 Chilean J. Agric. Anim. Sci., (2023) 39(3):276-287.
https://doi.org/10.29393/CHJAA39-24PDYG50024

ISSN 0719-3890 online

PRE-TREATMENTS AND DRYING METHODS ON THE PHYSICOCHEMICAL AND SENSORY CHARACTERISTICS OF WILD MUSHROOMS (*Suillus luteus)* FROM APURIMAC-PERU

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ABSTRACT

The objective of this research was to evaluate the effect of pre-treatments and drying methods on the physicochemical and sensory characteristics of edible wild mushrooms, *Suillus luteus*, collected in the pine forests of the Apurímac region, Peru. Two immersion pre-treatments were used: 5% lemon juice and 6% vinegar. Mushroom caps were cut into 3-cm thick slices, immersed at a ratio of 1:5 (w/v), and subsequently dried by direct solar drying and indirect solar drying using a *fitotoldo* (shade cover). The proximate composition, rehydration, color, total polyphenol content (TPC), antioxidant capacity (DPPH capacity), and sensory evaluation were determined for each sample. The results showed significant differences ($p<0.05$) between the treatments. Higher rehydration rates were observed in the samples subjected to direct solar drying and *fitotoldo* drying without pre-treatment, as well as those treated with vinegar. Regarding color, luminosity (L*) significantly decreased in the dried samples compared to the fresh sample. In the proximate analysis, the untreated samples had protein, crude fiber, and ash contents of 23.67 g/100 g, 11.10 g/100 g, and 5.59 g/100 g, respectively. Free-nitrogen extract (FNE) content increased to 47.13 g/100 g as mushrooms lost water. TPC and antioxidant capacity decreased significantly in the dried samples, but the pre-treated samples with vinegar recorded higher values of 8.38 mg GAE/g and 54.13 µmol TE/g, respectively. In the sensory evaluation, the samples pre-treated with vinegar had higher color, texture, and acceptability scores. Thus, the use of a *fitotoldo* without pre-treatment and with vinegar pre-treatment is the most efficient method for drying *Suillus luteus* mushrooms.

Keywords: *Suillus luteus*, natural pre-treatment, solar drying, fitotoldo drying.

Received: August 8, 2023 Accepted: November 19, 2023

INTRODUCTION

Suillus luteus is a common mycorrhizal fungus in coniferous forests. The species is commonly known as pine mushrooms because they are found in areas covered with pine trees (Aytar et al., 2020). The collection of wild mushrooms generally occurs during the rainy season, and they are collected in large quantities by residents living near these areas (Alvarado-Castillo et al., 2013; Lara-Vázquez et al., 2013). The collection and commercialization of these mushrooms could improve the quality of life of vulnerable communities in developing countries (Alvarado-Castillo et al., 2013), providing nutritious food that can be incorporated into various dishes to enhance their nutritional value and generate income as an alternative economic activity (Maray et al., 2017; Ramírez-Ortega and Thomé-Ortiz, 2019).

Edible wild mushrooms are highly appreciated in the human diet for their delicious taste, non-starchy carbohydrates, dietary fiber, minerals, vitamin B, low-fat content, high protein content (Liu et al., 2016; Rugolo et al., 2022), antioxidants, and phenolic compounds (Aytar et al., 2020; Bashir et al., 2020; Jacinto-Azevedo et al., 2021). Due to their high water content (87 to 95%) and mineral content, they are highly perishable products that start to deteriorate immediately after harvesting (Maray et al., 2017), which represents a drawback for their commercialization.

One way to preserve mushrooms is through drying, a widely used method to prevent different types of deterioration (Yang et al., 2020) and extend shelf life, with the advantage of reducing mass and volume, leading to cost savings in packaging, handling, storage, and transportation (Xue et al., 2016, Liu et al.,2018; Yang et al., 2020). There are several types of mushroom drying methods (Tian et al., 2016; Fernandes et al., 2013), including sun drying, cabinet air drying, fluidized bed drying, and atmospheric drying using different temperatures.

Mushrooms are most commonly sun dried at ambient temperatures of 25 to 30 °C (Mutukwa et al., 2019), particularly in tropical and subtropical regions. Rural inhabitants can use solar drying without sophisticated equipment if the climate is warm, relatively dry, and with little rainfall (Ibrahim et al., 2017). Moreover, low heat is beneficial for thermolabile foods since their quality attributes may be affected (Reyes et al., 2014). The drying methods most commonly used by rural communities for mushroom utilization include direct and indirect solar drying. Direct sun drying has the advantage of being efficient and cost-effective but is susceptible to rain or possible contaminations (Reyes et al., 2014). At present, indirect sun drying using a *fitotoldo* (shade cover) is widely used in rural areas because it has moderate investment costs and better results. Dried mushrooms are gaining economic importance for rural communities (Alvarado-Castillo et al., 2013) due to the extensive areas of pine forests with wild mushroom production in various regions, including Peru.

