UNIVERSITATEA LUCIAN BLAGA DIN SIBIU

Doctoral School of Engineering and Mathematics

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ABSTRACT DOCTORAL THESIS

RESEARCH ON THE DRYING PROCESSES OF PORCINI MUSHROOMS FOR THE PRESERVING THE PHISICAL CHEMICAL CHARACTERISTICS AND DEVELOPING AN INNOVATIVE PRODUCT

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SUMMARY

This doctoral thesis represents a personal approach carried out with the aim of preserving and capitalizing on some bioactive components following the drying processes applied to mushrooms of the species *Boletus edulis* (porcini), with potential for the development of a new functional drink, based on buckwheat and mushroom powder.

The choice of this raw material for the study focused on the following aspects: native mushroom species, little scientifically exploited for the purpose pursued in this doctoral thesis, accessible raw material, with a high content of bioactive compounds with a beneficial and nutritional role for the body, and application potential for different economic sectors.

To carry out the drying process, both classical processes (convective drying and lyophilization) and modern processes (centrifugal drying under vacuum, used for the first time in this thesis) were tested, its efficiency being evaluated by investigating different process parameters, such as time and temperature of drying, humidity, but also the rehydration ratio, physico-chemical and emulsifying properties, as well as the color and microstructure of the mushrooms after drying. Also, to increase the targeted biochemical potential, two different types of pre-treatments (UV-C light irradiation and blanching) applied to fresh mushrooms before drying were tested.

The extraction of the targeted bioactive compounds, with a polyphenolic structure, was achieved through various sustainable processes, which allow their subsequent use in products intended for human consumption. The influence of extremely low frequency electromagnetic radiation on the content of bioactive compounds and antioxidant activity in dried mushrooms was also investigated, as well as the influence of irradiation with UV-C light and microwaves respectively on the total content of bioactive compounds and antioxidant activity in mushrooms fresh and dry.

Mushroom powders were subjected to the analysis of some physical and physico-chemical properties (density, Hausner ratio, solubility, rehydration, emulsifying properties) as well as nutritional composition, fatty acid profile and flavor compounds content. Based on the results obtained from the application of drying and extractive technologies, the mushroom powder obtained by convective drying with hot air was the basis for the formulation of an innovative product – type of functional drink based on buckwheat and mushroom powder, lactically fermented.

The newly developed buckwheat-based functional beverage with the addition of 1.5% mushroom powder, *Boletus edulis*, fermented with *Bifidus* lactic cultures, proved greater stability compared to the buckwheat-only fermented beverage, the addition of mushrooms conferring superior sensory attributes to the new product.

The results obtained in this doctoral research bring original theoretical and applied contributions, being disseminated through the publication of scientific articles in ISI-indexed/indexed journals, BDI-indexed journals, by presenting my own work at national and international conferences and by proposing an OSIM invention patent.

KEY WORDS: antioxidants, *Boletus edulis*, edible mushrooms, bioactive compounds, mushroom extracts, FRAP, UV irradiation, microwave, sustainable, mushroom drying.

Words of appreciation,

I would like to thank all those who have been with me during these years of doctoral study. These thanks are addressed to the coordinator, Prof. dr. habil. Simona Oancea, for the scientific support and dedication given since my undergraduate years, then towards the fulfillment of the objectives of my doctoral thesis, in a field (mushrooms) for which I have developed a great passion and which I have loved since I was a child, for her patience and the art of communicating openly about the ideas I had during this thesis.

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Drd. Popa Florentina-Miruna

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INTRODUCTION

There is a continuous concern of some industrial sectors, such as the food and pharmaceutical industry, especially for the development of products that are oriented to improve health, diversified products, for example based on mushrooms, but also for the improvement of industrial technological processes of production and quality control of final products. At the national and international level, numerous scientific researches are carried out targeting different species of edible mushrooms, as valuable raw materials, which aim to identify some bioactive components in the composition, improve extractive processes, drying technologies, as well as investigate biologically active properties of them and the derived products.

The innovative and applied nature of this doctoral thesis is given by the study of *Boletus edulis* (porcini), from the area of Transylvania, Romania, from the perspective of evaluating the biologically active compounds with polyphenolic structure, in a comparative way between fresh and dry samples, subjected to different pre-treatments and drying techniques, being an area of interest for the identification of potentially valuable new sources of compounds with nutritional and bioactive properties for various industrial applications.

This PhD research focuses on the drying processes of the spontaneous mycota, with the aim of preserving the bioactive properties, the quality of the final product and the total antioxidant activity. Pursuing this aim, the native mushrooms targeted in this work were dried, with the idea of developing a functional drink type product based on buckwheat and mushroom powder, lactic fermented, which supplements the dietary intake of biomolecules necessary for the body, has an improved flavor and can be consumed even by people with the immune imbalance created by gluten intolerance. To achieve this goal, environmentally friendly technologies were used.

In this doctoral thesis, two classic drying technologies were used: hot air convective drying and lyophilization, and for the first time in this work the vacuum centrifugal drying technology applied to *Boletus edulis* mushroom paste was used.

The pre-treatments carried out before drying were aimed at inactivating some enzymes that lead to a rapid degradation of the mushrooms. Starting from this idea, in this work two types of physical pre-treatments were investigated: blanching and exposure to UV-C light under the aspect of their influence on the content of targeted bioactive compounds (polyphenols, tannins) and antioxidant activity.

The analysis of the quality of mushroom powders by the hot air drying method and respectively the centrifugal method under vacuum, aimed to investigate the effect of the two types of drying on physical properties, such as density, Hausner ratio, solubility, rehydration, but also emulsification properties, which can influence certain further industrial processing processes. Nutrient content, fatty acid profile and flavor compounds were also investigated.

The doctoral thesis entitled "Research on the drying processes of porcini mushrooms for the preserving the phisical chemical characteristics and developing an innovative product" achieved its proposed goal of testing the most effective technique for preserving *Boletus edulis* mushrooms, in the form of dry powder , to develop a new functional drink recipe based on buckwheat and mushroom powder, lactically fermented, with improved properties.

To achieve the proposed goal, the research objectives were:

- Identification and selection of an autochthonous raw material, from spontaneous mycota, with a high content of bioactive compounds suitable for achieving the final goal of the thesis.
- Use of classic and modern mushroom drying techniques to maintain a high content of target compounds – hot air drying technology, lyophilization and vacuum centrifugal drying.
- Extraction of targeted bioactive compounds using environmentally friendly techniques and investigating the influence of physical factors on the extraction efficiency (UV-C, magnetic field, microwaves).
- Evaluation of the content of bioactive components in the composition of mushrooms.
- Evaluation of the antioxidant potential of different *Boletus edulis* mushroom extracts, by the FRAP spectrophotometric method.
- Investigating the microstructure through SEM analysis, thermal changes through DSC-TG analysis, as well as color changes of fresh and dried mushroom samples through different technologies.

Evaluation of physical and functional properties (density, solubility, Hausner ratio, rehydration), emulsification properties and profile of fatty acids and flavor compounds of dried mushrooms by hot air drying technology and vacuum centrifugal drying technology.

Conception and technological development of an innovative product, type of functional drink based on buckwheat and *Boletus edulis* mushroom powder, fermented lactically.

Technological characterization in product dynamics and sensory analysis of the newly developed functional drink.

For the realization of this doctoral thesis and the completion of these objectives, the thesis was developed in a number of 198 pages, being structured in 3 main chapters, organized in corresponding sub-chapters, containing a number of 96 figures, 19 tables and a total number of 401 bibliographical references.

The introduction presents the necessity and motivation of choosing the topic by exposing the main objectives of the doctoral thesis.

Chapter 1 ("*Documentary study on the chemical composition and processing technologies of mushrooms*") describes the chemical composition and benefits of mushrooms, as well as the drying processing technologies of edible mushrooms.

Chapter 2 ("*Experimental researches on classical and modern methods of drying of Boletus mushroom investigated in order to preserve bioactive properties*") presents the original results obtained from pre-treatment and drying experiments applying different techniques, classical and modern, carried out with the aim of preserving the bioactive compounds with polyphenolic structure from the selected raw material.

Chapter 3 ("*Physical, physicochemical characterization and functional properties of buckwheat powder as a bioactive ingredient for the development of a functional buckwheat beverage*") contains original experimental data on physical properties, emulsification, fatty acid profile and of the aroma compounds from the studied mushrooms, *Boletus edulis*, in fresh and respectively dry state, the selection of the most efficient drying technology to obtain a mushroom powder necessary for the development of a new functional drink based on buckwheat and mushroom powder, fermented with the help of cultures *Bifidus*, as well as validation of experimental data.

Final conclusions, own contributions and future research directions contains the main conclusions arising from the research carried out within the present doctoral thesis, the own contributions made in the field and the new research directions derived from the proposed theme.

DOCUMENTARY STUDY ON THE CHEMICAL COMPOSITION AND PROCESSING TECHNOLOGIES OF MUSHROOMS - SUMMARY

GENERAL ASPECTS

Humanity's relationship with mushrooms dates back to ancient times, they were called "divine food" by the Romans, because it was believed that they appear thrown from somewhere in the sky to the earth with the help of lightning, because they appear after rain (Manzi et al., 1999) and served them only on special occasions. The Greeks believed that mushrooms gave strength in battle, to warriors; the Chinese people valued mushrooms as an "elixir of life"; Mexican Indians used different species of mushrooms with hallucinogenic effects in religious ceremonies and for therapeutic purposes. Throughout this evolution of knowledge of mushroom species, people have tried and tested mushrooms, often resulting in death, until they became familiar with which species to avoid and which to eat (Miles and Chang, 2004).

A healthy diet is represented by the intake of essential elements, which is necessary for the body's health to perform various functions of regulation, defense and improvement of imbalances or dysfunctions due to a less balanced diet, and in this case, there are alternative methods of nutritional supplements , which may be based on compounds extracted from edible mushrooms (Rizzo et al., 2021).

Long ago, mushrooms have been used as medicines in folk or traditional local medicine by healers in different parts of the world due to their nutritional composition, but without certain scientific evidence (Meng et al., 2017; Zhang et al., 2007).

Edible mushrooms have a very wide area of distribution, they are found in different natural habitats and have been eaten since ancient times to the present day. They present an important component both for the natural environment and for the human body. Edible mushrooms are part of the category of food necessary for the body, due to the biologically active compounds that have an important role in the proper functioning of the body (Bahrim and Petrescu, 1971).

Both wild edible mushrooms and cultivated species are recognized worldwide as functional foods due to important aromatic characteristics and the unique taste they have (Maity et al., 2021). For the food industry, they have attracted remarkable interest as an important source of protein, carbohydrates, fiber, fat, minerals and vitamins (Wang et al., 2014). A daily consumption of mushrooms brings medical benefits, such as regulating blood circulation or preventing certain types of diseases, including cancer (Roncero-Ramos and Delgado-Andrade, 2017).

There are edible mushrooms with good nutritional value, but they are only used as an ingredient in high-value gastronomy, for example species of the genus Agaricus. Other mushrooms are woody and cannot be used as food, but can be used for the extraction of bioactive components or as food supplements, for example Ganoderma lucidum, with medicinal value, but there are some mushrooms that can have both properties, such as Lentinula edodes (Popa and Oancea, 2020a).

In recent years, the human population has become more careful in terms of nutrition and more concerned about health issues, but also to supplement a diet based on a vegetarian diet by consuming natural food supplements, which shows us that mushrooms can perform two important functions: nutritional and medicinal functional food, being important for the prevention of certain types of diseases (Miles and Chang, 2004).

These delicious foods with high nutritional and medicinal values, have a rapid growth in culture, but also in nature if the weather conditions are favorable, which raised the interest in the culture production of certain types of mushrooms (Carrasco et al., 2021). In this sense, there are approximately 200 species cultivated for commercial or experimental purposes, out of the 2000 species of edible fungi existing in the spontaneous mycota (Montes et al., 2020). Among the species cultivated worldwide, 20 are intensively cultivated (Agaricus sp., Pleurotus sp., Auricularia sp., Lentinula edodes, etc.). Their consumption on the global market is increasing, with an estimated increase of approximately 9 million tons in the period 2018-2026 (Zhang et al., 2021). This growth rate is due to both the culinary aspects and the use of mushrooms for medicinal purposes or as nutritional supplements.

According to FAOSTAT (Statistics of the Food and Agriculture Organization) between 2009-2019, the average production of mushrooms and truffles increased worldwide by 4,615,798 tons. The most productive region on the globe is Asia with 93.9%, and the lowest production is represented by Africa 0.1% and Oceania 0.1%. In Europe, mushroom production has been increasing in recent years, representing 4.4% of world production, and America 1.5%, these values being represented in Figure 1.

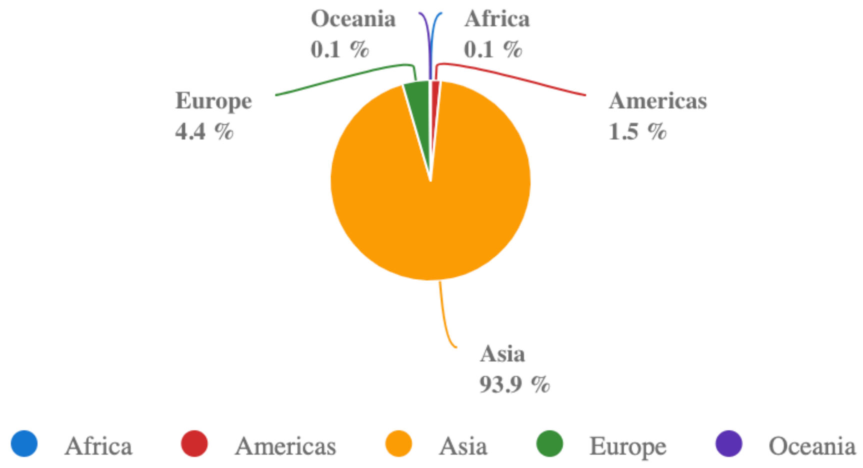

Figure 1. World production of mushrooms and truffles in the period 2009-2019, according to FAOSTAT

This increase in mushroom production and commercial distribution has increased significantly with global population growth and industry expansion (Popa and Oancea, 2020a).

Given that wild edible mushrooms have been part of the human diet for thousands of years, in recent years the most consumed mushroom species in Europe are Cantharellus cibarius, *Boletus sp*. and *Tuber melanosporum* (Cheung, 2008). Since the culinary properties of mushrooms are highly valued, they are used especially as a garnish for other foods, to provide aroma, texture and taste to a dish, being considered vegetables (Barros et al., 2007). According to recent studies, mushrooms are considered an important source of protein in the human diet, low in fat and calories, but rich in protein, fiber, vitamins and minerals (Chang and Hayes, 2013).

2. EXPERIMENTAL RESEARCH ON THE CLASSIC AND MODERN METHODS OF DRYING THE *BOLETUS* MUSHROOM INVESTIGATED FOR THE PURPOSE OF PRESERVING THE BIOACTIVE PROPERTIES

2.4.1.The influence of pre-treatments and the drying process on the physico-chemical properties of *Boletus edulis* mushrooms

Physical, thermal (blanching) and non-thermal (UV-C irradiation) pre-treatments were applied to the investigated mushroom samples before the drying operation, to decrease the microbial load, inactivate enzymes, remove toxic elements or retain color (Xiao et al., 2017).

Regarding dried products, previous results showed that exposure of dried *Boletus edulis* mushrooms to UV-C light contributed to a good retention of antioxidant compounds with polyphenolic structure in the final product (Oancea et al., 2021).

In this PhD thesis, three different drying techniques of *Boletus edulis* mushrooms were investigated to obtain mushroom powders with potential applications in the food industry or functional food supplements/ingredients: hot air drying (HAD), lyophilization (FD) and centrifugal vacuum drying (CVD), the latter being used as an innovative process for drying the boletus mushrooms.

Unlike most published studies dealing with the drying of sliced mushrooms, the present study used mushroom paste (pureed mushrooms).

The evaluation of the quality of dried mushrooms intended for different economic sectors was carried out by methods of analysis of physical properties (dry matter, moisture, rehydration capacity), (bio)chemical (polyphenols, antioxidant activity), microstructural (SEM, FTIR), thermal (DSC , TG) and color (CIELAB).

For the analysis of the performed samples, the terms fresh sample were used for fresh samples without treatment and with pre-treatment marked appropriately (blanched or UV-C), control sample for dry samples without pre-treatment, and for samples subjected to pre-treatment used samples pre-treated in the various specified forms (blanched or UV-C).

2.4.1.1.The influence of the pre-treatment and the drying process on the total drying time of the mushrooms

The effect of pre-treatment on the total drying time of the investigated samples, regardless of the drying method, showed an increase in time (1.39÷1.49 times) for mushrooms pre-treated with UV and for blanched samples.

