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Food and nutritional potential of two mushrooms native species to the Brazilian savanna (Cerrado)

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Abstract

Until recently, no native mushroom was considered food in the Cerrado biome, while there are records of the occurrence of about 638 species of fungi so far, many of which have numerous undefined potentials, with the potential for food among them. Our work presents the nutritional aspects of two mushroom species found in an agroforestry system in the Cerrado (*Auricularia nigricans* and *Schizophyllum commune*), and a morphological identification key for the edible mushroom species highlighted in this study. The nutritional composition analysis revealed a moisture content of 65 and 41%, proteins of 7 and 10%, ether extract (fat) of 1.3 and 1.5% and fiber of 2 and 2.2% for *A. nigricans* and *S. common*, respectively. In this work we highlight the nutritional potential of two species of edible mushrooms, *A. nigricans* and *S. commune*. These mushrooms show similar nutritional characteristics to those of commercially produced exotic mushrooms, being rich in proteins and minerals. These data, added to other reports of this nature recently presented, reinforce the importance of knowledge of local biodiversity and native mushrooms as a food source.

Keywords: edible fungi; savannah; composition; protein.

Practical Application: This work reveals new foods from the Cerrado to be consumed by society, especially native mushrooms with great nutritional potential.

1 Introduction

The global production of edible mushrooms increased 30 times between 1978 and 2013, going from one million to 34 million tons produced (Royse et al., 2017). The world market for edible mushrooms moves around 42 billion dollars annually, and this value is estimated to reach U$62.2 billion for the year 2023 (Research and Markets, 2017).

It is estimated that around 2,000 species of fungi are recognized as safe for human consumption (Kalac, 2016). Among these species, the fungi popularly known as mushrooms are included, which are spore-producing structures of a wide diversity of species within the phylum Basidiomycota. These fungi are part of the Fungi Kingdom, whose estimated number of species is 2.2 to 3.4 million, many of which may be species with not yet discovered or explored food potential (Hawksworth & Lücking, 2017). Although the literature reports more than 350 species collected and consumed as food, only 25 are widely commercially cultivated. Among these are *Agaricus bisporus* (J.E. Lange) Imbach (champignon), *Lentinula edodes* (Berk.) Pegler (shiitake), *Pleurotus* spp. (shimeji), and *Flammulina velutipes* (Curtis) Singer (enokitake) (Valverde et al., 2015). Furthermore, 85% of the world production of edible mushrooms is represented by only five genera: *Lentinula, Pleurotus, Auricularia, Agaricus* and *Flammulina* (Prescott et al., 2018).

Brazil has about 5,700 species of fungi cataloged, and approximately half of these belong to the phylum Basidiomycota, in which mushrooms are located (Maia et al., 2015). Even with this number of known species, Brazil is no exception to the world rule in relation to the commercial cultivation of mushrooms, as the main cultivated species are exotic. The mushroom of the sun (*Agaricus blazei* Murrill), a species discovered in Brazil, was taken to Japan in the 1960s. Contradictorily, about three decades later, new strains of this species were imported from Japan to strengthen commercial cultivation of mushrooms with medicinal properties in the state of São Paulo (Dias et al., 2004).

On the other hand, some examples in the Amazon region have shown the nutritional potential of native species, such as mushrooms cultivated by the Yanomami indigenous people, who already trade more than 10 Amazon species (Instituto Socioambiental, 2019). The Yanomami collect wild mushrooms in a complex agricultural system known as "slash-and-burn agriculture". In this system, an area of native forest is deforested and plant residues are burned. Then, agricultural crops are planted a few days after burning. In approximately four years, the planting site gives way to natural regeneration, giving rise to the '*capoeira*' physiognomy. It is during this period that the

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mushrooms are found growing on decaying trunks still remaining from the fire (Coimbra & Welch, 2018).