Drying is an adequate preservation method but has some limitations (Xue et al., 2016), such as shrinkage, lipid oxidation, vitamin loss, and enzymatic and non-enzymatic browning reactions. These factors lead to a dark brown color (Yang et al., 2020), resulting in quality and acceptability losses. Color is a crucial quality parameter for consumers, and the similarity between the final dried product and the fresh product can help maintain its price during commercialization (Izli and Isik, 2014; Altikat et al., 2022).

Pre-treatments applied before drying can reduce undesirable changes in color, texture, and flavor (Argyropoulos et al., 2011; Doymaz, 2014; Maray et al., 2017). They also decrease the drying time by relaxing tissue and structure, contributing to good product quality (Doymaz, 2014). Color and texture, as quality criteria for the product, are important for consumers and are affected by pre-treatments (Yang et al., 2020). Natural products like lemon juice and vinegar are easily adaptable at the household level, even in low-resource communities, and can be used as pre-treatments in mushroom drying (Mutukwa et al., 2019).

Considering the rural reality of the Apurimac region, the utilization of natural resources is proposed to generate local economic benefits, specifically the production of edible wild mushrooms, *Suillus luteus*, by prolonging their shelf life by direct solar drying and indirect solar drying using a *fitotoldo*. The aim is to prevent enzymatic and non-enzymatic browning with natural pre-treatments (lemon juice and vinegar). Therefore, the objective of this study was to evaluate the effect of pre-treatments and drying methods on the physicochemical and sensory characteristics of edible wild mushrooms *Suillus luteus* from the Apurímac region, Peru. The results will be applicable to mushroom producers and collectors in this region and throughout the country.

MATERIALS AND METHODS

Sampling

Edible wild mushrooms *Suillus luteus* (Fig. 1) were used for the study. The samples weighed approximately 30 kg and were collected from *Pinus radiata* pine forests in the Pataypampa

Fig. 1. Edible wild mushroom *Suillus luteus*.

district (Micaela Bastidas), Grau province, Apurímac region, Peru, at 3,777 meters above sea level. Mushrooms with a cap diameter between 5 and 15 cm were selected.

Physicochemical and sensory analyses were carried out in the laboratories of Agroindustrial Product Processing, General Chemistry, and Sensory Evaluation of the Academic Professional School of Agroindustrial Engineering of the Universidad Nacional Micaela Bastidas de Apurímac, Peru. Drying was conducted in the Tamburco district, Abancay, Apurímac, Coordinates: Latitude: -13.6219, Longitude: -72.8731 13°37'19" South, 72°52'23" West at 2,581 meters above sea level in February 2021, with ambient temperatures between 14 and17 °C and humidity of 71-72%.

Reagents

The reagents 1,1-Diphenyl-2-picrylhydrazyl (DPPH), Folin-Ciocalteu (FCR), gallic acid (3,4,5-trihydroxybenzoic acid), sodium carbonate (Na_2CO_3), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), and 80% methanol were acquired from Merck (Merck Peruana S.A.). Commercial vinegar of the Buenaventura brand and lemons were obtained from a supermarket in Abancay.

Sample pre-treatment

After harvesting, the mushrooms were classified according to cap diameter. The cap was peeled and then cut into portions of 3 cm in diameter. They were divided into six parts to undergo pre-treatments with 5% lemon juice and 6% vinegar solutions (Table 1). The samples were immersed in the solutions for 1 min at a ratio of 5:1 (solution/mushroom), following the method described by Hassan and Medany (2014) and Mutukwa et al. (2019) with some modifications.

Drying process

Two drying methods were used: direct sun drying and indirect sun drying using a *fitotoldo* (Fig. 2). The greenhouse-type structure was 5.2 m width x 10 m length x 2.10 height, covered on all four sides with Rashell mesh and with a roof made of white-colored agrofilm C-10 plastic (60% shading). Two pallets, one of 1.6 m width x10 m length and the other of 1 m width x10 m length, were placed 1 m high from the floor and covered with a stretched nylon #18 mesh based on an Andean initiative, with a production capacity of 50 kg for six days.

Samples were dried at an ambient temperature between 14 and 17 °C and a humidity of 71-72% until a constant weight was achieved, with an average 90% decrease in moisture completed within six days.

Rehydration capacity

The method 88-04 of the American Association of Cereal Chemists (AACC, 1990) was used for evaluating the rehydration capacity. The dried samples with defined weight were immersed in a glass containing 80 mL of distilled water at room temperature for 220 min. Subsequently, the samples were removed, dried with absorbent paper, and weighed. Weight was determined every 20 min until a constant weight was

Table 1. Pre-treatments of *Suillus luteus* mushrooms prior to the two drying methods.