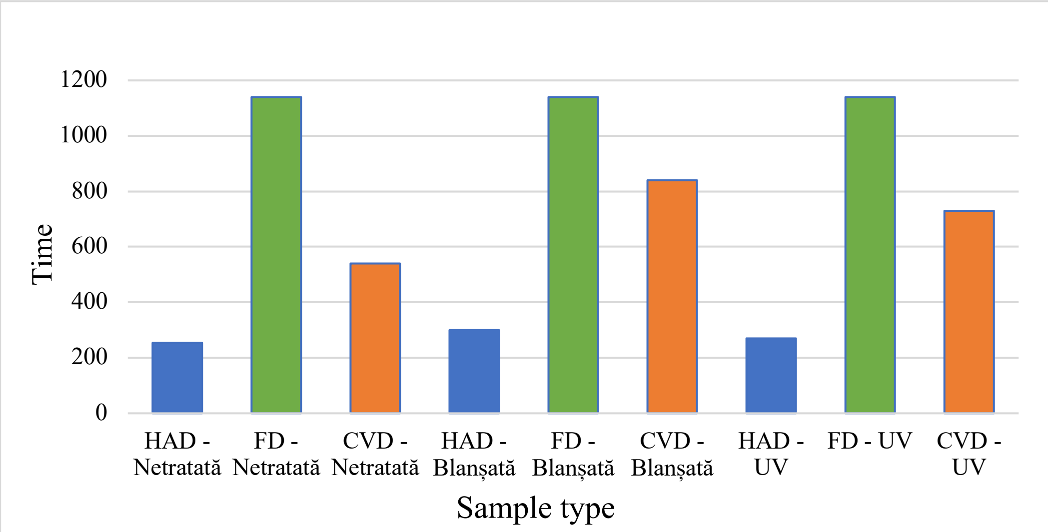

Figure 28. Total drying time of *Boletus edulis* samples depending on the pre-treatment applied and the drying process

The different drying methods applied to *Boletus edulis* mushrooms differently influenced the total drying time required to reduce the moisture content to 6.55% (HAD), 6.31% (FD) and 7.78% (CVD), regardless of the pre-treatment applied, as shown in Figure 29. FD required the longest drying time (1140 min), while HAD determined the shortest time (275 min). These results are in accordance with other published data on the drying time of different food products (Kaveh et al., 2021).

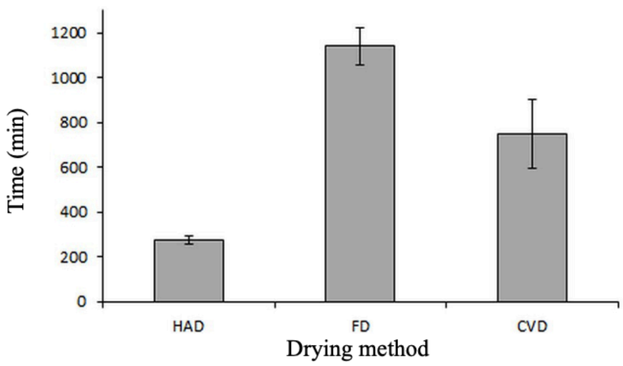

Figure 29. Total drying time of *Boletus edulis* samples depending on the drying process

2.4.2.Evaluation of rehydration capacity, polyphenol content and antioxidant activity of mushroom samples subjected to different types of pre-treatments and drying

2.4.2.1.The rehydration capacity of dried mushroom samples

The rehydration capacity of dried mushrooms was improved by using the freeze-drying technique, FD, compared to the other investigated techniques, HAD and CVD, which led to similar but lower rehydration ratios. The values of the rehydration ratios of the freeze-dried mushroom samples varied from 8.61 to 10.81 depending on the applied pre-treatment. This effectiveness of rehydration is related to the porous structure created by the solid water during the freeze-drying process (Ratti, 2001).

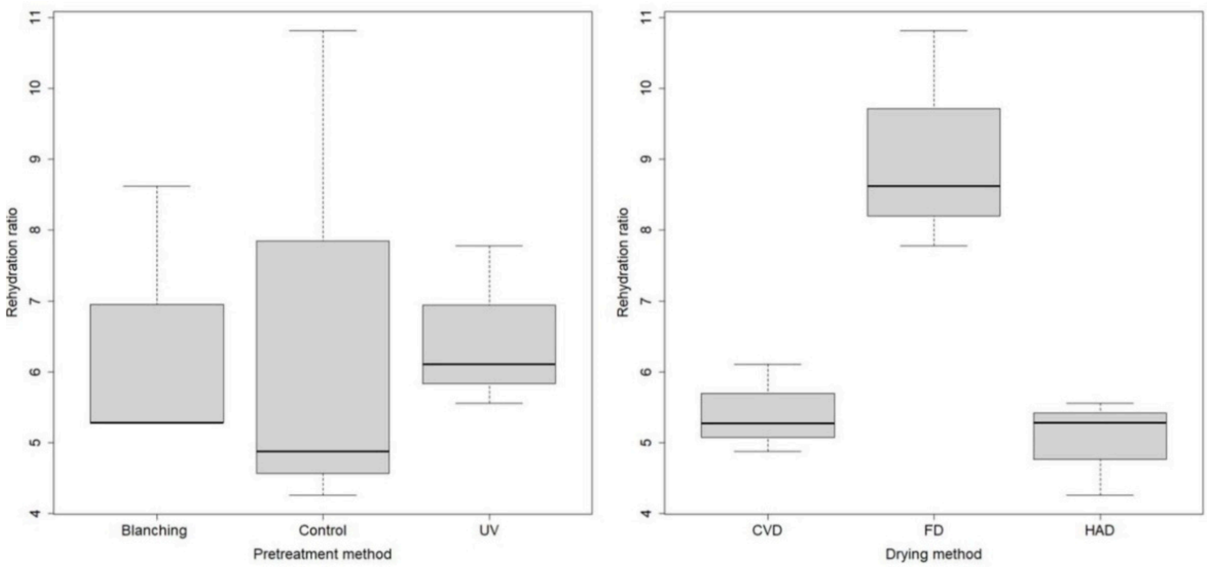

Figure 31. Graphic representation of the rehydration capacity of dried *Boletus edulis* mushrooms depending on the type of pre-treatment and drying applied

Regarding rehydration ability, FD drying without pretreatment or combined with UV-C radiation exposure as a non-thermal pretreatment is a good choice for processing these mushroom species.

2.4.2.2.Polyphenol content of mushroom samples subjected to thermal processing

The fruiting bodies of *Boletus edulis* mushrooms contain various antioxidant compounds such as polyphenols.

The average total polyphenol content of the fresh samples was 14-18% higher than that of the corresponding samples dried by HAD, FD or CVD techniques. A decrease in the total polyphenolic content of *Boletus edulis* mushrooms by lyophilization was also found by other researchers, but an increase in TPC was also detected by hot air drying (Jaworska et al., 2014).

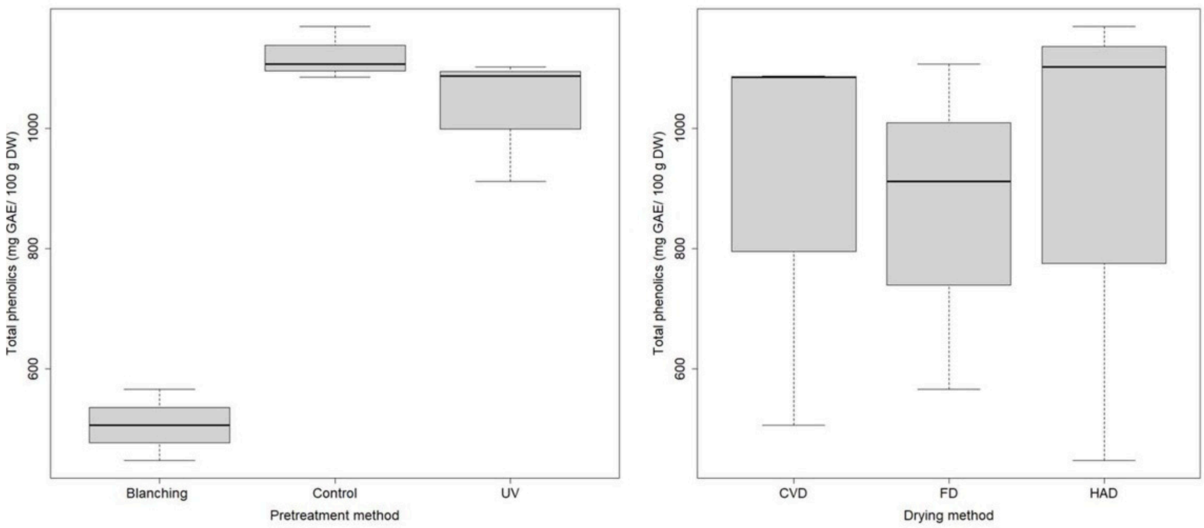

Figure 32. Graphic representation of the total polyphenol content of dried *Boletus edulis* mushrooms according to the type of pre-treatment and drying techniques applied

2.4.2.3.Antioxidant activity of mushroom samples subjected to thermal processing

Regarding the total antioxidant activity (TAA) measured by the FRAP test, the results showed that the average value of TAA in ethanolic extracts obtained from fresh *Boletus edulis* mushrooms (720.039±0.575 mg AA/ 100 g s.u.) was 24-28% higher high compared to that of the extracts obtained from the corresponding samples dried by HAD, FD or CVD.

The antioxidant activity of the fresh samples (864.631±0.137 mg AA/ 100 g d.u.) was lower than that of the fresh sample subjected to UV-C radiation pre-treatment (940.316 ± 0.468 mg GAE/ 100 g d.u.), but higher than that of the freshly blanched sample (355.171±0.120 mg GAE/ 100 g s.u.). These results indicate that UV-C irradiation of wild *Boletus edulis* mushrooms is a better choice as a pre-treatment before drying, while blanching leads to a considerable loss of antioxidant activity due to the high temperature involved.

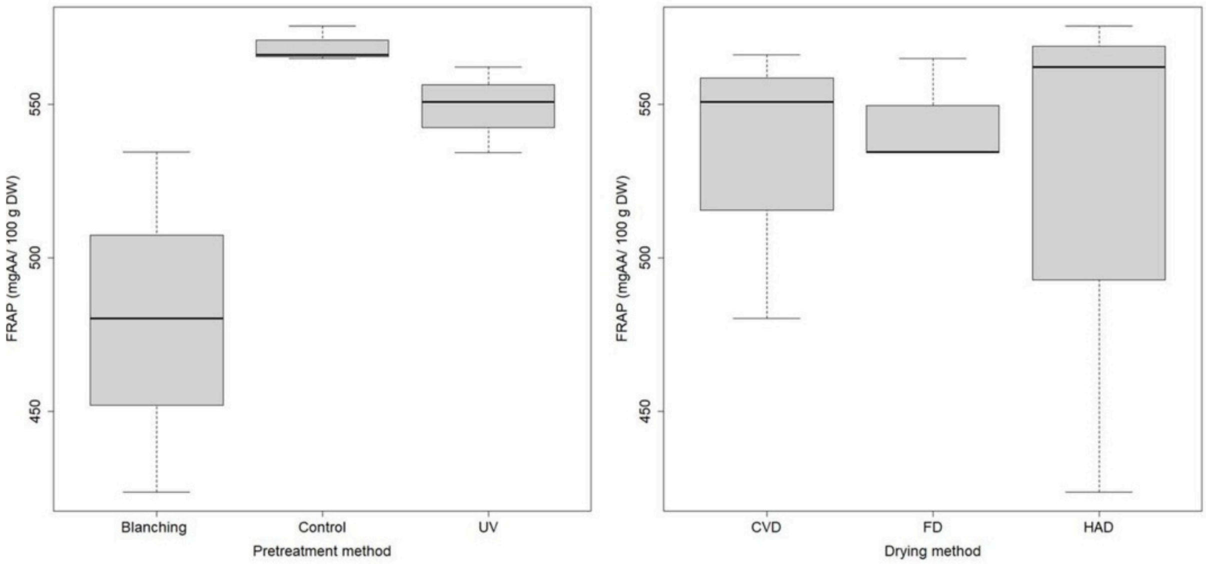

Figure 33. Graphic representation of the antioxidant activity of dried *Boletus edulis* mushrooms depending on the type of pre-treatment and the applied drying technique

2.4.2.4.Evaluation of color changes of mushroom samples subjected to thermal processing

The brightness values (L*) changed depending on the type of pre-treatment and the applied drying process. Blanching and exposure to UV-C radiation of the mushrooms caused an increase in brightness in both fresh and dried samples. The HAD and CVD drying techniques led to a darker color intensification of the untreated mushrooms, while the control samples dried by the FD technique were lighter than the untreated fresh ones. Blanching the mushrooms before the drying operation caused a slight decrease in the L* value in the case of the CVD drying method and a slight increase in the samples dried by the HAD and FD techniques compared to the values obtained for the freshly blanched sample.

Table 3. Color characteristics of fresh and dried *Boletus edulis* mushrooms

Pre treatment type	Drying procedure	L^*	a^*	b^*	E^*	White index	Yellow index
Control sample (without pre treatment)	– fresh	91.67±1.68	-11.38±0.64	81.41±1.85	-	-185.53	83.02
Blanched	– fresh	97.83±2.21	-13.39±1.43	42.14±1.44	-	-104.16	52.58
UV	– fresh	96.80±2.01	-12.39±1.66	43.77±1.11	-	-107.95	54.37
Control sample	HAD	81.58±1.07	4.42±0.47	79.02±1.33	18.91	-145.06	85.71
	CVD	83.33±1.87	0.57±0.11	91.33±2.04	17.63	-164.60	90.38
	FD	92.43±1.30	-7.52±0.75	28.57±0.61	52.98	-49.09	40.03
Blanched	HAD	98.54±3.22	-4.32±0.70	9.64±0.75	33.91	39.83	14.65
	CVD	97.64±2.50	-10.30±1.89	25.13±0.86	17.41	-36.44	34.69
	FD	98.71±2.25	-6.88±0.53	15.95±1.01	27.16	7.29	23.11
UV	HAD	94.04±1.86	-5.16±0.42	24.76±0.97	20.52	-34.37	35.06
	CVD	96.90±2.10	-3.65±0.21	17.41±0.82	27.78	-0.86	25.23
	FD	96.56±2.05	-5.32±0.78	15.73±1.03	28.93	6.87	23.11

2.4.2.5.Micro-structural properties through SEM analysis of mushroom samples subjected to thermal processing

The heat treatment caused physical changes in the microstructures of the samples, as a result of the rupture of the cell walls that determined a disordered structure (Lv et al., 2014). The images of all the samples show tears, cracks and holes due to the grinding process which causes the intermolecular bonds to break. A homogeneous compact structure was observed in the samples pre-treated by exposure to UV-C before drying. Among the different types of drying, freeze-drying, especially in the untreated or UV-treated samples, led to the least physical changes compared to the control samples, showing microporous and fibrous structures. Lewicki and Pawlak in 2003 confirmed that changes in the microstructure of food samples subjected to drying are largely due to thermal and hydro stress of the tissue, observable through macro- and micro-alterations of size, shape and internal structure.

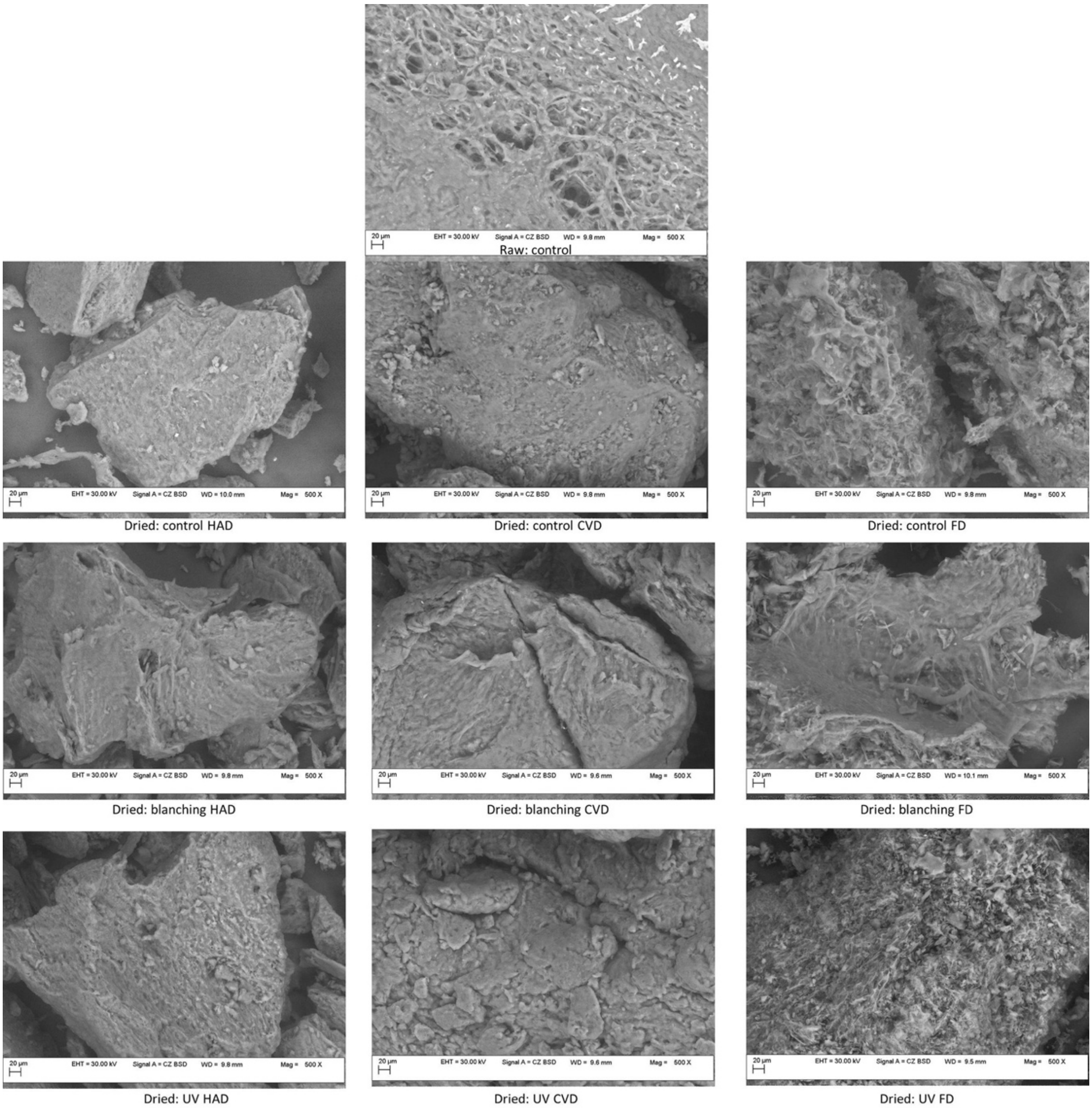

Figure 34. SEM micrograph images of fresh and pre-treated *Boletus edulis* mushrooms dried by different techniques (500 X)

2.4.2.6.Evaluation of chemical changes in dried mushrooms using Fourier Transform Infrared spectroscopy (FTIR)

Differences were observed in region I of the IR absorption spectra in dried mushroom samples without pre-treatment (Figure 36), especially for samples dried by HAD or CVD techniques, where absorption bands from 2923 cm^{-1} and 2853 cm^{-1} attributed to the stretching vibration of the carbohydrate C-H bond were of higher intensity.