In turn, until recently, no native mushroom in the Cerrado biome was considered food by contemporary society. In some recent studies by our research group (Silva-Neto et al., 2020; Silva-Neto et al., 2021) we highlighted that mushrooms used in the diet of indigenous peoples in the Amazon also occur and are abundant in the Cerrado. Furthermore, the nutritional compositions of *Lentinus critinus* (L.) Fr. and *Favolus brasiliensis* (Fr.) were presented in these same studies. There are at least 638 species of fungi known so far in the Cerrado with countless potentials, including the potential for food among these, but still unknown (Maia et al., 2015).

Mushrooms are considered a source of fiber, proteins, minerals, vitamins, and above all, bioactive compounds with antioxidant and antibiotic properties, among many others (Justo et al., 1998; Ahmed et al., 2009; Khatun et al., 2015; Fasoranti, 2019). Among the bioactive compounds, there are phenolic compounds, some polysaccharides and glycoproteins. Thus, mushrooms are touted as nutraceutical foods and can be consumed as dietary supplements, and sources of prebiotics. This occurs in carbohydrate functions such as chitin, hemicellulose, β and α-glucans, mannans, galactans and xylans; vitamins C and E; polyphenols; and other substances with antioxidant activity which are produced. They are still indicated for the prophylaxis and treatment of cancer as antimutagenic and antitumor effects have been observed, mainly due to the β-glucans, chitin and hemicellulose they produce which stimulate the immune system (Fortes & Novaes, 2006; Silva & Jorge, 2011; Furlani & Godoy, 2007).

Despite their potential, mushrooms are still not part of the diet of most of the Brazilian population. More studies are needed on the processing and development of food or industrialized products which contain mushrooms added as enrichers (Orsine et al., 2012).

Considering the potential of mushrooms for human consumption and the gaps in knowledge in both the richness of fungal species and their food use, this work aims to present the nutritional aspects of two species found in the Cerrado agroforestry system, *Auricularia nigricans* (Sw.) Birkebak, Looney & Sánchez-García and *Schizophyllum commune* Fr., including a comparative analysis with commercially cultivated species and an identification key for the Cerrado mushroom species which have already been studied for this purpose.

2 Materials and methods

The specimens were found in an agroforestry yard located in the Brazilian Cerrado in the municipality of Goiânia, Goiás. The area characterization, counting forest species, soil and climate are defined in Silva-Neto et al. (2020) amd Silva-Neto et al. (2021). Samples were collected and taxonomically identified using traditional methods based on macro and micromorphological characters and the pertinent literature was also already characterized in Silva-Neto et al. (2020) and Silva-Neto et al. (2021) (Largent & Thiers, 1977; Largent et al., 1977; Henriot & Cheype, 2017; Cui et al., 2019). Color codes follows Kornerup & Wansher (1978).

The nutritional composition was analyzed from determining the macro and micronutrients. Thus, a sample of 20 g in fresh mass was taken from each basidiome, which were then dried in an oven at 40 °C for 24 h, ground in a mill to 1 mm, packed in low-density polyethylene bags and kept under refrigeration at 4 °C for about 30 days until the moment of analysis. Bromatological analysis consisted of determining the moisture content, protein, ether extract, ash and crude fiber according to Silva & Queiroz (2006) and Santos et al. (2009).

After the pre-drying procedure, the sample was ground in an analytical mill with a 1 mm sieve and the dry mass was determined by placing them in an oven at 105 °C for 24 h to determine the total dry matter after the calculations. Mineral matter (MM) was determined by the following method: after pre-drying 5 g of the ensiled material, the samples were placed in porcelain crucibles and put into an oven to burn the organic material at a temperature ranging from 200 °C to 600 °C for a period of four hours, again to determine the total mineral matter after calculations (Silva & Queiroz, 2006).

A Kjeldahl steam distillation apparatus was used for nitrogen content, and the crude protein (CP) content was calculated using the conversion factor 6.25 according to Association of Official Analytical Chemists (2000) and Santos et al. (2009). Crude fiber was calculated by analyzing the total digestible nutrients, lignin, cellulose and hemicellulose performed according to the methodology described by Santos et al. (2009) and Silva & Queiroz (2006).

