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Dehydration of *Suillus luteus* mushroom at different drying temperature, drying method, and pretreatment

Desidratação do cogumelo *Suillus luteus* em diferentes temperaturas de secagem, métodos de secagem e pré-tratamento

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ABSTRACT

The aim of this research was to assess the influence of drying temperature, drying method, and pretreatment on the dehydration of the edible mushroom *Suillus luteus*, focusing on its physical, functional, and sensory characteristics. *Suillus luteus* were harvested from Soccllacasa, Apurímac-Peru. Two drying temperatures (50 and 70 °C), two drying methods (oven and vacuum), and two pretreatment techniques (1% citric acid and blanching) were employed. Mushroom slices were immersed in solutions and subsequently subjected to drying. Analytical parameters, including instrumental color, total polyphenol content, antioxidant capacity, Fourier Transform Infrared Spectroscopy (FTIR) analysis, and sensory evaluation using Flash Profile, were conducted. The findings revealed significant differences ($p<0.05$) among the treatments. Higher drying temperatures, vacuum drying, and blanching exhibited superior color attributes. Polyphenol content and antioxidant capacity decreased in the dried samples, confirmed by FTIR; however, treatments dried at elevated temperatures under vacuum, showed enhanced preservation of these compounds. Sensory analysis revealed the formation of four groups based on temperature and drying method, but not on pretreatment, samples dehydrated at 70 °C under vacuum showing superior sensory characteristics. Thus, it is recommended to dehydrate *Suillus luteus* at higher temperatures under vacuum, as they offer improved preservation quality and sensory acceptability.

Index terms: Edible mushrooms; vacuum drying; pretreatments; flash profile.

RESUMO

Nesta pesquisa avaliamos a influência da temperatura de secagem, método de secagem e pré-tratamento na desidratação do cogumelo comestível *Suillus luteus*, focando em suas características físicas, funcionais e sensoriais. Os *Suillus luteus* foram colhidos em Soccllacasa, Apurímac, Peru. Foram empregadas duas temperaturas de secagem (50 e 70 °C), dois métodos de secagem (estufa convectiva e vácuo) e duas técnicas de pré-tratamento (1% de ácido cítrico e branqueamento). Fatias de cogumelo foram imersas nas soluções e, posteriormente, submetidas à secagem. Parâmetros analíticos, incluindo cor, teor de polifenóis totais, capacidade antioxidante, análise por espectroscopia de infravermelho com transformada de Fourier (FTIR) e avaliação sensorial utilizando o método Flash profile, foram realizados. Os resultados revelaram diferenças significativas ($p<0,05$) entre os tratamentos. Maiores temperaturas de secagem, secagem a vácuo e branqueamento exibiram melhores atributos de cor. O teor de polifenóis e a capacidade antioxidante diminuíram nas amostras secas, conforme confirmado por FTIR; no entanto, tratamentos secos a altas temperaturas sob vácuo mostraram melhor preservação desses compostos. A análise sensorial revelou a formação de quatro grupos com base na temperatura e no método de secagem, mas não no pré-tratamento, com as amostras desidratadas a 70 °C sob vácuo apresentando características sensoriais superiores. Assim, recomenda-se desidratar o *Suillus luteus* em maiores temperaturas sob vácuo, pois isso oferece melhor qualidade de preservação e aceitabilidade sensorial.

Termos para indexação: Cogumelos comestíveis; secagem a vácuo; pré-tratamentos; perfil instantâneo.

Introduction

Edible mushrooms are popular macro fungi that have been consumed for millennia as part of our dietary source (Sim et al., 2017). About 2000 species of mushrooms exist in nature, but only a few species are consumed as food (Maray et al., 2017; Jacinto-Azevedo et al., 2021). Among them is the edible fungus *Suillus luteus*, a member of the Agaromycetes class, Boletales order, characterized by its ectomycorrhizal symbiosis exclusively with Pinaceae species such as *Pinus densiflora, Pinus thunbergii, Pinus sylvestris, Pinus strobus*, and *Picea glehnii* (Aytar et al., 2020).

Wild edible fungi hold considerable significance in human dietary practices for their palatable flavor profile, non-starch carbohydrates, dietary fiber, vitamins B, minerals, low-fat content, high protein levels, antioxidants, and phenolic compounds (Nour et al., 2011; Oancea et al., 2023). Due to their high-water content (87% to 95% w.b.), substantial mineral composition, and high

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metabolic activity, these fungi rapidly succumb to spoilage post-harvest, needing preservation treatments to extend their shelf life and preserve their nutritional integrity and chemical composition (Sim et al., 2017, Oancea et al., 2023; Popa et al., 2022). Preservation techniques involve drying processes, diverse methods of mushroom drying exist (Argyropoulos et al., 2011), encompassing sun drying, cabinet drying with air circulation, fluidized bed drying, and atmospheric drying, each with different temperature parameters (Maray et al., 2017). Conventional air drying is one of the most frequently used techniques for mushroom dehydration (Hassan & Medany, 2014). However, drying conditions impact their nutrient composition, bioactive compound concentrations, and flavor characteristics (Maray et al., 2017). Specifically, at elevated drying temperatures, the content of polysaccharides and proteins decreases, the level of saturated fatty acids increases due to various chemical reactions (e.g., oxidation, hydrolysis, Maillard reaction), and the profile of phenolic and organic acids changes (Oancea et al., 2023).