All dried mushrooms showed broad bands in the IV region compared to the fresh sample, probably due to heat-induced structural changes on carbohydrates. In dried samples pre-treated by bleaching or UV-C irradiation (Figures 37 and 38), additional absorption bands at 1744 cm^{-1} attributed to the C=O stretching vibration of phospholipids were observed (Bekiaris et al., 2020), except for the sample pre-treated with UV-C radiation and dried by the FD technique. The drying method determined some structural changes in the carbohydrates, as shown by the differences recorded in region IV of the absorption spectrum, compared to the fresh sample, where the absorption bands at 1075 cm^{-1} are no longer well defined.

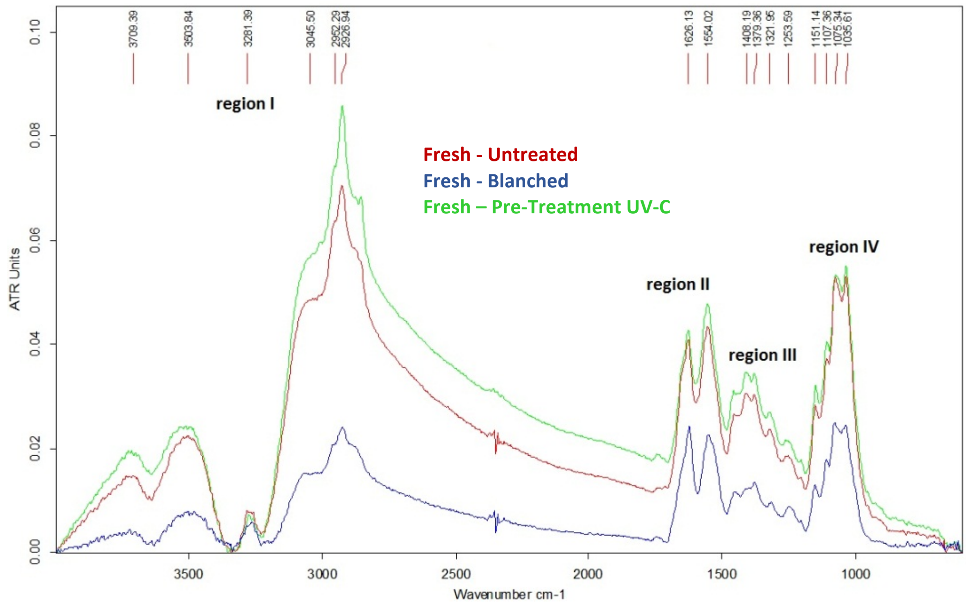

Figure 35. ATR FTIR spectra of *Boletus edulis* mushroom samples, fresh, untreated and subjected to different pre-treatment methods (blanching and UV-C)

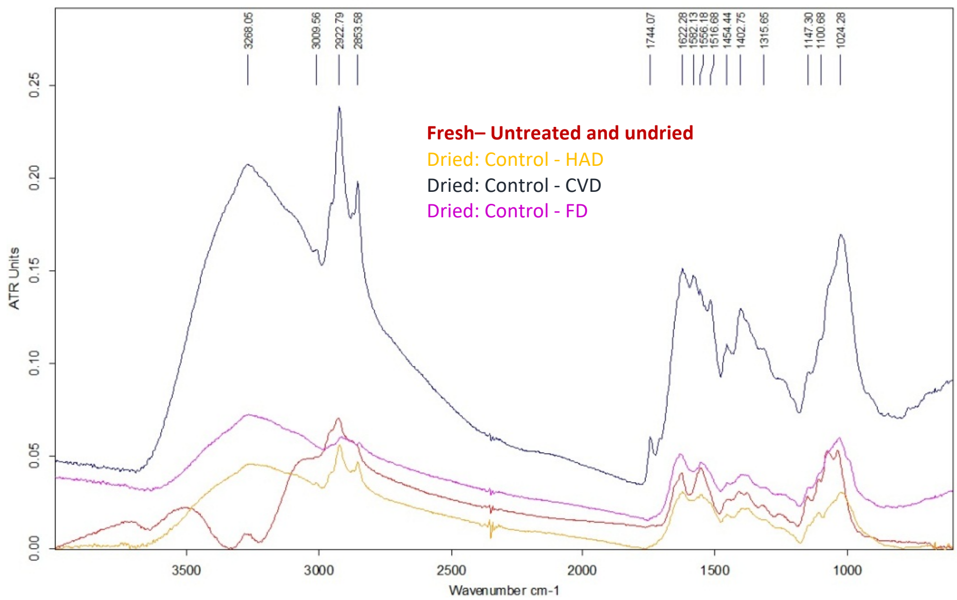

Figure 36. ATR FTIR spectra of *Boletus edulis* mushroom samples, fresh and dried without pre-treatment

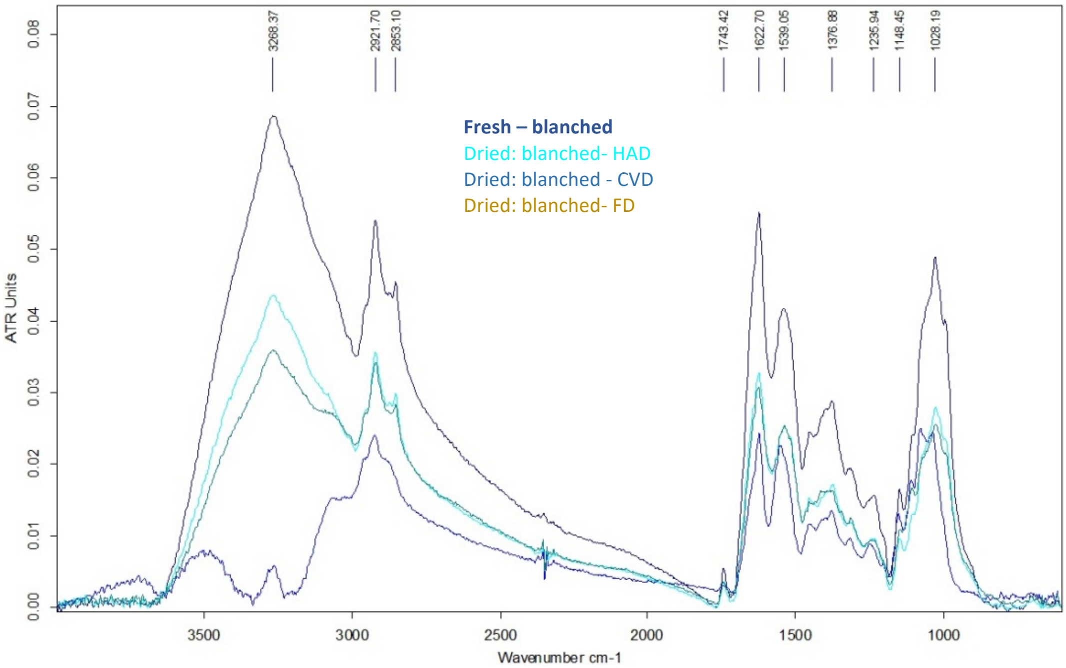

Figure 37. ATR FTIR spectra of fresh and dried *Boletus edulis* mushroom samples, pre-treated by blanching

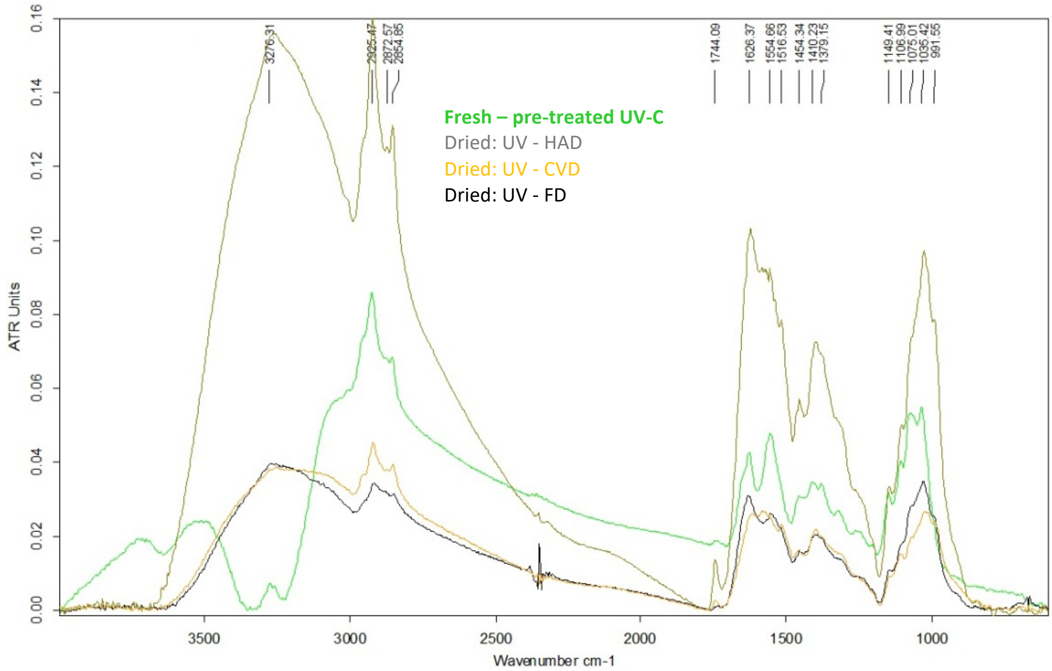

Figure 38. ATR FTIR spectra of *Boletus edulis* mushroom samples, fresh and dried, pre-treated with UV-C radiation

2.4.2.7.Thermal properties and mass loss of mushroom powders

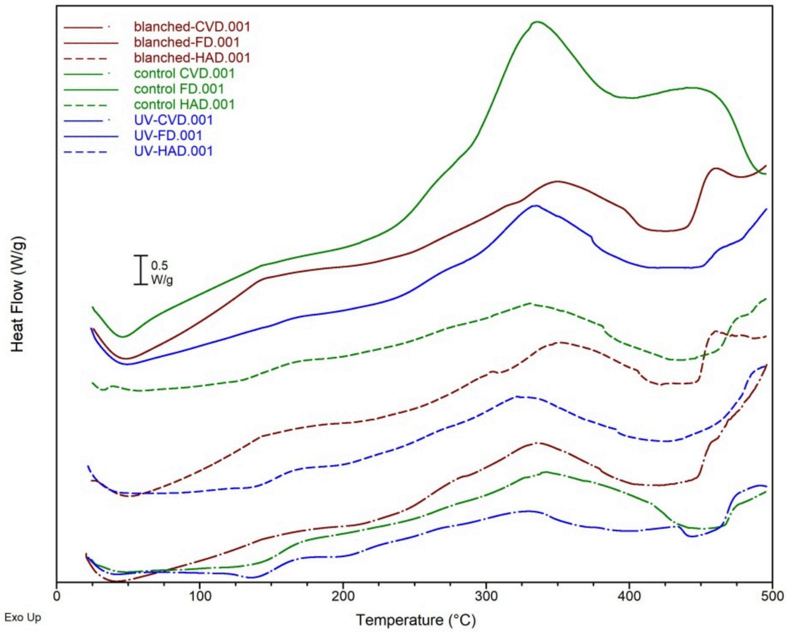

Figure 39. DSC plot of *Boletus edulis* mushroom samples subjected to different pre-treatment methods and drying techniques, for the temperature range 25 - 500 °C

The DSC curves indicate five thermal transitions of the mushroom powders, of which 2 endothermic and 3 exothermic peaks. The first broad endothermic peak in the temperature range of 42–57 °C, observed in all DSC curves except the UV-HAD sample, was mainly attributed to gelatinization of polysaccharides (Ferrero et al., 2016). Proteins undergo gelation upon heating, consisting of endothermic transitions (denaturation, 50–85 °C) and exothermic processes (intermolecular aggregation), as studied on different types of proteins (Ju et al., 1999). The lack of the first endothermic peak for the UV-HAD sample is correlated with the changes associated with the protein conformational change observed by FTIR analysis in the present PhD study. As seen in Figure 39, an additional second endothermic event in the temperature range of 106–145 °C was predominant for (UV-C) samples dried by HAD and CVD techniques.

These events could be due to changes in chitin, a structural polysaccharide present in fungi (Shakir et al., 2020; Ospina et al., 2014; Kalač, 2009).

2.4.3.The influence of irradiation of dried mushrooms with UV-C light on the content of polyphenols, tannins and antioxidant activity

Table 7. Values of total polyphenol content, total tannin content and antioxidant activity of dried mushroom samples, in the presence and absence of UV-C radiation depending on the time and distance of irradiation

Parameters	**Control**	**UV-C radation treated samples**			
		Exposure time (min)	Exposure distance (cm)		
			10	15	20
Polifenols (mg GAE/ 100 g s.u.)	588.21±7.53	15	576.33±7.20	591.31±7.39	589.43±9.91
		30	554.68±6.93	584.20±7.30	689.65±8.62
Tanins (mg catechina/ 100 g s.u.)	85.98±0.12	15	86.95±0.25	94.29±0.08	84.05±0.17
		30	86.93±0.17	99.53±0.19	94.17±0.14
Antioxidative Activity (mg AAE/ 100 g s.u.)	434.98±2.10	15	458.25±1.11	467.82±1.46	455.19±2.04
		30	467.81±1.06	470.85±2.40	467.24±2.21

Note: results represent mean values of duplicate determinations ± standard deviation.

TPC decreased to a small extent during UV-C treatment at the shortest exposure distance (10 cm), indicating a polyphenol degradation process, but at a low rate. Mushroom powder irradiated for 30 minutes at the largest investigated distance (20 cm) had the highest TPC value (689.65 ± 8.62 mg GAE/ 100 g s.u.), 17% higher than in the group control, which highlights the potential use of these experimental conditions to improve the extraction of polyphenols from dry *Boletus edulis* powder.

2.4.3.1.Comparative ATR-FTIR analysis of control and UV-C light irradiated samples

By recording the ATR-FTIR spectra of control and UV-C irradiated samples of dried *Boletus edulis* mushrooms, some differences were found as follows: 30 min at 15 cm, 15 min at 15 cm and 30 min at 20 cm. The ATR-FTIR spectra are shown in Figures 42 – 43.

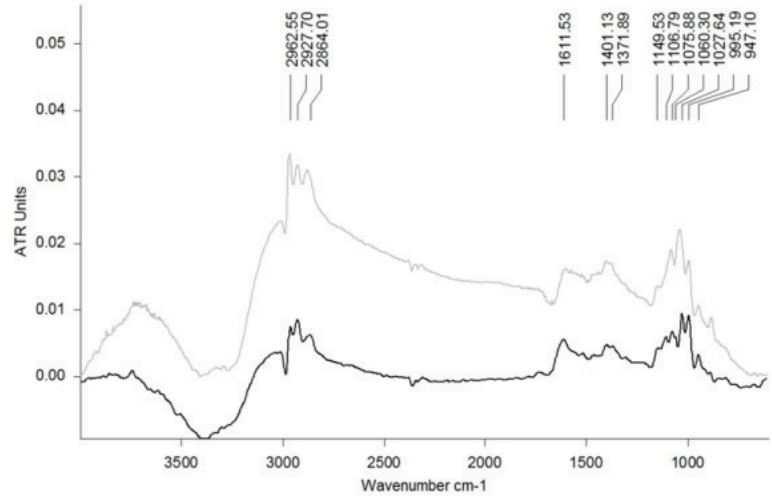

Figure 42. ATR-FTIR spectra of mushroom powders, control (–) and treated with UV-C radiation for 30 min at 15 cm exposure distance (–)

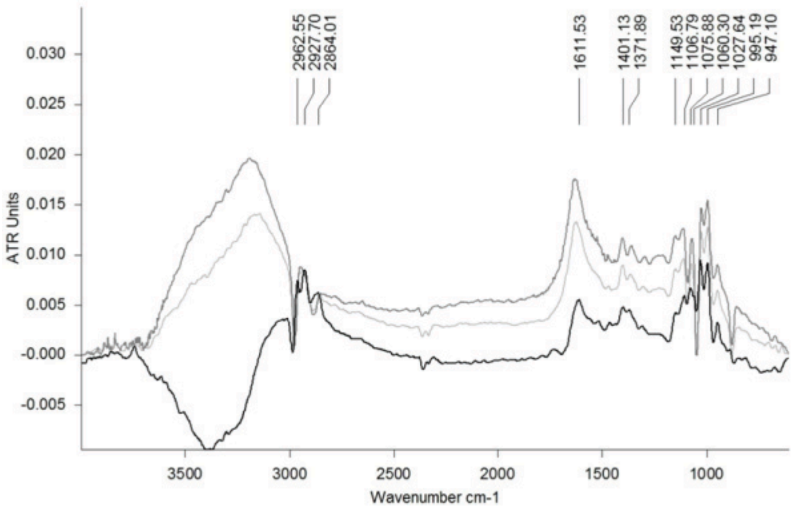

Figure 43. ATR-FTIR spectra of mushroom powders, control (–) and treated with UV-C radiation for 15 min at 15 cm (–) and 30 min at 20 cm exposure distance (–)

Changes in the FTIR spectra of the irradiated samples were identified. Thus, the absorption bands at 1106 and 1060 cm^{-1} attributed to polysaccharide groups no longer appear in the spectra of the irradiated sample, probably due to the hydrolysis of polyphenols attached to cell wall polysaccharides, especially tannins. This is correlated with previous results in the present study showing an increased TTC content for the irradiated sample (30 min, 15 cm) (Table 7).

