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ARTICLE

RESEARCH ARTICLE

Wild food from exotic conifer plantation and meadows in Patagonia (Argentina): nutritional and bioactive properties of edible mushrooms

Alimentos silvestres de plantaciones de coníferas exóticas y praderas en la Patagonia (Argentina): propiedades nutricionales y bioactivas de hongos comestibles

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Abstract: *Aim of study*: Exotic conifer plantations and grasslands with livestock farming constitute widely distributed and extensive anthropized landscapes in Patagonia, Argentina, hosting a diversity of wild edible mushroom species that remain underexplored nutritionally and functionally. This study measured the chemical composition and bioactivity of exotic wild edible mushrooms (WEM) from Patagonia (Argentina). *Area of study*: The study was conducted in Chubut, Neuquén and Rio Negro provinces of Patagonia, Argentina. *Material and methods*: Seven WEM species from anthropized meadows and pine plantations [*Agaricus campestris* L., *Lactarius deliciosus* (L.) Gray, *Leucocoprinus leucothites* (Vittad.) Redhead, *Macrolepiota procera* (Scop.) Singer, *Suillus lakei* (Murrill) A.H.Sm. & Thiers, *Suillus luteus* (L.: Fries) Gray and *Rhizopogon roseolus* (Corda) Th.Fr.] were assessed regarding their proximal composition (fatty acids, organic acids, soluble sugars, phenolic compounds, and ergosterol), their antioxidant activities (TBARS [Thiobarbituric Acid Reactive Substances] and OxHLIA [oxidative haemolysis inhibition assay)], and antimicrobial activities. *Main results*: Carbohydrates ranged from 39.00 g/100 g dw (dry weight) in *A. campestris* to 79.20 g/100 g dw in *S. luteus*. Significantly higher values were found for total fat in *S. lakei* (3.90 g/100 g dw), *Lactarius deliciosus* (3.84) and *S. luteus* (3.80). Crude protein was highest in *A. campestris* (32.6 g/100 g dw) followed by *Leucocoprinus leucothites* (18.80 g/100 g dw), while energy was higher for *Lactarius deliciosus* and *S. luteus* (396.70 Kcal/100 g dw and 396.00 Kcal/100 g dw, respectively). In total, 27 fatty acids were identified and quantified; polyunsatured fatty acids (PUFAs) were the main group, with high amounts of linoleic acid (C18:2), present in all species. The most effective extracts regarding the antioxidant capacity (TBARS) were those of *A. campestris* and *S. lakei*. The antibacterial effects were particularly pronounced against *Yersinia enterocolitica* while the antifungal activity was strongest against *Aspergillus brasiliensis*, with the extracts of *S. luteus* and *A. campestris* being the most effective, respectively. *Research highlights*: Pine plantations and grasslands from the Andean Patagonian region host numerous WEM that can be used as an alternative source of food, with high nutritional and bioactive benefits. They can help to achieve food sovereignty, and enhance activities such as mycogastronomy, mycotherapy, mycotourism and the production of functional foods from these environments.

Keywords: antioxidant; mycogastronomy; Patagonia; pine; *Suillus*; wild edible mushrooms.

Resumen: *Objetivo del estudio:* Las plantaciones de coníferas exóticas y los pastizales con ganadería constituyen paisajes antropizados ampliamente distribuidos y extensos en la Patagonia, Argentina, que albergan una diversidad de especies de hongos comestibles silvestres que aún permanecen poco exploradas desde el punto de vista nutricional y funcional. Este estudio evaluó la composición química y la bioactividad de hongos comestibles silvestres exóticos (WEM) de la Patagonia (Argentina). *Área del estudio*: El estudio se llevó a cabo en las provincias de Chubut, Neuquén y Río Negro, en la Patagonia, Argentina. *Material y métodos:* Se evaluaron siete especies de WEM provenientes de praderas antropizadas y plantaciones de pino [*Agaricus campestris* L., *Lactarius deliciosus* (L.) Gray, *Leucocoprinus leucothites* (Vittad.) Redhead, *Macrolepiota procera* (Scop.) Singer, *Suillus lakei* (Murrill) A.H.Sm. & Thiers, *Suillus luteus* (L.: Fries) Gray y *Rhizopogon roseolus* (Corda) Th.Fr.] en cuanto a su composición proximal (*ácidos* grasos, *ácidos* orgánicos, azúcares solubles, compuestos fenólicos y ergosterol), sus actividades antioxidantes (TBARS [sustancias reactivas al *ácido* tiobarbitúrico] y OxHLIA [ensayo de inhibición de la hemólisis oxidativa]) y sus actividades antimicrobianas. *Resultados principales:* Los carbohidratos oscilaron entre 39,00 g/100 g de peso seco (ps) en *A. campestris* y 79,20 g/100 g ps en *S. luteus*. Se encontraron valores significativamente más altos de grasa total en *S. lakei* (3,90 g/100 g ps), *Lactarius deliciosus* (3,84) y *S. luteus* (3,80). La proteína cruda fue mayor en *A. campestris* (32,6 g/100 g ps), seguida de *Leucocoprinus leucothites* (18,80 g/100 g ps), mientras que el valor energético fue mayor en *Lactarius deliciosus* y *S. luteus* (396,70 Kcal/100 g ps y 396,00 Kcal/100 g ps, respectivamente). En total, se identificaron y cuantificaron 27 *ácidos* grasos; los *ácidos* grasos poliinsaturados (PUFAs) fueron el grupo principal, con altas cantidades de *ácido* linoleico (C18:2), presente en todas las especies. Los extractos más efectivos en cuanto a capacidad antioxidante (TBARS) fueron los de *A. campestris* y *S. lakei*. Los efectos antibacterianos fueron particularmente marcados contra *Yersinia enterocolitica*, mientras que la actividad antifúngica fue más fuerte contra *Aspergillus brasiliensis*, siendo los extractos de *S. luteus* y *A. campestris* los más efectivos, respectivamente. *Aspectos destacados de la investigación:* Las plantaciones de pino y los pastizales de la región andino-patagónica albergan numerosos hongos comestibles silvestres que pueden utilizarse como fuente alternativa de alimento, con altos beneficios nutricionales y bioactivos. Pueden contribuir a alcanzar la soberanía alimentaria y potenciar actividades como la micogastronomía, la micoterapia, el micoturismo y la producción de alimentos funcionales a partir de estos ambientes.

Palabras clave: antioxidante; hongos silvestres comestibles; micogastronomía; Patagonia; pino; *Suillus*.

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Supplementary information ↓

1. INTRODUCTION

Wild edible mushrooms (WEM) have been a food source for humans for over two thousand years, owing to their organoleptic properties, nutritional benefits, and medicinal attributes (Barroetaveña et al., 2020, 2024; Jacinto-Azevedo et al., 2021; Salazar-Vidal et al., 2024). The high levels of protein and fiber, low fat content, and the presence of all essential amino acids and bioactive compounds improve their culinary and commercial value (Kalač, 2013; Barroetaveña & Toledo, 2017). Besides, numerous mushroom species have been investigated as potential sources of novel therapeutic alternatives, since they represent a significant source of bioactive compounds that exert beneficial effects on human health (Lindequist et al., 2005; Petrova et al., 2008; Łysakowska et al., 2023). They are abundant in polysaccharides, glycoproteins, ergosterols, triterpenes and antibiotics (Ribeiro et al., 2007; Barros et al., 2008a) that contribute to their antioxidant, antitumor, antiviral, antibacterial, antidiabetic, antiparasitic, immunomodulatory, and hepatoprotective properties (Ferreira et al., 2009; Reis et al., 2012; Jacinto-Azevedo et al., 2021).