The use of vacuum drying technology in food production and biotechnology plays a pivotal role in the preservation of heat-sensitive materials and the elimination of water vapor (Chorage & Singh, 2023). Under reduced pressures, water evaporates at an accelerated rate, with heat being supplied indirectly through either radiation or contact with a metallic surface. Materials prone to discoloration or degradation at elevated temperatures can effectively undergo drying at reduced temperatures under vacuum conditions (Bazyma & Kutovoy, 2005).

The proper selection of drying parameters, such as temperature, time, air velocity, pressure, etc. should be applied to produce a minimal impact on the quality of the final product (Popa et al., 2022). Pretreatments applied before drying mushroom can reduce undesirable changes in color, texture, and flavor (Argyropoulos et al., 2011; Maray et al., 2017). It is including immersion in solutions containing citric acid, ascorbic acid, potassium metabisulfite, ethylene diamine tetra acetic acid (EDTA), combined with steaming, blanching with water (Nour et al., 2011; Hassan & Medany., 2014; Maray et al., 2017; Mutukwa et al., 2019).

In a recent investigation, mushrooms underwent dehydration using two drying methods (tray drying and vacuum drying), three drying temperatures (60, 70, and 80 °C), and three pretreatments (control, vinegar treatment, and lemon juice immersion). The findings revealed that vacuum-dried mushrooms treated with vinegar showed superior quality characteristics (Chorage & Singh, 2023). Similarly, in the dehydration of mycelia from the Maitake mushroom (*Grifola frondosa*), a comparative analysis between vacuum dehydration and oven drying was conducted. Vacuum-dried mycelia showed higher levels of total polyphenols, antioxidant activity, and nutritional content of protein compared to those subjected to oven drying under conditions of 70 °C, 1000 mBar (Sim et al., 2017).

The *Suillus luteus* mushroom, indigenous to the pine forests of the Peruvian Andes, including the Apurímac region renowned for its expansive forest cover, epitomizes a prime candidate for prolonged shelf life through dehydration techniques. Thus, the objective of this study was to evaluate the influence of drying parameters, specifically temperature (50 and 70 °C), drying methodology (oven and vacuum), and pretreatments (blanching and immersion in citric acid) on the physical, functional, and sensory characteristics of *Suillus luteus* mushrooms to determine the optimal conditions for its preservation.

Material and Methods

Sample

In June 2023, a total of 20 kilograms of fresh *Suillus luteus* mushroom specimens were gathered from the pine forests (*Pinus radiata*) of Soccllaccasa (branch of Huanipaca), located in the Abancay province of the Apurímac region, Peru, at an elevation of 3,759 meters above sea level. The experimental procedures were conducted within the laboratories of Agroindustrial Product Processing and General Chemistry of the Academic Professional School of Agroindustrial Engineering, National University Micaela Bastidas of Apurímac, Peru.

Chemicals

The reagents and standards employed in the analytical procedures, including 1,1-Diphenyl-2-picrylhydrazyl (DPPH), Folin-Ciocalteu reagent (FCR), gallic acid (3,4,5-trihydroxybenzoic acid), sodium carbonate (Na_2CO_2), 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), and analytical grade 99.9 % methanol, were sourced from Merck (Merck Peruana S.A.). Additionally, 99.0% citric acid was obtained from J.T. Baker. The distilled water used in the analysis was of high quality and obtained from the Food Chemistry Laboratory of the same University to ensure the reliability of the results.

Sample pretreatments and drying of *Suillus luteus* mushroom

Following the harvesting of *Suillus luteus* mushroom specimens, they were transported to the laboratory, and damaged specimens were discarded. Subsequently, the caps were peeled, and the stipes were trimmed. The mushrooms were sliced into segments approximately 0.4 cm in thickness. The specimens were stratified into 12 portions to undergo different preliminary treatments, with four portions designated as untreated controls (Table 1). The remaining eight portions underwent specific pretreatments; four portions were subjected to blanching in boiling water for one minute, while the remaining four portions were immersed for 15 minutes in a 1 % citric acid solution (at room temperature), following a methodology previously described by Maray et al. (2017) with certain adaptations. The liquid-to-mushroom ratio employed in the preparation of the immersion

solutions was 5:1, following the methodology described by Hassan and Medany (2014) with some modifications (the blanching immersion time was decreased, and the citric acid concentration was increased from 0.3 to 1%). The drying process was carried out at two temperatures: 50 and 70 °C, employing two drying methodologies: 1) conventional oven drying with mechanical ventilation (Memmert 30-750), and 2) vacuum oven drying (Memmert VO49) with an air pressure set at 50 mbar (Table 1).

