Running title:Amazonian residues for *Ganoderma* spp. cultivation

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

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**Novelty statement**

Lignocellulosic residues from the Amazon may have great potential for mushroom cultivation, since the great diversity of plants can provide a differentiated composition of mushrooms. Ganoderma species are already cultivated in lignocellulosic residues, however, there are few studies with Amazonian residues, as well as with fungal species isolated in the Amazon, which may have different medicinal/nutritional potential. Thus, the results obtained confirm the difference in the composition of the basidiocarps of Ganoderma spp. according to the residue used in the cultivation.

**Abstract**

*Ganoderma* spp. arouse great interest due to their medicinal and pharmacological properties. These mushrooms have been artificially cultivated on a variety of lignocellulosic residues, exhibiting different properties to be explored. The objective was to verify the effect of different Amazonian residues on the production and composition of a *Ganoderma* sp. (isolated in the Amazon) and *Ganoderma* *lingzhi* (commercial strain). The fungi were cultivated in residues of açaí seeds and guaruba-cedro and marupá (three different origins) sawdust. Productivity was evaluated from biological efficiency (BE), yield (Y%), and loss of organic matter (LOM). The centesimal composition and macro and micronutrients of the basidiocarps was also analyzed. The fungi exhibited greater production when cultivated on marupá I. However, the highest Y% was observed in guaruba-cedro sawdust, with values below 10%. *Ganoderma* sp. 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 basidiocarps 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* sp. 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; Solid-state Fermentation; Biological Efficiency; Physicochemical Analysis; Micronutrients.

**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 basidiocarps collected in nature (El Sheikha, 2022).

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* sp.), 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), approximately 90% of the fruit is discarded, generating a large volume of waste (Boeira *et al*. 2020; Barros 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* sp. 1962) were obtained from the Collection of Microorganisms of Agroforestry Interest at the Instituto Nacional de Pesquisas da Amazônia (INPA). The residues of açaí seeds (*Euterpe* sp.) and sawdust from guaruba-cedro (*Vochysia maxima*) and three marupá (*Simarouba amara*) from different sources were collected at markets and timber industries in the city of Manaus, Amazonas, Brazil.

The spawn was produced from mycelia discs of *Ganoderma* species, grown in Petri dishes containing Potato Dextrose Agar (BDA). The residues (78%), 20% of a bran mixture (rice, wheat, and corn) in a ratio of 60:20:20 (w/w/w), and 2% of CaCO3 were added to culture flasks. Before inoculation with fungi, the substrates were autoclaved at 121°C for 1 hour (Aguiar *et al*. 2022). After complete colonization of the substrate at 25°C, 5% of this spawn was transferred to cultivation bags containing the same formulation of the spawn's substrate. The bags were incubated at 25°C, 90% humidity, with a 12-hour photoperiod.

The productive parameters, expressed as biological efficiency (BE), yield (Y%), and loss of organic matter (LOM), 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 in 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* sp.) and 5 Amazonian residues (açaí, guaruba-cedro, marupá I, marupá II and marupá III). The physicochemical analyses were performed in triplicate. 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 for the two *Ganoderma* species cultivated on açaí residue. The highest BE was found for *G*. *lingzhi* on marupá I and II. *G*. *lingzhi* showed higher yield percentages (Y%) compared to *Ganoderma* sp. Both fungi exhibited higher Y% when cultivated on guaruba-cedro sawdust substrate, with the values obtained for *G*. *lingzhi* about 2.5 times higher compared to *Ganoderma* sp (Table 1).

In the cultivation of *G*. *lingzhi*, no statistical difference was observed for the loss of organic matter (LOM), except for açaí, which exhibited the lowest LOM values. *Ganoderma* sp. showed higher LOM when cultivated in marupá I, being approximately 14% higher compared to *G*. *lingzhi* cultivated in the same residue (Table 1).

