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Full Length Article

Amazonian Residue Effect on the Production and Centesimal Composition of *Ganoderma* spp.

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Abstract

Ganoderma spp. attract great interest due to their medicinal and pharmacological properties. These mushrooms have been artificially cultivated on a variety of lignocellulosic residues. The objective was to evaluate the effect of different Amazonian residues on the production and composition of a *Ganoderma* spp. (isolated in the Amazon) and *Ganoderma lingzhi* (commercial strain). The fungi were cultivated on residues of açaí seeds (*Euterpe precatoria*) and guaruba-cedro (*Vochysia maxima*) and three lots (I, II and III) of marupá sawdust (*Simarouba amara*). Biological efficiency, yield (%), and loss of organic matter were evaluated. The centesimal composition, and macro and micronutrients of the basidiomata were also analyzed. The fungi exhibited greater biological efficiency (7.85%) when cultivated on marupá I sawdust. However, the highest yield was observed in guaruba-cedro sawdust substrate (3.81%). *Ganoderma* spp. showed higher levels of carbon, nitrogen, proteins and total fiber, while *G. lingzhi* presented higher values of moisture, ash, total carbohydrates and energy value. Regarding the cultivation substrates, the açaí residue provided a greater synthesis of proteins for both fungi. The elemental composition of the basidiomata showed high levels of oxygen, carbon, potassium and phosphorus, and lower concentrations of calcium, magnesium, silicon, sulfur and aluminum. Although the productive parameters are not favorable for *Ganoderma* spp. isolated in the Amazon, this mushroom showed high protein levels, suggesting promising potential for commercial and medicinal/nutritional purposes, especially when cultivated on açaí residues.

Keywords: Basidiomycetes; Biological efficiency; Micronutrients; Physicochemical analysis; Solid-state fermentation

Introduction

The species of the *Ganoderma* genus are basidiomycete fungi widely recognized in traditional Asian cultures as sources of biomolecules with medicinal properties, attracting worldwide attention (Kurd-Anjaraki *et al*. 2022; Sułkowska-Ziaja *et al*. 2022). The bioactivities of *Ganoderma* spp. are associated with the presence of polysaccharides, triterpenes, flavonoids, alkaloids, steroids, unsaturated fatty acids, proteins, amino acids, enzymes, vitamins and minerals (Ekiz *et al*. 2023). Studies report that species of this genus, when cultivated under controlled conditions, present a more significant medicinal profile compared to basidiomata collected in nature (Sheikha 2022).

Mushrooms can be cultivated on different substrates (Bajwa *et al.* 1999a, b). Species of *Ganoderma* have been cultivated on a large scale using agricultural residues such as rice, wheat, barley, oats, beans, corn and soybean as substrates. In this fermentative process, the mushroom is formed from the degradation of the structural components of these residues by specific lignocellulolytic enzymes, excreted by them during their mycelial growth (Elisashvili 2012; Sales-Campos and Chevreuil 2019). The use of locally available residues in the cultivation of mushrooms not only reduces production costs but also contributes to the recycling of substrates discarded in the region, resulting in a sustainable practice of reducing the environmental impact. In the Amazonas, Brazil, there are several residues with the potential to be used as mushroom cultivation substrates, such as açaí (*Euterpe* spp.), guaruba-cedro (*Vochysia maxima*), and marupá (*Simarouba amara*) (Aguiar *et al.* 2022).

Açaí is a native palm tree of the Amazon rainforest, highly valued for its benefits to human health. However, during the processing of the fruit to obtain the pulp (juice),

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approximately 90% of the fruit is discarded, generating a large volume of waste (Boeira *et al*. 2020; Barros *et al.* 2021). Guaruba-cedro is considered a wood species of neotropical distribution and is widely used in the local timber industry, mainly in construction (Reis *et al*. 2015; Ribeiro *et al*. 2019). Marupá is a tree species found in tropical forests and widely used in the manufacturing of crates, wood coatings, matchsticks, frames, plywood and musical instruments (Santos *et al*. 2021). In this scenario, the objective of this study was to cultivate two strains of *Ganoderma*, one isolated in the Amazon and another commercial strain, using different Amazonian residues and to evaluate their effects on the productive parameters and centesimal composition of the mushrooms, with the intention of generating a better use of the Amazonian species, mainly for commercial purposes.

