Nutritional and biological value of dried champignon powder

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Keywords:

Champignons
Proteins
Amino acids
Semi-finished products
Safety

Article history:

Received 20.06.2022
Received in revised form19.09.2022
Accepted 1.12.2022

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DOI:10.24263/2304-974X-2022-11-3-9

Abstract

Introduction. The aim of this study is to evaluate the nutritional and biological value of dried champignon powder in the indices of quality and safety.

Materials and methods. The nutritional and biological value of dried champignon powders, obtained by the methods of low-temperature drying (45 °C) and subsequent disintegration, were studied in terms of the biological value of proteins and their factional distribution, ratios of essential and non-essential amino acids, their balance and digestibility.

Results and discussion. More than two thirds of all proteins in semi-finished products made from mushrooms are represented by factions with the high biological value: water-soluble albumens (45.6–46.8%) and salt-soluble globulins (23.1–26.7%). In frozen semi-finished products, this ratio would reach 80%, running over the content of the noticed factions in fresh mushrooms. So, the complexes of proteins and high polymers are partly ruined under the temperature of drying 45 °, with subsequent release of proteins and their dissociation, which led to the increase of the biological value of product. Conversely, after drying at this temperature, the share of insoluble proteins increases twofold in comparison to fresh mushrooms, which showed the inexpedience to use the high temperatures to process mushrooms.

The dried champignon powder contained all eight essential amino acids, which comprises about 46% of their total amino acids amount. Otherwise, the sum of non-essential amino acids scores 54%. These data are the important index of dried champignon powders due to the well-known fact that the maximal biological effect of food proteins is achieved at the ratio between essential and non-essential amino acids equal to 42:58, which is practically the same as the results of our research (46:54). According to the calculated amino acid scores, the amount of all amino acids exceeds the level of the reference protein recommended by the World Health Organization. Based on the coefficient of amino acid score difference, it was determined the nutritional and biological value of protein of dried champignon powders counting 51.8%, which is quite a high index.

The sensory characteristics of dried champignon powders appeared to be satisfactory. Microbiological evaluation showed the safety of the finished mushroom powder and its stability during the storage.

Conclusions. The knowledge about the protein components of dried champignons, their nutritional and biological values and the possibility to use them as powdered product was significantly expanded.

Introduction

The human body does not practically contain the protein reserves. Meanwhile, all the vital processes are connected with its biological transformations on the level of cells and tissues, and with its ability to interact with unexceptionally all substances creating the complexes to constitute the base of a live organism (Nelson and Cox, 2017). One of the most essential sources of proteins are cultivated mushrooms that contain more than 35% of protein (in terms of dry matter), all the essential amino acids, unsaturated fatty acids, vitamins and trace elements (Asao et al., 2017). The modern food science considers them as the possible source of biologically active substances for food industry (Martinez-Medina et al., 2021; Stojković et al., 2014), in particular for creating the food additives capable of increasing the immunity to infections and oncologic diseases (Meera et al., 2009; Wasser et al., 2000), owing to the fact that anti-bodies formation is the modified process of normal biosynthesis of globulins (Haeney, 1994).

Production of cultivated mushrooms is considered one of the main tendencies in food industry to be constantly expanding (Bakratsas et al., 2021; Ferdousietal, 2020; Ivanov et al., 2021), primarily due to champignon and shiitake growing (Calvo et al., 2016; Martinez-Medinaetal., 2021; Shelke and Badhe, 2021; Stabnikova et al., 2010; Yurchak and Sharkova, 2023). Champignons contain about 3 percent of lipids, more than half of which are neutral fats. Their acid number is approximate to the similar index of plant oils, thanks to the high amount of free fatty acids that comprise more than 17% of the general lipid amount. These are butyric and acetic acids, along with oleic and stearic ones (Ribeiro et al., 2009). It is very important that mushrooms and their active compounds possess anticancer properties. Upon studying the influence of champignon chemical substances on the protein that damages the human DNA, there was revealed that the champignon components show far stronger effect than the standard pharmaceutical inhibitors (Shelke and Badhe, 2021). Along with that, cultivated mushrooms are low fat, low-calorie foods that, unlike the wild forest mushrooms, are free from heavy metals, radionuclides, and nitrates. They are considered to be the delicacies for cookery and used in many cuisines as the so-called 'vegetable meat.' The techniques and technologies of up-to-date level allow extracting antimicrobial, antioxidant, anti-allergenic substances and various nutrients in order to fortify the traditional food bases (Ramos et al., 2019). Important is the fact that the mushroom protein, in case of being processed by the certain technologies, would be well absorbed by the human body (Gonzálezetal, 2020).