In the centesimal composition, the moisture content determined in the basidiocarps of *G*. *lingzhi* ranged from 7.09% to 10.09%, with the lowest and highest values observed in the cultivation on marupá II and guaruba-cedro, respectively. The moisture content of *Ganoderma* sp. varied from 3.82% to 6.80%, with the lowest value found for the açaí-based substrate and the highest for marupá II (Table 2).

Among the species studied and the residues used in mushroom cultivation, there was a statistical difference for ash content, with values ranging from 0.06% to 0.43%. The lipid content was different only in *G*. *lingzhi* in açaí and marupá III, and in *Ganoderma* sp. in açaí and guaruba-cedro. For the other substrates, no statistical differences were observed, with average values of 5.6% (Table 2).

*G*. *lingzhi* and *Ganoderma* sp. exhibited average carbon values around 50. However, the nitrogen contents differed between the fungal species, with *G*. *lingzhi* showing values from 3.65% to 5.70%, while *Ganoderma* sp. ranged from 7.72% to 9.21%. Additionally, both fungi showed statistical differences between the residues used as cultivation substrates, with the highest percentages observed for *G*. *lingzhi* in marupá II and *Ganoderma* sp. in açaí (Table 2).

*Ganoderma* sp. exhibited higher protein percentages in all evaluated substrates, being approximately 2.5 times higher compared to *G*. *lingzhi*. Regarding the cultivation substrates, the açaí residue provided the highest protein content for both species (Table 2).

Regarding total fiber, both fungi showed high values, ranging from 41.17% to 52.45%, with the highest percentages found for *G*. *lingzhi* when cultivated on marupá II and for *Ganoderma* sp. on marupá III. The same trend was observed for total carbohydrates and energy value, with *G*. *lingzhi* having an average of 391.1 Kcal/100g, while *Ganoderma* sp. exhibited average of 242.1 Kcal/100g (Table 2).

In mushrooms, the element present in the highest concentration was oxygen (O), which emphasis for *G*. *lingzhi* cultivated on açaí. Potassium (K) exhibited concentrations ranging from 1.38% to 12.94%, with a notable value for *G*. *lingzhi* from cultivation on marupá III residue (Table 3).

Phosphorus (P) ranged from 0.38% to 8.71%, evidencing the basiocarps from *Ganoderma* sp. cultivated on marupá III sawdust. Calcium (Ca) was observed only in *G*. *lingzhi* cultivated on guaruba-cedro and marupá I and III. The chemical elements magnesium (Mg), silicon (Si), sulfur (S) and aluminum (Al) exhibited concentrations below 1% for both species (Table 3).

**Discussion**

The evaluation of biological bfficiency (BE) is important as it expresses the ability of fungi to convert the cultivation substrate into basidiocarps. *G*. *lucidum* grown on oat straw, bean straw, brachiaria grass, tifton grass and eucalyptus sawdust, under different supplementation conditions with wheat bran, showed BE 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 BE 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 EB from 3.98 to 15.05% (Baktemur *et al*. 2022). Basidiocarps of *G*. *lucidum* grown on mango sawdust (*Mangifera indica*) supplemented with 20% wheat bran showed a 42.86% BE (Mehta *et al.* 2014). The BE 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 basidiocarps (Jeznabadi *et al*. 2016; Jeznabadi *et al.* 2017).

*Ganoderma* strains did not achieve a profitable Y%, 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 Y% can be attributed to substrate compaction, as it hinders oxygen exchange, leading to the accumulation of carbon dioxide and, consequently, affecting the development of basidiocarps (Estrada and Pecchia 2017). This parameter can also be influenced by environmental conditions, mushroom species, and even between strains of the same species (Rashad *et al*. 2019).

The loss of organic matter (LOM) 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 PMO and BE for the two strains.