Materials and Methods

The strains of *Ganoderma* (*G. lingzhi* CC22 and *Ganoderma* spp. 1962) were obtained from the Collection of Cultures of Microorganisms of Agrosilvicultural Interest at the Instituto Nacional de Pesquisas da Amazônia (INPA). The residues of açaí seeds (*Euterpe precatoria*) and sawdust from guaruba-cedro (*Vochysia maxima*) and three lots (I, II and III) of marupá sawdust (*Simarouba amara*) from different sources were collected at markets and timber industries in the city of Manaus, Amazonas, Brazil.

Ganoderma species were reactivated in Petri dishes containing Potato Dextrose Agar (BDA) and kept under refrigeration (4ºC) until use. The spawn was composed of residues (78%), 20% of a bran mixture (rice, wheat and corn) in a ratio of 60:20:20 (w/w/w) and 2% of $CaCO_3$. The flasks containing the spawn were autoclaved at 121°C for 1 h and inoculated with 1/8 of the Petri dish containing the fungal mycelium (Aguiar *et al*. 2022). The mushroom cultivation substrate had the same composition as the spawn, with 5% of the spawn being used as fungal inoculum. The cultivation bags were incubated at 25°C, 90% humidity, with a 12-h photoperiod.

The productive parameters, expressed as biological efficiency (%), yield (%) and loss of organic matter (%), were calculated according to Sales-Campos and Andrade (2011). The moisture content, ash, lipids, carbon, total nitrogen, proteins, fibers, total carbohydrates and energy value was determined following the methodologies described by Aguiar *et al.* (2021). The macro (N, K, Ca, Mg, P and S) and micronutrients (Cl, Fe, B, Mn, Zn, Cu and Mo) was determined by energy-dispersive X-ray spectroscopy (EDX). The detector was coupled to a scanning electron microscope (SEM), emitting X-rays characteristic of each chemical element present in the sample, allowing for the chemical characterization of the analyzed material (Colpan *et al*. 2018).

The cultivation experiments of the *Ganoderma* species were arranged in a completely randomized design, in a factorial scheme composed of 2 fungal species (*G. lingzhi* and *Ganoderma* spp.) and 5 Amazonian residues (açaí, guaruba-cedro, marupá I, marupá II and marupá III), each with 20 replicates. The physicochemical analyses were performed in triplicate.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using the Statistica 7.0 software and the means were compared using the Tukey test at a 5% probability level.

Results

The biological efficiency (BE) ranged from 2.72 to 7.85%, with the lowest values observed in açaí residue. The highest biological efficiency values were observed for *G. lingzhi* on marupá I (7.85%) and II (7.33%) substrates. *G. lingzhi* also exhibited higher yield percentages values. Both fungi showed higher yields in guaruba-cedro sawdust substrate, with *G. lingzhi* values about 2.5 times higher than *Ganoderma* spp. No statistical difference was observed for loss of organic matter in the cultivation of *G. lingzhi*, except for açaí, which showed the lowest loss of organic matter values. *Ganoderma* spp. cultivated in marupá I exhibited a higher loss of organic matter, being approximately 14% higher than *G. lingzhi* cultivated in the same residue (Table 1).

In the centesimal composition, the moisture content determined in *G. lingzhi* basidiomata ranged from 7.09 to 10.09%, with the lowest and highest values observed in cultivation on marupá II and guaruba-cedro, respectively. *Ganoderma* spp. exhibited a moisture content range of 3.82 to 6.80%, with the lowest value found for the açaí-based substrate and the highest for marupá II. No statistical differences were found in ash content between the fungal species and residues, with values ranging from 0.06 to 0.43%. *Ganoderma* spp. showed no difference in lipid content between the different substrates, with the lowest lipid content observed in the açaí-based substrate for both fungi (Table 2).

