before weighing, samples were washed with water to remove impurities, sun-dried, and then dried to constant weight. Atmospheric parameters (ambient temperature, relative humidity, and soil temperature) were monitored daily throughout the 90 days.

Physicochemical and microbiological analyses of the surrounding soil were performed before and after the biodegradation experiments, following the methods detailed in Table 1. The biodegradation rate was calculated using Equation (1) [19], where W_i is the initial plate weight and W_t is the weight at time t. Statistically significant differences between plates and treatments were assessed using the Kruskal–Wallis test.

$$Biodegradation\ rate\ (\%) = \frac{W_i - W_t}{W_i}\ x\ 100 \qquad (1)$$

Results and discussion

Physico-mechanical properties across different starch and glycerol formulations

Table 2 presents the chemical composition of RH and SB. The results are consistent with literature values, which report that RH contains approximately 25–35% cellulose, 18–25% hemicellulose, 18–21% lignin, and 15–17% silica, with the remainder comprising soluble compounds and moisture (7–15%) [20-21]. The composition of SB aligns with reported ranges, being a rich source of cellulose (32–45%), hemicellulose (20–32%), and lignin (17–32%), along with 1–9% ash and minor extractives [22-23]. The values obtained in this study were 35% cellulose, 25% hemicellulose, and 20% lignin for RH, and 46.60% cellulose, 29.40% hemicellulose, and 20.70% lignin for SB. These results fall within or close to reported ranges, confirming the quality and suitability of both residues as feedstocks for biodegradable plate production.

Table 2. Raw material characterization of rice husk and sugarcane bagasse used for biodegradable plate production.

PARAMETER	Unit	RH	SB
Cellulose	%	35	46.60
Hemicellulose	%	25	29.40
Lignin	%	20	20.70

Source: Retrieved from [24].

The physico-mechanical properties of all formulations were lower compared to values reported in the literature (Table 3). Given these findings, and to better understand the influence of starch and glycerol content on performance, the discussion will focus on four key parameters: YM, TS, EL, and HR. YM is a measure of material stiffness, indicating resistance to elastic deformation under stress. In this study, a higher starch content and lower glycerol proportion (p/p) showed a positive effect on YM, with SB generally performing better than RH. In a study by Ilyas *et al*. [25], the addition of 0–1% palm sugar nanofibrillated cellulose to palm sugar starch films increased YM significantly, from 53.97 to 121.26 MPa.

TS measures the maximum stress a material can withstand before breaking. Higher starch content and lower glycerol content (p/p) tended to increase TS in both SB and RH plates. Huertas *et al*. [26] reported that fiber additions above 11.25% reduced TS, likely due to fiber agglomeration, starch chain breakage, and reduced expansion during thermoforming. EL represents the material's ability to stretch before breaking. In our formulations, variations in starch and glycerol content influenced EL differently between SB and RH plates. Lindriati *et al*. [27] found that adding 5–15% bagasse reduced elongation due to fiber incorporation in the matrix. In contrast, increasing glycerol content by 20–40% increased elongation because glycerol reduces tensile strength while enhancing flexibility.

HR indicates resistance to surface indentation or penetration. In our results, higher starch, and lower glycerol content improved hardness. Hoang and Tran [18] observed that glycerol concentrations from 3–6% (p/p) increased hardness in rice husk products but decreased it when exceeding 5%, as glycerol enhances flexibility while reducing brittleness and water vapor/oxygen permeability.

These performance differences guided the selection of formulations for subsequent biodegradability evaluation. As shown in Table 3, SB3 achieved the highest values for all physico-mechanical parameters, while RH3 had the best results for YM, TS, and BM. For this reason, SB3 and RH3 were selected for the biodegradability tests.

Table 3. Physico-mechanical parameters of biodegradable plates produced from rice husk and sugarcane bagasse.

Symbol	Unit	SB1	SB2	SB3	RH1	RH2	RH3
YM	MPa	0.22	0.49	1.04	0.59	0.20	0.94
TS	MPa	0.12	0.10	0.18	0.06	0.10	0.21
EL	%	1.17	0.71	0.66	0.31	1.16	0.74
EM	MPa	5.29	7.66	6.24	3.97	3.58	3.14
BM	MPa	0.08	0.10	0.18	0.12	0.10	0.17
HR	kg	13.69	7.24	25.50	9.53	13.16	11.55

Source: Retrieved from [24].

The comparatively low physico-mechanical values observed in this study are likely related primarily to processing conditions [28]. Possible contributing factors include insufficient molding pressure or inadequate consolidation time, which could have limited matrix compaction. Residual moisture after pressing may have softened the matrix, reducing stiffness and strength during testing. Additionally, non-uniform fiber distribution within the matrix, with localized agglomerations or voids, may have impaired stress transfer efficiency and further weakened mechanical performance [29].