*G*. *lucidum* grown on eucalyptus sawdust and sugarcane straw showed a direct correlation between LOM (52.79%) and BE (47.37%) (Saad *et al*. 2017). However, the two variables are not always correlated, as LOM corresponds to substrate decomposition, while BE refers to the conversion of the substrate into mushroom mass, without considering the organic matter lost by the release of CO2 and H2O 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 stage of basidiocarp development (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 mushroom basidiocarps 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 basidiocarp (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* sp. exhibited stable lipid composition, being less sensitive to variations in solid-state cultivation, allowing to maintain 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 within fungal cells, including proteins, lipids, nucleic acids, and cell wall polysaccharides, which are synthesized by anabolic processes in mushrooms (Miles and Chang 2004). As for nitrogen, Kurd-Anjaraki *et al*. (2022) found higher levels in the basidiocarp of *G*. *lucidum* (5.88 mg/100 g or 5.8%) when cultivated on poplar wood chips, suggesting that the nutritional composition of the basidiocarps 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* sp., above 30%, may be associated with a genetic predisposition for higher protein production (Jonathan *et al*. 2022).

The fibers of the basidiocarps 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; Aramabašić-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*. 2022). 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, as well as being a structural component of important macromolecules such as carbohydrates, lipids, and proteins (Alzand and Bofaris-Ugis 2018; 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 is able to 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 basidiocarps 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 basidiocarps 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**

Despite the fungi having shown low productive yield, they had high protein content, mainly *Ganoderma* sp. isolated from the Amazon. These findings suggest a promising potential for both commercial and nutritional/medicinal purposes, especially when cultivated on açaí-based substrates.

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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**

The data presented will be available upon request to the authors.

**Ethics Approval**

Not applicable.

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**References**

Aguiar LVB, PRS Gouvêa, SD Oliveira Júnior, C Sales-Campos, LR Chevreuil (2022). Production of Commercial and Amazonian Strains of *Pleurotus ostreatus* in Plant Waste. *Braz J Dev* 8:47299-47321

Aguiar LVB, C Sales-Campos, PRS Gouvêa, BF Vianez, LR Chevreuil (2021). Substrate disinfection methods on the production and nutritional composition of a wild oyster mushroom from the Amazon. *Cienc e Agrotecnologia* 45:1-9

Almeida UOD, RDC Andrade-Neto, AMP Lunz, SR Nogueira, DAD Costa, JMD Araújo (2018). Environment and slow-release fertilizer in the production of *Euterpe precatoria* seedlings. *Pesqui Agropecu Trop* 48:382-389

Alquati GP, OAPA Siqueira, SRF Viana, MCN de Andrade (2016). Residues from urban vegetable pruning in the production of the medicinal mushroom *Ganoderma lucidum*. *Afr J Agric Res* 11:3664-3670, 2016

Alzand KI, MSM Bofaris, A Ugis (2019). Chemical composition and nutritional value of edible wild growing mushrooms: a review. *World J Pharm Res* 8:31-46

Aramabašić-Jovanović J, M Mihailović, A Uskoković, N Grdović, S Dinić, M Vidaković (2021). The effects of major mushroom bioactive compounds on mechanisms that control blood glucose level. *J Fungus* 7:58

Atila F (2022). Utilization of Agricultural and Forestry by-Products in *Ganoderma lucidum* (Curt.: Fr.) P. Karst. production. *Mantar Dergisi* 13:1-8

Baktemur G, E Kara, M Yarar, MK Soylu, H Taskin (2022). Use of different agricultural wastes in *Ganoderma carnosum* Pat. cultivation. *Turk J Agric For* 46: 352-358

Barros SS (2021). Waste açaí (*Euterpe precatoria* Mart.) seeds as a new alternative source of cellulose: Extraction and characterization. *Res Doc Dev* 10: 1-16

Boeira LS, PHB Freitas, NR Uchôa, JA Bezerra, SV Cád, S Duvoisin-Junior, PM Albuquerque, JS Mar, AS Ramos, MB Machado, LR Maciel (2020). Chemical and sensorial characterization of a novel alcoholic beverage produced with native acai (*Euterpe precatoria*) from different regions of the Amazonas state*. LWT* 17:108632