2.4.4.Influence of microwave irradiation of fresh and dried mushroom extracts on polyphenol content and antioxidant activity

Table 9. Polyphenol content and antioxidant activity of fresh mushroom samples in the presence and absence of microwave irradiation in ethanol solution, depending on exposure time and frequency

Parameters	Control sample	exposure time [h]	Frequency [GHz]	Incident electric field power [$V\cdot m^{-1}$]	Samples tread with MW
Total Poliphenols (mg GAE/ 100 g s.u.)	894.182±0.447	3	1.7	775	1127.937±0.310
		0.5	2.5	750	1064.599±0.068
		3	2.5	700	1140.506±0.073
Antioxidative activity (mg AAE/ 100 g s.u.)	732.4862±0.710	3	1.7	775	983.219±27.059
		0.5	2.5	750	954.178±27.764
		3	2.5	700	976.238±27.586

According to the results obtained, the average values of both the content of polyphenolic compounds and the antioxidant activity of the samples exposed to microwave radiation, regardless of the time, frequency or incident electric field, were higher than those of the control sample.

The total polyphenol content of extracts obtained from fresh mushrooms increased by 27.5% after microwave treatment at the highest frequency (2.5 GHz) and a 3-hour exposure compared to the control sample, indicating that microwave radiation enhanced the extraction of compounds with a phenolic structure, most likely due to the disruption of the cell membrane that facilitates the release of such compounds (Delazar et al., 2012). Regarding the influence of the exposure time, a longer time resulted in an increase in the polyphenol value and the antioxidant activity, regardless of the radiation frequency. The highest value of antioxidant activity was established in the sample exposed to 1.7 GHz for 3 hours, showing an increase of 34.2% compared to the control sample.

Regarding the experiment of exposure to microwave radiation under different exposure conditions of mushroom powders mixed with 70% ethanol, the results obtained regarding the evolution of TPC and TAA content, subjected to microwave treatment, are presented in Table 10.

Table 10. Polyphenol content and antioxidant activity of mushroom powders in the presence and absence of microwave irradiation in ethanol solution, depending on the time and frequency of irradiation

Parameters	Control sample	Exposure time [h]	Frquency [GHz]	Incident electric field power [$V \cdot m^{-1}$]	Sample treated with MW
Total Poliphenols (mg GAE/ 100 g s.u.)	1141.741±2.090	0.5	2.5	450	1122.085±2.892
		1	2.5	430	1129.365±2.941
		3	2.5	700	1103.233±2.460
		0.5	1.7	450	1357.398±3.338
		1	1.7	430	1192.517±3.113
		3	1.7	370	1107.645±2.972
Antioxidative activity (mg AAE/ 100 g s.u.)	594.365±2.783	0.5	2.5	450	594.224±11.977
		1	2.5	430	589.897±14.654
		3	2.5	700	582.727±1.906
		0.5	1.7	450	581.510±10.878
		1	1.7	430	591.945±1.889
		3	1.7	370	560.972±0.619

No significant differences in total polyphenol content were found between the control and microwave-irradiated samples, except for the mixture of mushroom powder and ethanol solution exposed to microwaves at 1.7 GHz, exposure time of 0.5 hours, which recorded the highest content of polyphenols, respectively 1357.398±3.338 mg GAE/ 100 g s.u.. The TPC value for this sample was 18.8% higher than that of the control sample. The lowest content of polyphenols was obtained for a longer exposure time (3 h) at 2.5 GHz (1103.233±2.460 mg GAE/ 100 g s.u.). This is different from the results on the evolution of TPC in extracts obtained from fresh mushroom samples, indicating that the presence of water inside the samples can influence the extraction efficiency.

2.4.4.1.ATR-FTIR analysis of ethanolic extracts of fresh *Boletus edulis* mushrooms irradiated with microwaves

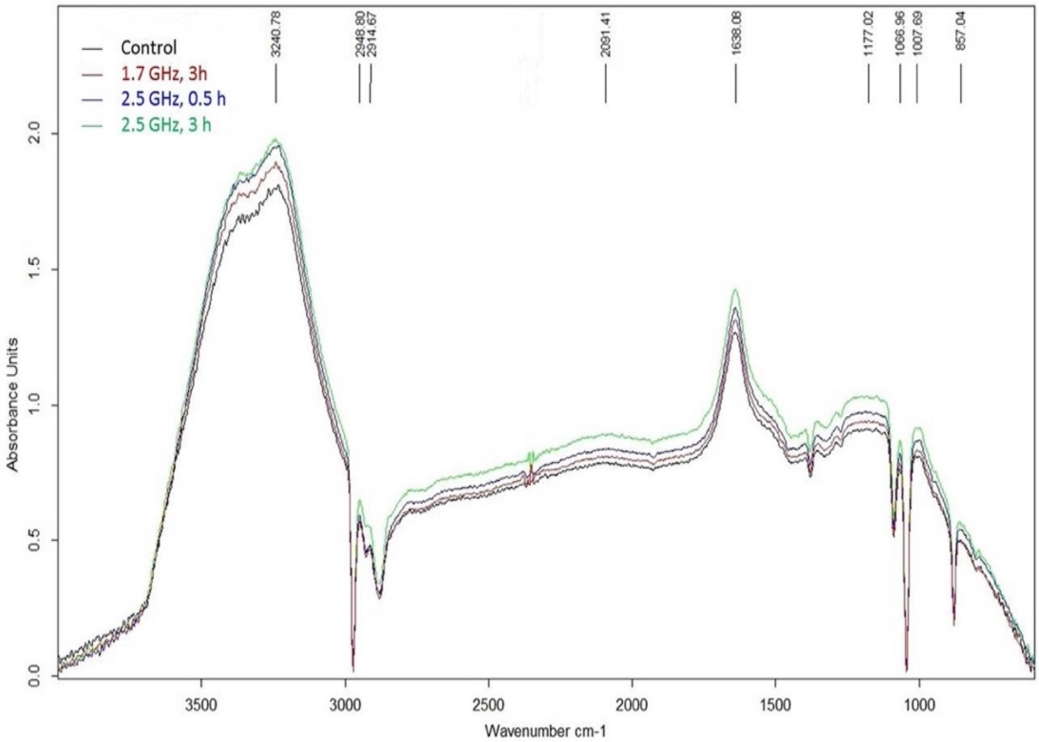

Figure 46. ATR-FTIR spectra of fresh, control and microwave-irradiated mushroom extracts under different experimental conditions

As can be seen from Figure 46, no major changes occurred in the microwave-irradiated samples compared to the control sample, indicating that these radiations did not influence the chemical structures of the compounds, but facilitated the extraction due to mechanical processes (breaking cell membrane).

2.4.5.The influence of exposure of dried mushrooms to extremely low frequency electromagnetic radiation on the content of polyphenols, tannins and antioxidant activity

The antioxidant activity of the sample exposed for 240 min does not greatly exceed the activity of the control sample. There are no significant differences for the content of polyphenols, regarding the control sample and the sample exposed for a long time (240 min), the percentage being 2.41%.

The content of tannins in the control sample is 85.98±0.12 mg/ 100 g s.u., and in the sample with the longest exposure 89.45±0.12 mg/ 100 g s.u., the difference being 3.87%. There are small, very insignificant differences between the control sample and the exposed samples.

Table 11. Total content of polyphenols, tannins and antioxidant activity of mushroom powders exposed to 50 Hz magnetic field and the control sample, depending on the exposure time

Parameters	Control Sample	Samples treated in magnetic field (3 mT, 50 Hz)				
		Timpul de expunere (min)				
		15	30	60	120	240
Polifenols (mg 100/ g s.u.)	588.21±7.53	573.51±6.80	577.73±7.88	570.96±7.76	592.40±7.56	602.78±6.55
Tanins (mg 100/ g s.u.)	85.98±0.12	85.05±0.07	87.18±0.10	87.93±0.11	88.39±0.12	89.45±0.12
Antioxidative activity (mg 100/ g s.u.)	434.98±2.10	430.08±1.22	432.86±1.21	434.53±1.13	435.92±0.98	435.82±0.95

2.4.5.1. ATR-FTIR analysis of ethanolic extracts of dried mushrooms subjected to ultra-low frequency electromagnetic radiation

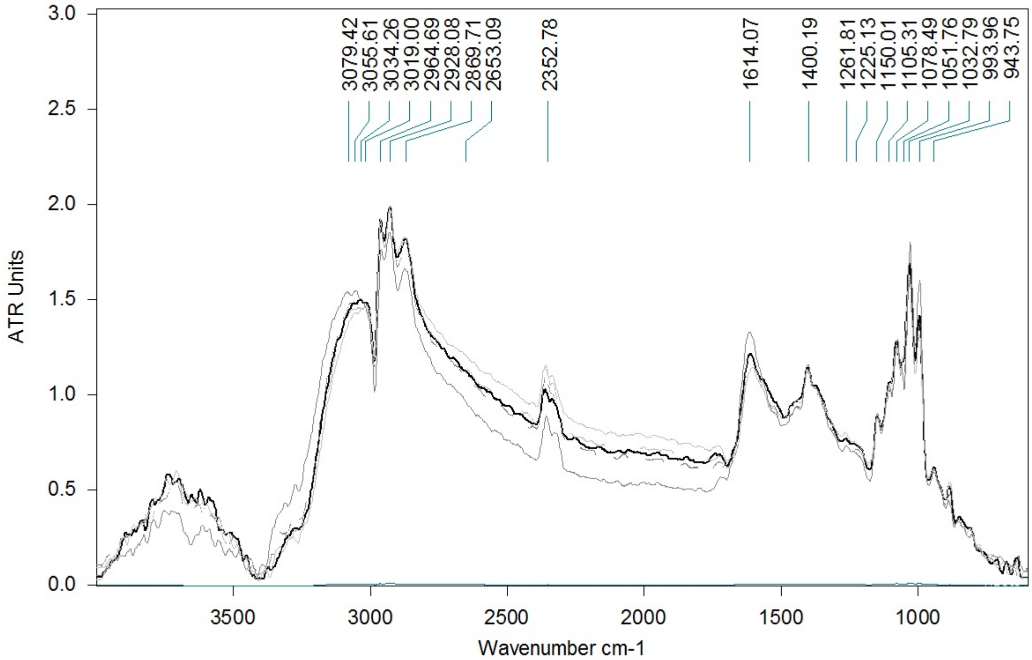

Figure 47. ATR-FTIR spectra of mushroom powders, control (–) and irradiated in magnetic field (3 mT, 50 Hz) at different exposure time 15 (–), 30 (–), 60 (–), 120 (–) and 240 (–) minutes

The obtained results indicate a slight increase in the content of TPC, TTC and FRAP antioxidant activity with increasing exposure time to MF, but the differences were not statistically significant compared to the control sample, at $p < 0.05$. The weak effect of the 50 Hz magnetic field could be explained by the effect given by the previous dehydration on the samples, since most studies have shown that MF mainly influences the physicochemical properties and structure of water (Răcuciu and Olosutean, 2019; Chang and Weng, 2006), which may indirectly favor the extraction of bioactive compounds from fresh samples or samples with higher water content.

3. PHYSICAL, PHYSICO-CHEMICAL CHARACTERIZATION AND FUNCTIONAL PROPERTIES OF BUCKWHEAT POWDER AS A BIOACTIVE INGREDIENT FOR THE DEVELOPMENT OF A FUNCTIONAL BEVERAGE BASED ON BUCKWHEAT

Considering the fact that the results obtained and described in the previous chapters for the hot air drying and vacuum concentrator technologies, respectively, confirmed the preservation of important bioactive properties (polyphenols and antioxidant activity), it was considered an important step to investigate the effect of using those two drying technologies on physical properties of mushroom powders (density, Hausner ratio, solubility, rehydration and emulsification parameters) as well as on nutrient composition, fatty acid profile and flavor compounds.

3.5.1.EVALUATION OF PHYSICAL AND PHYSICO-CHEMICAL PROPERTIES OF *BOLETUS EDULIS* MUSHROOM POWDER

The physical properties of *Boletus edulis* mushroom powders (moisture content, bulk density, compacted density, Hausner ratio, solubility, water solubility index – WSI, and rehydration ratio – RR) are represented in Table 14.

Table 14. Physical properties of dried mushroom powders by HAD and CVD methods

Samples	**Humidity content (%)**	**Aparent density in a free state (g/cm^3)**	**Density in compressed state (g/cm^3)**	**HR**	**Solubility (g/100 g apă)**	**WSI (%)**	**RR (g/g s.u.)**
Dried with HAD	6.52	0.885±0.007	1.050±0.037	1.186	0.266±0.025	24.688±2.670	4.020±0.216
Dried with CVD	5.89	0.765±0.057	1.047±0.074	1.368	0.316±0.015	28.525±1.475	3.012±0.441

3.5.2.EMULSIFICATION PROPERTIES OF *BOLETUS EDULIS* MUSHROOM POWDER

Figure 70 illustrates the emulsifying activity index (EAI) and emulsion stability index (ESI), evaluated for *Boletus edulis* mushroom powders obtained by the two drying technologies, HAD and CVD.

The samples dried by the CVD drying technology presented slightly higher values of EAI (4.963±0.828 m2/g) and ESI (34.741±7.701 min), compared to the samples dried by the HAD technology that presented EAI values (4.687±0.923 m2 / g) and ESI (33.741±7.510 min), which indicates better emulsion stability for samples dried by CVD technology.

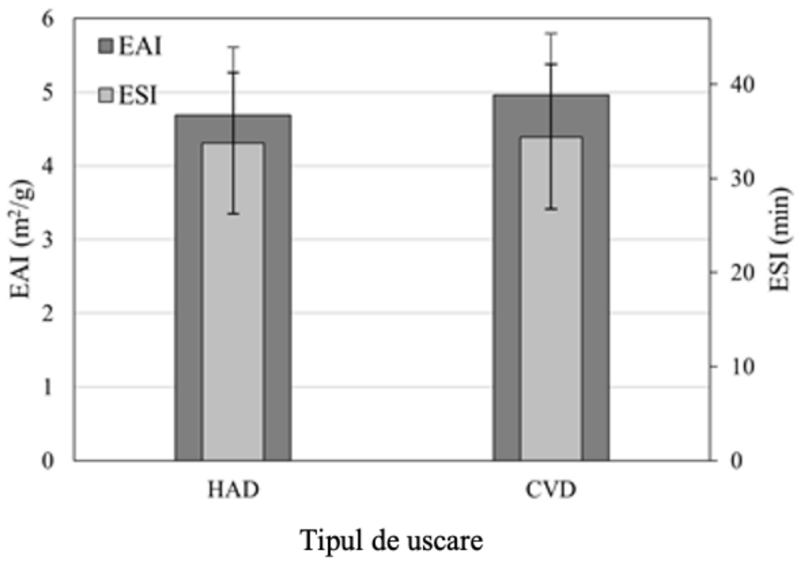

Figure 70. Emulsifying activity index (EAI) and emulsion stability index (ESI) of *Boletus edulis* mushroom powders, depending on the applied drying technologies

3.5.3. NUTRIENT CONTENT OF *BOLETUS EDULIS* MUSHROOMS

In our study, the nutritional composition of fresh and dried mushroom samples was determined, taking into account the moisture content values, which varied from 82.5±0.25% for the fresh sample to 6.51±0.20% for the HAD dry sample and 5.89±0.05% for the CVD dry sample. The nutritional value of mushrooms, in terms of moisture and protein content, decreases rapidly after harvest (Braaksma and Schaap, 1996). The protein content of the dry samples is 36.35±0.17 g/ 100 g in the CVD dry sample and 34.65±0.17 g/ 100 g in the HAD dry sample, respectively, compared to the value of 7.45±0, 17 g/100 g determined in the fresh sample. The carbohydrate content, calculated by difference, is in the highest amount: 52.15±0.07 g/ 100 g in the HAD dry sample, followed by 50.45±0.22 g/ 100 g in the CVD dry sample and 8.24±0.12 g/ 100 g in the fresh sample.