3 Results and discussion

The fungi addressed in this study are classified in the phylum Basidiomycota, class Agaricomycetes, with *A. nigricans* (Sw.) Birkebak, Looney & Sánchez-García belonging to the order Auriculariales, family Auriculariaceae; and *Schizophyllum commune* Fr. to the order Agaricales, family Schizophyllaceae. Fungi of the genus *Auricularia*, proposed by Jussieu (1789), are of great economic importance, as they are among the most cultivated for human consumption, especially in Asian countries (Sekara et al., 2015; Prescott et al., 2018).

Species of this genus such as *A. auricula-judae* (Bull.) Quél., *A. fuscosuccinea* (Mont.) Henn. and *A. nigricans* are valued in traditional oriental cuisine and medicine due to the health benefits their ingestion brings, including antitumor, cholesterol-lowering, anticoagulant, antioxidant, immunomodulatory, anti-inflammatory, and antimicrobial potential (Sekara et al., 2015; Liu et al., 2021). *Auricularia*, together with the genera *Lentinula*, *Pleurotus*, *Agaricus*, *Flammulina*, *Lentinus* and *Tremella* represent the most commercially produced and consumed genera globally, with a market estimate of around 42 billion dollars annually in 2018 (Prescott et al., 2018; Elkhateeb et al., 2021).

The species investigated in the present study (*A. nigricans*) has a cosmopolitan distribution, predominantly in the Neotropics and Paleotropics (Lowy, 1952). There are records of its occurrence in the states of Amazonas, Amapá, Bahia, Ceará, Federal District, Goiás, Minas Gerais, Mato Grosso, Pará, Santa Catarina, São Paulo, Rio de Janeiro, Rondônia, Roraima and Rio Grande do Sul in Brazil (Alvarenga et al., 2015). It is characterized by its cartilaginous basidiome and greyish brown (6D3) when fresh, and brittle when dry, with a tomentose abhymenial face and smooth hymenium (Lowy, 1952).

The genus *Schizophyllum*, proposed by Fries (1821), holds the species type *Schizophyllum commune* Fr., which has a cosmopolitan distribution, colonizing dead trunks of a wide diversity of plants, or parasitizing live plants. This species is recognized as edible, being known as chewing-gum fungus or split-gill mushroom (Cooke, 1961; Takemoto et al., 2010). This fungus has a known antioxidant property (Arbaayah & Umi-Kalsom, 2013; Jiamworanunkul, 2019) and a high potential for bioaccumulation of metals such as Fe and Zn in the mycelium, suggesting that this species could be used as a food source in diets which require these micronutrients (Umeo et al., 2020). *S. commune* occurs in all geographic regions in Brazil, with no record of occurrence only for the state of Tocantins, although distribution models of this species suggest that it should have a wide distribution in these unexplored regions (Braga-Neto, 2013).

The nutritional composition data of *A. nigricans* and *S. commune* obtained in the present trial, as well as those of other both wild and cultivated mushroom species obtained from the literature are presented in Table 1. A comparative analysis of these data reveals that the studied species have intermediate moisture content compared to both wild and cultivated species. *Favolus brasiliensis* Fr. (Fr.) (native to the Brazilian Cerrado) stands out in this parameter for having the highest moisture content (93.60%), while *Termitomyces eurrhizus* (Berk.) R. Heim (native to Asia) had the lowest (7.00%) moisture content.

F. brasiliensis also deserves to be highlighted regarding protein content (with 27%), followed by *L. critinus* (14%), *S. commune* (10%) and *A. nigricans* (7%). The values found in these native species of the Cerrado (7 to 27%) show their protein potential, being higher than those observed in some commercial cultivation species such as oyster mushrooms (*Pleurotus* spp. 24.10%) and shitake (*Lentinus edodes* 43.81%) (Ru & He, 2016), and also in wild species such as *Agaricus abruptibulbus* Peck, *Termitomyces* spp., *Russula vesca* Fr., *Auricularia thailandica* Bandara & K.D. Hyde, *Lentinus crinitus* (L.) Fr.. The ether extract (fat) content was similar among the studied species, varying between 1.3 and 1.5%, being considered inferior to *Pleurotus ostreatus* with 2.45% (cultivated species).