Burstrom HG (1968). Calcium and plant growth. *Biol Rev* 43:287-316

Carvalho CSM, C Sales-Campos, LP de Carvalho, MT de Almeida, ALM Saad, GP Alquati, MCN de Andrade (2015). Cultivation and bromatological analysis of the medicinal mushroom *Ganoderma lucidum* (Curt.: Fr.) P. Karst cultivated in agricultural waste. *Afr J Biotechnol* 14:412-418

Colpan CO, Y Nalbanty, M Ercelik, 2018. Fundamentals of fuel cell technologies. *Compr Energy Syst* 5:1107–1130

Dronkelaar C, A Van-Velzen, M Abdelrazek, AVD Steen, PJ Weijs, M Tieland (2018). Minerals and sarcopenia; the role of calcium, iron, magnesium, phosphorus, potassium, selenium, sodium, and zinc on muscle mass, muscle strength, and physical performance in older adults: a systematic review. *J Am Med Dir Assoc* 19:6-11

Dubey SK, VK Chaturvedi, D Mishra, A Bajpeyee, A Tiwari, MP Singh (2019). Role of edible mushroom as potent therapeutics for the diabetes and obesity. *3 Biotech* 9:1-12

Ekiz E, E Oz, AA El-Aty, C Proestos, C Brennan, M Zeng, I Tomasevic, T Elobeid, K Çadirci, M Bayrak, F Oz (2023). Exploring the Potential Medicinal Benefits of *Ganoderma lucidum*: From Metabolic Disorders to Coronavirus Infections. *Foods* 12: 1512

El-Sheikha AF (2022). Nutritional profile and health benefits of *Ganoderma lucidum* “Lingzhi, Reishi, or Mannentake” as functional foods: Current scenario and future perspectives. *Foods* 11:1030

Elisashvili, V (2012). Submerged cultivation of medicinal mushrooms: bioprocesses and products*. Int J Med Mushrooms* 14:211-239

Estrada AER, J Pecchia (2017). Cultivation of *Pleurotus ostreatus*. In: *Edible and medicinal mushrooms: technology and applications*, pp: 339-360. Zied DC, Pardo-Giménez. John Wiley & Sons, Chichester, United Kingdom

Falandysz J, Y Wang, M Saniewski, AR Fernandes (2020). 137Caesium, 40Potassium and potassium in raw and deep-oil stir-fried mushroom meals from Yunnan in China. *J Food Compos Anal* 91:103538

Ferreira AO, ÉS Freire, HC Polonini, PJLC da Silva, MAF Brandão, NRB Raposo (2018). Anti-aging effects of monomethylsilanetriol and maltodextrin-stabilized orthosilicic acid on nails, skin and hair. *Cosmetics* 5:41-56

Jeznabadi EK, M Jafarpour, S Eghbalsaied (2016). King oyster mushroom production using various sources of agricultural wastes in Iran. *Int J Recycl Org Waste Agric* 5:17-24

Jeznabadi EK, M Jafarpour, S Eghbalsaied, M Pessarakli (2017). Effects of various substrates and supplements on king oyster (*Pleurotus ostreatus*). *Compost Sci Util* 25:1-10

Jonathan M, JN Keta, S Dharmendra (2022). Identification and evaluation of proximate and antinutritional profile of some underutilized mushrooms in Yauri Local Government Area, Kebbi State, Nigeria. *J Adv Educ Sci* 2:61-66

Kalač P (2009). Chemical composition and nutritional value of European species of wild growing mushrooms: A review. *Food Chem* 113:9-16

Kour H, D Kour, S Kour, S Singh, SSAJ Hashmi, AN Yadav, K Kumar, YP Sharma, AS Ahluwalia (2022). Bioactive compounds from mushrooms: an emerging bioresources of food and nutraceuticals. *Food Biosci* 50:102124

Kurd-Anjaraki S, D Ramezan, S Ramezani, A Samzadeh-Kermani, M Pirnia, BY Shani (2022). Potential of waste reduction of agro-biomasses through Reishi medicinal mushroom (*Ganoderma lucidum*) production using different substrates and techniques. *Acta Ecol Sin* 42:90-101