Instrumental color analysis

Color is a parameter for determining product quality. For color measurement, the samples were crushed and sieved (mesh #80). Using the colorimeter PCE-CSM7 Instruments Deutschland GmbH. The equipment was calibrated in black and white according to the manual to measure the colorimetric coordinates (L*, a*, b*), where L* represents lightness ranging from 0 (black) to 100 (white), serves as a color indicator in samples, with higher L* values indicating closer resemblance to white and lower L* values indicating proximity to black. a* indicates chromatic variation from green (-) to red (+), and b* indicates chromatic variation from blue (-) to yellow (+). Additionally, to calculate color saturation, color purity (C*) = [(a*)^2 + (b*)^2]^0.5 and hue angle (h°) = [arctg (b*/a*)] was calculated (Mathias-Rettig & Ah-Hen, 2014). The color variation (ΔE) was carried out using the following Equation 1:

$$\Delta E = \sqrt{(Lm - Lc)^2 + (am - ac)^2 + (bm - bc)^2} \quad (1)$$

Where:
"m" represent sample data with pretreatment drying at different times and methods
"c" represent data from fresh sample

Total polyphenols

The determination of total polyphenol content in *Suillus luteus* mushroom extracts subjected to various treatments was conducted following the modified method by Singleton and Rossi (1965). Initially, a standard curve for total polyphenols was established. A stock solution containing 25 mg of gallic acid in 100 ml of distilled water was prepared. Six Falcon tubes were labeled with concentrations of 50, 100, 200, 400, 600, and 800 ppm, and respective volumes of 0.5, 1, 2, 4, 6, and 8 mL of gallic acid solution were added to each tube. The volumes were adjusted to 10 ml with distilled water. Subsequently, 1.125 mL of the stock solution was transferred to test tubes from each concentration, followed by the addition of 125 microliters of 1 N Folin Cioulcalteau reagent. After a 5-minute incubation period, 3.5 ml of ultra-pure water and 2.5 ml of 7.5 % sodium carbonate solution were added. The mixture was allowed to stand for 60 minutes, and absorbance was measured at 750 nm using a UV-visible spectrophotometer. For the mushroom samples, 0.125 ml of the crude extract was mixed with 0.125 ml of 1 N Folin reagent. After 5-10 minutes of incubation, 3.5 ml of ultra-pure water and 2.5 ml of 7.5 % sodium carbonate solution were added, and absorbance was measured at 750 nm. All measurements were performed in triplicate.

Antioxidant capacity (DPPH)

The antioxidant capacity of *Suillus luteus* mushroom extracts subjected to different treatments was assessed using the method proposed by Brand-Williams et al. (1995) with modifications. This method involves the capture and reduction of DPPH (2,2-diphenyl-1-picrylhydrazyl) radicals by antioxidants. A standard curve for antioxidant capacity was prepared using a solution containing 20 mg of Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) dissolved in 100 mL of 80% (v/v) methanol. Each Falcon tube was then supplemented with 0.5 mL of Trolox solution and 2.5 mL DPPH solution. Seven Falcon tubes were labeled with concentrations of 1.56, 3.13, 6.25, 12.50, 25.0, 50.0, and 100.0 mg Trolox/L. Additionally, a blank tube containing 3 mL of 80% (v/v) methanol and a control tube containing 0.5 mL of Trolox solution and 2.5 mL DPPH solution were prepared. The samples to be measured were also prepared. All tubes were analyzed in triplicate and incubated in a dark environment for 30 minutes before measuring the absorbance at 517 nm using a spectrophotometer. A standard curve was constructed, and the concentrations of the samples were determined in µM Trolox Equivalent/100g.

Fourier transform infrared spectroscopy (FTIR)

The identification of functional groups within fresh samples of *Suillus luteus* mushrooms and across the 12 treatment variants of crushed and sieved samples (mesh size #80) was conducted using Fourier Transform Infrared Spectroscopy (FTIR) with a Nicolet IS50 instrument (Thermo Scientific, Madison, WI, USA). The objective was to identify differences on drying method, drying temperature, and/or pretreatment. Spectra data were obtained within the mid-infrared (IR) range of 400-4000 cm^-1, using 64 scans at a resolution of 4 cm^-1.

Sensory evaluation using Flash Profile

Flash profile (FP) is a descriptive sensory methodology derived from free-choice profiling, wherein each subject autonomously selects and articulates their own perceptions using individualized descriptors to comparatively assess the array of products. This assessment is conducted in three sessions. In the first session, evaluators are presented with the samples and must list sensory attributes. In the second session, a consensus is achieved to eliminate redundancies. In the third session, the samples are once again presented simultaneously and randomly, with each evaluator assessing them according to their chosen attributes, ranked in ascending order to intensity on an ordinal scale (Dairou & Sieffermann, 2002). Post-data collection, a generalized procrustes analysis (GPA) is conducted to synthesize

the evaluators´ collective perceptions, thereby generating a sensory map indicative of their consensus (Terhaag & Benassi, 2010). In this study, 24 evaluators (consumers), representing both genders, participated in the sensory evaluation.

Statistical analysis

Statistical analysis of the 12 treatment modalities and the fresh sample was conducted through a one-way analysis of variance (ANOVA) using a completely randomized design. Experimental results were presented as mean ± standard deviation with three replicate measurements for polyphenols, antioxidant capacity, and eight measurements for color. Tukey's test was applied to compare means when values were considered significant ($P < 0.05$). For this purpose, R statistical software version 4.1.3 was used. The sensory evaluation data by Flash Profile were evaluated using Generalized Procrustes Analysis (GPA) with XLSTAT 2014 trial version software (Addinsoft, New York, NY, USA).