In Argentinian Patagonia, many introduced and cosmopolitan edible fungi fruit in anthropized meadows and conifer plantations (Barroetaveña et al., 2007; Pildain et al., 2021; Rugolo & Salazar-Vidal 2024). Afforestation with exotic pine species has been widely implemented within the ecotone area, between the native forest and the steppe, along north and central Patagonia. These plantations, with rapid growth and significant economic value, cover approximately 106,912 hectares (MAGyP, 2025), are dominated by *Pinus ponderosa* (Dougl.) (about 77% of the plantation area), followed by *Pinus contorta* (Dougl.) ex. Loud (6%), and to a lesser extent *Pinus radiata* D. Don., *Pseudotsuga menziesii* (Mirb.) Franco (2%) and other *Pinus* species. In addition to contributing to land recovery and carbon sequestration, these afforestation efforts offer opportunities for productive forest management. However, the introduction of non-native species may raise ecological concerns, including the reduction of native flora and fungal biodiversity, invasion processes mediated by foreign ectomycorrhizal species into nearby native ectomycorrhizal forests (Dickie et al., 2010), alterations to the hydrological cycle, and soil acidification (Jackson et al., 2005) To address these challenges, a balanced approach that considers both economic benefits and ecological impacts is essential for sustainable forest management. Moreover, as these forest stands are under productive use, silvicultural practices can be adapted to encourage mushroom fruiting, promoting the integration of mycosilviculture (Tomao et al., 2017; Salerni et al., 2023).

Within the forest landscape (whether native or exotic), there are depressions prone to flooding (flood meadows or 'mallines') (Cassola, 1988) distributed throughout the region, both in native mountainous forestland and patchy areas with less precipitation adjacent to the Patagonian steppe, comprising 778,750 ha. These grasslands, widely used for cattle feeding (Quinteros et al., 2016), are a suitable habitat for different saprophytic WEM species (Barroetaveña & Toledo, 2016). Wild edible mushrooms considered safe and already included in the Argentine Food Code include *Lactarius deliciosus* (L.) Gray*, Suillus lakei* (Murrill) A.H.Sm. & Thiers*, Suillus luteus* (L.: Fries) Gray and *Rhizopogon roseolus* (Corda) Th.Fr. from conifer plantations, and *Agaricus campestris* L. and *Macrolepiota procera* (Scop.) Singer from grasslands (Barroetaveña & Toledo, 2016; Pildain et al., 2019, Molares et al., 2020). Currently, *Suillus* is the most harvested genus in these environments; its informal exploitation constitutes an additional source of income for local families or Mapuche communities that engage in their harvest and sale (fresh and dried) in markets or retail stores. These fungi complement local diets and are seasonally gathered with deep awareness of natural cycles. Beyond their nutritional value, mushrooms are embedded in the Mapuche worldview, which sees nature as a living, interconnected system.

In recent years, the role of mushrooms has also gained attention in initiatives related to food sovereignty, cultural revitalization, and sustainable land use (Fernández et al., 2012, 2021; Molares et al., 2020). However, the nutritional and medicinal profiles of WEM from anthropized Patagonian landscapes have not yet been characterized in detail, with existing data limited to specimens collected in other countries (Barroetaveña et al., 2020; Jacinto-Azevedo et al., 2021). Intraspecific variation in the chemical composition and bioactivity of WEM species from different geographic regions and environments has already been reported (Al-Laith, 2010; Liu et al., 2016).

This study seeks to expand the analysis of the nutritional composition and biological properties of WEM from these environments, focusing on their macronutrient profiles, individual sugars, fatty acids, organic acids, phenolic compounds, and their antimicrobial and antioxidant properties. Building on previous studies of WEM from native Andino-Patagonian forests (Toledo et al., 2016; Jacinto-Azevedo et al., 2021; Rugolo et al., 2022), this study aims to provide complementary data on species from other Patagonian environments to support their promotion as nutritious foods and encourage the development of value-added products.

2. MATERIALS AND METHODS

2.1. Collection and identification of fungi

Seven wild edible mushrooms species *(Agaricus campestris, Lactarius deliciosus, Leucocoprinus leucothites, Macrolepiota procera, Suillus lakei, Suillus luteus* and *Rhizopogon roseolus)* were harvested during the autumn and spring of 2019 and 2020 from *Pinus* spp. and *Pseudotsuga menziesii* (Mirb.) Franco plantation stands (over 20 years old and under silvicultural management), as well as from grasslands, in the western Patagonian provinces of Neuquén, Rio Negro and Chubut (Argentina) in mountainous foothill areas (Figure 1). The collected specimens were macroscopically verified using specific mycological literature. Specimens in good condition, well-developed but not overmature, were considered. Collections were freeze-dried for 48 h (BK-FD10 Biobase), ground into a fine powder, and stored (- 18 °C) in polyethylene bags until further analyses. Specimens of each species were dried and deposited in the Herbarium of the Patagonian Forest Research Center (CIEFAP; Esquel, Chubut, Argentina) for future reference.

Figure 1. Samples of wild edible mushrooms (WEM) A) *Agaricus campestris,* B) *Lactarius deliciosus,* C) *Leucocoprinus leucothites,* D) *Macrolepiota procera,* E) *Suillus lakei,* F) *Suillus luteus,* G) *Rhizopogon roseolus.* Photographs by Maximiliano Rugolo, except for image C, authored by Leo Ridano.

2.2. Nutritional characterization

The amounts of protein, fat, carbohydrates, ash, and energy were quantified using the methods reported in AOAC (Association of Official Analytical Chemists, 2016), as described in Barros et al. (2013) and Rugolo et al. (2022). The results are presented in g or Kcal per 100 g dry weight (dw), as appropriate.

2.3. Chemical composition

2.3.1. Organic Acids

Organic acids were identified using high-performance liquid chromatography coupled with a photodiode array detector (UFLC-PDA), as outlined by Barros et al. (2013). Their concentrations were determined by comparing the results with calibration curves for standard compounds L(+)-ascorbic acid, citric acid, malic acid, oxalic acid, shikimic acid, succinic acid, fumaric acid, and quinic acid, all from Sigma, St. Louis, MO, USA. Results are presented in mg/100 g dry weight (dw).

2.3.2. Free sugars

Free sugars were analysed by high-performance liquid chromatography (HPLC, Knauer, Smartline 1000 systems, Berlin, Germany) equipped with a refractive index detector (Knauer Smartline 2300), as explained in Barros et al. (2013). Results are reported as g/100 g of dry weight (dw).

2.3.3. Ergosterol

Ergosterol was extracted following the method described by Vieira Junior et al. (2021) and quantified using the HPLC described previously, with a UV detector (Knauer Smartline 2500), using 280 nm as the preferred wavelength as outlined in Cardoso et al. (2020). Identification and quantification were performed by comparing the results to a pure chemical standard (Sigma Aldrich, St. Louis, MO, USA). Results are presented in mg/100 g dry weight (dw).