Li S, C Dong, HÁ Wen, X Liu (2016). Development of Ling-zhi industry in China–emanated from the artificial cultivation in the Institute of Microbiology, Chinese Academy of Sciences (IMCAS). *Mycol* 7:74-80

Mahari WAW, W Peng, WL Nam, H Yang, XY Lee, YK Lee, RK Liew, NL Ma, A Mohammad, C Sonne, QV Le, PL Mostrar, WH Chen, SS Lam (2020). A review on valorization of oyster mushroom and waste generated in the mushroom cultivation industry. *J Hazard Mater* 400: 123156

Mehta S, S Jandaik, D Grupta (2014). Effect of cost-effective substrates on growth cycle and yield of lingzhi or reishi medicinal mushroom, *Ganoderma lucidum* (higher Basidiomycetes) from Northwestern Himalaya (India). *Int J Med Mushrooms* 16:585-591

Miles PG, Chang ST (2004). *Mushrooms: cultivation, nutritional value, medicinal effect, and environmental impact*. CRC press, Boca Raton, Florida

Ogbe AO, AD Obeka (2013). Proximate, mineral and anti-nutrient composition of wild *Ganoderma lucidum*: Implication on its utilization in poultry production*. Iran J Appl Anim Sci* 3:161-166

Pedneault K, P Anders, TJ Avis, A Gosselin, RJ Tweddell (2007). Fatty acid profiles of polar and non-polar lipids of *Pleurotus ostreatus* and *P. cornucopiae* var.‘citrino-pileatus’ grown at different temperatures. *Mycol Res* 111:1228-1234

Priyadarshni KC, R Krishnamoorthi, C Mumtha, PU Mahalingam (2022). Biochemical analysis of cultivated mushroom, *Pleurotus florida* and synthesis of silver nanoparticles for enhanced antimicrobial effects on clinically important human pathogens. *Inorg Chem Commun* 142:109673

Rackerby B, HJ Kim, DC Dallas, SH Park (2020). Understanding the effects of dietary components on the gut microbiome and human health. *Food Sci Biotechnol* 29:1463-1474

Rashad FM, MH El-Kattan, HM Fathy, DA El-Fattah, M Tohamy, AA Farahat (2019). Recycling of agro-wastes for *Ganoderma lucidum* mushroom production and *Ganoderma* post mushroom substrate as soil amendment. *Waste Manag* 88:147-159

Reis ARS, JX dos Santos, JR da Silva, PL Lisboa (2015). Anatomia do xilema secundário de sete espécies de *Vochysia* Aubl. (Vochysiaceae), conhecidas como guaruba no estado do Pará, Brasil. *Biota Amazôn* 5:45-51

Ribeiro DS, AL Gonçalves, CF Melo, ARS Reis (2019). Reação da densidade e das propriedades mecânicas de três espécies amazônicas submetidas a ensaio de campo. *Rev Ciên Mad*10:18-28

Rolim CS, RT de Oliveira, LR do Nascimento, EC Saraiva-Bonatto, MDGG Saraiva, RPM Oliveira, CC Silva, CV Lamarão (2020). Análise da composição centesimal, físico-química e mineral da polpa e casca do fruto de *Endopleura uchi*. *Braz J Dev* 6:16368-16383

Saad ALM, SRF Viana, OAPA Siqueira, C Sales-Campos, MCN Andrade (2017). Use of agricultural residues in the cultivation of the medicinal mushroom *Ganoderma lucidum* using the" Jun-Cao" Chinese technology. *Ambiência* 13:572-582

Sales-Campos C, LR Chevreuil (2019). Macromicetos Amazônicos: potenciais biotecnológicos de modo sustentável. In: *Conhecimento, Conservação e Uso de Fungos*, pp: 14-17. Editora INPA, Amazonas, Brasil

Sales-Campos C, MCN Andrade (2011). Aproveitamento de resíduos madeireiros para o cultivo do cogumelo comestível *Lentinus strigosus* de ocorrência na Amazônia. *Acta Amazon* 41:1-8