Mushrooms have the short term of storage and microbiological and fermentative processes are continued in mushroom fruiting bodies after harvesting. All this makes it necessary to consume or process mushrooms immediately after they are harvested. To increase the shelf life of mushrooms, it is possible to use their drying, and convective drying followed with biomass grinding as the most wide-spread and effective technology for mushroom treating (Waldeetal, 2006). Therefore, the convective low-temperature drying method was chosen to obtain the powdered champignon product as the material for research.

An analysis of the literature data showed a limited number of research studying the amino acid composition of mushroom proteins, the ratio between essential and non-essential amino acids and comparison with the reference protein proposed by WHO (Dietary Protein, 2011). The objectives of the present research were to study protein component of dried at low temperature champignon powders to expand their usage in food technologies.

Materials and methods

Dried champignon powder

The dried champignon (*Agaricus bisporus*) was the subject of the research. The mushroom fruit bodies were washed, sliced, and dried by convective method at a temperature of 45 °C during 340 minutes. Dried champignons were then grounded to the particles with size of 100–150 microns and protein fractional distribution was determined in obtained powder. The calculations of amino acid scores to evaluate the level of protein utilization in human body were done.

Figure 1. Champignons and dried champignon powder

Determination of dry substances content

The content of dry substances was determined by differential refractometry using IRF-454 B2M refractometer (Laboratornatekhnika Ltd., Kharkiv) (Hernandez et al., 1998)

Determination of protein and amino acid content

The total amount of proteins, their qualitative and quantitative composition were determined using the capillary electrophoresis by the method of (Redweik et al., 2012).

Determination of total carbohydrates content

The content of total carbohydrates was determined by the methods of ion analysis using the chromatograph Bioscan 817 (Metrohm, 2023). To prepare the specimens for analysis, mushrooms were powdered to homogenous mass and placed into the automatic sampler of the chromatograph.

Determination of cellulose content

The amount of cellulose was determined by the gravimetric method: after oxidation, dissociation and dissolving various chemicals contained in mushrooms, cellulose residue was thenceforth removed, dried and weighed (Kumar and Turner, 2015).

Determination of factional composition of mushroom protein

Mushroom proteins were fractioned in different media: albumens in water; globulins in 1 M NaCl and 0.1 M phosphate buffer (pH 6.8); glutelins in 0.1 N NaOH; prolamins in 70 % ethyl alcohol. The samples of disintegrated products were introduced into the correspondent media, with the ratio between mushroom mass and the solvent 1 : 3 for determination of albumens and globulins; 1 : 2.5 for glutelins and prolamins; then the samples were centrifuged during 15 minutes at 6,000 rpm. The precipitate was then washed, and the volume of extract was added to 150 ml with washing water. The content of protein substances in extracts and the precipitates was determined by the method (Redweik et al., 2012).

Microbiological analysis

Microbiological analysis of bacterial contamination of dried champignon powders (particularly the presence of pathogenic microorganisms, bacteria, yeast and moulds) were carried out by quantitative accounting of contaminants on solid media (Tarabees et al., 2015).

Samples (25 g) of champignons were placed in 225 ml buffered peptone water and homogenized for 30 seconds in a lab blender. Decimal serial dilutions were prepared up to dilution 10^{-7} in sterile Ringer's solution and plated on selective agar media (Schill et al., 2021).

The quantities of mesophilic aerobic and facultative anaerobic microorganisms, bacteria of *Escherichia coli* group, pathogenic bacteria *Salmonella*, and moulds in dried mushroom powder were enumerated by methods (Schill et al., 2021).

Results and discussion

Characteristic of proteins of dried at low-temperature mushrooms

It is a well-known fact that proteins, regarding their solubility in different media, are categorized into four classes – albumens, globulins, prolamins and glutelins (Garidel, 2013). Albumens, or water-soluble proteins, are characterized with the highest nutritional and biological value. They are transformed in the human body with the minimal energy losses and therefore are the most balanced by their amino acid content. Globulins, or salt-soluble proteins, are also outstanding by their biological value, but they are mostly limited by the amount of sulfur-containing amino acids. The two other factions, alcohol- and alkali-soluble proteins (glutelins and prolamins, respectively) lack some essential amino acids, so they are harder exposed to proteolytic enzyme action and have lower nutritional value.