G. lingzhi and *Ganoderma* spp. exhibited average carbon values around 50%. However, nitrogen contents differed between the fungal species, with *G. lingzhi* presenting values ranging from 3.65 to 5.70%, while *Ganoderma* spp. varied from 7.72 to 9.21%. Both fungi showed statistical differences in protein content between the residues used in mushroom cultivation, with the highest percentages observed in marupá II and açaí for *G. lingzhi* (24.96%) and *Ganoderma* spp. (43.32%), respectively. The protein content was higher in *Ganoderma* spp. for all evaluated substrates, being about 2.5 times higher than *G. lingzhi*. Fiber levels were elevated in both fungi, with the highest percentages in marupá II and marupá III for *G. lingzhi* (52.45%) and *Ganoderma* spp. (48.96%), respectively. *G. lingzhi* also showed higher values of total

Table 1: Productive parameters of *G. lingzhi* and *Ganoderma* spp. cultivated on substrates formulated with different lignocellulosic residues. BE: biological efficiency. Y: yield. LOM: loss of organic matter

Strain	Substrate	BE (%)	Y (%)	LOM (%)
G. lingzhi	Açaí	2.72 ± 1.8^{Bb}	1.41 ± 0.9^{Cc}	31.00 ± 3.5^{Be}
	Guaruba-cedro	4.14 ± 1.1^{Bb}	3.81 ± 1.4^{Aa}	58.45 ± 5.8^{Ab}
	Marupá 1	7.85 ± 4.1^{Aa}	2.41 ± 1.2^{Bb}	58.89 ± 7.8^{Ab}
	Marupá 2	7.33 ± 3.9^{Aa}	2.26 ± 1.2^{BCb}	60.52 ± 5.0^{Ab}
	Marupá 3	4.06 ± 1.9^{Bb}	1.38 ± 0.6^{Cd}	58.98 ± 4.8^{Ab}
Ganoderma spp.	Açaí	2.76 ± 0.7^{Cc}	1.43 ± 0.3^{Ac}	38.03 ± 5.5^{Cd}
	Guaruba-cedro	4.54 ± 1.7^{Ab}	1.51 ± 0.5^{Ac}	55.79 ± 5.8^{ABc}
	Marupá 1	4.80 ± 1.2^{Ab}	1.47 ± 0.3^{Ac}	70.56 ± 3.4^{Aa}
	Marupá 2	4.64 ± 1.2^{Ab}	1.43 ± 0.3^{Ac}	64.53 ± 6.6^{Ab}
	Marupá 3	4.55 ± 0.9^{Ab}	1.46 ± 0.3^{Ac}	45.48 ± 10.0^{Bc}

The data are expressed as mean ± standard deviation (n = 20). Capital letters compare the same species cultivated on different substrates. Lowercase letters compare all samples from the two species. Treatments with the same letter do not differ at the 5% ($P \leq 0.05$) level of probability, according to the Tukey test

Table 2: Centesimal composition of the basidiomata of *Ganoderma lingzhi* and *Ganoderma* spp. cultivated on different lignocellulosic substrates