Santos JSPA, AVR Mendonça, EC da Silva, MDH de Souza, MO de Souza (2021). Storage of *Simarouba amara* Aubl. Seeds. *Bol Mus Para Emilio Goeldi Cienc Nat* 16:89-95

Shams R, J Singh, KK Dash, AH Dar (2022). Comparative study of freeze drying and cabinet drying of button mushroom. *Appl Food Res* 2:100084

Siqueira FG, ET Martos, RD Silva, ES Dias (2011). Cultivation of *Pleurotus sajor-caju* on banana stalk and Bahia grass-based substrates. *Hortic Bras* 29:199-204

Stojković DS, L Barros, RC Calhelha, J Glamočlija, A Ćirić, LJV Griensven, M Sokovic, IC Ferreira (2014). A detailed comparative study between chemical and bioactive properties of *Ganoderma lucidum* from different origins. *Int J Food Sci Nutr* 65:42-47

Sułkowska-Ziaja K, G Zengin, A Gunia-Krzyżak, J Popiół, A Szewczyk, M Jaszek, J Rogalski, B Muszyńska (2022). Bioactivity and mycochemical profile of extracts from mycelial cultures of *Ganoderma* spp. *Molecules* 27:275

Swallah MS, P Brondzie-Quaye, H Wang, CH Shao, P Hua, MA Bashir, JB Holman, FL Sossah, Q Huang (2023). Potentialities of *Ganoderma lucidum* extracts as functional ingredients in food formulation. *Food Res Int* 172:113161

Wang J, K Lan, G Wu, Y Wang, C Zhou, H Lin, Z Ma (2022). Effect of dietary carbohydrate level on growth, feed utilization, energy retention, body composition, and digestive and metabolic enzyme activities of juvenile cobia, *Rachycentron canadum*. *Aquacult Rep*25:101211

White PJ, MR Broadley (2003). Calcium in plants. *Ann Bot* 92: 487-511

Zadrazil F, RH Kurtzman (1982). The Biology of *Pleurotus* Cultivation in the Tropics. In: *Tropical mushrooms: Biological nature and cultivation methods*, pp: 277-298. The Chinese University Press, Hong Kong

**Table 1:** Productive parameters of *G*. *lingzhi* and *Ganoderma* sp. 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 ± 1.8Bb | 1.41 ± 0.9Cc | 31.00 ± 3.5Be |
| Guaruba-cedro | 4.14 ± 1.1Bb | 3.81 ± 1.4Aa | 58.45 ± 5.8Ab |
| Marupá 1 | 7.85 ± 4.1Aa | 2.41 ± 1.2Bb | 58.89 ± 7.8Ab |
| Marupá 2 | 7.33 ± 3.9Aa | 2.26 ± 1.2BCb | 60.52 ± 5.0Ab |
| Marupá 3 | 4.06 ± 1.9Bb | 1.38 ± 0.6Cd | 58.98 ± 4.8Ab |
| *Ganoderma* sp. | Açaí | 2.76 ± 0.7Cc | 1.43 ± 0.3Ac | 38.03 ± 5.5Cd |
| Guaruba-cedro | 4.54 ± 1.7Ab | 1.51 ± 0.5Ac | 55.79 ± 5.8ABc |
| Marupá 1 | 4.80 ± 1.2Ab | 1.47 ± 0.3Ac | 70.56 ± 3.4Aa |
| Marupá 2 | 4.64 ± 1.2Ab | 1.43 ± 0.3Ac | 64.53 ± 6.6Ab |
| Marupá 3 | 4.55 ± 0.9Ab | 1.46 ± 0.3Ac | 45.48 ± 10.0Bc |

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 ≤ 0.05) level of probability, according to the Tukey test.