2.3.4. Fatty acids

Fatty acid extraction and identification were performed using gas chromatography with flame ionization detection (GC-FID)/capillary column, as described previously by Pereira et al. (2012) based on the relative retention times of FAME (Fatty Acid Methyl Esters) peaks compared to known standards (mixture 37, 47885-U, Sigma). The analysis was carried out with a DANI model GC 1000 instrument equipped with a split/splitless injector, a flame ionization detector (FID at 260 °C) and a Macherey–Nagel column (30m×0.32mm ID×0.25µm d_f). Results are presented as each detected fatty acid's relative percentage (%).

2.3.5. Phenolic composition

For hydroethanolic extracts preparation, approximately 0.5 g of finely ground, freeze-dried samples (20 mesh) was mixed with 30 mL ethanol-water mixture (80:20, v:v) at 25 °C and stirred at 150 rpm for one hour. After this initial extraction, the remaining solids were subjected to a second extraction using another 30 mL of the same solvent under identical conditions. The resulting solutions were combined, filtered through Whatman No. 4 filter paper, and concentrated at 35 °C in a Büchi R-210 (Flawil, Switzerland) rotary evaporating system following Rugolo et al. (2022). The concentrates were then reconstituted in their respective solvents to a final concentration of 10 mg/mL (stock solution) and stored at 4 °C. Phenolic compounds identification and quantification followed Bessada et al. (2016) using a Dionex Ultimate 3000 UPLC system (Thermo Scientific, San Jose, CA, USA), equipped with a quaternary pump and a diode array coupled in series to an electrospray ionization mass spectrometry detector (HPLC-DAD ESI/MS). Results were expressed in mg per g of lyophilized extract.

2.4. Bioactivities Evaluation

Antioxidant Activity: An *in vitro* assay was conducted to evaluate the extract's capacity to inhibit thiobarbituric acid reactive substances (TBARS) formation using malondialdehyde (MDA) - thiobarbituric acid (TBA) complexes as previously described by Mandim et al. (2019). Porcine brain cells, commonly employed as a model system in lipid peroxidation research, were used as the biological substrate. Results were reported as IC_{50} values (µg /mL). The IC_{50} values were determined by incubating porcine brain homogenates with different concentrations of the mushroom extracts in the presence of a pro-oxidant to induce lipid peroxidation. After incubation, malondialdehyde (MDA) formed as a result of lipid peroxidation was measured by its reaction with thiobarbituric acid (TBA), producing a colored complex quantified spectrophotometrically at 532 nm. The percentage inhibition of MDA formation was plotted against extract concentrations, and IC_{50} values were obtained using nonlinear regression analysis of the dose-response curve.

The oxidative haemolysis inhibition assay (OxHLIA) was performed using sheep erythrocytes, following the procedure described by Lockowandt et al. (2018). Results are expressed as the inhibitory concentration (IC50 µg/mL) required to delay hemolysis by Δt = 60 and 120 minutes. This parameter serves as an indicator of antioxidant activity, reflecting the protective capacity of the tested extracts against oxidative damage. In this assay, the delay in hemolysis indicates the extent to which the sample can inhibit lipid peroxidation and maintain membrane integrity. Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, obtained from Sigma) was used as a positive control in both assays.

Antimicrobial activity: The extracts were tested against standard reference strains provided from American Type Culture Collection (ATCC). An ATCC strain refers to a well-characterized and documented reference strain widely accepted for use in comparative studies and experimental validation.

Antibacterial Activity: The extracts were tested against five Gram-negative bacteria: *Escherichia coli* (ATCC 25922), *Enterobacter cloacae* (ATCC 49741), *Salmonella enterica* subsp (ATCC 13076), *Pseudomonas aeruginosa* (ATCC 9027), *Yersinia enterocolitica* (ATCC 8610) and three Gram-positive bacteria: *Listeria monocytogenes* (ATCC 19111), *Bacillus cereus* (ATCC 11778) and *Staphylococcus aureus* (ATCC 25923), all of which were purchased from Frilabo (Porto, Portugal). The MIC (minimum inhibitory concentration for detecting visible growth) and MBC (minimum bactericidal concentration to kill the bacteria) were determined for all strains using a colorimetric assay as described by Pires et al. (2018). The MIC was defined as the lowest concentration inhibiting visible bacterial growth, determined by a change from yellow to pink coloration if the microorganisms are viable. The MBC was defined as the lowest concentration required to kill bacteria.

Antifungal Activity: The methodology used was based on the approach described by Heleno et al. (2013). Antifungal activity was evaluated against *Aspergillus fumigatus* (ATCC 204305) and *Aspergillus brasiliensis* (ATCC 16404) strains sourced from Frilabo (Porto, Portugal). The minimum inhibitory concentration (MIC) and minimum fungicidal concentration (MFC) were determined by a serial dilution technique using 96-well microplates. The lowest concentrations without visible growth (at the binocular microscope) were defined as the MICs. The lowest con centration with no visible growth was defined as the MFC, indicating 99.5% killing of the original inoculum. Ketoconazole, a commercial fungicide (Frilabo, Porto, Portugal), was a positive control (1mg/mL).

2.5. Statistical analysis

For each mushroom species, three independent samples were collected and analyzed, and the results are presented as the mean ± standard deviation. All statistical analyses were conducted using RStudio (version 1.1.485© 2009–2022 RStudio, Inc.) with a significance level of 5%. The normality of residuals and variance homogeneity were assessed using the Shapiro–Wilk and Levene tests to meet the assumptions of one-way ANOVA. Tukey's test was applied to compare all dependent variables. If normality or homogeneity of variance was not confirmed, the variables were transformed using the Box–Cox method before conducting the ANOVA. In cases where normality and homoscedasticity were not achieved even after Box–Cox transformation, Kruskal–Wallis tests were performed.

3. RESULTS AND DISCUSSION

The results of proximate chemical composition and energetic value (expressed in dry weight basis) are shown in Table 1. This is the first report of macronutrients for *A. campestris* and *R. roseolus* collected from Patagonia. Concerning protein content, the highest value was found in *A. campestris* (32.60 g/100 g dw, significantly greater than the other species) and for the rest, values ranged from 11.20 g/100 g dw in *S. luteus* to 18.80 g/100 g dw in *Leucocoprinus leucothites*. In our work *A. campestris* showed higher values than those reported by Pereira et al. (2012) for *A. campestris* (18.57 g/100 g dw) and by Jacinto-Azevedo et al. (2021) for *A. bisporus* (18.53 g/100 g dw) purchased in local markets in Chile. *Lactarius deliciosus*, *M. procera, S. lakei* and *S. luteus* exhibited lower levels than those found by Jacinto-Azevedo et al. (2021). Amounts for *Leucocoprinus leucothites* were similar than those reported by Pereira et al. (2012). Other studies related to edible *Rhizopogon* species were conducted by Altaf et al. (2020) and Akata et al. (2012), reporting higher protein content in comparison with our results, with values of 18.20 g/100 g dw and 20.55 g/100 g dw in *R. luteolus* from India and *R. roseolus* from Turkey, respectively. However, it is important to consider that protein determination could pose a challenge due to the utilization of varying conversion factors, as calculated based on nitrogen content (Barroetaveña & Toledo, 2017), that complicates comparisons between studies. Also, the fungal cell walls encompass a significant proportion of nonprotein nitrogen, mainly as chitin (Barros et al., 2007), leading to fluctuations in crude protein values depending on the chosen conversion factor. Nevertheless, on a dry weight basis, mushrooms typically have a protein content of 19 to 35%, which is lower than most animal meats but significantly higher than many other foods, such as milk, rice, or wheat (Chang & Miles 2004).