The scientific literature does not currently have any data about the protein fractional composition of dried champignon powders; therefore, it was one of the main tasks in the present work. Since the champignons, as well as the other types of plant raw materials, can be processed by different ways, comparative analysis of mushrooms after freezing, after thermal treatment, and after low-temperature drying were done (Table 1).

These results confirm the expedience of obtaining the dried champignon powders, owing to the fact that 70% of protein substances are albumens and globulins, i. e. proteins of high biological value (Martinez-Medinaetal., 2021; Shelke and Badhe, 2021; Stojković et al., 2014).The data present in Table 1 show that the factional composition of champignon proteins significantly depends on the method to process the raw material. In other words, upon selecting the certain method of technological effect, it is quite possible to predict the increased ratio of the protein factions most valuable in terms of their biological activity, albumens first of all, and thenceforth reduce the part of the insoluble residue.

Table1

Effect of the method to process champignons on their protein fractional composition

Procession method	Mass part of protein faction, % of the total protein mass				
	Water-soluble	Salt-soluble	Alkali-soluble	Alcohol-soluble	Insoluble residue
Fresh mushrooms	43.6±1.6	24.0±0.5	12.8±1.1	5.2±2.4	14.4±0.5
Mushrooms after freezing (-28 to-35°C)	52.8±0.9	26.6±0.7	11.9±0.7	4.4±0.3	4.3±1.9
Mushrooms after thermal treatment (85–90°C)	33.5±2.2	20.4±1.4	8.8±0.9	6.3±0.8	31.0±1.4
Mushrooms after low-temperature drying (45°C)	46.4±0.4	24.9±1.8	10.4±0.15	3.08±1.2	15.0±1.6

In this case, the most efficient is freezing of mushrooms at temperatures of -28 to-35°C, using the quick freezing method, in which the share of albumens increased by 13.8%, and the share of the insoluble residue decreased by 28.7%. This can be explained by the fact that upon the temperature shock to which all mushroom cells and tissues are exposed while the temperature is falling to -35 °C, the firmly aggregated protein molecules composing the insoluble residue get freed and attain the ability to dissolve in water, consequently gaining the share of albumens and easily-soluble globulins.

Champignons dried at a low-temperature had approximately the same factional composition as after freezing; they contained the prevalent amount of easily soluble factions (79.4% in frozen mushroom and 71.3% in low-temperature dried ones). It would predictably increase the level of their digestibility and absorption by the human body.

On the contrary, champignons dried at high temperature were subjected to thermal destruction with the formation of insoluble protein-polysaccharide complexes, with a decrease in of water-soluble proteins by 27.8% and an increase of insoluble residue by 48.4%.

Amino acid content of proteins in dried champignon powder

The biological activity of food proteins is dependent on their amino acid content. The introduction of amino acids into nutrition is now becoming increasingly important (Asao and Asaduzzaman, 2017). Therefore, it is advisable to study the amino acid composition of low-temperature dried champignons and compare the ratio of an essential and non-essential amino acids. For more complete information, the proportion of amino acids in free and bound forms was determined. Amino acid content of proteins in dried champignon powder including amount of amino acids in free and bonded forms are presented in the Table 2.

The proteins of champignon dried at a low-temperature contain all essential amino acids with a total amount of 9.83 mg/100 g of the products. The amount of the total non-essential amino acids was 11.57 mg/100 g of the product and counts 54.06% of the total amino acid.

The dried champignon proteins contain free amino acids, which is 0.725 mg/100 g of the product for essential and 0.686 mg/100 g of the product for those non-essential amino acids. It can be predicted that after special methods for increasing the bioavailability of mushrooms, the proportion of free amino acids will increase significantly.

The result of calculating the balance of the amino acid composition, that is, the ratio of the amounts of non-essential and essential amino acids, was very important. For most proteins of natural origin, it is about 0.55-0.6% (Yastreba and Pasichny, 2010). In our studies, this indicator is 0.85%, which indicates the predominant part of the non-essential amino acids.