Table 15. Nutritional value of wild mushrooms *Boletus edulis* – fresh samples, dried by HAD and CVD technology, compared to that reported in other studies

Sample type/ Caracteristics	Humidity (%)	Proteins (g/ 100 g product)	Lipids (g/ 100 g product)	Sugars (g/ 100 g product)	Ash (g/ 100 g product)	Energy (Kcal/ 100 g product)
Fresh Sample	82.5±0.25	7.45±0.27	0.87±0.03	8.24±0.12	0.935±0.04	70.62±0.31
Dried Sample HAD	6.51±0.20	34.65±0.17	3.06±0.01	52.15±0.17	4.614±0.04	370.82±0.41
Dried Sample CVD	5.89±0.05	36.35±0.17	2.52±0.03	50.45±0.22	4.781±0.05	369.91±0.45
Nutritional values for the species *Boletus edulis* from the specialized literature						
***Boletus edulis* fresh** (Heleno and colab., 2011)	89.15±0.90 g/ 100 g s.u.	21.07±0.66 g/ 100 g s.u.	2.45±0.09 g/ 100 g s.u.	70.96±0.66 g/ 100 g	5.53±0.23 g/ 100 g s.u.	390.11±2.58 g/ 100 g s.u.
***Boletus edulis* dried** (Beluhan and Ranogajec, 2011)	12.23±0.41 %	36.91±0.02 g/ 100 g	2.29±0.41 g/ 100 g	64.27±0.21 g/ 100 g	5.3±0.87 g/ 100 g	1488.10±0.18 g/ 100 g
***Boletus edulis* dried** (Fogarasi and colab., 2018)	7.73±0.18 g/ 100 g s.u.	36.24±0.12 g/ 100 g s.u.	1.92±0.09 g/ 100 g s.u.	46.23±0.22 g/ 100 g s.u.	8.38±0.07 g/ 100 g s.u.	347.5±0.52 g/ 100 g s.u.

3.4.5. EVALUATION OF THE FATTY ACID PROFILE FROM *BOLETUS EDULIS* MUSHROOMS, THROUGH THE GC-MS TECHNIQUE

The results regarding the content of fatty acids, saturated and unsaturated, identified by the GC-MS technique in the analyzed mushroom samples, indicate a total number of 21 compounds for the fresh sample, the dried sample by hot air drying (HAD) technology and the dried sample by vacuum spin drying (CVD) technology (Table 16).

The main fatty acids identified in large amounts were linoleic acid (C18:2 n-6), followed by oleic acid (C18:1 n-9) and palmitic acid (C16:0). Linoleic acid is known to be the precursor of mushroom alcohol (1-octan-3-ol), being the main flavor compound of mushrooms (Barros et al., 2008). In addition to these 3 identified fatty acids, 18 more acids were identified and are shown in Table 16.

Table 16. The content of fatty acids identified in the fresh sample and in the dried samples by the two methods (HAD and CVD) of *Boletus edulis* mushrooms

Name of fatty acids and type of omega	Content (%)		
	Raw sample	Dried by HAD	Dried by CVD
Caproic acid (C6:0)	0.06±0.01	0.09±0.02	0.02±0.01
Caprylic acid (C8:0)	0.04±0.01	0.14±0.04	0.02±0.01
Capric acid (C10:0)	0.04±0.01	0.09±0.01	0.03±0.01
Myristic acid (C14:0)	0.24±0.02	0.39±0.04	0.22±0.02
Pentadecanoic acid (C15:0)	0.39±0.04	0.39±0.04	0.30±0.03
Palmitic acid (C16:0)	11.31±0.62	11.68±0.64	12.49±0.69
Hypogeic acid (C16:1 n-9)	0.21±0.03	0.24±0.04	0.22±0.03
Palmitoleic acid (C16:1 n-7)	0.63±0.03	0.69±0.03	0.74±0.03
Margaric acid (C17:0)	0.13±0.01	0.05±0.01	0.11±0.01
Stearic acid (C18:0)	2.39±0.11	1.64±0.07	1.75±0.08
Oleic acid (C18:1 n-9)	28.75±1.28	22.31±0.99	23.94±1.07
Vaccenic acid (C18:1 n-7)	1.95±0.09	1.66±0.07	2.07±0.09
Linoleic acid (C18:2 n-6)	51.91±2.08	58.52±2.34	56.45±2.26
α-linolenic acid (C18:3 n-3)	0.08±0.02	0.03±0.01	0.03±0.01
Arachidic acid (C20:0)	0.34±0.02	0.35±0.04	0.19±0.02
Gondoic acid (C20:1 n-9)	0.30±0.05	0.00±0.00	0.25±0.04
Eicosadienoic acid (C20:2 n-6)	0.22±0.02	0.38±0.04	0.25±0.03
Behenic acid (C22:0)	0.30±0.06	0.42±0.08	0.25±0.05
Erucic acid (C22:1 n-9)	0.16±0.03	0.22±0.04	0.17±0.03
Lignoceric acid (C24:0)	0.31±0.03	0.34±0.03	0.25±0.03
Nervonic acid (C24:1 n-9)	0.23±0.03	0.36±0.05	0.24±0.04

The results in Table 16 indicate an increase in the content of linoleic acid in the samples dried by both drying technologies, accompanied by a decrease in the content of some monounsaturated fatty acids (oleic acid and gonoic acid). This could be explained by the changes produced in the lipid structures during the processing of the raw materials (homogenization, drying, shredding), which can favor the action of some enzymes, desaturase and elongase, involved in the conversion of oleic acid into linoleic acid and the elongation of gondolic acid into erucic and neural respectively (Yuan and Bloch, 1961; Zhang et al., 2016). A slight increase in linoleic acid content was also reported by other authors in mandarin seed oil after drying the seeds at 60 °C or 70 °C (Al Juhaimi et al., 2018).

3.5.5.EVALUATION OF THE PROFILE OF VOLATILE FLAVOR COMPOUNDS FROM *BOLETUS EDULIS* MUSHROOMS, THROUGH THE HS-ITEX/GC-MS TECHNIQUE

The most aroma compounds identified in the fresh sample were 1-octan-3-ol (70.52±1.13%), 2-methyl-2-butanal (11.88±0.15%), 1-octan-3-one (9.06±0.11%) and (E)-2-octanal

(5.74±0.06%). Odor-wise, the C8 aroma compounds 1-octan-3-ol and 1-octan-3-one were described as "earthy/mushroomy", while the other compounds were given other characteristics, such as: (E)-2-octanal "green, grass"; 3-octanone "sweet, fruity, musty"; 1-octanol "detergent, soap"; "grass" (E)-2-octan-1-ol; "Metallic" 1-octan-3-one (Sun et al., 2020; McGorrin, 2002). The aromatic profile of fresh edible mushrooms can vary depending on their maturity (Sun et al., 2020), storage time and temperature, but also the analysis techniques applied (Leffingwell and Alford, 2011).

Table 17. Flavor compounds from fresh and dried *Boletus edulis* mushrooms by HAD and CVD techniques

Compound	Content (%)		
	Raw Sample	Dried by HAD	Dried by CVD
Alcohols			
3-Metil-1-butanol	n.d.	0.28±0.04	0.37±0.03
1,7-Octadien-3-ol	0.03±0.001	n.d.	n.d.
1-Octanol	n.d.	0.16±0.01	n.d.
1-Octen-3-ol	70.5±1.13	91.71±1.32	91.25±1.41
(€-2-Octen-1-ol	0.04±0.001	0.20±0.01	n.d.
(Z)-2-Octen-1-ol	1.12±0.03	2.48±0.09	2.99±0.03
Octen-1-ol, acetate	n.d.	0.22±0.02	n.d.
(Z)-3-Octen-1-ol, acetate	n.d.	0.07±0.001	n.d.
Aldehydes			
Benzaldehyde	0.20±0.008	0.10±0.001	n.d.
Benzene acetaldehyde	n.d.	0.30±0.01	0.20±0.02
Dodecanal	0.03±0.001	n.d	n.d.
2-Ethyl-2-hexenal	n.d.	0.28±0.03	n.d.
2-Ethyl-trans-2- butenal	0.29±0.01	n.d.	n.d.
Heptanal	n.d.	0.39±0.39	0.41±0.02
Hexanal	0.41±0.01	0.98±0.04	1.44±0.02
2-Methyl-2-butenal	11.88±0.15	n.d.	n.d.
2-Methyl-2-hexenal	0.12±0.02	n.d.	n.d.
Nonanal	0.07±0.001	n.d.	n.d.
((E)-2-Octenal	5.74±0.06	n.d.	n.d.
(E)-2-Pentenal	0.16±0.02	1.61±0.02	n.d.
Ketones			
2-Heptanone	n.d.	0.61±0.02	0.59±0.04
3-Octanone	0.34±0.05	n.d.	n.d.
1-Octen-3-one	9.06±0.11	n.d.	n.d.
Others (hydrocarbons, sesquiterpenes, sulfur compounds, etc.)			
Caryophyllene	n.d.	0.07±0.001	n.d.
Dimethyl disulfide	n.d.	n.d.	1.59±0.02
D-Limonene	n.d.	0.52±0.04	0.35±0.04
2-n-Pentyl-furan	n.d.	n.d.	0.82±0.09

n.d. – not detected

3.5.6.DEVELOPMENT OF A FUNCTIONAL FERMENTED BEVERAGE, BASED ON BUCKWHEAT AND *BOLETUS EDULIS* MUSHROOM POWDER

3.5.6.1.The influence of the ratio of buckwheat grinding / braising water and the amount of inoculum on obtaining the drink

In order to study this influence, in the first phase, 3 plasters were made with the following plastering ratios of whole raw buckwheat flour (as s.u.%): plastering water, using the heat treatment diagram in Figure 58, but with the plaster cooling to the temperature of 38 °C, namely: 1:14, 1:15 and 1:16. Each of these plants were inoculated with two different amounts of starter milk culture inoculum as such: 0.50% w/w resulting in series S1 (S1-1, S1-2 and S1-3) and 0.75% w/w m, resulting in the S2 series (S2-1, S2-2 and S2-3) of samples.

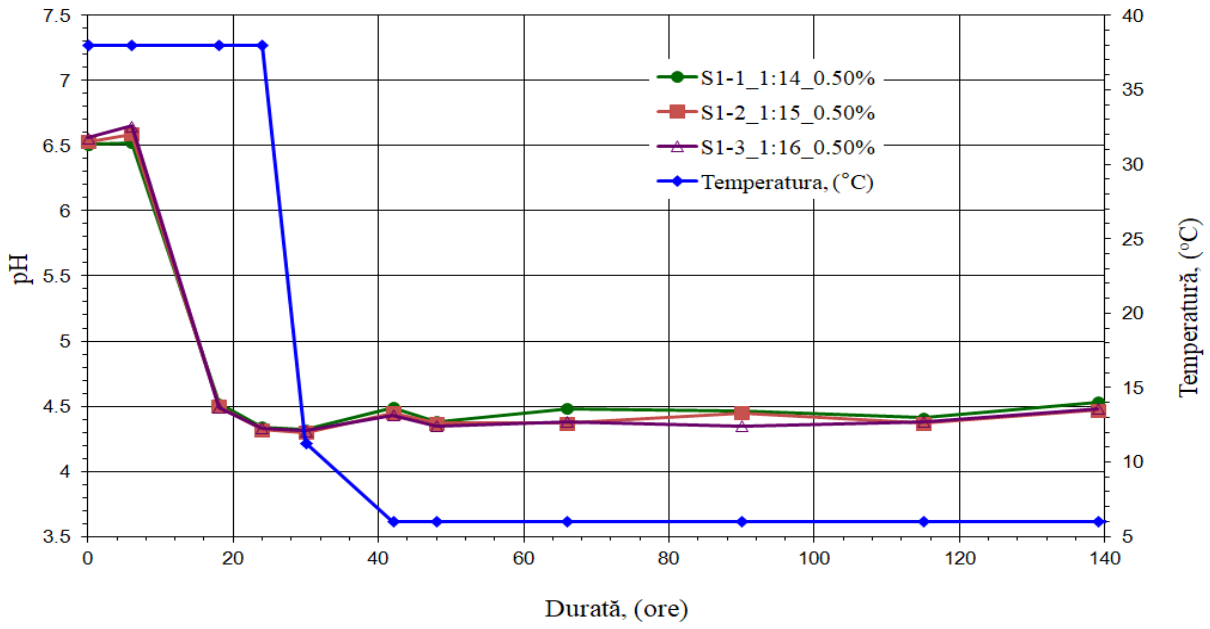

Figure 75. Evolution of the pH of buckwheat samples with 1:14, 1:15 and 1:16 pitch ratios, fermented with an inoculum of 0.50% m/m

Based on Figures 75 and 76 and the sensory analysis of the technologically corresponding samples, samples S1-3 and S2-3 are considered optimal, i.e. those with a 1:16 topping ratio for both amounts of inoculum, 0, 50% m/m and 0.75% m/m respectively.

If these two samples are compared to each other (Figure 77), it can be observed that for sample S2-3 the pH decrease gradient is higher. From the sensory point of view, sample S1-3 was selected for investigation. Consequently, in the continuation of the experimental research, sample S2-3 was taken as a benchmark (plaster ratio 1:16, inoculum 0.75% m/m).

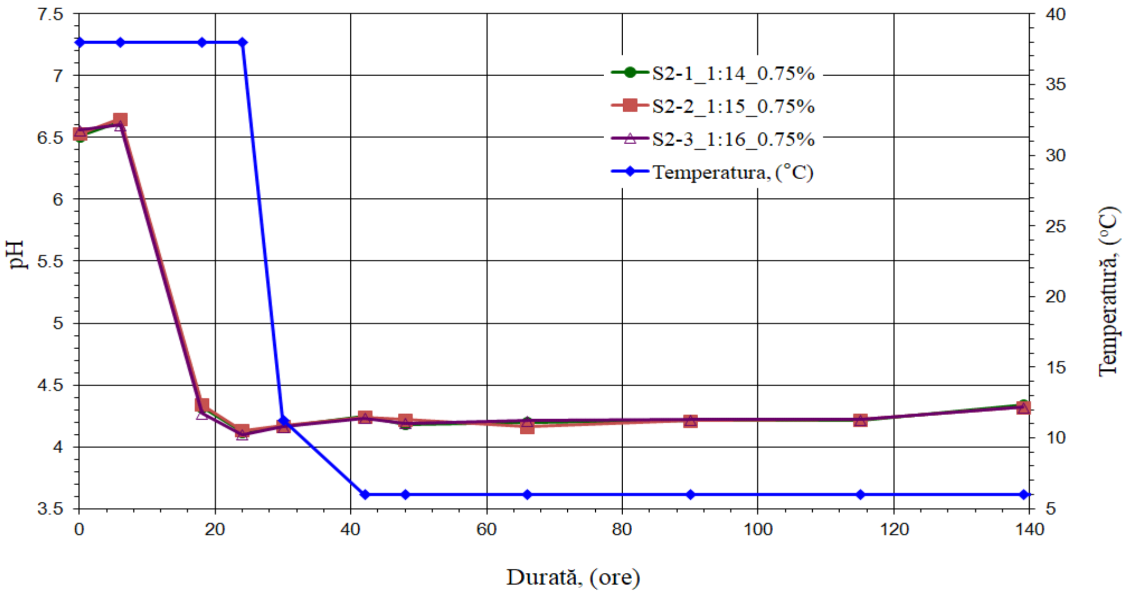

Figure 76. Evolution of the pH of buckwheat samples with 1:14, 1:15 and 1:16 pitch ratios, fermented with an inoculum of 0.75% w/w

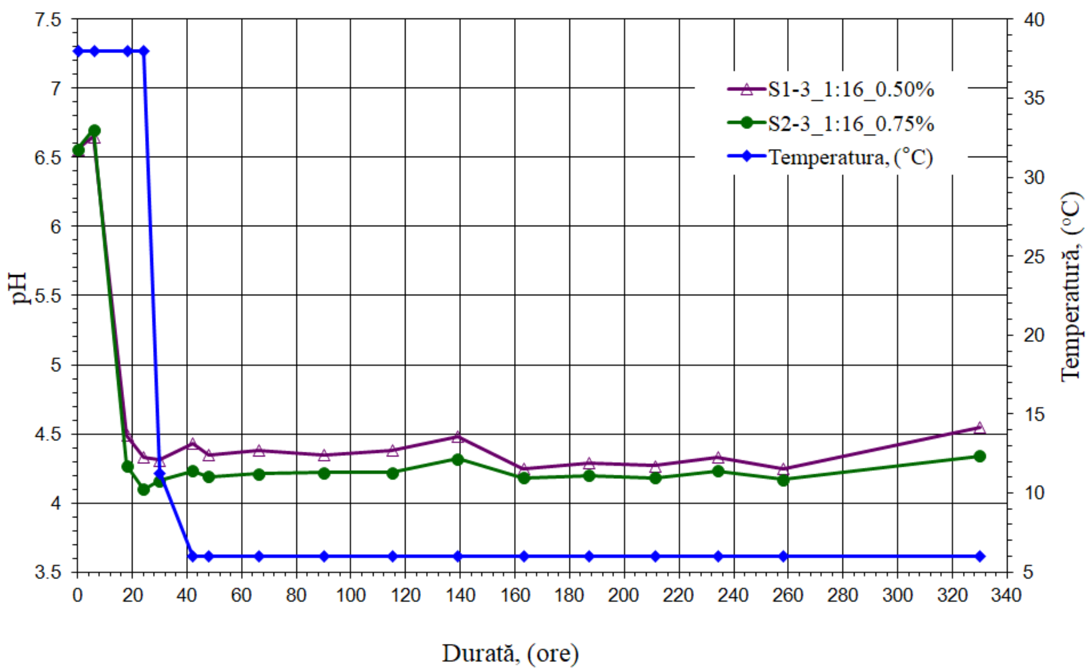

Figure 77. Evolution of the pH of samples S1-3 with the inoculum of 0.50% and S2-3 with the inoculum of 0.75% for plastination