Table 1. Nutritional composition (g/100 g) and energy value (Kcal/100 g) of the wild mushrooms studied in the Argentinian Patagonia, expressed on a dry weight basis (mean ± SD). nd: not detected. For each mushroom sample, means within a column with different letters differ significantly ($p < 0.05$)

Species	Crude Protein	Total Fat	Carbohydrates	Ash	Energy
Agaricus campestris	32.60 ± 0.20 [a]	1.29 ± 0.03 [d]	39.00 ± 1.00 [d]	27.00 ± 1.00 [a]	277.00 ± 2.00 [c]
Lactarius deliciosus	14.10 ± 0.10 [c]	3.84 ± 0.01 [a]	76.40 ± 0.20 [b]	5.60 ± 0.10 [d]	396.70 ± 0.40 [a]
Leucocoprinus leucothites	19.00 ± 1.00 [b]	2.16 ± 0.01 [c]	51.00 ± 1.00 [c]	27.70 ± 0.10 [a]	300.00 ± 0.20 [c]
Macrolepiota procera	13.20 ± 0.10 [cd]	2.70 ± 0.10 [b]	76.10 ± 0.10 [b]	7.90 ± 0.10 [b c]	382.10 ± 0.40 [a b]
Rhizopogon roseolus	13.90 ± 0.20 [c]	2.81 ± 0.02 [b]	74.00 ± 1.00 [b]	9.50 ± 0.40 [b]	376.00 ± 2.00 [b]
Suillus lakei	12.20 ± 0.10 [d]	3.90 ± 0.10 [a]	76.15 ± 0.02 [b]	7.70 ± 0.20 [c]	389.00 ± 1.00 [a]
Suillus luteus	11.20 ± 0.10 [d]	3.80 ± 0.20 [a]	79.20 ± 0.30 [a]	5.80± 0.20 [d]	396.00 ± 0.05 [a]

As shown in Table 1, crude fat content varied between 1.29 g/100 g dw in *A. campestris* (significantly lower than the other species) and 3.90 g/100 g dw in *S. lakei*. Elevated values were also recorded in *Lactarius deliciosus* and *S. luteus* (3.84 and 3.80 g/100 g dw, respectively). Additionally, the crude fat content of *Lactarius deliciosus*, *M. procera, S. lakei* and *S. luteus* were similar than those reported by Jacinto-Azevedo et al. (2021). Other studies, although with different values, show the same trend with crude fat content ranging from 0.11 to 8.02 g/100 g dw in wild *Agaricus campestris* from Portugal (Pereira et al., 2012) and *Lactarius deliciosus* (Akata et al., 2012) as reviewed by Kalač (2013). The low-fat content in edible mushrooms partly explains their recognition as good food sources, varying from 1 to 15 g/ 100 g dw, including all lipid types (Chang & Miles, 2004). Ash content ranged from 5.60 g/100 g dw in *Lactarius deliciosus* to 27.70 g/100 g dw in *Leucocoprinus leucothites*. High levels were also detected in *A. campestris* (27.00 g/100 g dw) and *R. roseolus* (9.50 g/100 g dw). *Agaricus campestris* yielded higher values than those reported by Jacinto-Azevedo et al. (2021) for *A. bisporus* (12.68 g/100 g dw), who also reported lower values for *Lactarius deliciosus* and *S. lakei,* higher for *M. procera*, and similar for *S. luteus.* Akata et al. (2012) showed similar values for *Lactarius deliciosus* from Turkey (6.58 g/100 g dw). The ash content in wild mushrooms can range from 5.53 g/100 g dw in *Boletus edulis* Bull. to 37.78 g/100 g dw in *Russula olivacea* (Schaeff.) Fr., according to Grangeia et al. (2011). It serves as a source of essential minerals, with the concentrations of potassium, phosphorus, sodium, calcium, and magnesium accounting for approximately 56 to 70% of the total ash content (Chang & Miles, 2004).

Carbohydrates (expressed as total carbohydrates) were the most abundant macronutrients and ranged from 39.00 g/100 g dw in *A. campestris* to 79.20 g/100 g dw in *S. luteus* (as shown in Table 1, significantly higher than the other species) although closely followed by *Lactarius deliciosus, S. lakei, R. roseolus* and *M. procera* (showing no significant differences between them) (Table 1). These findings are mostly in agreement with Grangeia et al. (2011), who observed that the ectomycorrhizal species they studied had a higher total sugar content (16–42 g/100 g dw) compared to saprotrophic ones (0.4–15 g/100 g dw). However, the saprophitic *M. procera* yielded high values in our study, significantly separated from the other saprophitic species (Table 1). Nonetheless, our value is even lower than what was reported by Jacinto-Azevedo et al. (2021), who also found the largest amount of carbohydrates in this species (83.65 g/100g) out of the 24 Chilean WEM studied. On the contrary, higher carbohydrate contents were detected for *Lactarius deliciosus*, *S. lakei*, and *S. luteus* compared to Jacinto-Azevedo et al. (2021), and very similar to Pereira et al. (2012) for *Leucocoprinus leucothites.* Akata et al. (2012) showed lower values for *Lactarius deliciosus* and *Suillus* from Turkey (51.54 and 46.17 g/100 g dw).

Compared to the other species analyzed, *A. campestris* exhibited the lowest caloric content, at 277.00 Kcal/100 g dw, while the highest values were detected in *Lactarius deliciosus* and *S. luteus* (396.70 Kcal/100 g dw and 396.00 Kcal/100 g dw, respectively). Mushrooms are valued for their low caloric content, typically ranging from 350 to 400 Kcal/100 g dw (Kalač, 2013).

Organic acids are a group of mono-, di-, and tricarboxylic acids that naturally occur as intermediates in various intracellular metabolic pathways, including amino acid catabolism, the tricarboxylic acid cycle, neurotransmitter production, and cholesterol biosynthesis. (Kölker 2014). Concerning organic acids composition (Table 2), oxalic and malic acids were detected in all studied species. Succinic acid content was considerably higher for *A. campestris* (787.00 mg/100 g dw). Malic acid was found in large quantities in *Lactarius deliciosus*, *S. lakei*, *M. procera,* and *Leucocoprinus leucothites*. As shown in Table 2, high amounts of oxalic acid were detected in *Leucocoprinus leucothites* (13.34 mg/100 g dw) and *M. procera* (11.95 mg/100 g dw). *Suillus luteus* and *Leucocoprinus leucothites* showed the greatest amount of fumaric acid (9.77 mg/100 g dw and 9.00 mg/100 g dw, respectively). High levels of fumaric acid were also reported in *S. luteus* and *S. granulatus* from Portugal, with significant variation between samples depending on two geographical origins (Ribeiro et al., 2009). Regarding total organic acid content, *A. campestris* exhibited the highest value (803.61 mg/100 g dw), whereas *S. luteus* showed the lowest (30.47 mg/100 g dw). Other work detected nine organic acids in *Agaricus* species, with oxalic, lactic, and succinic acids as the most prevalent (Gąsecka et al., 2018).