There are currently no national or international standards that define minimum physico-mechanical requirements for biodegradable disposable plates. In practice, this means that values are often compared against those reported for commercial references. For example, Pardo [30] reports palm-leaf biodegradable plates with TS = 16.09 MPa, E = 1%, and YM = 17.94 MPa, while commercial polypropylene plates present TS = 6.75 MPa, E = 16.60%, and YM = 2.86 MPa. Although the plates produced in this study showed lower values in some parameters, they were comparable in others, indicating potential for improvement through optimization of processing conditions.

To improve the commercial applicability of these plates and enhance stiffness and tensile strength, several strategies could be explored. First, the thermopressing process should be optimized by evaluating the effects of molding pressure,

pressing time, and temperature on matrix consolidation and mechanical performance. Second, reinforcing fillers or crosslinking agents, such as cellulose, nanocellulose, or citric acid, could be incorporated to improve structural integrity [31-32]. Finally, the starch-to-glycerol ratio should be optimized to achieve a better balance between strength and flexibility.

Biodegradability assessment

Soil baseline and post-degradation properties: Soil properties directly influence the biodegradation process and should therefore be considered when interpreting degradation results [33]. Table 4 presents the baseline physicochemical characteristics of the three soil types evaluated: open soil (OS), eucalyptus-reforested soil (ER), and organic waste compost soil (OC).

Table 4. Soil physicochemical parameters in the three treatments evaluated during the biodegradation assay.

Parameter	Unit	Open soil			Eucalyptus-reforested soil			Organic waste compost soil		
		BLOS	SB3OS	RH3OS	BLER	SB3ER	RH3ER	BLOC	SB3OC	RH3OC
pH	pH	5.06	4.9	4.94	5.05	4.91	4.82	4.93	5.53	5.92
EC	µS/cm	52.62	35.75	41.19	37.38	43.78	36.8	35.36	50.27	51.76
OM	%	3.41	3.69	3.95	2.92	3.59	3.63	1.54	2.92	2.27
H	%	9.94	23.76	22.85	14.71	21.95	20.19	13.76	16.01	15.97
TN	mg/kg	1 704	1 844	1 976	1 462	1 794	1 814	770	1 462	1 134
P	mg/kg	15.3	9.54	10.18	9.74	8.44	8.51	6.68	27.15	24.11
K	mg/kg	70.55	20.78	20.64	41.64	25.33	30.14	18.86	27.08	32.91
AD	g/mL	1.19	1.22	1.25	1.18	1.21	1.21	1.52	1.50	1.59
FC	%	30.8	31.78	38.32	25.54	32.82	32.3	25.81	27.81	28.34
HB	CFU/g	4.6E+06	3.1E+06	3.8E+06	1.3E+07	1.7E+06	1.0E+06	4.0E+04	6.0E+03	4.0E+03
MY	CFU/g	1.3E+03	1.2E+03	1.3E+03	1.1E+03	1.0E+03	1.02E+03	ND	ND	ND

Source: Authors. EC = electrical conductivity; OM = organic matter; H = humidity; TN = total nitrogen; P = available phosphorus; K = available potassium; AD = apparent density; FC = field capacity; HB = heterotrophic bacteria; MY = molds and yeasts; BL = baseline (no plate); SB = sugarcane bagasse plate; RH = rice husk plate. ND = not detected.

An increase in humidity percentage was observed. Research by Yang *et al*. [34] supports these findings, indicating that materials with high fiber and starch content improve the soil's water-holding capacity, reflected in the higher moisture in treated plots. Physical soil properties also changed: apparent density increased compared to control soils. This suggests that the plates, during biodegradation, contributed organic matter affecting porosity and compaction. Such effects are consistent with studies showing that biodegradable materials can improve soil quality by increasing water retention and promoting biological activity. Total nitrogen increased in treated soils, while phosphorus and potassium decreased. In OS, larger decreases occurred in potassium, manganese, and zinc, along with an increase in calcium. Cation exchange capacity decreased in treated soils, which may negatively affect long-term fertility [35]. However, these changes were observed during the 90-day biodegradation period, when the plates were actively decomposing, and therefore reflect short-term responses rather than long-term soil conditions. Previous studies have shown that applying mature compost containing biodegradable materials and plant fibers at industrial or agricultural scale generally improves soil physicochemical properties and contributes to soil quality over time [36]. Consequently, the short-term reductions observed in the present study should not be directly extrapolated to medium or long-term nutrient imbalances without further long-term field evaluations. Heterotrophic bacteria increased in treated soils, likely due to the additional degradable carbon supplied by the plates during biodegradation. Molds and yeasts showed variable responses depending on soil type, which may be linked to changes in moisture and nutrient availability caused by the degradation process. These shifts suggest that the breakdown of the plates not only released organic matter but also altered microhabitat conditions, influencing microbial community composition and activity.