Code	Drying Method	Pre-treatment
SDN	Direct sun drying	No pre-treament
SDL	Direct sun drying	5% lemon juice
SDV	Direct sun drying	6% vinegar
FDN	Fitotoldo drying	No pre-treament
FDL	Fitotoldo drying	5% lemon juice
FDV	Fitotoldo drying	6% vinegar

Fig. 2. Indirect solar dryer (*fitotoldo* or greenhouse shade cover).

obtained with a sample/water ratio of 1:15. The rehydration capacity in mushrooms is the absorbed water weight (g) over the dried sample weight (g), expressed as g H_2O/g dry weight (DW) or g H_2O/g DW.

Instrumental color measurement

The samples were evaluated using a PCE CSM7 colorimeter (Instruments, Deutschland GmbH), measuring three values (L*, a*, b*) to locate the color within a visible three-dimensional space. According to the manual, the equipment was calibrated with standard white and black plates under D65 illumination. Readings were taken by placing the colorimeter head on the sample. Luminosity (L*) ranged from white (0) to black (100); a* is the intensity of the color from green (-) to red (+); and b* is the intensity of the color from blue (-) to yellow (+). Chroma (C*) indicates the color saturation in the samples and was determined using the equation C* = (a^2 + b^2)^0.5 (Mathias-Rettig and Ah-Hen, 2014).

Proximate analysis

The proximate analysis was performed using the methodology described by the Association of Official Analytical Chemists (AOAC) in the Nutritional Evaluation of Foods Laboratory (LNEF) at the Agrarian University La Molina, Lima, Peru. The AOAC method (2005) was used

for the following determinations: moisture content, 950.46; total protein, 984.13; fat, 2003.05; crude fiber, 962.09; and ash, 942.05. Nitrogen-free extract (NFE) was obtained by the difference of 100%.

Total phenolic compounds

Total polyphenol content (TPC) was determined using the spectrophotometric methodology of Singleton et al. (1999) with modifications, with Folin-Ciocalteu reagent and gallic acid as the standard. In test tubes, 0.125 mL of the extract was prepared, and 125 µL of 1N Folin-Ciocalteu reagent was added. The mixture was shaken and left to rest for 10 min, followed by the addition of 3.5 mL of ultra-pure water and 2.5 mL of 7.5% sodium carbonate. The solution was left to rest for 60 min in the dark, and then the absorbance was measured at 750 nm using a UV-Visible spectrophotometer (Genesis 20 Thermo Electron). TPC was determined according to the gallic acid equation, and the results were expressed as mg equivalents of gallic acid (GAE) per gram on dry basis (mg GAE/g). Prior to this, the extracts were prepared with 0.05 g of fresh and dried ground samples passed through an 80 µ sieve. The samples were diluted with 10 mL of 80% (v/v) methanol and left to macerate for 24 h with agitation. The mixture was centrifuged at 4000 RPM for 15 min at 10 °C. The clarified extract was collected and refrigerated for later use in phenolic compounds and antioxidant activity assays.

Antioxidant capacity using DPPH

The free radical scavenging activity was determined through the DPPH (2,2-Diphenyl-1-picrylhydrazyl) assay with the methodology of Bondet et al. (1997) with Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) as the standard. 180 µL of the crude extract was placed in test tubes, and 2.82 mL of DPPH solution was added. The mixture was left to rest for 15 min, and the absorbance was measured at 517 nm, with 80% methanol used as a blank, using a UV-Visible spectrophotometer (Genesis 20 Thermo Electron). The inhibition of DPPH radical by the sample was calculated as follows: % Inhibition = (1 - Abs Sample / Abs DPPH) x 100. The percentage of inhibition provided by the extract was calculated based on the inhibition (%) and extract concentration graph. The results were expressed as µmol Trolox equivalents (TE) per gram on dry basis.

Sensory characteristics

The color, texture, and acceptability of the dehydrated samples were evaluated by 18 panelists using a linear sensory evaluation scale (1-13) for color and texture: dark brown (1) to light yellow (13) for color and soft (1) to hard (13) for texture. Acceptability was evaluated using a hedonic scale from 1 to 9, from dislike extremely to like extremely (Lawless and Heymann, 2010).

Statistical Analysis

A one-way analysis of variance (ANOVA) was performed under a completely randomized design using R statistical software version 4.1.3. The independent variable was the cap, the treatments of lemon juice and vinegar, and direct and indirect drying methods. The untreated cap served as the control. The response variables were rehydration capacity, color, moisture, protein, crude fiber, ash, fat, TPC, antioxidant capacity, texture, and acceptability. The experimental results were expressed as mean ± standard deviation (SD) of three parallel measurements. The Tukey test was used when values ($p<0.05$) were considered significant.