Strain	Substrate	Moisture (%)	Ash (%)	Lipids (%)	Carbon (%)	Nitrogen (%)	Proteins (%)	Total fiber (%)	Carbohydrates (%)	Energy (kcal 100 g^{-1})
G. linghzi	Açaí	9.46 ± 0.0^{ABa}	0.11 ± 0.0^{Aa}	3.66 ± 0.1^{Cd}	47.33 ± 0.6^{Ab}	3.65 ± 0.0^{Ei}	16.00 ± 0.0^{Ae}	41.17 ± 0.2^{Cf}	70.80 ± 0.2^{Bb}	380.00 ± 1.7^{Cc}
	Guaruba-cedro	10.09 ± 0.0^{Aa}	0.06 ± 0.0^{Aa}	5.12 ± 0.1^{Ba}	45.52 ± 0.7^{Bc}	5.25 ± 0.0^{Bf}	22.95 ± 0.2^{Cg}	44.07 ± 1.5^{Bd}	72.01 ± 0.6^{Bb}	385.00 ± 1.6^{Cb}
	Marupá I	9.33 ± 0.0^{Ca}	0.43 ± 0.5^{Aa}	5.91 ± 0.1^{Aa}	44.93 ± 0.6^{Bcd}	4.40 ± 0.2^{Dh}	19.97 ± 0.2^{Cg}	44.58 ± 0.8^{Bc}	71.36 ± 1.1^{Bb}	390.50 ± 3.4^{Bb}
	Marupá II	7.09 ± 0.0^{Ec}	0.08 ± 0.5^{Aa}	6.03 ± 0.1^{Aa}	45.12 ± 0.3^{Bc}	5.70 ± 0.0^{Ae}	24.96 ± 0.2^{Cd}	52.45 ± 0.4^{Aa}	74.30 ± 0.3^{Aa}	401.46 ± 0.3^{Ab}
	Marupá III	8.38 ± 0.0^{Db}	0.14 ± 0.0^{Aa}	5.15 ± 0.2^{Bb}	44.06 ± 0.6^{Bd}	$4.96 \pm 0.^{0Cg}$	21.72 ± 0.9^{Bf}	42.20 ± 1.1^{Bf}	72.20 ± 1.1^{Ba}	398.53 ± 0.9^{Aa}
Ganoderma spp.	Açaí	3.82 ± 0.0^{De}	0.09 ± 0.0^{Aa}	4.44 ± 0.3^{Ac}	50.45 ± 0.3^{Aa}	9.21 ± 0.0^{Aa}	40.32 ± 0.9^{Aa}	44.76 ± 1.1^{Cf}	51.30 ± 1.1^{Ba}	241.17 ± 0.9^{Be}
	Guaruba-cedro	5.14 ± 0.0^{Cd}	0.06 ± 0.0^{Aa}	4.63 ± 1.1^{Ab}	49.60 ± 0.0^{ABa}	7.72 ± 0.0^{Ed}	33.82 ± 0.0^{Ea}	44.77 ± 1.4^{Cc}	56.32 ± 0.4^{Ae}	241.36 ± 1.5^{Be}
	Marupá I	5.80 ± 0.0^{Cd}	0.09 ± 0.0^{Aa}	5.88 ± 0.4^{Aa}	49.19 ± 0.3^{Ba}	8.34 ± 0.0^{Bb}	36.51 ± 0.0^{Bd}	46.33 ± 0.6^{BCa}	51.70 ± 1.2^{Bc}	225.80 ± 5.0^{Cf}
	Marupá II	6.80 ± 0.0^{Ac}	0.10 ± 0.0^{Aa}	5.29 ± 0.4^{Aa}	40.09 ± 0.5^{De}	7.90 ± 0.0^{Dc}	34.61 ± 0.1^{Db}	47.43 ± 0.7^{BCb}	53.19 ± 0.9^{Bf}	249.73 ± 1.5^{Ad}
	Marupá III	6.72 ± 0.0^{Bc}	0.08 ± 0.0^{Aa}	5.27 ± 0.3^{Aa}	46.29 ± 0.3^{Cc}	7.97 ± 0.0^{Cc}	34.93 ± 0.1^{Cc}	48.96 ± 0.8^{Bb}	52.99 ± 0.4^{Bd}	252.37 ± 1.7^{Ad}

Data expressed as mean ± standard deviation (n = 3). Capital letters compare the same species in different growing substrates. Lowercase letters compare all samples from the two species. Treatments with the same letter do not differ at the 5% ($P \leq 0.05$) level of probability, according to the Tukey test

Table 3: Elemental composition of *Ganoderma lingzhi* and *Ganoderma* spp. basidiomata cultivated in different lignocellulosic substrates, determined by energy-dispersive X-ray spectroscopy (EDS)