Environmental conditions throughout the experiment: Humidity and temperature are critical factors affecting biodegradation [19,34]. The humidity and temperature conditions in the study area are representative of a tropical climate [37]. Environmental parameters were recorded daily for the 90 days (Table 3). Ambient temperature in ER showed less variation, reaching a maximum of 32 °C and a minimum of 23 °C, with an average of 28 °C. In contrast, treatments OS and OC showed wider ranges of variation, with a maximum temperature of 39 °C, a minimum of 15 °C, and an average of 29 °C. Relative humidity remained relatively constant across the three treatments. The greater temperature stability in ER likely provided more consistent conditions for microbial growth, whereas the wider temperature fluctuations in OS and OC could have periodically slowed microbial activity. Constant humidity conditions are essential to facilitate biological activity, as they promote the decomposition of organic matter and the development of microorganisms [38].

Biodegradability rate: Fig. 2 shows the biodegradability rate for the SB and RH plates in the three treatments over the 90-day study. Weight loss on day 90 was compared to assess differences between plate types and soil treatments (Table 4). The appearance of the plates before burial (day 0) and after 90 days of soil biodegradation is shown in Fig. 1. No statistically significant differences were found between soil treatments, indicating that soil type did not influence biodegradation under the experimental conditions. In contrast, there were significant differences between plate types, with SB showing greater biodegradation than RH in the OS and ER treatments. For OC, no significant differences were observed between plates. Similar results were reported by Oberlintner *et al*. [10].

This pattern may reflect that the range of soil parameter variations in our treatments was not large enough to influence biodegradation, whereas intrinsic differences in plate composition and structure played a more important role in degradation rate.

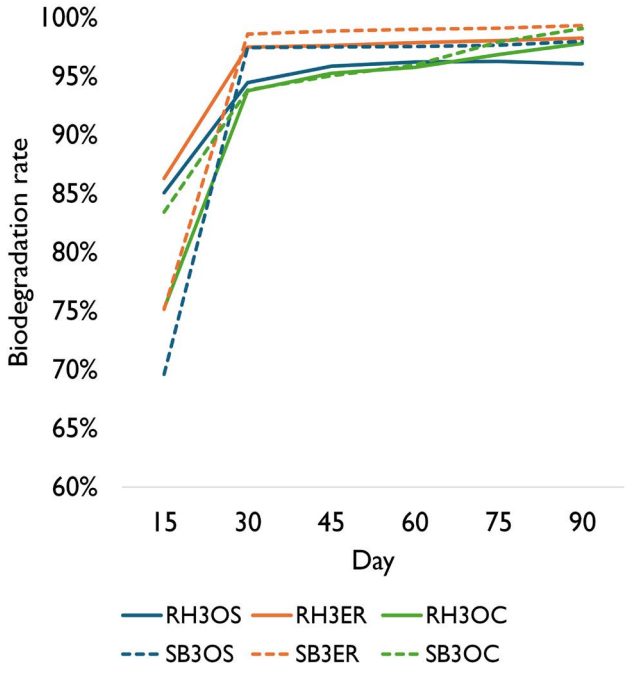

Figure 2. Biodegradability rate of biodegradable RH and SB plates.
Source: Authors. Kruskal–Wallis analysis detected a statistically significant difference among treatments only for the biodegradation rate at 30 days in SB plates ($p < 0.05$); no statistically significant differences were observed for the remaining biodegradation variables (Table 4).

Across all treatments, the highest weight loss occurred within the first 15 days. From day 30 onwards, degradation slowed, with values converging between treatments. After day 60, the average weight loss was less than 1 g, indicating a more stable and controlled degradation phase [39]. This trend aligns with Jiang *et al*. [40], who observed rapid initial mass loss in the first 21 days, followed by slower decomposition from day 34 due to the removal of bound water and the breakdown of easily degradable components, leaving a more resistant matrix. This highlights that the initial degradation phase is critical for overall biodegradation efficiency. Yap *et al*. [19] also reported substantial mass loss in rice husk-based polymers, achieving up to 92% degradation in six months, while Buxoo and Jeetah [9] found that cups made from fruit peels completely disintegrated in active soil after five weeks but persisted longer in moist sand. Our results show similar trends, with rapid early degradation followed by a slower, more stable phase, consistent with literature reports.

According to ISO 14855-2:2018, the biodegradation percentage obtained in this study (exceeding 96% at day 90) is within the expected range for biodegradable materials. Furthermore, ASTM D5338-15 specifies that a material is considered biodegradable if it reaches at least 90% conversion to CO_2 compared to a reference material in 180 days. Given the high degradation rates observed, the tested materials would meet and likely surpass this criterion, confirming their suitability for applications requiring high biodegradability under controlled composting conditions.