Crude fiber content also varied greatly between species, with values ranging from 2% in *A. nigricans* and *S. commune* to 26% in *L. crinitus*, which is visually a fibrous mushroom. The average crude fiber content found in the studied species is similar to the values compiled by Wang et al. (2014) for wild edible mushrooms found in China of between 5 and 40%, in addition to showing great variation between wild and cultivated species (Andrade et al., 2008). Fiber contents are determinants of palatability, softness, digestibility, among other aspects that will define whether fungi will or will not be used in food. In any case, high fiber contents do not make it impossible to use the fungus in food, but they may require some type of preparation prior to consumption or will serve for other purposes, such as feed (Cheung, 2013).

Ash is the inorganic residue or mineral composition of fungi. The ash content in the studied species ranged between 1.1 and 3.4%, lower than that of cultivated mushrooms, which reached 11.9%.

Each mushroom species has a distinct compound profile, but cultivated mushrooms generally showed to have more nutritious characteristics with higher protein and fiber content. In addition

Table 1. Nutritional composition between wild and cultivated mushroom species (g/100 g).

	Species	Moisture	Protein	Ethereal extract	Crude fiber	Ash	Reference
Wild	***Auricularia nigricans***	**65**	**7**	**1.2**	**2.2**	**1.1**	**Present study**
	Schizophyllum commune	**41**	**10**	**1.3**	**2.0**	**1.1**	**Present study**
	F. brasiliensis	93.60	27.00	1.50	17.00	1.70	Silva-Neto et al., 2021
	Lentinus crinitus	61.00	14.00	1.50	26.00	3.40	Silva-Neto et al., 2020
	Agaricus abruptibulbus	93.30	20.30	--	8.85	--	Sudheep & Sridhar, 2014
	Termitomyces globulus	91.80	23.83	--	9.66	--	Sudheep & Sridhar, 2014
	Russula vesca	15.00	14.00	--	--	--	Singdevsachan et al., 2014
	Termitomyces eurrhizus	7.00	22.83	--	--	--	Singdevsachan et al., 2014
	Lentinula edodes	82.80	43.81	--	3.60	--	Ao & Deb, 2019
	Lentinus torulosus	80.97	27.31	--	--	--	Singdevsachan et al., 2013
	Auricularia thailandica	80.75	12.99	--	4.62	--	Bandara et al., 2017
Cultivated	*Pleurotus ostreatus*	--	35.40	2.45	11.27	6.70	Carvalho et al., 2012
	Lentinula edodes	79.78	4.40	--	--	--	Reis et al., 2012
	Agaricus bisporus	--	37.88	--	10.31	11.98	Andrade et al., 2008
	Agaricus blazei	88.00	39.80	--	9.65	7.75	Shibata & Demiate, 2003
	Pleurotus ostreatus	87.70	24.10	--	4.30	--	Duprat et al., 2015
	Pleurotus sajor-caju	87.00	24.63	--	22.87	--	Alam et al., 2008
	Pleurotus djamor	90.07	20.50	--	22.43	--	Rampinelli et al., 2010

to the genetic determinants inherent to each species, part of these differences can be attributed to the growing conditions that provide better conditions for fungus development (Mleczek et al., 2021). It is important to emphasize that the studied mushrooms were extracted from nature, growing naturally in mango tree trunks (*Mangifera indica* L.), without the influence of artificially-prepared substrates for cultivation. As a rule, commercial cultivation is carried out on fortified substrates or selected woods, thus constituting factors which can influence the nutritional contents of the mushrooms. Sales-Campos et al. (2011) observed that the nutritional composition of the oyster mushroom (*Pleurotus ostreatus* (Jacq.) P. Kumm.) varies depending on the substrate. Sales-Campos et al. (2013) also found substrate effects on the nutritional contents of *Lentinus strigosus* Fr., a mushroom naturally occurring in the Amazon. Other factors in addition to the substrate can influence the nutritional composition such as species and their varieties, strains, maturity degree of the mushroom, parts of the mushroom examined, among others (Sales-Campos et al., 2013).