RESULTS AND DISCUSION

Rehydration capacity

The initial moisture was 92.25 g/100 g and this was reduced up to nine times (Table 2) after being dried for six days with an exposure of eight hours per day. Regarding rehydration, significant differences were observed ($p<0.05$) between the dehydrated samples with and without pre-treatment. The highest rehydration was found in the untreated samples and those pre-treated with vinegar, recording 4.75 and 3.55 g H_2O/g DW, respectively. The samples with the lowest rehydration were those pre-treated with lemon, recording values of 2.84 and 2.14 g H_2O/g DW using direct sun drying and *fitotoldo* drying, respectively.

The rehydration capacity of the dried product is a critical parameter that indicates the extent of material damage (Nour et al., 2011). Fig. 3 shows the rehydration curves of dehydrated *Suillus luteus* mushrooms with and without pre-treatment, observing higher rehydration within the first 80 min. The rehydration time was between 140 and 160 min.

The results of rehydration capacity are similar to those reported by Nour et al. (2011) in edible mushrooms pre-treated with citric and ascorbic acid, observing a rehydration range of 2.46-2.34 g H_2O/g DW. Argyropoulos et al. (2011) found a rehydration range of 3.17-7.87 g H_2O/g DW. in mushrooms pre-treated with 1% citric acid for 5 minutes. Several authors have also stated that higher rehydration indicates better quality of dried products (Nour et al., 2011; Kamal et al., 2015; Hassan and Medany, 2014).

Table 2. Rehydration of wild *Suillus luteus* mushrooms under different pre-treatments and two drying methods.

Rehydration time, min	SDN g H_2O/g DW	SDL g H_2O/g DW	SDV g H_2O/g DW	FDN g H_2O/g DW	FDL g H_2O/g DW	FDV g H_2O/g DW
0	0	0	0	0	0	0
20	2.12±0.20b	1.47±0.04a	2.14±0.05b	1.94±0.02b	1.50±0.13a	1.40±0.11a
40	2.93±0.27b	1.76±0.09a	2.89±0.24b	2.62±0.27b	1.71±0.15a	1.69±0.15a
60	3.65±0.45b	1.98±0.14a	3.18±0.30b	2.94±0.31b	1.95±0.30a	1.82±0.19a
80	4.23±0.49c	2.22±0.21ab	3.52±0.60c	3.21±0.53ab	2.06±0.27a	2.04±0.27a
100	4.45±0.64c	2.38±0.30ab	3.90±0.94bc	3.39±0.63ac	2.07±0.29a	2.28±0.30a
120	4.65±0.57c	2.89±0.76ab	3.89±0.76bc	3.50±0.68ac	2.12±0.29a	2.59±0.40ab
140	4.75±0.55c	2.60±0.42ab	3.97±0.76bc	3.56±0.71ac	2.14±0.31a	2.70±0.38ab
160	4.75±0.56c	2.51±0.50ab	3.99±0.86bc	3.53±0.75ac	2.14±0.31a	2.78±0.39ab
180	4.75±0.56c	2.85±0.41ab	3.99±0.89bc	3.53±0.75ac	2.14±0.31a	3.00±0.50ab
200	4.75±0.56c	2.84±0.39ab	3.99±0.89bc	3.53±0.75ac	2.14±0.31a	3.36±0.63ac
220	4.75±0.56c	2.84±0.39ab	3.99±0.89bc	3.53±0.75ac	2.14±0.31a	3.35±0.63ac

Mean ± SD (*n*=3). SDN: Direct sun drying without pre-treatment; SDL: Direct sun drying with 5% lemon juice; SDV: Direct sun drying with 6% vinegar; FDN: *Fitotoldo* drying without pre-treatment; FDL: *Fitotoldo* drying with 5% lemon juice; FDV: *Fitotoldo* drying with 6% vinegar. Different letters are statistically significant P≤ 0.05.