Results and Discussion

Instrumental Color

The findings indicate a reduction in the lightness (L*) of the fresh mushroom across drying temperatures, methods, and pretreatments (Table 2, Figure 1b and 1c). Significant differences ($p < 0.05$) reveal that higher drying temperatures and blanching result in improved lightness. For instance, the lightness of the fresh sample was 79.60, higher than T12 (sample dried at 70 °C under vacuum and blanched) with 42.53. Conversely, T9 (sample dried at the same temperature, in an oven, and blanched) exhibited lower lightness (40.50), lower than 65.9 reported for mushrooms dried using hot air at the same temperature, as documented by Nour et al. (2011). Similar trends are observed in other studies where the lightness significantly decreases as moisture is lost due to varied drying methodologies and pretreatments (Espinoza-Ticona et al., 2023)

Figure 1 shows a detailed representation of edible mushrooms *Suillus luteus* in three sections. In the first section (Figure 1a), the fresh mushrooms are shown, highlighting their natural color and texture, the second section (Figure 1b) illustrates the dehydrated samples of *Suillus luteus*, where the effect of two drying temperatures, two pretreatments and two drying methods can be observed, finally, the third section (Figure 1c) shows the crushed dehydrated mushrooms.

The results show lower lightness in samples dried in oven with 25.55 indicating a darker tone. On the other hand, samples dried under vacuum have higher luminosity of 47.33. Blanched samples exhibited greater lightness compared to those pretreated with citric acid or left untreated. This observation aligns with previous research where blanching immediately inactivates enzymes, resulting in reduced enzymatic browning (Nour et al., 2011), which are inactivated by heat. Blanching pre-treatments were also found to have better color retention capacity than untreated dried cabbage (Sarkar et al., 2021). Enzymatic browning becomes more evident at lower temperatures, as an extended drying period allows for more reactions, resulting in pigment concentration and intensified color, correlated to the darkening of plant tissues (Kurozawa et al., 2011). In a study of drying of cherry (*Cornus mas* L.) in natural, convective and combined dried with microwaves, found that at 90 °C more efficient drying was obtained, resulting in less color loss compared to lower temperature, such as 50 °C (Parveez Zia & Alibas, 2021).

Table 1: Dehydration treatments of edible mushrooms *Suillus luteus* at different temperatures, drying methods, and pretreatments.

Treatment	Temperature (ºC)	Drying method	Pretreatment
T1	50	Oven	No pretreatment
T2	50	Oven	Citric acid 1 % for 15 min
T3	50	Oven	Blanching for 1 min
T4	50	Vacuum oven	No pretreatment
T5	50	Vacuum oven	Citric acid 1 % for 15 min
T6	50	Vacuum oven	Blanching for 1 min
T7	70	Oven	No pretreatment
T8	70	Oven	Citric acid 1 % for 15 min
T9	70	Oven	Blanching for 1 min
T10	70	Vacuum oven	No pretreatment
T11	70	Vacuum oven	Citric acid 1 % for 15 min
T12	70	Vacuum oven	Blanching for 1 min

Table 2: Instrumental color of the fresh and dehydrated mushroom *Suillus luteus* at different temperatures, drying methods, and pretreatments.

Treatments	L*	a*	b*	C	h°	ΔE
Fresh	79.60±0.89^{k}	8.08±0.40^{a}	15.92±0.19^{c}	17.86±0.26^{a}	63.09±1.14^{i}	----
T1	37.70±0.59^{g}	13.09±0.04^{d}	19.00±0.23^{f}	23.07±0.21^{e}	55.43±0.25^{f}	42.31±1.10^{d}
T2	25.55±0.23^{a}	12.67±0.03^{c}	12.45±0.14^{a}	17.76±0.08^{a}	44.50±0.39^{a}	54.36±0.97^{h}
T3	40.09±0.42^{h}	11.56±0.02^{b}	18.27±0.08^{e}	21.62±0.07^{d}	57.69±0.13^{g}	39.74±1.08^{c}
T4	30.39±0.46^{c}	13.45±0.29^{e}	16.40±0.28^{d}	21.21±0.13^{c}	50.63±1.04^{c}	49.51±1.11^{g}
T5	26.42±0.94^{b}	13.29±0.11^{e}	13.60±0.48^{b}	19.02±0.27^{b}	45.64±1.27^{b}	53.41±1.38^{h}
T6	47.73±0.06^{j}	13.32±0.06^{e}	22.07±0.10^{j}	25.77±0.11^{h}	58.89±0.10^{h}	32.88±0.87^{a}
T7	36.41±0.07^{f}	14.79±0.01^{h}	21.20±0.03^{h}	25.85±0.02^{h}	55.09±0.03^{f}	44.03±0.89^{e}
T8	32.01±0.36^{d}	15.27±0.14^{i}	19.71±0.21^{g}	24.94±0.25^{f}	52.24±0.06^{d}	48.28±1.01^{g}
T9	40.50±0.20^{h}	13.69±0.02^{f}	21.25±0.23^{h}	25.28±0.19^{g}	57.22±0.27^{g}	39.86±0.99^{c}
T10	36.32±0.29^{f}	15.99±0.04^{j}	22.71±0.08^{k}	27.78±0.09^{k}	54.85±0.04^{f}	44.53±0.90^{e}
T11	34.05±0.13^{e}	16.22±0.05^{k}	21.73±0.08^{i}	27.11±0.10^{j}	53.26±0.03^{e}	46.64±0.93^{f}
T12	42.53±0.40^{i}	14.16±0.08^{g}	22.12±0.17^{j}	26.27±0.18^{i}	57.38±0.09^{g}	38.08±1.05^{b}

Lightness (L*); green/red (a*); yellow/blue (b*); chromaticity values (C*); hue angle (hº). Different letters within each column indicate significant differences ($p < 0.05$), while similar letters denote no significant differences (n = 5).