The primary sugars were mannitol, trehalose, and fructose (Table 2). Sugars comprise energetic, storage or structural roles (Pereira et al., 2012). Mannitol predominated in *Leucocoprinus leucothites* (8.04 g/100 g dw), *A. campestris* (7.70 g/100 g dw), and *Lactarius deliciosus* (7.10 g/100 g dw). Meanwhile, trehalose content was significantly higher for *M. procera* (6.00 g/100 g dw) and *S. luteus* (4.26 g/100 g dw). Fructose showed the highest values in *Suillus.* Mannitol, trehalose and fructose contents in *S. lakei* and *S. luteus* from Patagonia were higher than *S. granulatus* from Portugal and Serbia (Reis et al., 2014). Regarding *A. campestris, Leucocoprinus leucothites* and *M. procera*, our study showed similar values in trehalose content, but lower values in mannitol content, compared with wild Portuguese samples (Pereira et al., 2012; Ćirić et al., 2019). *Lactarius deliciosus* showed high values of mannitol, in concordance with wild samples from China (Xu et al., 2019). One unidentified sugar was present in higher abundance in *A. campestris* (3.50 g/100 g dw). Regarding the total sugar content, *R. roseolus* revealed the lowest value (3.68 g/100 g dw), due to mannitol and trehalose. Mannitol is a polyol, and its consumption has practically no influence on blood glucose (Reis et al., 2014). In addition, its medicinal

Table 2. Organic acids (mg/100 g dw), sugars (g/100 g dw) and ergosterol (mg/100 g dw) composition of the studied wild mushrooms on a dry weight basis (mean ± SD). nd: not detected. For each mushroom sample, means within a column with different letters differ significantly ($p < 0.05$)

	Organic acids				Sugars				Ergosterol
Species	**Oxalic**	**Malic**	**Succinic**	**Fumaric**	**Not identified**	**Fructose**	**Mannitol**	**Trehalose**	
Agaricus campestris	6.70 ± 0.10^{b}	9.93 ± 0.02^{cd}	787.00± 3.00^{a}	nd	3.50 ± 0.10^{a}	0.32 ± 0.02^{b}	7.70 ± 0.30^{a}	2.01 ± 0.02^{b}	12.10 ± 0.20^{d}
Lactarius deliciosus	3.85 ± 0.01^{cd}	59.00 ± 31.00^{a}	101.00 ± 1.00^{b}	4.27 ± 0.03^{bc}	nd	nd	7.10 ± 0.10^{ab}	0.30 ± 0.01^{d}	87.00 ± 4.00^{b}
Leucocoprinus leucothites	13.30 ± 0.30^{a}	30.00 ± 2.00^{b}	nd	9.00 ± 0.02^{a}	0.49 ± 0.02^{b}	0.11 ± 0.01^{b}	8.00 ± 0.20^{a}	3.70 ± 0.10^{b}	53.00± 4.00^{c}
Macrolepiota procera	11.90 ± 0.20^{a}	33.00 ± 6.00^{b}	93.00 ± 3.00^{b}	7.50 ± 0.01^{ab}	0.82 ± 0.01^{b}	0.12 ± 0.01^{b}	6.57 ± 0.02^{bc}	6.00 ± 0.30^{a}	89.00 ± 8.00^{b}
Rhizopogon roseolus	3.20 ± 0.20^{d}	4.40 ± 3.10^{d}	45.00± 6.00^{c}	3.80 ± 0.10^{c}	nd	nd	2.10 ± 0.10^{d}	1.59 ± 0.04^{c}	118.00± 4.00^{a}
Suillus lakei	4.66 ± 0.04^{bc}	34.50 ± 0.50^{b}	39.00 ± 1.00^{c}	4.72 ± 0.02^{b}	nd	8.40 ± 0.10^{a}	5.00 ± 0.20^{cd}	1.17 ± 0.04^{c}	38.00± 3.00^{c}
Suillus luteus	3.33 ± 0.01^{d}	17.00 ± 1.00^{c}	nd	9.80 ± 0.10^{a}	0.14 ± 0.02^{b}	9.20 ± 0.40^{a}	3.80 ± 0.10^{d}	4.30 ± 0.10^{ab}	11.20 ± 0.10^{d}

properties are related to its osmotic diuretic properties. In mushroom metabolism, it supports and promotes the growth of fruiting bodies (Richards et al., 2002). Trehalose has an antioxidant capacity of unsaturated fatty acids, suppressing the detrimental effect and aging process (Reis et al., 2014). In addition, this disaccharide should not be responsible for digestibility problems (Richards et al., 2002), but its absorption in the human intestine requires prior hydrolysis by trehalase, a specific disaccharidase located in the brush border. Through, an enzymatic analysis of human intestinal biopsies, found that 2% of samples exhibit very low levels of trehalase, indicating a likely clinical intolerance to even small amounts of trehalose (Bergoz et al., 1982). This disease is little known and referred to as trehalose intolerance or mushroom intolerance.

Ergosterol content (Table 2) ranged from 11.20 mg/100 g dw in *S. luteus* to 118.20 mg/100 g dw in *R. roseolus.* Differences in ergosterol content among wild edible mushrooms from Patagonia have been previously reported and ranged from 0.40 mg/100 g dw in *C. hariotii* to 123.57 mg/100 g dw in *G. gargal* (Toledo et al., 2016; Rugolo et al., 2022). Regarding *A. campestris,* our study showed lower values (12.10 mg/100 g dw) compared with wild Greater Poland samples (42.40 mg/100 g dw) (Gąsecka et al., 2018). Ergosterol is a vital sterol found naturally in edible mushrooms, notable not only for its nutritional value but also for its wide-ranging pharmacological benefits. As a provitamin, ergosterol is the biochemical precursor to vitamin D_2, which is produced when mushrooms are exposed to ultraviolet (UV) light, positioning mushrooms as one of the few natural dietary sources of this essential vitamin. Vitamin D_2 plays a crucial role in human health, supporting bone metabolism, immune function, and overall well-being. Beyond its role in vitamin D synthesis, ergosterol itself exhibits significant bioactive properties, including antioxidant, antimicrobial, anticancer, antidiabetic, and neuroprotective effects (Rangsinth et al., 2023). The ergosterol profile, like other compounds, of mushrooms is directly influenced by factors such as species, developmental stage, tissue type, nutrient substrate, and microclimate (Jasinghe et al., 2005).