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

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Strain | Substrate | Moisture (%) | Ash (%) | Lipids (%) | Carbon (%) | Nitrogen (%) | Proteins (%) | Total fiber (%) | Carbohydrates (%) | Energy (Kcal/100 g) |
|  | Açaí | 9.46 ± 0.0ABa | 0.11 ± 0.0Aa | 3.66 ± 0.1Cd | 47.33 ± 0.6Ab | 3.65 ± 0.0Ei | 16.00 ± 0.0Ae | 41.17 ± 0.2Cf | 70.80 ± 0.2Bb | 380.00 ± 1.7Cc |
|  | Guaruba-cedro | 10.09 ± 0.0Aa | 0.06 ± 0.0Aa | 5.12 ± 0.1Ba | 45.52 ± 0.7Bc | 5.25 ± 0.0Bf | 12.71 ± 0.2Cg | 44.07 ± 1.5Bd | 72.01 ± 0.6Bb | 385.00 ± 1.6Cb |
| *G. linghzi* | Marupá I | 9.33 ± 0.0Ca | 0.43 ± 0.5Aª | 5.91 ± 0.1Aª | 44.93 ± 0.6Bcd | 4.40 ± 0.2Dh | 12.97 ± 0.2Cg | 44.58 ± 0.8Bc | 71.36 ± 1.1Bb | 390.50 ± 3.4Bb |
|  | Marupá II | 7.09 ± 0.0Ec | 0.08 ± 0.5Aª | 6.03 ± 0.1Aª | 45.12 ± 0.3Bc | 5.70 ± 0.0Ae | 12.49 ± 0.2Cd | 52.45 ± 0.4Aa | 74.30 ± 0.3Aa | 401.46 ± 0.3Ab |
|  | Marupá III | 8.38 ± 0.0Db | 0.14 ± 0.0Aa | 5.15 ± 0.2Bb | 44.06 ± 0.6Bd | 4.96 ± 0.0Cg | 14.16 ± 0.9Bf | 42.20 ± 1.1Bf | 72.20 ± 1.1Ba | 398.53 ± 0.9Aa |
| *Ganoderma* sp. | Açaí | 3.82 ± 0.0De | 0.09 ± 0.0Aa | 4.44 ± 0.3Ac | 50.45 ± 0.3Aª | 9.21 ± 0.0Aa | 40.32 ± 0.9Aa | 44.76 ± 1.1Cf | 51.30 ± 1.1Ba | 241.17 ± 0.9Be |
| Guaruba-cedro | 5.14 ± 0.0Cd | 0.06 ± 0.0Aa | 4.63 ± 1.1Ab | 49.60 ± 0.0ABa | 7.72 ± 0.0Ed | 33.82 ± 0.0Ea | 44.77 ± 1.4Cc | 56.32 ± 0.4Ae | 241.36 ± 1.5Be |
| Marupá I | 5.80 ± 0.0Cd | 0.09 ± 0.0Aa | 5.88 ± 0.4Aª | 49.19 ± 0.3Bª | 8.34 ± 0.0Bb | 36.51 ± 0.0Bd | 46.33 ± 0.6 BCa | 51.70 ± 1.2Bc | 225.80 ± 5.0Cf |
| Marupá II | 6.80 ± 0.0Ac | 0.10 ± 0.0Aa | 5.29 ± 0.4Aª | 40.09 ± 0.5De | 7.90 ± 0.0Dc | 34.61 ± 0.1Db | 47.43 ± 0.7BCb | 53.19 ± 0.9Bf | 249.73 ± 1.5Ad |
| Marupá III | 6.72 ± 0.0Bc | 0.08 ± 0.0Aa | 5.27 ± 0.3Aª | 46.29 ± 0.3Cc | 7.97 ± 0.0Cc | 34.93 ± 0.1Cc | 48.96 ± 0.8Bb | 52.99 ± 0.4Bd | 252.37 ± 1.7Ad |

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 ≤ 0.05) level of probability, according to the Tukey test.

**Table 3:** Composição elementar dos basidiocarpos de *Ganoderma lingzhi* e *Ganoderma* sp. cultivados em diferentes substratos lignocelulósicos, determinado por espectroscopia de raios X (EDS) de energia dispersiva.

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

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 ≤ 0.05) level of probability, according to the Tukey test. (-) Not detectable by the method.