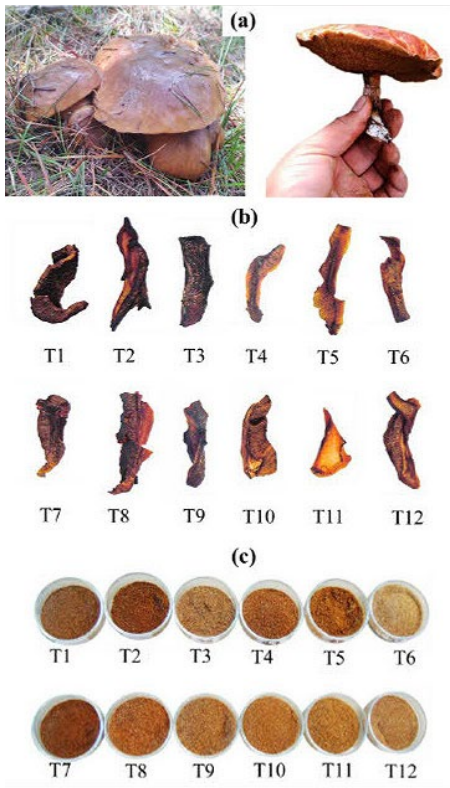

Figure 1: Graphical representation of the edible mushroom *Suillus luteus* in its fresh state (a); dehydrated samples subjected to different temperatures, drying methods, and pretreatments (b); crushed dehydrated mushroom samples subjected to different temperatures, drying methods, and pretreatments (c).

Regarding the parameters (a*), (b*), chroma (C*), and color hue (hº), these exhibited a notable increase as lightness decreased (Figure 1c), manifesting varied tones and shades compared to the fresh sample (Figure 1a). The b* parameter significantly increased both in the oven and vacuum drying, like those dried at 70 ºC and pretreated with 0.5 % citric acid (24.53), as documented by Nour et al. (2011). Color saturation (C*) values increased as the lightness increased, with the highest chroma observed in blanched samples dried in a vacuum oven and the lowest in samples oven-dried with hot air. Each coordinate result formed its unique color hue (hº), compared to fresh sample (h° = 63.09°), all treatments show a decrease in h° value, indicating change towards more reddish tones, T6 (58.89°) and T12 (57.38°) show a more moderate change. Vacuum drying generates the smallest color changes (ΔE) in Suillus luteus mushrooms, maintaining its appearance closer to the fresh state. On the other hand, pretreatment with citric acid at 50°C and drying in oven produces the greatest color changes.

Total polyphenols and antioxidant capacity

Table 3 displays the total polyphenol (CPT) content of the 12 treatments of *Suillus luteus* edible mushrooms, including their fresh state, with values ranging from 686.17 to 2462.73 mg GAE/100 g dry sample. The polyphenolic compound content varies significantly ($p < 0.05$) among the treatments of *Suillus luteus*, except between treatments T7 and T8, as well as T2 and T5, which are statistically similar. This suggests that the pretreatment, along with the type and temperature of drying applied in the different treatments, influenced the total polyphenol content of the samples obtained.

Table 3: Bioactive compounds in *Suillus luteus* edible mushrooms from the Apurímac region under different drying methods and pretreatments.

Treatment	CPT mg GAE /100g	DPPH µmol TE/100g
Fresh	2462.73±139.26^{g}	99.31±2.97^{b}
T1	827.07±114.61^{abd}	83.32±0.22^{a}
T2	1004.58±143.85^{cde}	82.94±0.19^{a}
T3	746.56±87.86^{ab}	82.54±0.43^{a}
T4	1048.52±34.00^{de}	83.45±0.08^{a}
T5	1023.27±10.53^{cde}	83.29±0.11^{a}
T6	686.17±67.55^{a}	83.36±0.15^{a}
T7	1079.77±39.72^{e}	82.63±0.13^{a}
T8	1080.92±19.48^{e}	82.66±0.39^{a}
T9	755.73±39.27^{ab}	83.13±0.37^{a}
T10	1425.03±101.53^{f}	83.29±0.27^{a}
T11	977.85±38.58^{be}	82.75±0.38^{a}
T12	803.97±33.66^{abc}	83.20±0.25^{a}

Different letters within the same column are significantly different ($p < 0.05$), similar letters indicate no significant differences ($n = 3$).