Table 3 displays the fatty acid composition of each species, including the values for total saturated fatty acids (SFAs), polyunsaturated fatty acids (PUFAs), and monounsaturated fatty acids (MUFAs). A total of 27 fatty acids were identified and quantified: (C8:0) caprylic acid; (C11:0) undecanoic acid; (C13:0) tridecanoic acid; (C14:0) myristic acid; (C15:0) pentadecanoic acid; (C16:0) palmitic acid; (C16:1) palmitoleic acid; (C17:0) heptadecanoic acid; (C18:0) stearic acid; (C18:1n9) oleic acid; (C18:2n6) linoleic acid; (C18:3n3) linolenic acid; (C20:0) arachidic acid; (C20:1) cis-11-eicosaenoic acid; (C20:2) cis-11,14-eicosadienoic acid; (C21:0) heneicosanoic acid; (C22:0) behenic acid; (C22:1) erucic acid; (C22:2) Cis-13,16-docosadienoic acid; (C23:0) tricosanoic acid; (C24:0) lignoceric acid; (C24:1) nervonic acid; (C22:6n3) docosahexaenoic acid. From them, linoleic, oleic and palmitic acids were the most abundant in the studied species, in agreement with previous reports (Ribeiro et al., 2007; Toledo et al., 2016; Rugolo et al., 2022). Because of the significant contribution of linoleic acid (C18:2), PUFAs were the predominant fatty acid group in *Leucocoprinus leucothites* (68.11%), *A. campestris* (66.10%), *S. lakei* (45.29%), *S. luteus* (44.80%), and *R. roseolus* (40.59%). Levels of MUFAs were important in *Lactarius deliciosus* (34.78%), *S. lakei* (43.97%), *S. luteus* (35.83%) and *R. roseolus* (32.44%) due to high amounts of oleic acid (C18:1) (as shown in Table 3). Samples from Portugal showed that oleic acid was the predominant fatty acid in *Suillus bellini*, *S. granulatus* and *S. luteus* (Ribeiro et al., 2009). Palmitic acid (C16:0) was predominant in *M. procera* (64.76%) resulting in most important SFAs. The amounts of linoleic acid (C18:2) (20.76%), oleic acid (C18:1) (34.78%), estearic acid (29.43%) and palmitic acid (C16:0) (9.67%) showed in *Lactarius deliciosus* are in concordance with those reported by Xu et al. (2019) for wild samples from China, 29.49%, 48.37%, 16.96% and 5.17%, respectively. Studies of the fatty acid profile of *S. granulatus* from Portugal and Serbia showed similarities to *Suillus* from Patagonia, showing higher levels of MUFAs and PUFAs compared to SFAs (Reis et al., 2014). For *Leucocoprinus leucothites,* the main fatty acids were palmitic (C16:0) (17.20%) and oleic (C18:1) (65.41%), in concordance with Pereira et al. (2012) (with values of 12.16% and 74.72%, respectively).

Table 3. Fatty acids composition (%) of the studied wild mushrooms on a dry weight basis (mean ± SD)

Fatty acid	*Agaricus campestris*	*Lactarius deliciosus*	*Leucocoprinus leucothites*	*Macrolepiota procera*	*Rhizopogon roseolus*	*Suillus lakei*	*Suillus luteus*
C8:0	nd	nd	nd	0.21 ± 0.003	nd	nd	nd
C11:0	nd	nd	nd	nd	0.21 ± 0.00	nd	nd
C13:0	0.34 ± 0.001[a]	nd	0.17 ± 0.01[a]	nd	nd	nd	nd
C14:0	nd	nd	0.23 ± 0.02[b]	0.94 ± 0.003[a]	nd	nd	nd
C15:0	nd	nd	0.35 ± 0.02[b]	0.81 ± 0.01[a]	0.25 ± 0.01[b]	nd	0.76 ± 0.02[a]
C16:0	16.06 ± 0.01[b]	9.70 ± 0.60[c]	17.20 ± 0.8[b]	64.76 ± 0.04[a]	9.91 ± 0.04[c]	8.00 ± 0.30[d]	11.70 ± 0.10[bc]
C16:1	nd	0.33 ± 0.02[c]	0.41 ± 0.02[c]	2.10 ± 0.10[ab]	4.32 ± 0.01[a]	nd	1.07 ± 0.02[b]
C17:0	1.31 ± 0.02[b]	0.32 ± 0.01[c]	nd	2.37 ± 0.002[a]	0.15 ± 0.01[c]	nd	nd
C18:0	4.52 ± 0.001[c]	29.00 ± 1.00[a]	2.10 ± 0.10[d]	5.24 ± 0.001[b]	6.90 ± 0.20[b]	2.70 ± 0.10[d]	2.94 ± 0.10[d]
C18:1n9t	7.56 ± 0.02	nd	nd	nd	nd	44.00 ± 0.20	nd
C18:1n9c	nd	34.80 ± 0.30[a]	9.60 ± 0.30[c]	16.13 ± 0.03[b]	32.40 ± 0.10[a]	nd	35.80 ± 0.20[a]
C18:2n6t	3.17 ± 0.02[a]	0.36 ± 0.01[b]	1.78 ± 0.02[a]	nd	nd	nd	nd
C18:2n6c	59.39 ± 0.01[a]	20.80 ± 0.20[c]	65.4 ± 1.00[a]	1.32 ± 0.01[d]	40.59 ± 0.01[b]	45.30 ± 0.50[b]	44.80 ± 0.30[b]
C18:3n3	0.60 ± 0.01[a]	0.33 ± 0.01[b]	0.38 ± 0.01[b]	nd	0.25 ± 0.01[b]	nd	0.24 ± 0.01[b]
C20:0	1.87 ± 0.02[a]	0.32 ± 0.01[c]	nd	1.00 ± 0.003[ab]	0.76 ± 0.01[b]	nd	0.24 ± 0.01[c]
C20:1	nd	0.35 ± 0.02[b]	0.18 ± 0.01[b]	1.52 ± 0.02[a]	1.36 ± 0.02[a]	nd	0.30 ± 0.02[b]
C20:2	1.90 ± 0.10[a]	0.65 ± 0.03[b]	0.98 ± 0.03[b]	nd	nd	nd	nd
C21:0	1.37 ± 0.04	nd	nd	nd	nd	nd	nd
C22:0	0.60 ± 0.03[a]	0.27 ± 0.01[c]	nd	0.54 ± 0.001[b]	0.68 ± 0.01[a]	nd	0.18 ± 0.01[c]
C22:1	nd	nd	nd	nd	0.21 ± 0.01[a]	nd	0.33 ± 0.02[a]
C22:2	nd	0.30 ± 0.01[a]	nd	0.47 ± 0.003[a]	nd	nd	nd
C23:0	nd	nd	0.39 ± 0.03[a]	nd	0.26 ± 0.01[a]	nd	0.14 ± 0.01[b]
C24:0	0.27 ± 0.01[bc]	0.41 ± 0.01[b]	0.80 ± 0.10[b]	2.00 ± 0.004[a]	0.38 ± 0.03[b]	nd	0.12 ± 0.01[c]
C24:1	nd	nd	nd	nd	0.91 ± 0.02[a]	nd	0.42 ± 0.01[a]
C22:6n3	0.23 ± 0.01[a]	0.12 ± 0.004[a]	nd	0.23 ± 0.01[a]	0.12 ± 0.01[a]	nd	nd
SFAs	26.34 ± 0.10[c]	40.42 ± 0.20[b]	21.25 ± 0.10[cd]	77.87 ± 0.01[a]	19.48 ± 0.20[d]	10.74 ± 0.10[f]	16.10 ± 0.05[e]
MUFAs	7.56 ± 0.01[c]	35.46 ± 0.20[b]	10.14 ± 0.01[c]	19.78 ± 0.01[a]	38.80 ± 0.01[ab]	43.97 ± 0.01[a]	37.95 ± 0.10[ab]
PUFAs	66.10 ± 0.01[a]	24.12 ± 0.01[d]	68.61 ± 0.10[a]	2.35 ± 0.10[e]	41.72 ± 0.20[c]	45.29 ± 0.01[b]	45.95 ± 0.05[b]

(C8:0) caprylicacid; (C11:0) undecanoicacid; (C13:0) tridecanoicacid; (C14:0) myristicacid; (C15:0)pentadecanoicacid; (C16:0) palmiticacid; (C16:1) palmitoleicacid; (C17:0) heptadecanoicacid; (C18:0)stearic acid; (C18:1n9) oleicacid; (C18:2n6) linoleicacid; (C18:3n3)-linolenicacid; (C20:0) arachidicacid; (C20:1) cis-11-eicosaenoicacid; (C20:2) cis-11,14-eicosadienoic acid; (C21:0) heneicosanoicacid; (C22:0) behenicacid; (C22:1) erucicacid; (C22:2) Cis-13,16-docosadienoicacid; (C23:0) tricosanoicacid; (C24:0) lignocericacid; (C24:1) nervonicacid; (C22:6n3) docosahexaenoicacid; (SFAs) saturatedfattyacids; (MUFAs) monounsaturatedfattyacids; (PUFAs) polyunsaturatedfattyacids. nd: no detected. For each mushroom sample, means within a column with different letters differ significantly ($p < 0.05$).