Nutritional contribution of the degraded plates

Table 5 summarizes the nutritional composition of the selected biodegradable plates (RH3 and SB3). RH3 contained higher total ashes, phosphorus, calcium, carbohydrates, magnesium, potassium, protein, fat, and sodium compared to SB3, whereas SB3 showed higher iron content and slightly higher total energy. These differences suggest that, if degraded plates are composted or incorporated into soil, RH3 could provide a broader range of macro- and micronutrients, potentially contributing to soil fertility. The addition of organic matter from both plate types may improve soil structure, water retention, and microbial activity. Micronutrients such as iron, magnesium, and potassium could support plant growth and soil biochemical processes.

However, nutrient dilution is possible due to the relatively low nutrient concentrations compared to conventional organic amendments, and the decomposition rate will determine the actual release and availability of nutrients. The higher iron content in SB3 may be particularly beneficial in iron-deficient soils, but excessive levels could pose risks in sensitive environments. Overall, the contribution of these plates to nutrient pools would likely be modest but potentially valuable, especially when combined with other soil management practices.

Table 5. Nutritional content of biodegradable RH and SB plates.

Plates	Unit	RH3	SB3	Method
Total ashes	%	4.69	2.15	Gravimetry (AOAC 942.5)
Phosphorus	%	0.21	0.16	UV-visible spectrophotometry (AOAC 942.5)
Calcium	%	0.15	0.09	Atomic absorption (AOAC 968.08)
Moisture	%	10.88	9.87	Gravimetry (AOAC 925.10)
Carbohydrates	%	0.8	0.60	By difference (AOAC 986.25)
Iron	mg/kg	54.36	115.42	Atomic absorption (AOAC 999.11)
Magnesium	%	0.11	0.09	Atomic absorption (AOAC 968.08)
Total energy	kcal/ 100 g	354.96	366.73	Calculation (Atwater factors)
Energy from carbohydrates	kcal/ 100 g	3.19	2.39	Calculation (Atwater factors)
Potassium	%	0.26	0.21	Atomic absorption (AOAC 985.35)
Energy from fat	kcal/ 100 g	2.43	1.80	Calculation (Atwater factors)
Energy from protein	kcal/ 100 g	15.64	10.32	Calculation (Atwater factors)
Total protein	%	3.91	2.58	Kjeldahl method (AOAC 981.10)

Fat	%	0.27	0.20	Gravimetry (AOAC 920.39)
Sodium	%	0.02	0.01	Atomic absorption (AOAC 985.35)

Source: Authors.

Conclusions

Both SB and RH plates achieved biodegradation rates above 96% within 90 days under tropical soil conditions, fulfilling internationally recognized biodegradability criteria. SB plates generally degraded faster than RH plates, particularly in open soil and eucalyptus-reforested soil, highlighting differences in degradation dynamics between the two feedstocks. The high biodegradability rates indicate that agricultural-residue-based plates can effectively return organic matter to soil systems without leaving persistent residues. The initial rapid degradation observed is likely linked to the breakdown of more labile fractions, such as hemicellulose and starch, followed by a slower phase associated with the mineralization of lignin-rich structures. This study demonstrated that locally available agricultural residues can be transformed into functional, short-lifecycle food-service items that meet biodegradability standards. These findings indicate that SB and RH plates can be considered viable biodegradable alternatives to conventional plastics in tropical regions, with sugarcane bagasse plates showing the best overall physico-mechanical performance. Maintaining suitable field conditions (i.e., stable temperature, adequate moisture, and active organic matter cycling) could sustain biodegradation efficiency in real-world applications. However, the study has several limitations, including the low physico-mechanical properties of the tested plates, the limited range of environmental conditions monitored, and the lack of performance assessment during actual food-service use. Future research should address these limitations by testing SB and RH plates under a broader range of environmental conditions, improving tensile strength and Young's modulus to enhance plate durability while maintaining adequate flexibility, and evaluating their performance in real-world food-service applications.

CRediT author statement

Grober Panduro-Pisco: funding acquisition, resources, investigation, methodology, project administration; Edwar Edinson Rubina-Arana: conceptualization, investigation, methodology, formal analysis, project management, supervision, validation, visualization, writing, review, and editing; Kiara Heidy Perez-Torres: investigation, formal analysis; Lady Fiorella Flores-Lopez: investigation, formal analysis; Dalia Carbonel: writing (original draft), writing (review & editing, formal analysis.

Conflicts of interest

The authors declare they do not have any conflict of interest.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Statement on artificial intelligence

The authors confirm that no generative Artificial Intelligence (AI) tools were used in the preparation of this manuscript. The authors take full responsibility for the originality and content of the publication.

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