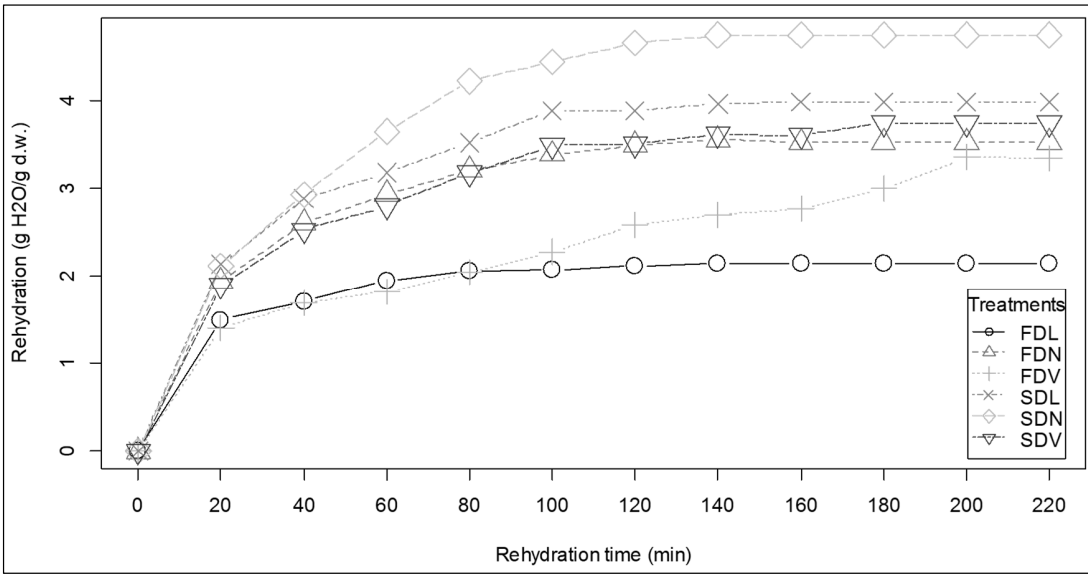

Fig. 3. Rehydration in *Suillus luteus* at room temperature for 220 min.

Drying temperature, blanching, and sample pre-treatment also influence rehydration (Nour et al., 2011; Hassan and Medany, 2014; Yang et al., 2020). Thus, mushrooms dried at lower temperatures experience less cell destruction, and consequently show higher rehydration than those dried at higher temperatures (Nour et al., 2011). A study by Hassan and Medany (2014) on *Pleurotus ostreatus* pre-treated with citric acid, NaCl, and sodium metabisulfite and dried at 70 °C, 60 °C, and 50 °C showed that samples dried at lower temperatures had better rehydration, with values of 4.36 - 4.80 g H_2O/g DW; 4.83 - 5.02 g H_2O/g DW; and 5.31 - 5.57 g H_2O/g DW, respectively. Doymaz et al. (2014) conducted a study on *Agaricus bisporus* pre-treated with citric acid and dried at 25 °C and 50 °C, and found that samples dried at lower temperatures recorded better rehydration values, which agrees with the findings of the present study conducted at room temperature. This suggests that not only temperature but also pre-treatment plays

an important role in mushroom drying. The rehydration curves also agree with Argyropoulos et al. (2011) in mushrooms.

Instrumental color

The results of color for fresh, dehydrated, and pre-treated samples (Table 3) show significant differences ($p<0.05$). Regarding luminosity (L*), the fresh sample had a value of 32.91, while the dehydrated samples presented values ranging from 4.16 to 8.01, indicating that the fresh sample has less darkening than those dehydrated. Regarding a*, the fresh samples had values of 20.07 with a tendency to light red color, while the dehydrated samples showed a more intense red color (49.22-55.67). As for b*, the fresh sample had a more intense yellow hue (40.61) compared to the dehydrated samples (21.68-25.68). The instrumental color indicates that there was enzymatic and non-enzymatic browning involving carbonyl and amino groups, responsible for brown pigments called melanoidins (Kurozawa et al., 2011). All of these parameters indicate that pre-treatments did not prevent oxidation; extended drying time (around six days), and high humidity associated with low temperature (room temperature) may cause browning, leading to a decrease in L* (Davidek and Davidek, 2004).

Chroma (C*) increased in the pre-treated and dried samples, especially under *fitotoldo* drying. This parameter is closely related to luminosity (L*) since when chroma C* decreases, color saturation increases (Table 3). Regarding chroma C*, Kurozawa et al. (2011) mentioned that water loss leads to concentration, intensification, and saturation.

Proximate analysis

The proximate composition of the samples showed significant differences ($p<0.05$) in the components of all the treatments compared to the fresh sample (Table 4). The untreated samples lost more moisture during dehydration

Table 3. Quantification of instrumental color.