These results align with the literature, which identifies palmitic (C16:0), oleic (C18:1), linoleic (C18:2), stearic (C18:0), and linolenic (C18:3n3) acids as the primary fatty acids in wild mushrooms, with the latter two present in smaller percentages (Xu et al., 2019; Rugolo et al., 2022). Oleic acid (C18:1), a member of the omega-9 monounsaturated fatty acid family commonly found in vegetable oils, is well-known for its beneficial effects on human health, particularly in lowering cholesterol levels and preventing cardiovascular diseases. Among polyunsaturated fatty acids, omega-3 and omega-6 are mainly found in mammals. Their precursors, α-linolenic acid (ALA) and linoleic acid (LA), are classified as essential fatty acids, vital for normal bodily functions but unable to be internally synthesized. Within the omega-3 series, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are of utmost importance in the human diet, both difficult to synthesize internally yet serving crucial functions in the human body. DHA is a major structural component of the brain and retina. It is vital for neurodevelopment and cognitive function, particularly during fetal development and early childhood. It contributes to the integrity of neuronal membranes, influences neurotransmission, and supports synaptic plasticity, which are essential for learning and memory processes (Glick & Fischer, 2013). In the retina, it is involved in the regeneration of rhodopsin, a visual pigment necessary for low-light vision. EPA, on the other hand, is primarily involved in modulating inflammation. It serves as a precursor for eicosanoids, signaling molecules that play a role in inflammatory responses (Jesionowska et al., 2023).

Four phenolic acids were identified and quantified: p-coumaric, gallic, p-hydroxybenzoic, and protocatechuic (Table 4). Gallic acid was present in all species except *R. roseolus*, with values between 1.77 for *Leucocoprinus leucothites* and 5.19 mg/g dw for *M. procera*. The p-hydroxybenzoic acid was present in *A. campestris* (highest value 3.83 mg/g dw), *Lactarius deliciosus*, *S. lakei*, and *S. luteus,* and protocatechuic acid in *A. campetris* and both *Suillus* species, with the highest amount in *S. lakei* (4.40 mg/g dw). In addition, p-coumaric acid was registered only in *A. campestris*, the only species that presented the four acids and yielded the highest amount of phenols (10.69 mg/g dw). In this regard, values for Patagonian *A. campestris* samples align with those reported by Barros et al. (2008b), who reported values ranging from 2.72 mg/g dw for *Agaricus arvensis* to 8.95 mg/g dw for *A. silvaticus*. No phenolic compounds were detected in *R. roseolus*.

Due to their high total phenol content, *A. campestris* and *S. lakei* displayed the strongest antioxidant activity (Table 4). The relationship between antioxidant activity and the content of phenolic compounds in mushrooms has been previously established (Barros et al., 2007; Rugolo et al., 2022; González et al., 2023). TBARS and OxHLIA values for *A. campestris* (468.00 µg/mL and 19.30 µg/mL, respectively) and for *S. lakei* (590.00 µg/mL and 61.00 µg/mL, respectively) were lower compared with the rest of the species. The strong antioxidant activity of *Suillus* is consistent with existing literature; for instance, *S. variegatus* demonstrated DPPH scavenging activity, reducing power, and β-carotene bleaching inhibition assays with IC50 values less than 1 mg/ml, as reported by Pereira et al. (2012). *Lactarius deliciosus, Leucocoprinus leucothites*, and *M. procera* presented the lowest antioxidant activity for TBARS, and no activity was detected for OxHLIA assay. The antioxidant activity by DPPH, ABTS, and FRAP was also evaluated by applying different solvents for extracting *Lactarius deliciosus* samples (Xu et al., 2019), resulting in greater activity when the phenol content is increased in ethanolic extracts. Other studies have shown that *R. roseolus* mycelium exhibited high values of scavenging DPPH and ABTS activity among 21 species (Kalyoncu et al., 2010). Another study conducted with *Agaricus* samples from Portugal showed the antioxidant capacity using the TBARS technique (Barros et al., 2008b), with better results in chemical assays than in the biochemical assay using animal cells. This is the first study on inhibiting lipid peroxidation using thiobarbituric acid reactive substances and on the anti-hemolytic capacity of the WEM species analyzed in this study.

All extracts were evaluated for efficacy against ten bacteria and fungi known to contaminate food (see Table 5). Each mushroom species exhibited varying degrees of antimicrobial activity against the microorganisms tested. The antibacterial effects were particularly pronounced against *Yersinia enterocolitica* (Gram-negative bacteria), as well as *Staphylococcus aureus* (a Gram-positive bacterium). Meanwhile, the antifungal activity was most effective against *Aspergillus brasiliensis*. Better extracts regarding antibacterial activity were those produced by *M. procera* and *A. campestris.* The Gram-negative bacteria *Enterobacter cloacae*, *Escherichia coli*, and *Pseudomonas aeruginosa*, and the Gram-positive *Listeria monocytogenes*, showed lower sensitivity to the extracts. None of the extracts exhibited bactericidal activity. Fungicidal activity was detected only against *A. fumigatus*. Other research on the genus *Lactarius* from Serbia demonstrated the best antibacterial and antioxidant properties of *L. sanguifluus* extract, in comparison with *L. deliciosus, L. volemus, L. semisanguifluus*, and *L. piperatus* (Stanković et al., 2022). Additionally, extracts of *L. deliciosus* and *M. procera* from Serbia exhibited

Table 4. Phenol content (mg/g of extract) and Antioxidant activity of the mushroom extracts measured by inhibition of lipid peroxidation (TBARS) and the oxidative haemolysis inhibition assay (OxHLIA). IC50 values were expressed in µg/mL. na: no activity (Δt values less than 60 min were obtained). nd: no detected. For each mushroom sample, means within a column with different letters differ significantly ($p < 0.05$).

Species	***p*-Coumaric acid** (mg/g E)	**Gallic acid** (mg/g E)	***p*-hidroxibenzoic acid** (mg/g E)	**Protocatechuic acid** (mg/g E)	**Sum of Phenolics** (mg/g E)	**TBARS IC_{50}** (µg/mL)	**OxHLIA IC_{50}** (µg/mL)
Agaricus campestris	2.00± 0.10[a]	2.80 ± 0.10[b]	3.80 ± 0.10[a]	2.10 ± 0.10[b]	10.60 ± 0.40[a]	468.00 ± 17.00[b]	19.30 ± 0.90[a]
Lactarius deliciosus	nd	2.36 ± 0.01[bcd]	0.84 ± 0.01[c]	nd	3.20 ± 0.02[cd]	1750.00 ± 10.00[d]	na
Leucocoprinus leucothites	nd	1.77 ± 0.01[d]	nd	nd	1.77 ± 0.01[d]	799.00 ± 20.00[c]	na
Macrolepiota procera	nd	5.20 ± 0.10[a]	nd	nd	5.20 ± 0.10[b]	700.00 ± 200.00[c]	na
Rhizopogon roseolus	nd	nd	nd	nd	-	610.00 ± 10.00[b]	141.00 ± 3.00[c]
Suillus lakei	nd	2.68 ± 0.02[bc]	1.69 ± 0.02 [b]	4.40 ± 0.10[a]	8.80 ± 0.10[a]	590.00 ± 90.00[b]	61.00 ± 3.00[b]
Suillus luteus	nd	2.00 ± 0.10 [cd]	1.14 ± 0.01[bc]	0.89 ± 0.01[c]	4.00 ± 0.10[bc]	700.00 ± 100.00[c]	219.00 ± 14.00[d]
Trolox						18.40 ± 0.10[a]	21.80 ± 0.30[a]