The findings indicate that the fresh edible mushroom *Suillus luteus* and treatment T10 (dried at 70 °C, under vacuum, and without pretreatment) exhibited significant higher total polyphenol compound content. This observation is consistent with the research of Popa et al. (2022) and Oancea et al. (2023), who dehydrated *Boletus edulis* at 60 °C in a vacuum oven and observed effective preservation of total polyphenol content. Similarly, treatments T7 (dried at 70 °C, in a conventional oven, without pretreatment) and T8 (dried at 70 °C, in a conventional oven, with 1 % citric acid) showed higher values compared to other treatments. Notably, despite undergoing drying at higher temperatures, these treatments showed better retention of polyphenol compounds compared to the blanched samples (T3, T6, T9, and T12), which displayed the lowest levels. This trend aligns with the findings of Jaworska et al. (2014), who observed a decrease in polyphenol content with blanching. However, the results obtained from treatments T1, T3, T9, and T12 are closer to the value reported by Mutukwa et al. (2019), who dehydrated *Suillus luteus* mushrooms in a solar dryer at 43 °C and treated them with a solution of white vinegar, obtaining 831 mg GAE/100 g sample.

The antioxidant capacity of the extracts from the 12 treatments and the fresh state of the edible mushroom *Suillus luteus* was evaluated using the DPPH assay. Statistical analysis revealed that the antioxidant capacity among the treatments was statistically similar ($p > 0.05$) except for the fresh sample (Table 3). Notably, the fresh *Suillus luteus* mushroom showed a higher antioxidant capacity compared to the treated samples, while those treated were statistically equal.

The findings regarding the antioxidant capacity of fresh *Suillus luteus* mushroom using DPPH assay exhibit similarities with the study conducted by Pogoń et al. (2017) converting units, which reported a value of 25.6 ± 1.0 µg/100 g dry sample. However, it differs from that reported by Aytar et al. (2020) and Jacinto-Azevedo et al. (2021). The values obtained for the other treatments were higher than the results of 51.95 to 62.88 µmol TE/g reported by Espinoza-Ticona et al. (2023) and different from those reported by Jacinto-Azevedo et al. (2021). The thermal treatment and pretreatments applied to *Suillus luteus* mushroom samples reduced their nutritional and bioactive properties in comparison to the fresh mushroom. Jaworska et al. (2014) reported that heat treatment reduces the nutrition of foods, resulting in the loss of essential constituents such as vitamins, minerals, and unsaturated fatty acids, among others.

Fourier transform infrared spectroscopy (FTIR)

In Figure 2, the FTIR spectra of fresh and dried samples reveal nearly similar behavior among the dried samples, with differences observed in comparison to the fresh mushroom. A broad band in the region of 3285 cm^{-1} is observed in the fresh sample and at 3270 cm^{-1} in the dried samples of the 12 treatments, corresponding to the stretching vibration of O-H groups (Yu et al., 2019; Mueses-Mafla & Benavides-Calvache, 2022), or stretching involving H bonds, characteristic of polyphenolic compounds (Coates, 2000). Additionally, a peak is observed only in the dried samples in the region of 2923 cm^{-1}, corresponding to the stretching vibration of C-H groups (Yu et al., 2019; Mueses-Mafla & Benavides-Calvache, 2022).

Furthermore, the spectra reveal peaks in the regions of 1628, 1555, and 1371 cm^{-1}, potentially corresponding to amide groups, indicative of protein presence within the samples (Mueses-Mafla & Benavides-Calvache, 2022), with a peak around 1639 cm^{-1} assigned to amide I of proteins and another at 1556 cm^{-1} assigned to amide II (Yew Keong et al., 2014). A peak near 1635 cm^{-1} suggests the presence of phenolic compounds. Despite this region being typically associated with proteins, the relatively intense band overlaps with phenolic stretching vibrations (Kozarski et al., 2012), which are also presumed to be present in our samples, particularly in the fresh sample. This peak could also be linked to N-H bending vibrations in flavonoids (Oliveira et al., 2016).

Furthermore, an observed band at approximately 1019 cm^{-1} indicates the potential presence of polysaccharides. Bands falling within the range of 1000 to 1100 cm^{-1} indicate the presence of polysaccharides, which is assigned to the stretching vibration of C-O in carbohydrates (Kozarski et al., 2012). Overlapping bands spanning between 1200 and 950 cm^{-1} are also attributed to C-C stretching vibrations of pyranoid rings, a distinctive feature of polysaccharides (Oliveira et al., 2016), which are likely associated with the bioactive compounds present in the samples.