The studied mushrooms grew in low density wood (less than 5 g/cm^3), as well as those from the Yanomami territory which occur in swiddens, brushwoods and dense forests on decomposing trunks, growing in/on wood such as embaúba (*Cecropia* spp.) (Coimbra & Welch, 2018). The same condition of mushrooms growing on low density trunks was also observed for *L. crinitus* and *F. brasiliensis* mushrooms found in agroforestry systems in the state of Goiás (Silva et al., 2020; Silva-Neto et al., 2020). We emphasize that the wood types preferred by wild fungi are important for defining the composition of substrates for the commercial cultivation of these species. Furthermore, specific studies are needed to define the types of substrates mushrooms grow on, in addition to tests involving other materials as substrates, as their composition can directly influence the nutritional characteristics of the fungus. Few works have been found in the literature on substrates for cultivating native Cerrado species so far. An exception is a recent work on *L. crinitus*, in which the authors highlight the capacity of this species to grow in environments and situations considered extreme for fungal development (Colla et al., 2020)

Next, we present a dichotomous key based on external morphology which will facilitate the identification of the macrofungi analyzed in this work in the field, constituting native species of the Brazilian Cerrado with food potential. Figure 1 presents the main characteristics mentioned in the key which complement recognizing the species in the field.

3.1 Identification key for some fungi species from the Brazilian Cerrado with food potential

1 – Pileated basidiome lamellar or tubular hymenophore .... **2.**

1' – Basidiome not pileated, smooth or gilled-like hymenophore .... **3.**

2 – Gregarious basidiomata, rarely solitary, flabellate to spatulate, white (1A1) to yellowish white (1A2) when fresh, tubular hymenium, glabrous abhimenium, glabrous stipes, laterally inserted............ *Favolus brasiliensis* (Figure 1, A1-A2).

2' – Gregarious basidiomata, rarely solitary, densely tomentose cap, rarely glabrous, slightly infundibuliform, arising lamellae, basidiomas grayish yellow (4B4) to yellowish brown (5E7), central stipe................ *Lentinus crinitus* (Figure 1B).

3 – Cespitose basidiomata, coriaceous, flabelliform, hymenium composed of gilled-like folds which are split in half, tomentosus abhimenium, irregular to lobed margins, grey (4B1) to greyish beige in color (4C2)........................ *Schizophyllum commune* (Figure 1C, C1).

3' – Cespitose basidiomata, rarely solitary, auricular in shape, gelatinous, smooth hymenial surface, brown to grayish brown (6D3), tomentose abhimenium, pale grey in color (1B1).......................... *Auricularia nigricans* (Figure 1D, D1).

As in the studies by Silva-Neto et al. (2020); Silva-Neto et al. (2021), these data reinforce the potential for using mushrooms in agroforestry yards in the Brazilian Cerrado. The number of *Auricularia nigricans* and *Schizophyllum commune* specimens found in the sampled location is similar to that of *F. brasiliensis* and *L. crinitus* in previous years, highlighting that one hectare of agroforestry yard can generate a production of approximately 20 kg. Nevertheless, mushroom collection within the principle of diversity in agroforestry systems cannot be just one species, but all collected species can jointly contribute to the productivity of edible mushrooms in the areas.

Generating knowledge about wild edible mushrooms may further influence the development of forest management techniques which aim to favor developing these fungi in the future. Pérez-Moreno et al. (2021) highlight that the conservation of forest environments promotes production and marketing of a high commercial value non-timber forest product. These authors define "myco-forestry" as forest management practices which can benefit the development of wild edible mushrooms. Thus, developing management techniques for agroforestry systems in the Cerrado may also be promising in order to favor developing these fungi, as they are agricultural systems which mimic forest environments.