Samples	L*	a*	b*	C*
Fresh	32.91±1.07c	20.07±0.45a	40.61±0.89d	45.30±1.23a
SDN	5.55±0.50a	53.37±0.42bd	21.68±0.92a	57.62±0.40bc
SDL	5.43±0.74a	53.58±0.49cd	22.07±1.43ab	57.96±0.99bc
SDV	6.11±0.73ab	49.22±2.67b	20.65±1.68a	53.38±2.99b
FDN	8.01±0.42b	51.54±1.62bc	21.70±1.70a	55.94±1.52b
FDL	5.32±1.19a	56.18±1.58d	25.68±0.29c	61.78±1.50c
FDV	4.16±0.71a	55.67±1.86cd	25.41±1.26bc	61.19±2.21c

Mean ± SD ($n=3$). SDN: Direct sun drying without pre-treatment; SDL: Direct sun drying with 5% lemon juice; SDV: Direct sun drying with 6% vinegar; FDN: *Fitotoldo* drying without pre-treatment; FDL: *Fitotoldo* drying with 5% lemon juice; FDV: *Fitotoldo* drying with 6% vinegar. L*: luminosity range from white (0) to black (100); a*: intensity of green color (-) to red color (+); b*: intensity of blue color (-) to yellow color (+); C*: chroma or hue of an object. Superscripts with different letters in columns are significantly different $P\leq 0.05$.

Table 4. Proximate analysis of fresh *Suillus luteus* under different pre-treatments and two drying methods (g/100 g).

Treatments	Moisture	Protein	Crude fiber	Ash	Fat	NFE
Fresh	92.25±0.02f	30.71±0.13g	09.94±0.39f	06.93±0.08c	11.31±0.19e	41.25±0.18a
SDN	08.12±0.13b	23.13±0.01e	11.10±0.20g	05.51±0.03b	05.55±0.07b	46.60±0.28b
SDL	09.42±0.21cd	18.18±0.02a	05.62±0.08b	04.39±0.07a	04.90±0.06a	57.51±0.29d
SDV	09.19±0.07c	21.43±0.16c	08.23±0.23d	04.55±0.15a	05.90±0.28b	50.70±0.29c
FDN	07.75±0.01a	23.67±0.01f	09.10±0.29e	05.59±0.06b	06.80±1.16c	47.13±0.18b
FDL	10.03±0.08e	18.52±0.01b	04.53±0.06a	04.48±0.09a	04.82±0.11a	57.57±0.06d
FDV	09.56±0.01d	21.86±0.09d	06.25±0.04c	04.39±0.03a	07.30±0.17d	50.64±0.01c

Mean ± SD ($n=3$). SDN: Direct sun drying without pre-treatment; SDL: Direct sun drying with 5% lemon juice; SDV: Direct sun drying with 6% vinegar; FDN: *Fitotoldo* drying without pre-treatment; FDL: *Fitotoldo* drying with 5% lemon juice; FDV: *Fitotoldo* drying with 6% vinegar. Superscripts with different letters in columns are significantly different $P\leq 0.05$.

but had higher contents of protein, ash, and fat. Conversely, lower values were observed in the pre-treated samples, except for the samples pre-treated with vinegar and *fitotoldo* drying, which retained more fat (7.3 g/100 g). As for crude fiber, the samples with 5% lemon juice dried under direct sun showed higher fat, indicating that lemon juice may have contributed with fiber to the mushroom tissue. FNE increased as the mushrooms lost water, concentrating more in the samples pre-treated with lemon.

In the proximal analysis, the moisture content of the fresh sample was 92.25 g/100 g, which is within the range reported by Liu et al. (2016) and Reis et al. (2011) for fresh *Suillus luteus* mushrooms (90.14 and 90.79 g/100 g, respectively), and similar to the value of 95.92 g/100 g reported by Jacinto-Azevedo et al. (2021). The protein content reached 30.71 g/100 g, being similar to that reported by Liu et al. (2016) (30.11 g/100 g) but higher than the value obtained by Boa (2005) (20.0 g/100 g) in *Suillus luteus*. Crude fiber and ash contents reached values of 9.94 g/100 g and 6.93 g/100 g, respectively. However, Jacinto-Azevedo et al. (2021), reported higher values of 11.85 and 7.73 g/100 g, respectively. The fat content was 11.31 g/100 g, being higher than the values of 3.45 g/100 g and 1.97g/100 g reported by Jacinto-Azevedo et al. (2021) and Liu et al. (2016), respectively. However, Heleno et al. (2009) reported a similar fat content of 2.61 g/100 g in *Suillus mediterraneensis*. NFE reached 41.25 g/100 g, being slightly lower compared to the results obtained by Jacinto-Azevedo et al. (2021), Liu et al. (2016), and Ouzouni and Riganakos (2007), who reported values of 67.7 g/100 g, 54.85 g/100 g, 74.3 g/100 g in *Suillus granulatus*, respectively.