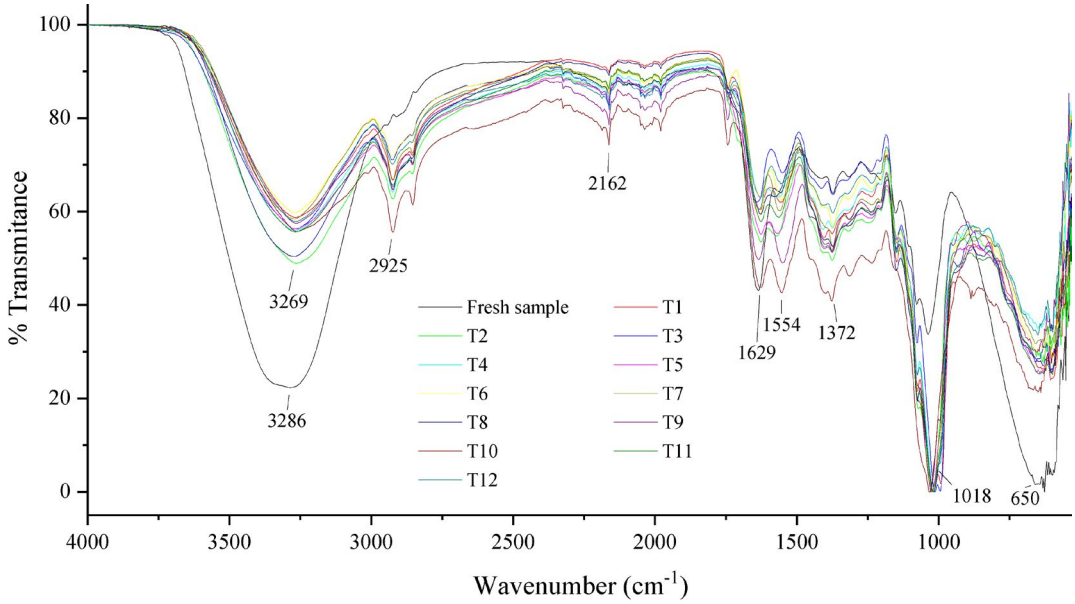

Figure 2: FTIR spectra of fresh and dehydrated *Suillus luteus* edible mushrooms at different temperatures, drying methods, and pretreatments.

Sensory evaluation using Flash Profile

Descriptive sensory evaluation through Flash Profile was conducted on samples of *Suillus luteus* mushrooms dehydrated at various temperatures, using different drying methods and pretreatments. This evaluation involved 24 consumers (judges) and yielded 164 attributes. These attributes were subsequently subjected to Analysis of Proximity Graphs (APG), resulting in their representation in two dimensions (F1 = 41.88 and F2 = 28.91), capturing 70.79% of the data variability (Figure 3a and 3b). This variability exceeds that observed in a study on the drying edible *Pleurotus ostreatus* mushrooms using various methods and temperatures, which involved six panelists and achieved a 62.89% variability through Principal Component Analysis (PCA) (Nöfer et al., 2018).

Figure 3a shows the arrangement of the 12 treatments in the sensory space, demonstrating their segregation into four groups across dimensions F1 and F2 (70.79%). Group I (located in the positive zone of dimension 1 and the negative zone of dimension 2) comprises T2 and T3, indicating that consumers identified similar sensory attributes within these treatments. Following this, Group II (positive zones of dimensions 1 and 2) consists of T1, T7, T8, and T9. Next is Group III (negative zone of dimension 1 and positive zone of dimension 2), composed of T6, T10, T11, and T12, followed by Group IV (negative zones of dimensions 1 and 2), where T4 and T5 are situated, indicating similar sensory attributes perceived by the judges within these treatments.

Figure 3b displays the sensory space of attributes generated by the judges across dimensions F1 and F2 (70.79%), corresponding to Figure 3a (sensory space of samples). Here, the differences in sensory attributes among groups and their characteristic descriptors are evident. Group I (T2 and T3) is characterized by attributes such as dark color, black color, dark brown color, burnt-like color, fragile texture, flexible elasticity, and fragrant aroma. Samples in Group II (T1, T7, T8, T9) were described with attributes including black color, burnt color, lumpy texture, fibrous, porous, rough, and hard. Group III samples (T6, T10, T11, T12) were defined by caramelized, mustard, orange, yellowish, dark orange colors, fragile texture, brittle, crunchy, and cinnamon-mint flavor. Lastly, Group IV (T4 and T5) judges indicated caramel, coppery, mustard colors, soft texture, spongy, fibrous, porous, smooth glossy surface, lumpy, soft to the touch, and meaty aroma.

These results indicate that both temperature and drying methods exerted a greater influence on the judge's sensory perception than pretreatment. A clear formation of four distinct groups (Figures 3a and 3b) is observed, with a pronounced division between samples dehydrated at different temperatures (50 °C in groups I and IV, and 70 °C in groups II and III). Additionally, there is a separation between samples dried in an oven (groups I and II) and under vacuum (groups III and IV) within the quadrants.

In a study investigating the drying process of *Suillus granulatus* mushrooms using hot air at temperatures of 40, 50, 60, 70, and 80 °C, it was observed that the aroma profile, particularly characterized by mushroom and almond notes, reached desirable levels at 60 °C. This temperature was identified as optimal for preserving the mushroom´s flavor and overall quality (Hou et al., 2022). Another study focusing on the drying of *Suillus granulatus* mushrooms employed various methods including natural drying, hot air drying, vacuum drying, and freeze-drying.

Among these techniques, vacuum drying at 60 °C was identified as the most effective in retaining the characteristic umami flavor of the mushrooms (Zhao et al., 2020). Furthermore, slices of *Pleurotus ostreatus* mushrooms subjected to hot air drying at 50 and 70 °C and pretreated with a combination of 0.5% citric acid and 0.5% ascorbic acid showed a significant effect on color and whiteness. These results surpassed those obtained from alternative pretreatment methods such as blanching, immersion in sodium metabisulfite, and EDTA (Nour et al., 2011). Likewise, in a separate investigation on the dehydration of *Suillus luteus* using solar drying and pretreatment with vinegar and lemon juice in a phytotent, samples dried under both conditions showed improved acceptance, with preference observed for those pretreated with vinegar (Espinoza-Ticona et al., 2023).