Strain	Substrate	Atomic concentration (%)							
		O	K	P	Ca	Mg	Si	S	Al
G. lingzhi	Açaí	89.95 ± 3.4^{Aa}	2.63 ± 1.3^{Bab}	1.44 ± 1.08^{Ab}	-	0.42 ± 0.3^{ABb}	-	0.53 ± 0.4^{Aa}	0.23 ± 0.1^{Abc}
	Guaruba-cedro	67.84 ± 6.6^{Be}	1.38 ± 0.6^{Bb}	0.38 ± 0.13^{Ab}	0.37 ± 0.1^{Bb}		0.22 ± 0.0^{Aa}	0.36 ± 0.1^{Aa}	0.36 ± 0.3^{Aa}
	Marupá I	88.49 ± 2.0^{Aab}	3.59 ± 1.47^{Bab}	1.55 ± 0.49^{Ab}	1.45 ± 0.6^{Bb}	0.73 ± 0.1^{Ab}	0.30 ± 0.8^{Aa}	-	-
	Marupá II	89.43 ± 3.5^{Aab}	4.73 ± 4.02^{Bab}	0.95 ± 0.77^{Ab}	-	0.50 ± 0.2^{ABb}	0.31 ± 0.2^{Aa}	0.50 ± 0.4^{Aa}	0.50 ± 0.4^{Aa}
	Marupá III	75.98 ± 7.6^{Bcd}	12.94 ± 4.3^{Aa}	1.08 ± 0.2^{Ab}	7.82 ± 2.69^{Aa}	0.89 ± 0.0^{Ab}	0.09 ± 0.0^{Aa}	0.55 ± 0.3^{Aa}	0.55 ± 0.35^{Aa}
Ganoderma spp.	Açaí	68.76 ± 0.2^{Cde}	9.15 ± 10.05^{Aab}	1.86 ± 1.0^{Bb}	-	0.54 ± 0.2^{Cb}	0.38 ± 0.3^{Aa}	0.77 ± 0.4^{Aa}	-
	Guaruba-cedro	64.57 ± 0.8^{Ce}	4.77 ± 0.0^{Aab}	1.84 ± 0.6^{Bb}	-	0.04 ± 0.0^{Cb}	-	0.47 ± 0.1^{Aa}	-
	Marupá I	76.07 ± 0.9^{Bcd}	3.65 ± 2.3^{Aab}	1.78 ± 1.6^{Bb}	-	-	-	0.76 ± 0.6^{Aa}	-
	Marupá II	79.72 ± 1.84^{ABbc}	4.53 ± 2.6^{Aab}	2.73 ± 0.8^{ABb}	-	1.06 ± 0.2^{ABab}	-	0.72 ± 0.5^{Aa}	-
	Marupá III	85.24 ± 4.06^{Aabc}	$3.78\ 0 \pm 1.43^{Ab}$	5.71 ± 1.5^{Aa}	-	2.61 ± 1.71^{Aa}	0.45 ± 0.2^{Aa}	1.13 ± 0.8^{Aa}	-

Data expressed as mean ± standard deviation (n = 3). Capital letters compare the same species in different growing substrates. Lowercase letters compare all samples from the two species. Treatments with the same letter do not differ at the 5% ($P \leq 0.05$) level of probability, according to the Tukey test. (-) Not detectable by the method

carbohydrates (74.30%) and energy (401.46 Kcal 100 g^{-1}) when grown in marupá II compared to the other cultivation substrates. While *Ganoderma* spp. exhibited higher carbohydrate content (56.32%) in guaruba-cedro and higher energy (252.37 Kcal 100 g^{-1}) in marupá III. Comparing the two fungal species, *G. lingzhi* showed a higher carbohydrate content and energy value than *Ganoderma* spp. (Table 2).

In mushrooms, the element present in the highest concentration was oxygen (O), which emphasis for *G. lingzhi* cultivated in açaí. Potassium (K) exhibited concentrations ranging from 1.38 to 12.94%, with a notable value for *G. lingzhi* cultivated in marupá III residue (Table 3). Phosphorus (P) ranged from 0.38 to 5.71%, highlighting the basiodiomata of *Ganoderma* spp. cultivated in marupá III sawdust. Calcium (Ca) was observed only in basidiomata of *G. lingzhi* from cultivations in guaruba-cedro and marupá

I and III. Magnesium (Mg), silicon (Si), sulfur (S) and aluminum (Al) exhibited concentrations below 1% for both species in most residues (Table 3).

Discussion

The evaluation of biological efficiency is important as it expresses the ability of fungi to convert the cultivation substrate into basidiomata. *G. lucidum* grown on oat straw, bean straw, brachiaria grass, tifton grass and Eucalyptus sawdust, under different supplementation conditions with wheat bran, showed biological efficiency ranging from 0.0 to 6.7%, with the highest results for bean straw and tifton grass supplemented with 20% wheat bran (Carvalho *et al.* 2015). *G. lucidum* cultivated on agroforestry residues exhibited biological efficiency ranging from 21.0 to 31.5%, with emphasis on poplar sawdust (Atila 2022).