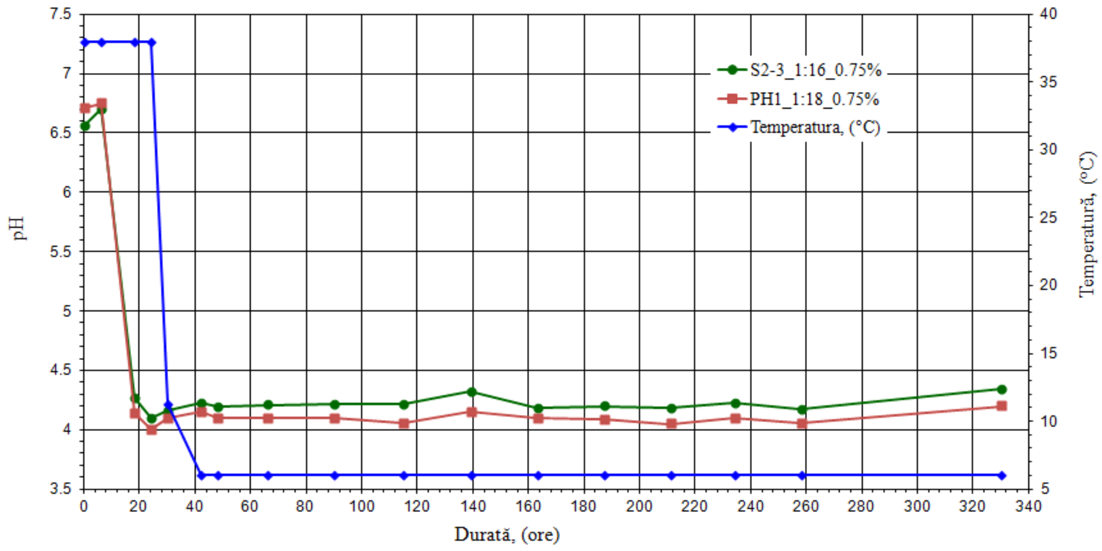

Figure 78. Evolution of the pH of samples PH1 and S2-3 in the dynamics of lactic fermentation, with the inoculum of 0.75%

3.5.6.2.The influence of the amount of mushroom powder on obtaining the developed drink

When determining the amount of mushroom powder addition, to obtain the matrix of ingredients based on buckwheat and chickpeas, the pH recommended for inoculation with *Bifidus*-type lactic bacteria used in research of 6.3 – 6.8 was taken into account. The addition of mushroom powder lowers the pH. A greater addition of mushroom powder causes a greater decrease in the pH of the resulting plum. At the same time, a higher ratio of buckwheat flour: water causes a higher pH of the mixture, but which can be brought to the desired value by increasing the dose of mushroom powder.

Table 18. The pH of buckwheat paste according to the mixture ratio of water

Knead ratio Grinder : water	*1:12*	*1:14*	*1:15*	*1:16*	*1:17*	*1:18*	*1:19*
pH	6.42	6.51	6.53	6.56	6.68	6.71	6.78

Table 19. Experimental series of samples used to study the influence of the amount of *Boletus edulis* mushroom powder addition

Sample	Composition of the sample to be analyzed Grinding raw buckwheat (as s.u. %): water=1:18, Initial inoculum (I.I.) = 0.75 % m/m
Pm	Sample without added mushroom powder
P1	Sample with addition of 1.5 % s.u. mushroom powder
P2	Sample with addition of 2.0 % s.u. mushroom powder
P3	Sample with addition of 3.5% s.u. mushroom powder

The assessment of how the added amount of *Boletus edulis* mushroom powder influences the fermentation process was based on the pH change of the samples (Figure 79) and their discriminative sensory analysis. The conclusion is that sample P1 with 1.5% addition of mushroom powder evolves best, being recommended for obtaining the product proposed for development, in this doctoral thesis.

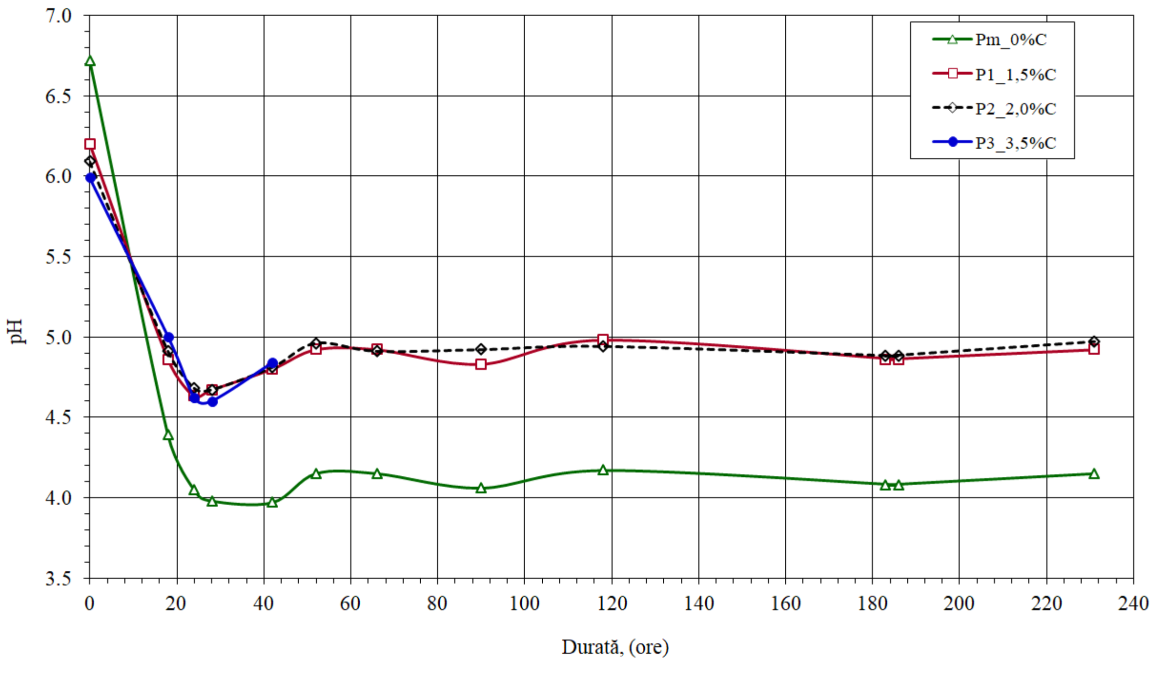

Figure 79. The influence of the amount of *Boletus edulis* mushroom powder on obtaining the functional drink, studied as the evolution over time of the pH of the investigated mixtures

3.5.7.TECHNOLOGICAL CHARACTERIZATION IN DYNAMICS OF THE FUNCTIONAL BEVERAGE. SENSORY ANALYSIS

A first, positive observation is that for both samples, PM1 and PH1, respectively, the decrease in pH is similar to that described for yogurt-type dairy products, with the difference that the hot fermentation period (Figure 80), in the case of front, it is longer, by about 6 hours; a finding that must also be correlated with the amount of inoculum added, which is lower compared to the classical technological variants, on milk medium (Peng et al., 2009).

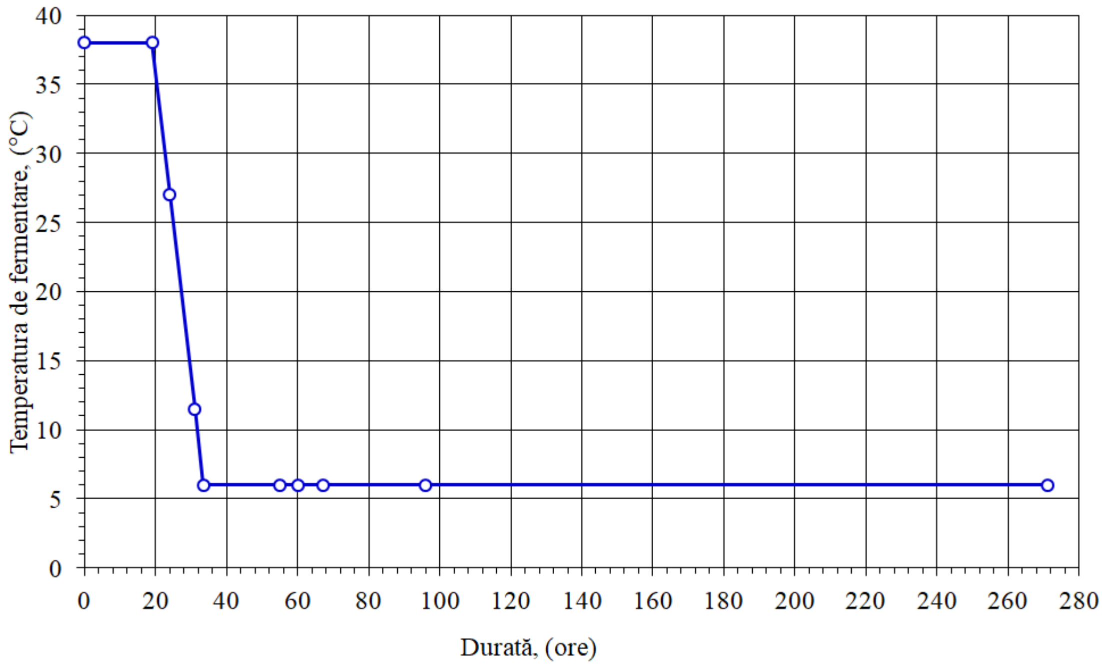

Figure 80. Temperature evolution during the fermentation of PM1 and PH1 mixtures seeded with *Bifidus* lactic cultures

The monitoring of the pH value, for both analyzed functional drinks, over a fermentation course of 271 hours, was carried out to observe its evolution and to identify if they have a stable course for the finished product. A study carried out only on buckwheat bran, by Cardinali et al., 2021, shows that the evolution of the pH during 271 hours, of the samples also made with *Bifidus*-type lactic bacteria, was carried out from the pH starting initially being 7.42, and after 271 hours it decreasing to 3.47.

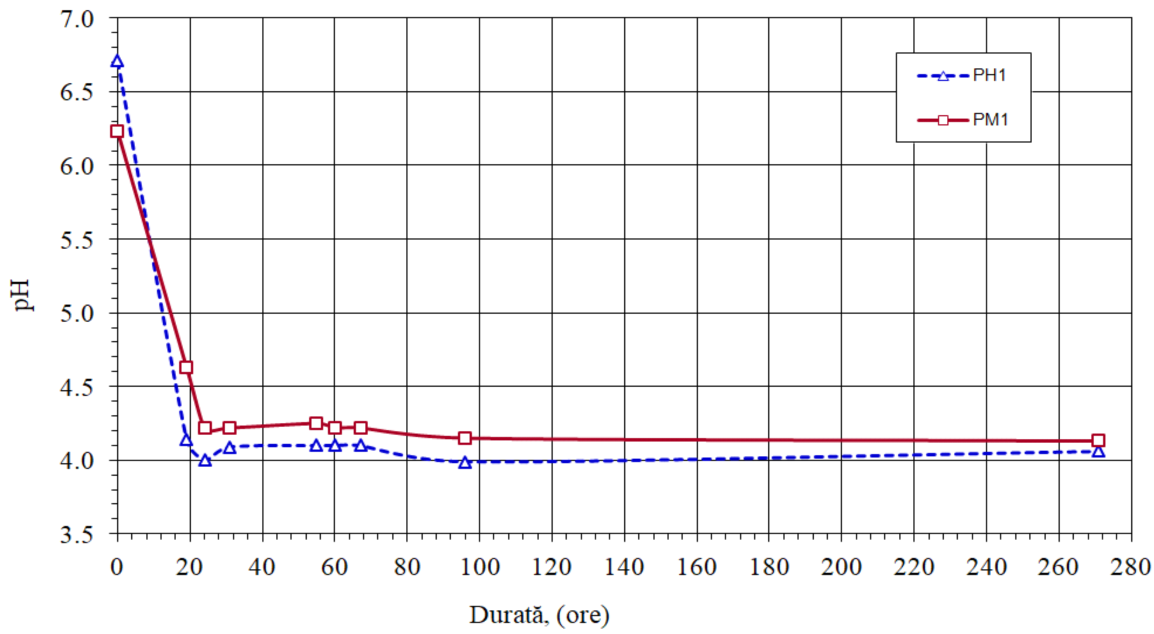

Figure 81. pH evolution of PH1 buckwheat mixture and buckwheat mixture plus *Boletus edulis* PM1 mushroom powder, seeded with *Bifidus* lactic cultures

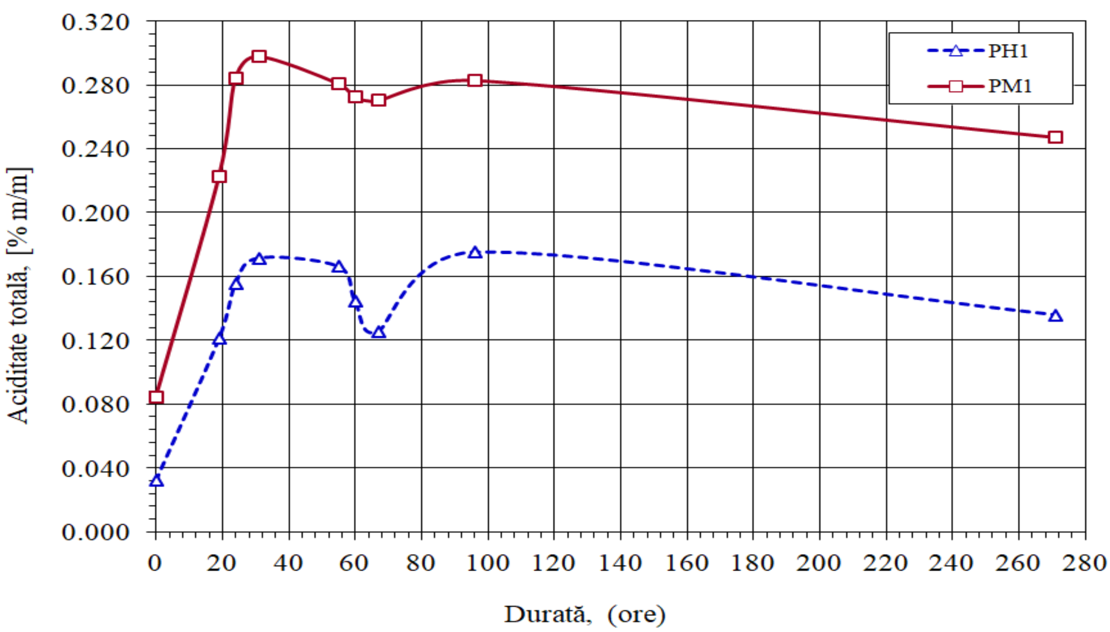

Figure 82. Evolution of total acidity of PH1 buckwheat mixture and buckwheat mixture plus *Boletus edulis* PM1 mushroom powder, seeded with *Bifidus* lactic cultures

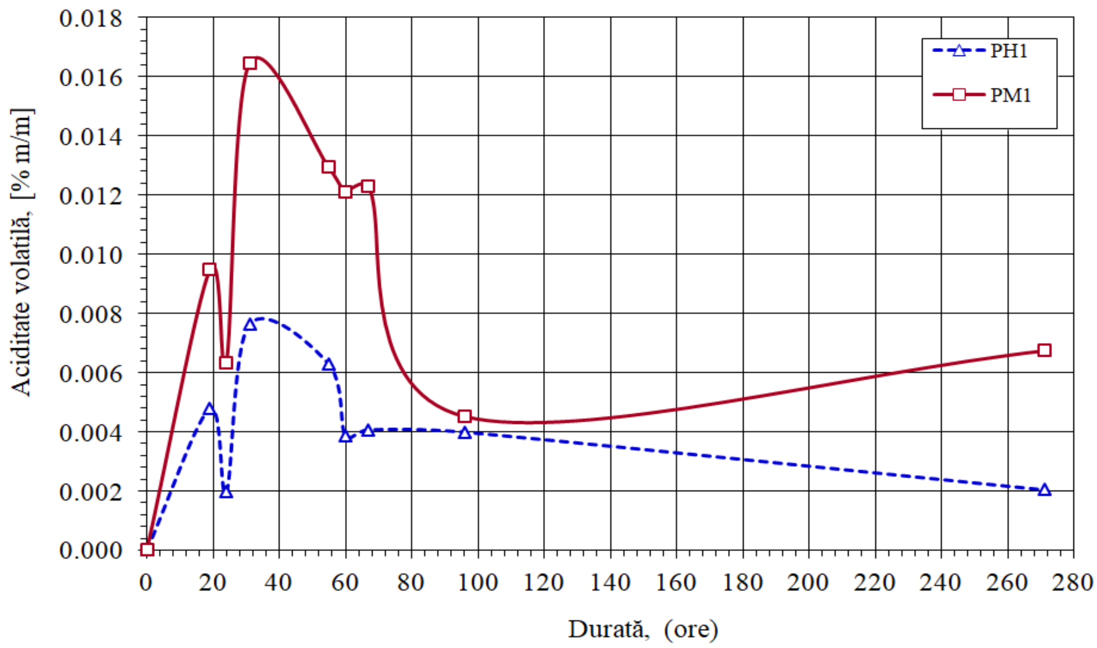

Figure 83. Volatile acidity evolution of buckwheat plums PH1 and buckwheat plums plus *Boletus edulis* mushroom powder PM1, seeded with *Bifidus* cultures