During the dehydration process, certain sensory attributes experience alterations, including an increase in burnt odor and aroma, caramel sweetness, bitterness, crispiness, and stickiness. These changes are associated with a reduction in moisture content, which contributes to increased stickiness and decreased solubility and rehydration ability (Hassan & Medany, 2014).

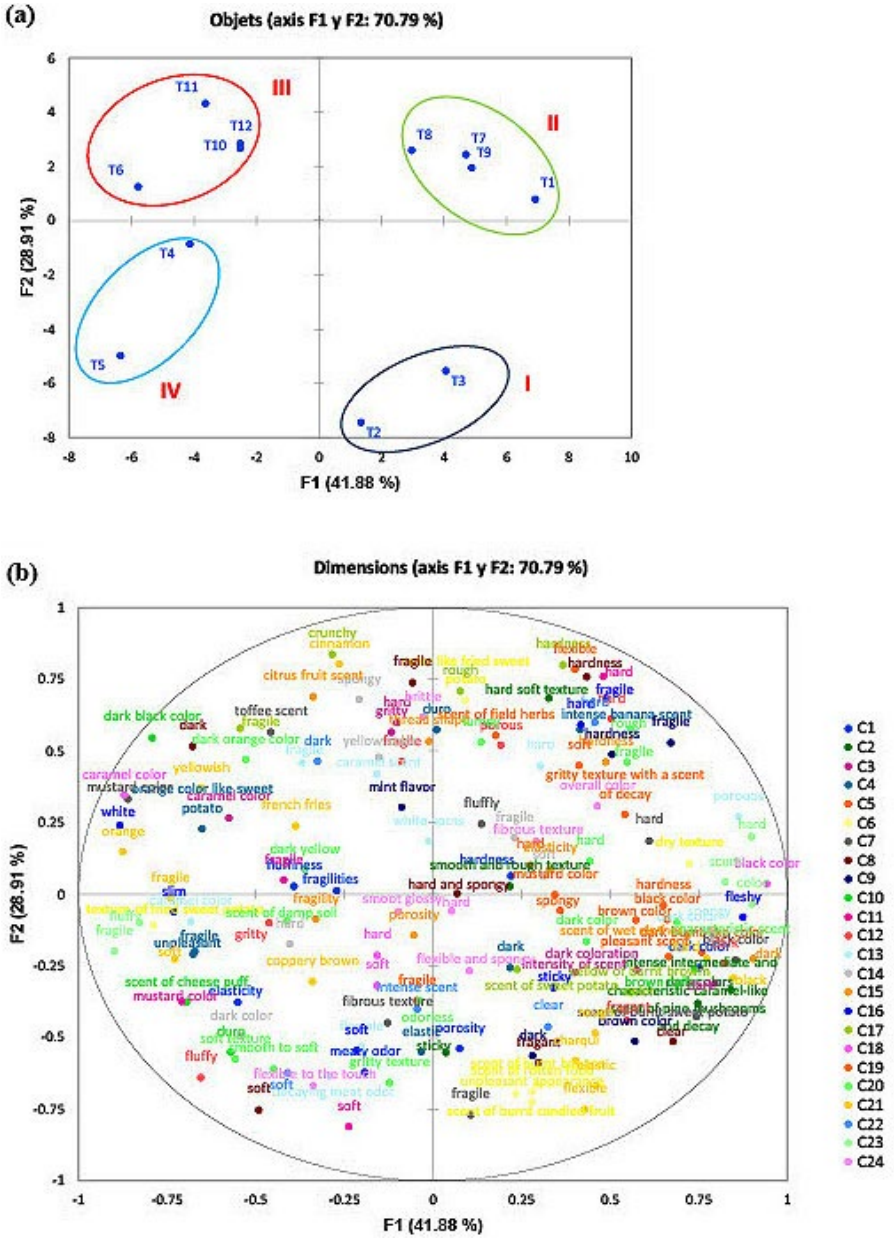

Figure 3: (a) Sensory space of 12 treatments of *Suillus luteus* mushrooms dehydrated at different temperatures, methods, and pretreatments, (b) sensory space of attributes or descriptors from Flash Profile.

Conclusions

In dehydration of *Suillus luteus*, higher drying temperatures, vacuum drying, and blanching exhibited superior color attributes, like luminosity. Substantial levels of total polyphenol were detected in fresh state and samples dried at 70 °C under vacuum, in antioxidant capacity, fresh mushroom higher value than the other treatment, confirmed by FTIR. Sensory evaluation using Flash Profile revealed that temperature and drying methods had a more pronounced impact compared to pretreatment. Samples dried at 70 °C under vacuum exhibited more favorable attributes.

Author contributions

Conceptual idea: Chaquilla-Quilca G.; Lozano F. Methodology design: Fernandez-Ayma A.; Pérez-Falcón L.F.; Silva-Paz R.J. Data collection: Espinoza-Ticona Y.; Fernandez-Ayma A.; Pérez-Falcón L.F. Data analysis and interpretation: Lozano F.; Pérez-Falcón L.F.; Silva-Paz R.J.; Huamani-Meléndez V.J. and Writing and editing: Chaquilla-Quilca G.; Lozano F.; Pérez-Falcón L.F.; Huamani-Meléndez V.J.

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