G. carnosum cultivated on oak sawdust, peanut shells and corn cobs supplemented with oat bran exhibited biological efficiency from 3.98 to 15.05% (Baktemur *et al.* 2022). Basidiomata of *G. lucidum* grown on mango sawdust (*Mangifera indica*) supplemented with 20% wheat bran showed a biological efficiency of 42.86% (Mehta *et al.* 2014). The biological efficiency of the present study was lower than most of the works cited, suggesting that differences between the residues used, including the composition and structure of fibers (hemicellulose, cellulose and lignin), may influence mycelial development and penetration, affecting the formation of basidiomata (Jeznabadi *et al.* 2016, 2017).

Ganoderma strains did not achieve a profitable yield percentage, because for a good index the values must be greater than 10%, considering the weight of fresh mushrooms in relation to the weight of the moist substrate (Siqueira *et al.* 2011). The low yield percentage can be attributed to substrate compaction, as it hinders oxygen exchange, leading to the accumulation of carbon dioxide and, consequently, affecting the development of basidiomata (Estrada and Pecchia 2017). Furthermore, the yield percentage can also be influenced by environmental conditions, mushroom species, and even variation among strains between strains of the same species (Rashad *et al.* 2019).

The loss of organic matter is a promising alternative to reduce lignocellulosic biomass in the environment, as well as the waste of these materials in the agroindustry (Alquati *et al.* 2016). However, in this study, no direct correlation was observed between loss of organic matter and biological efficiency for the two strains. *G. lucidum* grown on Eucalyptus sawdust and sugarcane straw showed a direct correlation between loss of organic matter (52.79%) and biological efficiency (47.37%) (Saad *et al.* 2017). However, the two variables are not always correlated, as loss of organic matter corresponds to substrate decomposition, while biological efficiency refers to the conversion of the substrate into mushroom mass, without considering the organic matter lost by the release of CO_2 and H_2O during fungal respiration (Zadrazil and Kurtzman 1982; Rashad *et al.* 2019).

The production of mushrooms using lignocellulosic residues as a growth substrate is responsible for adding value to these underutilized materials and reducing the environmental impact caused by improper disposal and providing supplemental income to rural producers (Almeida *et al.* 2018). However, several factors affect mushroom production and their nutritional composition, *e.g.*, genetics, origin, substrate composition, growth conditions, acclimatization and basidiomata maturation stage (Mahari *et al.* 2020). Mushrooms are capable of accumulate mineral elements more efficiently than most plant. Therefore, the content of mineral elements becomes one of the main indicators of mushroom quality (Li *et al.* 2016). Ash content in basidiomata normally ranges from 5 to 12% of dry matter (Kalač 2009). Thus, the low ash content found in the present study can be attributed to the chemical nature of the substrates used in the cultivation, as well as to the harvesting stage of the basidioma (Ogbe and Obeka 2013).

The lipid content in *Ganoderma* spp. can be influenced by environmental factors such as nutritional components, oxygen, and temperature (Pedneault *et al.* 2007). *Ganoderma* spp. exhibited stable lipid composition, being less sensitive to variations in solid-state cultivation, allowing to maintaining consistent lipid levels. This can be advantageous for its cultivation and use in various applications, including for medicinal and nutritional purposes. The high carbon content found in *G. linghzi* and *Ganoderma* corroborate the fact that carbon is an essential component in several biomolecules (Miles and Chang 2004). As for nitrogen, Kurd-Anjaraki *et al.* (2022) found higher levels in the basidiomata of *G. lucidum* (5.88 mg 100 g^{-1}) when cultivated on poplar wood chips, suggesting that the nutritional composition of the basidiomata is affected by the growth conditions and type of substrate.