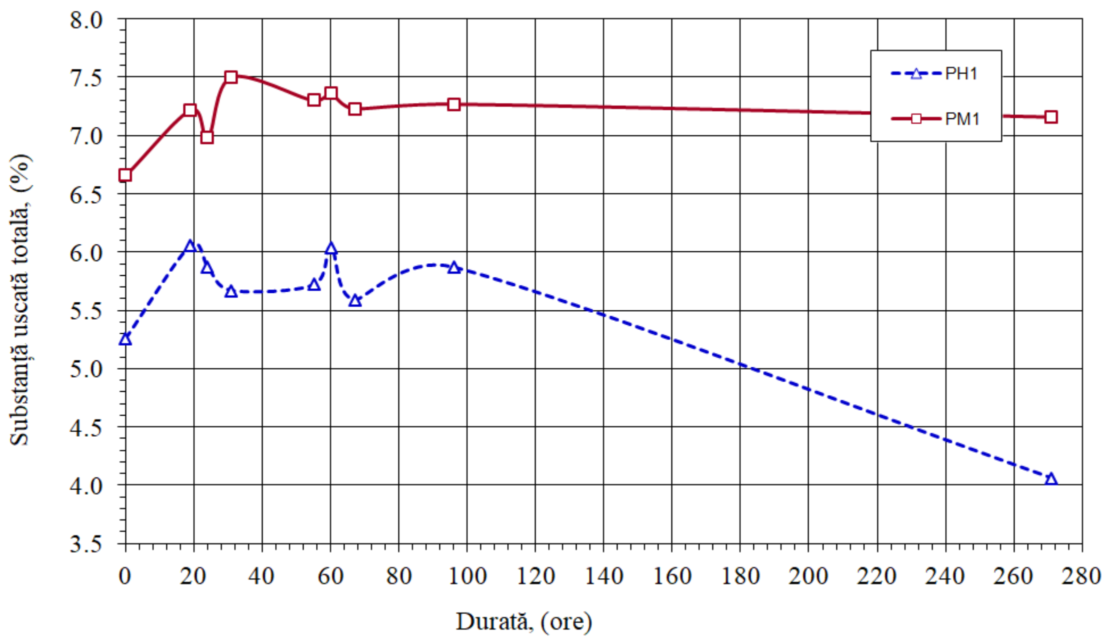

Figure 84. Dry matter evolution of PH1 buckwheat and buckwheat plus *Boletus edulis* PM1 mushroom powder seeded with *Bifidus* lactic cultures

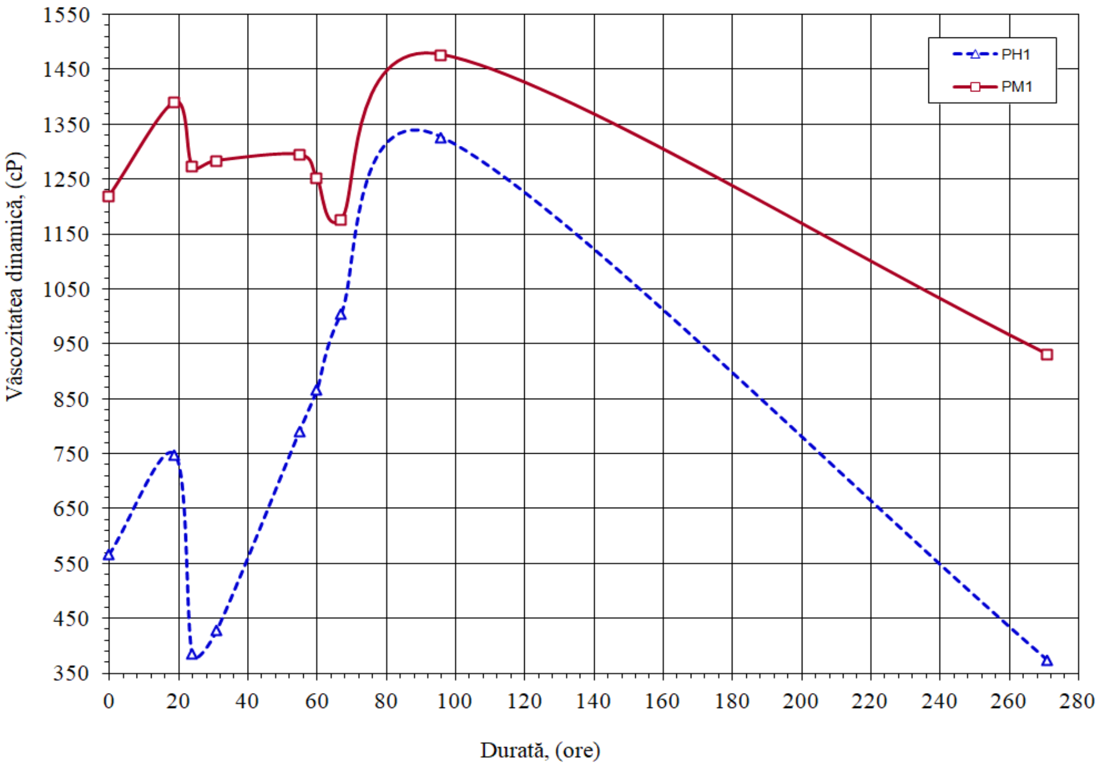

Figure 85. Dynamic viscosity evolution of PH1 buckwheat plums and buckwheat plums plus *Boletus edulis* mushroom powder PM1, seeded with *Bifidus* lactic cultures

Sensory analysis

The color of the product with the addition of boletus powder, in the content, is uniform with taste of caramel and shades of brown and was evaluated by the team of tasters with knowledge in the sensory analysis of food products with a maximum score compared to witness evidence. The resulting color enhances the pleasant, slightly sour, refreshing mushroom taste of the drink.

The persistent taste of mushrooms is not disturbing and if we also refer to the textural properties manifested during the manipulation in the mouth of the functional drink we can say that it is perceived as soft, typical of drinking yogurt, but not sticky or gummy, with a consistency and a fullness being detected pleasant, suggesting the ingestion of a substantial, nutritious food, which even gives a feeling of satiety upon consumption.

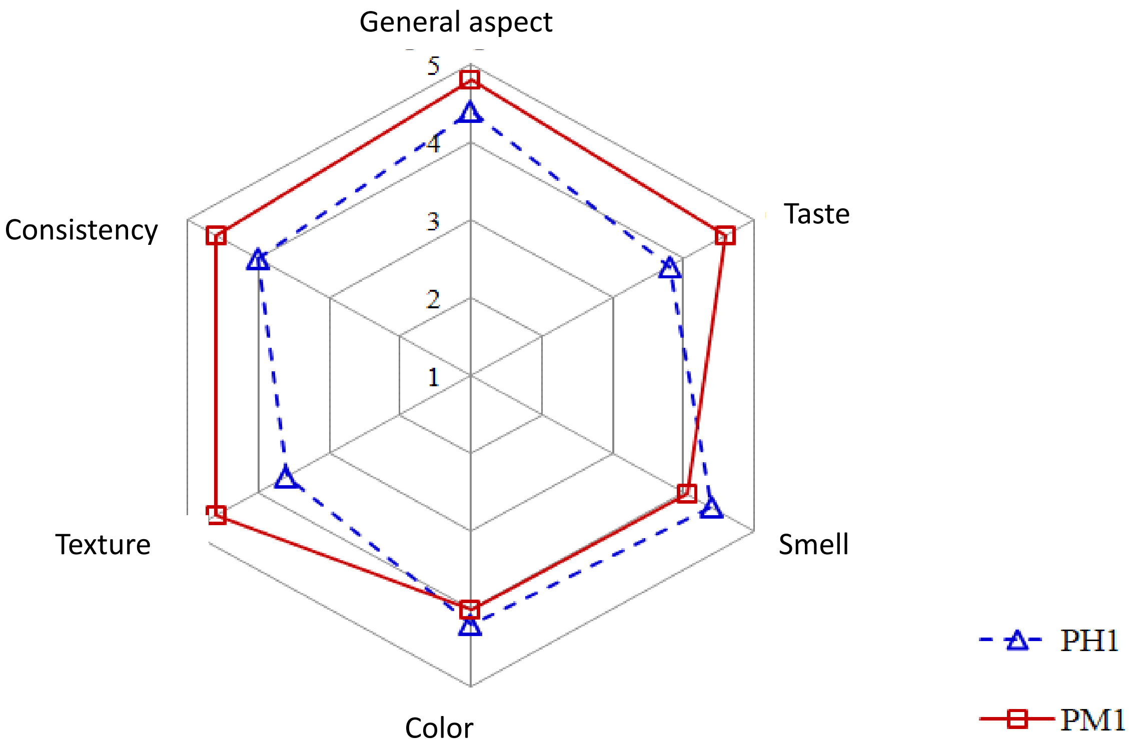

Figure 95. Graphic representation of the results of the evaluation of the sensory characteristics of functional beverages based on PH1 buckwheat and buckwheat with the addition of mushroom powder PM1, after 12 days (group of 10 experienced people)

For the product based on buckwheat with the addition of hribi, the second sensory analysis was carried out, on a group of 72 tasters, in the 20-30 years old category, both from the urban environment (50%) and from the rural environment (50 %), with completed secondary education, but with ongoing higher education (students), without experience in the sensory evaluation of such innovative products. the results are shown in Figure 96.

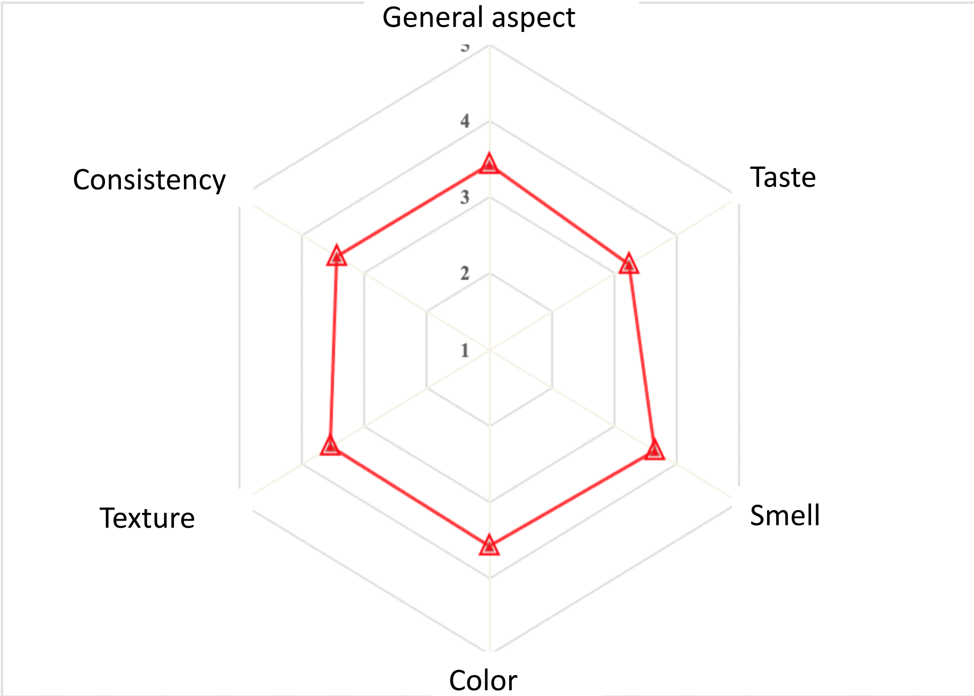

Figure 96. Graphic representation of the results of the evaluation of the sensory characteristics of the functional drink based on buckwheat with the addition of mushroom powder, after 12 days (group 72 people)

When analyzing the visual aspect, the tasters compared the buckwheat drink with the addition of buckwheat powder, with foods already known to them such as: coffee with milk, cappuccino, milk with chocolate. The taste of the drink has been compared to that of a protein drink, sweet and sour with the appearance of yogurt or nutty marks. The smell was compared to that given by caramel candies, caramelized sugar, plums, quinces or dried apples, halva, cereals, baked pumpkin, sweet potato, nuts, freshly baked muffins or the smell of sourdough bread. The color was compared to that given by peanut butter, caramel, nectar, almonds, cappuccino or coffee with milk. The texture for some of the tasters was fresh, fine, creamy, compared to cream of mushroom soup, and for another part of the tasters it was compared to semolina with milk, having a slightly rough consistency of semolina. The consistency has been compared to a nectar drink or kefir.

Following the second sensory analysis, the average for each category analyzed was above 3.2, similar to the first test by experienced tasters, as follows: overall appearance averaged 3.43, taste 3.23, smell 3.63, color 3.56, texture 3.54 and consistency 3.44. The total average of this drink is 3.47 out of 5.

4. FINAL CONCLUSIONS, OWN CONTRIBUTIONS AND FUTURE RESEARCH DIRECTIONS

This chapter of the doctoral thesis represents a synthesis of the original contributions for the fulfillment of the proposed objectives, as well as new research directions for the proposed subject.

Final conclusions

1. The raw material used for drying, the species *Boletus edulis* (porcini), is a species chosen from the spontaneous mycota of Romania, autochthonous, collected from the area of Transylvania, identified as valuable for the present doctoral study, both from the point of view of nutritional value, as well as the bioactive potential. This raw material was selected based on sustainability criteria, being a native species, little exploited for the purpose proposed in this doctoral thesis, being an accessible raw material with a high content of bioactive compounds with a beneficial role for the human body.
2. Being a perishable raw material, it was subjected to drying techniques, investigated in the presence or absence of pre-treatments initially applied to fresh samples. The classic drying techniques (hot air, lyophilization) and the innovative technique (centrifugal under vacuum) used for the first time in this PhD thesis, as well as the temperature at which the drying was carried out, were established with a better preservation of the compounds in mind targeted bioactives, but also through the lens of sustainability related to minimal electricity consumption.
3. The extraction techniques for the analysis of the targeted bioactive compounds (polyphenols, tannins) were selected taking into account the principles of sustainability regarding the minimum consumption of reagents and the use of these solvents, being environmentally friendly solvents, so as to ensure a high yield of useful compounds, also studying the influence of certain physical factors (UV-C radiation, magnetic field) on the extraction efficiency.
4. In order to identify the optimal pre-treatment and drying conditions, the physico-chemical characteristics of the final products obtained were evaluated, such as rehydration capacity, total content of polyphenolic compounds, antioxidant activity, color changes,

microstructure and elemental composition, structural changes through ATR-FTIR analysis and thermal changes by DSC and TG analyses.

5. The mushroom drying technology, by the vacuum centrifugal method, at a temperature of 60 °C lasted 540 and 840 min, respectively, depending on the pre-treatment, and was successfully used for the first time in this doctoral study; the technology of drying mushrooms by the hot air method at a temperature of 60 °C lasted about 300 min, depending on the pre-treatment; and the technology of drying mushrooms by the lyophilization method at -60 °C lasted 1140 min, regardless of pre-treatment or without pre-treatment.

6. The rehydration capacity of dried mushrooms indicated the best results for the sample obtained by drying through the lyophilization technique, the rehydration capacity varying from 8.61 to 10.81, both for the samples with or without pre-treatment. For the samples dried by the hot air method and centrifugal under vacuum, the rehydration capacity values are lower, which may be due to the porous structure that was formed after the drying process.

7. The results obtained on the content of polyphenols, regarding the pre-treatment applied, showed that the highest amount was identified in the fresh samples pre-treated with UV-C radiation (1387.091±0.115 mg GAE/ 100 g s.u.), followed by the control sample without pre-treatment 1319.227±0.285 mg GAE/ 100 g s.u.. The control sample was significantly richer in polyphenols than the blanched sample. Regarding the drying technology, the control sample dried by the hot air drying technique recorded the highest total content of polyphenols (1169.602±0.325 mg GAE/ 100 g d.u.), while the blanched sample dried by the hot air drying showed the lowest value (447.617±0.121 mg GAE/ 100 g s.u.). The hot air drying technology determined a 5% higher total polyphenol content compared to that of the samples dried by the lyophilization technique. The centrifugal drying method under vacuum had the highest content of polyphenols in the UV-C pre-treated sample (1086.728±0.231 mg GAE/ 100 g s.u.), and the lowest content being in the sample pre-treated by blanching (506.112±0.231 mg GAE/ 100 g s.u.).