Another relevant factor in relation to wild edible fungi is the growing local and also international trade. Frutos (2020) analyzed the international flows of wild foods with a focus on the edible fungi market, reaching the conclusion that wild mushrooms were the foods which most stood out in recent years in the inter-industrial international trade. Knowledge about these Cerrado foods can not only help to strengthen the local trade of these products, but also provide a basis for industries and companies to operate in the international market.

Among an important little-studied aspect of native mushrooms is the allergenic potential of fungal species. Some Basidiomycota species may have allergenic components in their basidiomes (mushrooms), such as *Ganoderma* spp., *Coprinus* spp. and *Pleurotus* spp., which can cause an allergic reaction in people sensitive to these foods. There are still no reports of similar reactions for mushrooms native to Brazil and the Cerrado, not even among traditional peoples (Simon-Nobbe et al., 2008).

Figure 1. A: *Favolus brasiliensis* over decaying wood. a1-2: tubular hymenium and flabellum morphology of the basidioma. B: *Lentinus crinitus* (Appendix by Silva-Neto et al., 2020). C: *Schizophyllum commune* on decaying wood. c1: hymenium detail, composed of gilled-like, split folds, reminiscent of the lamella morphology. D: *Auricularia nigricans* on decaying trunk. d1: smooth hymenium.

Nonetheless, it is an aspect which should be considered in future studies on mushrooms used in food.

Studies are also needed on the most appropriate processing techniques when considering these fungi as a food product in order to maintain the nutritional and medicinal characteristics present in mushrooms. According to the technical regulation for edible mushrooms in Brazil (Brasil, 2005), commercialization in dried, whole, fragmented, ground or preserved form is allowed. Other processes which promote food safety and increase shelf-life are drying, smoking, cooking, salting or fermentation. Thus, the development of studies on preparation forms and processing is suggested, followed by additional studies on nutritional composition, sensory analysis and acceptability by consumers of these promising species.

A. nigricans, as well as *S. commune,* are just a few of the 20 species of mushrooms presented by the Yanomami people, being considered by them a very abundant mushroom, but not necessarily the tastiest or most palatable. Many other mushrooms are preferred for food (Coimbra & Welch, 2018). New studies that value local and traditional knowledge of Brazil, especially the knowledge of indigenous communities, are important to recover knowledge about mushrooms, plants, and food, and as valuing communities and positively influencing the maintenance of their territories and knowledge.

Further studies are encouraged due to the food and economic importance of the subject, which can contribute to broader prospecting of the food potential of fungi that occur in agroforestry systems in the Cerrado. Importantly, four species used as food by indigenous peoples of the Amazon region were found in these agricultural production systems in the Cerrado in a short time (Silva et al., 2020; Silva-Neto et al., 2021; the present research). Additional research in the search for these native mushrooms may contribute to developing and optimizing production systems, especially regarding the composition of the substrate and climate, among other factors, in order to enable controlled cultivation for commercial purposes, diversifying and expanding the prospects for agricultural production in these agroecosystems.

4 Conclusion

In this work, we highlight the natural occurrence in forest agroecosystems in the Cerrado biome and the nutritional potential of two species of edible mushrooms, *A. nigricans* and *S. commune*, which are consumed by Amazonian indigenous peoples. These mushrooms show similar nutritional characteristics to those of commercially produced exotic mushrooms, being rich in proteins and minerals. Even so, mushrooms from the Cerrado also have different aspects to cultivated mushrooms, such as moisture content, which can give particularities to these mushrooms.

Added to other reports of this nature recently presented, these data reinforce the importance of knowledge of local biodiversity and native mushrooms as a food source, in addition to being an indication of the possibility of cultivating these species of spontaneous occurrence, thus expanding and diversifying agricultural production in agroforestry systems in the Cerrado.

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