Proteins are the main biomolecules that contribute to the nutritional value of mushrooms. In *Ganoderma* species, the protein ranges from 9.93 to 16.8%, corroborating the data found for the *G. lingzhi* (Ogbe and Obeka 2013; Stojković *et al.* 2014). The high protein content in *Ganoderma* spp., above 30%, may be associated with a genetic predisposition for higher protein production (Jonathan *et al.* 2022). Edible mushrooms *Pleurotus ostreatus* when cultivated in substrates based on açaí seed and elephant grass straw showed 27.19 and 17.70% of protein, respectively (Sales-Campos *et al.* 2021). In comparison, a commercial *Agaricus bisporus* presented 39.84% of crude protein (Krishnamoorthi *et al.* 2022).

The fibers of the basidiomata are part of the non-digestible carbohydrates by digestive enzymes in organisms and, consequently, they help to reduce the levels of lipids, cholesterol and glucose in the bloodstream (Dubey *et al.* 2019; Jovanović *et al.* 2021). Polysaccharides correspond the main carbohydrates found in *Ganoderma* species, including *β*-glucan, mannose, xylose and other sugars present in smaller quantities, which are associated with several health benefits (Kalač 2009; Swallah *et al*. 2023). Additionally, it is important to highlight that the energy value is related to the content of fat, protein, and available carbohydrates (Shams *et al*. 2022).

The significant presence of oxygen is commonly associated with various crucial biological functions (Alzand *et al.* 2019; Wang *et al*. 2022). On the other hand, potassium is an essential mineral for humans to maintain normal functions of all cells, including nerve and muscle cells (Falandysz *et al*. 2020). Magnesium plays an important role in the human body, as it can activate vitamin D and contributing to protein synthesis (Dronkelaar *et al*. 2018). In relation to calcium, this is a mineral that acts as a co-factor for several enzymes, besides assisting in the maintenance and movement of chromosomes (Burstrom 1968; White and Broadley 2003). Sulfur is a component of amino acids such as taurine, methionine and cysteine, which are essential for collagen synthesis (Rolim *et al*. 2020). Silicon is related to increased collagen synthesis and reduced skin aging (Ferreira *et al*. 2018). The presence of aluminum in mushrooms may be related to the metallic nature of the stub (sample holder) used during the analysis, causing a residual reading of electrons from this element.

Ganoderma species play an important role as bioconverters and bioaccumulators of inorganic elements, converting them into organic compounds. Thus, these minerals can be used to improve the nutritional/chemical profile of mushrooms through biofortification approaches (Priyadarshni *et al*. 2022). In addition, the presence of macro and micronutrients in basidiomata plays a crucial role in promoting health and well-being, as they are essential for proper immune system function, metabolism and various physiological processes in the body (Rackerby *et al*. 2020; Kour *et al*. 2022). Although *Ganoderma* spp. are not considered edible, the results regarding the centesimal and mineral composition are promising, as the basidiomata showed high levels of proteins, fibers, carbohydrates and energy value, low lipid content and significant amounts of minerals. Thus, it is suggested that *Ganoderma* spp. have the potential to be used as a dietary supplement for health promotion and can be consumed in the form of capsules, tablets or teas (Ekiz *et al*. 2023).

Conclusion

The study describes, for the first time, the use of Amazonian lignocellulosic residues in the cultivation of *Ganoderma* spp., a fungus isolated in the Amazon. *G. lingzhi* and *Ganoderma* spp. showed low productive yields in Amazonian lignocellulosic residues. However, they exhibited a high protein content, with *Ganoderma* spp. standing out. These findings suggest a promising potential for both commercial and nutritional/medicinal purposes, especially when cultivated on açaí-based substrates. Additionally, it demonstrates the potential utilization of lignocellulosic residues from the Amazon region, providing a purpose for what would be discarded in the environment while generating products with added value.

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Author Contributions

PRSG conducted the fungal cultivation, determined the centesimal composition, performed the statistical analysis of the data and wrote the original manuscript. LBNS and VAP assisted in writing, formatting, presenting, and discussing the results of the manuscript. SDOJ assisted in writing the article and contributed to the activities of determining the centesimal composition. LRC and CSC designed the research, secured financial resources, supervised the experiments, thoroughly reviewed the article, and assisted in the translation of the manuscript.

Conflicts of Interests

The authors declare that there are no conflicts of interest regarding the publication of this article.

Data Availability

Data presented will be available upon request to the authors.

Ethics Approval

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