Regarding the dried samples with/without pre-treatments and drying methods, the moisture content ranged from 7.75 to 10.03 g/100 g. This agrees with Maray et al. (2017) and Ibrahim et al. (2017), who reported values of 8.15g/100 g and 7.6 g/100 g, respectively, for pre-treated *Pleurotus ostreatus*. Similar values were also obtained by Tolera and Abera (2017), who reported 9.58 g/100 g in *Pleurotus ostreatus* pre-treated with osmotic impregnation of salt under sun drying. The protein content ranged from 18.8 to 23.67 g/100 g and was affected by the treatments and drying method. Maray et al. (2017) and Yang et al. (2020) reported similar protein contents of 23.4 g/100 g and 21.9 g/100 g, respectively. Conversely, slightly lower values were observed in samples under direct sun drying and in a drying cabinet pre-treated with 0.5% citric acid in *Pleurotus ostreatus*, reaching 25.5 and 24.39 g/100 g, respectively (Ibrahim et al., 2017). Regarding fiber content, values ranged from 4.53 to 9.10 g/100 g. In this sense, Tolera and Abera (2017) reported a value of 10.14 g/100 g, and only direct sun drying without pre-treatment had a slightly higher value of 11.10 g/100 g. In addition, Ibrahim et al. (2017) found that mushrooms dried under direct sun and in a drying cabinet, without treatment and pre-treated with 0.5% citric acid, recorded lower fiber contents of 3.5 and 3.2 g/100 g, respectively. The ash content ranged from 4.39 to5.51 g/100 g, being lower than the value of 6.6 g/100 g reported by Maray et al. (2017) and the range of 8.2 - 7.8 g/100 g by Ibrahim et al. (2017). Fat content was in the range of 4.82-7.30 g/100 g, which does not agree with Tolera and Abera (2017) and Yang et al. (2020), who reported values of 2.2 and 2.3g/100 g, respectively. Finally, NFE varied between 47.13 and 57.57 g/100, significantly increasing as mushroom lost water. These results are consistent with the values reported by Ibrahim et al. (2017) (48.85-56.1 g/100 g) and slightly higher than 39.99 g/100 g reported by Tolera and Abera (2017). The variations could be due to different ecological environments, mushroom varieties, drying methods, and type of study conducted in different regions and climatic conditions (Boa, 2005; Ouzouni and Riganakos, 2007; Ramírez-Ortega and Thomé-Ortiz, 2019).

Polyphenolic compounds and antioxidant capacity

Significant differences were observed ($p<0.05$) between the samples in terms of TPC (Table 5). The fresh sample had a TPC of 11.85 mg GAE/g, and it significantly decreased in the dehydrated samples, such as in direct sun drying without pre-treatment and indirect drying treated with lemon, with values of 8.99 and 7.61 mg GAE/g, respectively.

In the present study, TPC reached 8.38 mg GAE/g. In this sense, Jacinto-Azevedo et al. (2021) conducted a study in fresh *Suillus luteus* mushrooms from Chile, reporting a lower value of 3.02 mg GAE/g, while a previous study on dried *Pleurotus ostreatus* reported a similar value of 8.31 mg GAE/g in samples with direct sunlight and pre-treated with vinegar, being higher than other pre-treatments evaluated (Mukutwa et al., 2019), which agree with our results of 8.38 and 8.42 mg GAE/g in samples dried in direct and indirect sunlight, both pre-treated with vinegar, respectively. Vinegar contains polyphenols that impregnate *Suillus luteus* mushrooms when immersed in the solution, significantly increasing their value (López et al., 2005). Other studies have reported values of 8.76 and 8.98 mg GAE/g in dried *Suillus luteus* and *Boletus badius*, respectively (Witkowska et al., 2011). Similarly, Keles et al. (2011) reported a value of 5.06 mg GAE/g in dried

Table 5. Total phenol content (TFC) and antioxidant activity (DPPH) of fresh *Suillus luteus* mushrooms under different pre-treatments and two drying methods.

Treatments	TFC (mgGAE/g)	DPPH µmolTE/g
Fresh	11.85±0.39d	115.27±7.62b
SDN	8.99±0.22c	59.53±1.57a
SDL	8.56±0.48c	56.34±2.35a
SDV	8.38±0.33bc	54.13±1.90a
FDN	7.51±0.06a	62.88±6.50a
FDL	7.61±0.21ab	60.04±2.92a
FDV	8.42±0.21bc	51.95±1.34a

Mean ± SD (*n*=3). SDN: Direct sun drying without pre-treatment; SDL: Direct sun drying with 5% lemon juice; SDV: Direct sun drying with 6% vinegar; FDN: *Fitotoldo* drying without pre-treatment; FDL: *Fitotoldo* drying with 5% lemon juice; FDV: *Fitotoldo* drying with 6% vinegar. Superscripts with different letters in columns are significantly different P≤ 0.05.

Suillus luteus, while Zen et al. (2012) reported 0.67 mg GAE/g in *Suillus luteus*. These low values can be explained by high and long temperature exposure as well as enzymatic activity catalyzed by light and air, decreasing TPC during drying (Youssef and Mokhtar, 2014). Despite some contradictory results, Keles et al. (2011) claim that *Suillus luteus* has greater antioxidant properties with respect to other mushrooms due to its higher phenolic content.