8. The obtained results showed that the antioxidant activity of the untreated fresh samples (864.631±0.137 mg AA/ 100 g s.u.) was lower than that of the fresh sample subjected to UV-C radiation pre-treatment (940.316 ± 0.468 mg GAE/ 100 g s.u.), but higher than that of the blanched fresh sample (355.171±0.120 mg GAE/ 100 g s.u.). The untreated fresh sample showed 24-28% higher antioxidant activity compared to that subjected to hot air drying, lyophilization and vacuum centrifugal, respectively. Other

significant differences were observed between the pre-treated and dried samples, such as between the blanched and control samples, but also between the blanched and UV-C pre-treated samples. These results indicate that UV-C irradiation of mushrooms is a good choice as a pre-treatment modality before drying, while blanching leads to a considerable loss of antioxidant activity, due to the thermal shock to which they were subjected both by this pre -treatment as well as by drying.

9. Evaluation of color changes of mushroom samples indicates small color changes for control and dried samples by vacuum centrifugal technique and large color changes for blanched and dried samples, especially by hot air method. The obtained results showed that UV-C pre-treatment of mushrooms is a better alternative with less color changes.

10. By analyzing the microstructural properties of the mushroom samples subjected to different pre-treatments through SEM analysis, results were obtained that indicate structural changes explained by breaking the cell walls. Freeze-drying led to the least physical changes compared to the other types of drying. The analysis of the elemental composition of the pre-treated and dried samples indicates the presence of eight common chemical elements, aluminum being present in only three of them, this may be due to the subsequent contamination of the samples.

11. Through ATR-FTIR analysis, structural differences were identified in region I of the absorption spectra in the dried samples without pre-treatment, especially for those dried by the hot air technique or the centrifugal technique under vacuum. Region II attributed to proteins, aromatic bonds in polyphenols or unsaturated fatty acids, was more evident for samples dried by vacuum centrifugal technique. Region III attributed to fatty acids, amino acids, polysaccharides, alcohols, but also proteins. Region IV attributed especially to polysaccharides such as cellulose indicates structural changes induced by heat treatment on carbohydrates. In UV-C pre-treated or bleached dried samples structural bands of carbohydrates were observed as evident in region IV of the absorption spectrum.

12. Thermal changes resulting from DSC and TG analyzes indicated five thermal transitions: two endothermic peaks and three exothermic peaks. The endothermic peaks in the temperature range 42-57 °C indicate the gelatinization of polysaccharides, and the next peak in the range 50-85 °C indicates the denaturation of proteins. The exothermic peaks are associated with the intermolecular aggregation of proteins, the first peak being identified in the temperature range 105-172 °C correlated with the melting phase of oligosaccharides and polysaccharides (hemicellulase), but also with the aggregation of denatured proteins.

The second exothermic peak was identified in the temperature range 106-145 °C, being predominant in the UV-C samples dried by hot air and vacuum centrifugal techniques, probably due to the modification of chitin, a polysaccharide specific to fungi. The third exothermic peak appears at temperatures higher than 250 °C and is due to sample decomposition and pyrolysis of polysaccharides with release of volatiles. TG-DTG analysis indicated weight loss throughout the studied interval. The elimination of water took place at temperatures below 110 °C, and from temperatures higher than 180 °C the decomposition of polysaccharides began. TG-DTG thermogravimetric analysis indicated weight loss over the entire temperature range studied, with the derived DTG curves showing the five peaks identified in the DSC curve. Weight loss was <1% in control samples dried by HAD and CVD techniques, while FD freeze-dried and blanched samples showed higher values of Δm. Losses in weight and volatile matter continued in the next step, except for the blanched and dried samples. The samples dried by the CVD technique showed higher values of Δm compared to those dried by the HAD or FD techniques.

13. The efficiency of the extraction of polyphenolic compounds from mushrooms, fresh or properly dried, has been studied under the influence of physical factors such as UV-C radiation, low frequency magnetic field and microwave radiation.

14. Thus, regarding the study on the exposure of mushroom powders to UV-C radiation in different experimental conditions (15 and 30 minutes respectively, distance of 10, 15 and 20 cm respectively), the results obtained showed that a time of exposure of 30 minutes, at an exposure distance of 20 cm led to a 17% increase in the content of polyphenolic compounds and a ~16% increase in the content of tannins compared to the untreated sample. At a smaller exposure distance (10 cm), a slight degradation of polyphenols was found, the kinetic study carried out (first-order kinetics model) indicating a rate constant (k) of 2.80×10–3 min–1 and a half-life (t1/2) of 247.50 minutes. Significant positive effects of UV-C irradiation were also found on antioxidant activity, especially at an irradiation distance of 15 cm and an exposure time of 30 minutes. The ATR-FTIR spectra of the irradiated and non-irradiated samples confirmed the results on the changes in the content of polyphenolic compounds and tannins and on the antioxidant activity of the mushroom powder.

15. With regard to the study of the exposure of humus powders to extremely low frequency electromagnetic radiation in different experimental conditions (3 mT, 50 Hz, exposure time: 15, 30, 60, 120 and 240 minutes respectively), the results obtained showed

a positive but weak effect of magnetic field treatment on polyphenol and tannin content and antioxidant activity compared to the control sample. The antioxidant activity of the sample exposed for 240 minutes was 435.82±0.95 mg/ 100 g s.u. similar to the activity of the control sample 434.98±2.10 mg/ 100 g s.u.. The content of tannins in the control sample is 85.98±0.12 mg/ 100 g s.u., and in the sample with the longest exposure (240 minutes) 89.45±0.12 mg/ 100 g s.u., the difference being 3.87%. Regarding the content of polyphenols for the sample exposed for 240 minutes, the content is 602.78±6.55 mg/ 100 g s.u., and for the control sample 588.21±7.53 mg/ 100 g s.u., the difference being 2.41% between samples.

16. These results underline the potential use of non-thermal processing of mushrooms (pre-treatment with UV-C radiation or magnetic field) to improve the extraction of the studied antioxidant compounds from *Boletus edulis* mushroom powder. The two types of physical treatments investigated do not affect the composition of the raw material, but improve the quality of the extracts and reduce the extraction time of the targeted bioactive compounds. These results reveal the practical use of non-thermal technologies without affecting the quality of the mushrooms.

17. With regard to the study on the exposure of the hibiscus, fresh or dry and mixed with 70% ethanol, to microwave radiation, the results obtained showed a significant increase in the content of polyphenolic compounds in the fresh samples, especially at an exposure time higher (3 h vs. 0.5 h) at both investigated frequencies (1.7 and 2.5 GHz, respectively) under incident electric fields of 700-775 $V\cdot m^{-1}$. The antioxidant activity by FRAP technique of mushroom extracts increased after microwave exposure, especially in the sample irradiated for 3 hours at 1.7 GHz (775 $V\cdot m^{-1}$). On the other hand, by exposing dry samples to microwave radiation and mixed with 70% ethanol, no increases were obtained in the total content of polyphenolic compounds or in the total antioxidant activity, measured by the FRAP method. Statistical analysis using the Kruskal-Wallis test indicated significant differences in antioxidant activity between fresh and dried samples, while differences in polyphenol content were statistically insignificant between fresh and dried mushrooms. ATR-FTIR analysis of ethanolic extracts obtained from fresh samples shows no structural changes after microwave irradiation, confirming that the effect is due to the disruption of the cell membrane that facilitates the release of the targeted chemical compounds. These results highlight the potential of microwaves under irradiation conditions of 1.7-2.5 GHz, 700-775 $V\cdot m^{-1}$, 0.5-3 h, to positively influence the total content

of polyphenolic compounds and the antioxidant activity of extracts of *Boletus edulis* mushrooms.

18. With the applicative aim of obtaining a new functional drink type food product, this study also aimed to investigate the effects of drying *Boletus edulis* mushrooms by hot air and centrifugal techniques under vacuum, on the physical, physico-chemical, compositional and functional properties of the powders of mushrooms.

19. Thus, the results of the analysis of physical and functional properties indicate that the samples dried by hot air drying technology had a Hausner ratio corresponding to better fluidity and a higher rehydration ratio, while the samples dried by vacuum centrifugal technology had showed better water solubility index and emulsification activity.

20. The investigation of the nutritional composition indicates that the drying of the investigated mushrooms led to a crude protein content of 34.65±0.17 g/ 100 g for the hot air dried samples and 36.35±0.17 g/ 100 g respectively for the dry sample by vacuum centrifugal technology, compared to the value of 7.45±0.17 g/ 100 g determined in the fresh sample; the carbohydrate content, determined by difference, was 52.15±0.07 g/ 100 g in the HAD dry sample, 50.45±0.22 g/ 100 g in the CVD dry sample compared to the value of 8.24± 0.12 g/ 100 g in the fresh sample; the highest amount of lipids was detected in the dry sample by HAD technology 3.06±0.01 g/ 100 g; the ash content of the samples did not vary greatly between HAD and CVD dried samples (4.614±0.04 g/ 100 g and 4.781±0.005 g/ 100 g).

21. The results obtained from the analysis of the fatty acid content of *Boletus edulis* mushrooms, showed variations between fresh and dry samples. Drying at 60 °C by centrifugal vacuum technology or hot air drying did not affect the total content of saturated fatty acids, but led to a decrease in the content of oleic acid, and an increase in that of linoleic acid. The ratio of polyunsaturated fatty acids PUFA/saturated fatty acids SFA, was >3.3 in both fresh and dried samples, meeting the requirements for healthy lipids according to health guidelines.

22. The investigated *Boletus edulis* mushroom drying technologies determined important changes in the types and content of flavor compounds. Among the aroma compounds, only 3 compounds (hexanal, 1-octan-3-ol and (Z)-2-octan-1-ol) were identified in both fresh and dried samples, but in different amounts. The 1-octan-3-ol compound represented the predominant flavor compound in all samples, its content in the fresh sample of 70.52±1.13% increasing in the dry samples, both by hot air technology

(91.71±1, 32%), as well as by vacuum centrifugal technology (91.25±1.41%); statistical analysis indicates a strong positive correlation of these volatile compounds with their precursor, linoleic acid. Small amounts of new volatile compounds, alcohols, aldehydes and ketones or other compounds, such as: D-limonene and caryophyllene, were detected in the powders obtained by hot air drying technology; D-limonene, dimethyl disulfide and 2-n-pentyl-furan in powders obtained by vacuum centrifugal technology. Drying led to a total loss of some aroma compounds, such as 2-methyl-2-butenal, (E)-2-octanal and 1-octan-3-one.

23. The technological parameters of the final variant studied for the newly developed functional drink based on raw buckwheat and the addition of *Boletus edulis* mushroom powder, are: the ratio of homogenous flour, grinder: water is 1:18; 1.5% addition of mushroom powder based on dry matter; inoculation with 0.75% *Bifidus* lactic cultures; hot fermentation temperature of 38 °C; cold fermentation temperature of 6 °C. The addition of mushroom powder in the proportion of 1.5% of dry substance has the role of gelling and giving positive rheological characteristics to the obtained drink. An addition of mushroom powder greater than 1.5% relative to dry matter causes the reduction or inhibition of the metabolic activity of the microorganisms in the *Bifidus* type starter culture.

24. The experimental results carried out for the development of functional beverages based on buckwheat and *Boletus edulis* mushroom powder, through lactic fermentation with a *Bifidus* type starter culture, indicate that the evolution of pH, total acidity and volatile acidity, but also of total dry matter over 271 hours, proves a higher stability for the finished product compared to that of the drink obtained only from raw buckwheat, in light of the fact that the dry matter of the mushroom sample decreases very little in the second part of the cold fermentation , and during this period the volatile acidity increases, which suggests the continuation of the ripening process, which benefits the sensory characteristics. Following the rheological analysis, it can be stated that the addition of *Boletus edulis* mushroom powder has the role of gelling and does not induce the phase separation effect, and the apparent dynamic viscosity decreases more slowly with increasing shear stress, valid for the temperature of 6 °C , but also of 20 °C, for rheological characterization. The results of the sensory analysis show that the addition of mushroom powder in a functional drink based on buckwheat, offers superior sensory characteristics to the matrix of ingredients raw buckwheat - mushroom powder and a sensory profile that confirms the possibility of its acceptance by consumers. Mushroom powder gives a

persistent taste and a particularly pleasant aroma to the product: of nuts, of well-baked cake, of milk yogurt with a fruity smell and at the same time it significantly improves the color of the product with the achievement of a pleasant texture, specific to drinking yogurt, which masks the grain's fibrous texture.

25. The monitoring program of the technological process and the technical product specification of the technological process, for the realization of the final product of the functional beverage type, demonstrate that the product manufactured in accordance with the input and output activities made from the specified raw materials is in accordance with the quality and safety standards imposed.

Original contributions

Through this doctoral thesis, important contributions have been made at the theoretical, experimental and applied level in the field of engineering sciences aimed at the technologies of drying hills, extracting some bioactive chemical compounds, the biochemical composition of mushrooms, with the aim of developing a product functional new with applications in the food sector:

- Contributions to the enrichment of the theoretical base regarding the processing technologies of *Boletus edulis* mushrooms, as well as the use of a new drying technique - convective drying under vacuum.
- Experimental research on the use of two types of pre-treatments (blanching and pre-treatment with UV-C) in order to better preserve the quality of the product.
- Studies on the influence of some irradiation technologies (UV-C, microwaves, magnetic field) on the bioactive content and antioxidant activity of *Boletus edulis* mushrooms.
- Characterization of the hills in the dry state through the prism of physical, physico-chemical, emulsification properties, microstructure, color, chemical composition.
- Conception and development of a new food product, by using valuable natural ingredients (buckwheat and buckwheat), approved by vegetarians and respectively by people with celiac disease - functional drink fermented with *Bifidus* lactic cultures.

Recommendations and future research directions

Through the experiments carried out in this doctoral thesis, remarkable results were obtained and they want to be continued in terms of the investigation and testing of several species of edible mushrooms from the spontaneous mycota, since, as demonstrated by other studies carried out for this purpose, the mushrooms dried have a high content of bioactive molecules that vary from one species to another, being influenced mainly by the drying temperature, storage conditions, exposure to different physical, chemical and mechanical factors, as well as the geographical area in which they were developed and environmental conditions.

Another recommendation consists in research from the point of view of the newly developed product, so as to achieve a more thorough chemical and microbiological characterization, by determining the number of live lactic bacteria in the product, identifying and dosing some compounds with an important role in defining the beverage product functional. Also, future research can be directed towards interdisciplinary approaches, which aim to carry out clinical studies to accurately identify the benefits brought to the human body, in addition to the studies carried out in the laboratory in this doctoral thesis.

List of publications resulting from doctoral research

- **Articles published in ISI listed/indexed journals, cf. WoS:**

- **Popa, M.F.,** Cocîrlea, M. D., Miclăus, S., & Oancea, S. (2022). The Influence Of Microwave Exposure Of *Boletus* Mushroom-Solvent Mixtures On The Extractability Of Phenolics And Antioxidant Activity. *Scientific Study & Research. Chemistry & Chemical Engineering, Biotechnology, Food Industry*, *23*(3), 243-254. Factor de impact: 0,08

  https://pubs.ub.ro/?pg=revues&rev=cscc6&num=202203&vol=3&aid=5474
- **Popa, M.,** Tăușan, I., Drăghici, O., Soare, A., & Oancea, S. (2022). Influence of Convective and Vacuum-Type Drying on Quality, Microstructural, Antioxidant and Thermal Properties of Pretreated *Boletus edulis* Mushrooms. *Molecules*, *27*(13), 4063. https://doi.org/10.3390/molecules27134063 Factor de impact: 4,927
- Oancea, S., **Popa, M.,** Socaci, A. S. & Dulf F.V. (2023). Comparative Study of Raw and Dehydrated *Boletus edulis* Mushrooms by Hot Air and Centrifugal Vacuum

Processes: Functional Properties and Fatty Acid and Aroma Profiles. *Applied Sciences-Basel*, 13(6), 3630. https://doi.org/10.3390/app13063630 Factor de impact: 4,5

- **Papers presented and published at national/international conferences:**

- **Popa, F.M.,** & Oancea, S. (2020). An overview on edible mushrooms with health benefits and applications in the food industry. Simpozionul Național „Agricultura și implicațiile ei în alimentația și sănătatea omului", 08 octombrie 2020, publicată în revista indexată în ISI Master Journal List *Acta Musei Brukenthal*, *15*(3), 525-536. https://www.brukenthalmuseum.ro/pdf/BAM/BAM%20XV3.pdf
- **Popa, M**. & Oancea, S. (2020). Studies On Bioactive Compounds Of Mushrooms And Their Potential Antiviral Effects Against Covid-19, *44th Conference For Students Of Agriculture And Veterinary Medicine With International Participation*, 15 December 2020, At: University Of Novi Sad, Serbia
- **Popa, M**., Maria, G., Danci, O., Banciu, C., & Oancea, S. (2021). Evaluation Of Relevant Mineral Content Of Medicinal Wild-Grown Mushroom Ganoderma Lucidum From Different Romanian Areas, *45th Conference For Students Of Agriculture And Veterinary Medicine With International Participation,* 18 November 2021*,* At: University Of Novi Sad, Serbia

- **Articles published in BDI indexed journals (SCOPUS):**

- Oancea, S., **Popa, F. M**., & Răcuciu, M. (2021). Effects of non-thermal postharvest irradiation of dried mushrooms on their antioxidant content and activity. *Romanian Reports in Physics*, *73*, 712. https://rrp.nipne.ro/2021/AN73712.pdf Factor de impact: 0,51
- **Participation in the project POCU/993/6/13/153310 „Development of advanced and applied research skills in the logic of STEAM + Health" https://sites.euro.ubbcluj.ro/steam/**

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