Table 5. Antimicrobial activity of all the extracts against selected food-contaminating bacteria and fungi. The maximum concentration used was 10 mg/mL. MIC: Minimum inhibitory concentration; MBC: Minimum bactericidal concentration; MFC: Minimum fungicidal concentration; n.t. not tested. AC *Agaricus campestris*; LD *Lactarius deliciosus*; LL *Leucocoprinus leucothites*; MP *Macrolepiota procer*a; SLA *Suillus lakei*; SLU *Suillus luteus*; RR *Rhizopogon roseolus*

																	Positive Control			
	AC		**LD**		**LL**		**MP**		**SLA**		**SLU**		**RR**		**Streptomicin 1mg/mL**		**Methicilin 1mg/mL**		**Ampicillin 20mg/mL**	
ANTIBACTERIAL ACTIVITY	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC
Gram-negative bacteria																				
Enterobacter cloacae	>10	>10	10	>10	>10	>10	10	>10	10	>10	>10	>10	10	>10	0.007	0.007	n.t.	n.t.	0.15	0.15
Escherichia coli	10	>10	>10	>10	10	>10	10	>10	>10	>10	>10	>10	10	>10	0.01	0.01	n.t.	n.t.	0.15	0.15
Pseudomonas aeruginosa	>10	>10	>10	>10	>10	>10	>10	>10	>10	>10	>10	>10	>10	>10	0.06	0.06	n.t.	n.t.	0.63	0.63
Salmonella enterocolitica	5	>10	10	>10	5	>10	5	>10	10	>10	10	>10	10	>10	0.007	0.007	n.t.	n.t.	0.15	0.15
Yersinia enterocolitica	10	>10	2.5	>10	2.5	>10	1.25	>10	5	>10	1.25	>10	2.5	>10	0.007	0.007	n.t.	n.t.	0.15	0.15
Gram-positive bacteria																				
Bacillus cereus	5	>10	2.5	>10	10	>10	5	>10	5	>10	10	>10	>10	>10	0.007	0.007	n.t.	n.t.	n.t.	n.t.
Listeria monocytogenes	10	>10	10	>10	>10	>10	>10	>10	>10	>10	10	>10	>10	>10	0.007	0.007	n.t.	n.t.	0.15	0.15
Staphylococcus aureus	2.5	>10	1.25	>10	2.5	>10	0.6	>10	2.5	>10	2.5	>10	>10	>10	0.007	0.007	0.007	0.007	0.15	0.15
																	Ketaconazole 1mg/mL			
ANTIFUNGAL ACTIVITY	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC			MIC	MFC		
Aspergillus brasiliensis	1.25	>10	2.5	>10	10	>10	5	>10	2.5	>10	10	>10	10	>10			0.06	0.125		
Aspergillus fumigatus	0.07	0.15	>10	>10	0.07	0.15	0.07	0.15	0.07	0.15	0.07	0.15	0.07	0.15			0.5	1		

similar MIC values against *B. cereus*, the most sensitive bacterium, and *E. coli*, the most resistant (Kosanić et al., 2016) compared with our assays. Furthermore, Solak et al. (2006) demonstrated the limited antibacterial potential of *Rhizopogon roseolus* from Turkey, which aligns with our findings. Similarly, Volcão et al. (2021) reported the antimicrobial effect of *Suillus* species, highlighting the potential of *Suillus granulatus* extracts from Brazil for controlling *Pseudomonas* phytopathogens.

Our study focuses on WEM of high regional importance, which, despite their wide dispersion, linked to afforestation or to their cosmopolitan distributions, have not been fully evaluated in other parts of the world. We report for the first time the nutritional and bioactive profile of *Suillus lakei*, an ectomycorrhizal fungus exclusive to *Pseudotsuga menziesii* (Barroetaveña et al., 2007); it fruits in autumn, coinciding with S. luteus, and represents an important non-timber forest products (NTFPs) harvested by Patagonian rural families in other major forest plantation environments of the region (Barroetaveña et al., 2007). Regarding *Rhizopogon roseolus*, is an ectomycorrhizal fungus associated with various *Pinus* spp. afforestations (Barroetaveña et al., 2007; Pildain et al., 2019) that have gained attention from foragers and chefs recently. This study further advances the nutritional and bioactive profiling of these species, which to date has been limited and largely incidental. Notably, *R. luteolus* remains the most extensively studied species within this group (Altaf et al., 2020). In the case of wild button mushrooms (*Agaricus spp*), well-known and harvested worldwide, they had not been fully characterized regarding their antioxidant and antimicrobial profiles. The antioxidant capacity of all the studied WEM species had been so far demonstrated, although only through colorimetric assays like DPPH or ABTS (Kosanić et al., 2016; Xu et al., 2019); this is the first report assessing their activity on cells (TBARS and OxHLIA), excepting *A. campestris* (Barros et al., 2008b).

4. CONCLUSIONS

This study indicated that wild edible mushroom from exotic plantations and landgrasses from Patagonia contain high nutritional values: good inputs of protein, sugars and polyunsatured fatty acids and low crude fat and calories, along with other bioactive compounds such as organic acids or phenols. Moreover, some species, such as *A. campestris* and *S. lakei*, have the potential to be marketed as natural antioxidants and promoted as bioactive food. *Macrolepiota. procera* and *A. campestris* showed the best antimicrobial activity against selected food-contaminating bacteria and fungi; this information showed the potential of fungal extracts to prevent food-contaminating microorganisms.

Additionally, *Lactarius deliciosus* and *R. roseolus* offer an opportunity to diversify mushroom sales in local markets, complementing the established commercialization of *Suillus luteus*. As these three species share the same habitats and mycorrhize with pines, this approach enhances the use of non-timber forest resources, which are rich in nutritional value and have significant potential for incorporation into gastronomic practices. *Leucocoprinus leucothites* and *M. procera* broaden the range of WEM available in rural zones. *Leucocoprinus leucothites* could be better valued as a food, high in polyunsaturated fatty acids, with significant amounts of linoleic acid. The data provided by this study, along with our previous ones for native forests, allowed the inclusion of new species of wild edible fungi in the Argentine food code. Knowing the nutritional and nutraceutical profile of edible species available in the region, enable to maximize their promotion as high value products within the regional economy of Patagonia. Ensuring the proper management of these non-timber forest products, promoting mycoforestry as an option for multiple use of plantations, will allow to enhance activities such as mycotourism, mycogastronomy and mycotherapy out of these environments.

Supplementary information ↑

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Supplementary material

Not applicable.

Data availability

All data generated or analyzed during this study are included in this article.

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Authorship contribution statement

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Competing interests

Not applicable.

Statement on the use of Artificial Intelligence

Not applicable.

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