Regarding antioxidant activity measured by DPPH (Table 5), significant differences ($p<0.05$) were found between fresh and dehydrated samples but not between untreated and pre-treated samples. The highest inhibition percentage was recorded under *fitotoldo* drying without pre-treatment and *fitotoldo* drying with 6% vinegar, with values of 62.88 and 51.95 µmol TE/g, respectively, while the fresh sample recorded 115.27 µmol TE/g.

The antioxidant activity was lower than that reported by Morel et al. (2018) in *Suillus luteus* from France, with a value of 178.72 µmol TE/GDS. Pogoń et al. (2016) obtained 256 µmol TE/g in fresh *Suillus luteus*, which decreased to 206 and 209 µmol TE/g when preserved with acetic acid and brine, respectively.

Sensory evaluation

There were significant differences ($p<0.05$) in terms of sensory evaluation of color, texture, and acceptability attributes between dehydrated mushrooms with and without pre-treatment (Table 6). In all the three attributes, the highest score was obtained in solar drying with 6% vinegar and *fitotoldo* drying with 6% vinegar, with acceptability ratings of 4.50 and 4.28, respectively. The untreated samples received lower scores from the judges, with 3.22 in both cases. The results are similar to those reported by Maray et al. (2017), who observed higher acceptability in sun-dried samples with 0.5% citric acid pre-treatment (65.4), followed by hot air drying (63.5) and vacuum drying (58.2).

The untreated samples had low scores compared to the samples with pre-treatment. This also agrees with the results of Dunkwal et al. (2007) in sun-dried and pre-treated samples with 0.25% citric acid, with better sensory attributes of color, texture, and aroma. A more acceptable product was obtained with pre-treatments by immersion in 0.5% citric acid and ascorbic acid with better color retention (Nour et al., 2011). This indicates that an appropriate pre-treatment before drying improves color, texture, and reconstitution properties of mushrooms (Pogoń et al., 2016).

CONCLUSIONS

The drying method and pre-treatment significantly influence the preservation of edible wild mushrooms *Suillus luteus*. Samples dried without pre-treatment reached rehydration in a shorter time but with very low consumer acceptability. In contrast, pre-treated samples with vinegar achieved complete rehydration 20 min later and had higher acceptance. Pre-treatments did not have the expected effect on color since the untreated sample recorded the lightest color. As expected, the proximal analysis revealed that untreated samples showed better characteristics with respect to pre-treated and dried samples, but the nutrient content was not significantly

Table 6. Sensory evaluation of *Suillus luteus* mushroom under different pre-treatments and drying methods.

Samples	Color	Texture	Acceptability
SDN	5.36±2.88ab	6.22±3.57ab	3.22±1.11ab
SDL	7.80±2.60bc	7.43±2.89ab	4.50±1.65b
SDV	8.26±2.74c	8.21±3.10b	4.50±1.20b
FDN	4.93±2.54a	4.93±3.27a	3.22±1.59ab
FDL	3.97±1.84a	5.68±2.95ab	2.61±1.29a
FDV	7.85±2.45c	7.88±2.72ab	4.28±1.23b

Average ± SD (*n=18*). SDN: Direct sun drying without pre-treatment; SDL: Direct sun drying with 5% lemon juice; SDV: Direct sun drying with 6% vinegar; FDN: *Fitotoldo* drying without pre-treatment; FDL: *Fitotoldo* drying with 5% lemon juice; SFV: *Fitotoldo* drying with 6% vinegar. Different letters in columns are significantly different P≤ 0.05.

reduced. The wild mushrooms *Suillus luteus* from Apurímac, Peru, have a considerable content of polyphenols and antioxidant activity, especially when pre-treated with vinegar and dried. The sensory characteristics of pre-treated samples with vinegar obtained higher scores in color, texture, and acceptability than the rest of the samples. Preservation and promotion of native wild product consumption is suggested. Many of them can become appreciated products in the food industry not only as a food source but also for their qualities. Thus, the consumption and preservation of wild mushrooms *Suillus luteus* from Apurímac, Peru, is valuable for their high content of total polyphenols and antioxidant activity. Furthermore, collectors should be instructed on pre-treatments with vinegar and indirect sun drying using a *fitotoldo* (shade cover) as an alternative preservation technology to preserve mushrooms with better characteristics.

ACKNOWLEDGEMENTS

The authors would like to thank the Agroindustrial Engineering School of the Universidad Nacional Micaela Bastidas de Apurímac UNAMBA, Peru, for providing facilities for the experimental part of this work.

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