Table 2

Content of amino acids in proteins of powdered champignon dried at a low-temperature, mg/100 g of the product

Amino acids	Content of amino acid	Content of amino acid	
		Free	Bonded
Lysine	1.25	0.10	1.15
Phenylalanine	1.75	0.03	1.72
Leucine	2.25	0.13	2.13
Isoleucine	0.74	0.16	0.58
Valine	1.27	0.18	1.1
Methionine	0.42	0.00	0.42
Threonine	1.90	0.13	1.77
Tryptophan	0.26	-	0.26
Total essential amino acid	9.83	0.73	9.11
Total non-essential acid	11.57	0.69	10.89
Total amino acid	21.40	1.41	19.99
Balance by amino acid scores, %	0.85	1.05	0.83

Furthermore, the proportion between essential and non-essential amino acids (which shares, in our research, count 45.93% and 54.06%, respectively) is worth of re-evaluation, since it is the well-known fact that it is just this correlation to play the crucial role in establishing the good conditions for catabolic processes in body tissues. The maximal biological effect of food proteins may be reached in case of 42% of essential amino acids (NelsonandCox, 2017); the rest 58% should fall to non-essential amino acids. According to our results, the correlation between non-essential and essential amino acids in dried champignons is approximate to these optimal indices.

Finally, yet importantly, the share of free amino acids in fresh mushrooms counts 0.537 mg/100 g of the product, whereas in dried ones it grows up to 1.411 mg/100 g of the product. In other words, due to the low-temperature drying, some bonded amino acids transform into free ones, which would increase the biological value of both mushrooms themselves and the products with their additives. This is correspondent to the conclusions of Avdieva et al. (2021).

According to the scientifically proven conception of valuable nutrition, the biological value of a product is determined by not only the amount and the ratio of separate amino acids, but mainly their balance and accessibility for proteolytic enzymes effect (Vetter, 2019). Therefore, to make the complete characteristics of the protein constituent in dried champignon powders, we conducted the necessary calculations and compared the obtained results to the amino acid content of WHO reference protein.

The amino acid scores of essential amino acids in dried champignon powder are presented in Table 3.

Regarding the calculations, the amount of practically all essential amino acids exceeds the level proposed by WHO. In particular, it seems typical for the following amino acids: lysine (score 106), phenylalanine (score 146), methionine (score 125), which play the important role in the human body functioning, alike to the other essential amino acids (Asao and Asaduzzaman, 2017): lysine, liable for restoration of muscle tissues and rehabilitation after stresses; phenylalanine, constructing material for neuromediators synthesis; methionine, relevant for chronic fatigue syndrome treatment.

Table 3

Amino acid scores in dried champignon powder in comparison with WHO reference protein

Amino acids	WHO reference amino acid, mg/100 g of protein	Amino acid amount, mg/100 g of the product	Score, %	CAASD, %
Lysine	55	1.245	106	20
Phenylalanine+tyrosine	60	1.88	146	60
Leucine	70	2.25	150	64
Isoleucine	40	0.735	86	-
Valine	50	1.27	119	33
Methionine+cystine	35	0.94	125	39
Threonine	40	1.2	171	85
Tryptophan	10	0.26	122	36
Total amino acid	-	21.4		

Note: CAASD, coefficient of amino acid score difference.

During digestion, practically all essential amino acids contained by foodstuffs, including dried champignon powders, transform into important biochemical substances to fulfill the specific functions in human body (Joye, 2019). In this case, isoleucine is the amino acid to limit the biological value of proteins (score 86%).

The data presented in Table 3 also allowed defining the grade of dried champignon powders proteins utilization with a help of calculating the coefficient of amino acid score difference. Actually, this is counted by subtracting the score of the limiting amino acid (isoleucine) from the score of any essential amino acid.

The average arithmetical coefficient of amino acid score difference in a mushroom semi-finished product is equal to 48.2%; respectively, the biological value of low-temperature dried champignon proteins is 51.8%. These data are correlated to the similar results presented in the work (Yastreba and Pasichny, 2010), in which the biological value of oyster mushrooms semi-finished products was estimated in 44-45%.

Sensory and microbiological characteristics of dried champignon powder

Table 4 represents the sensory characteristics of powders made from champignons.

Table 4

Sensory quality parameters of dried champignon powder

Parameters	Characteristics
Appearance	Fine-disperse, 100–150 microns, powder with moisture content of 8–12%, homogenous, without lumps
Taste and smell	Typical for fresh champignons, without any strange taste and smack, palatable, delicious
Color	From light-cream in case the caps are separated from legs to different hues of brown
Texture	Dependent on the mushrooms' maturity grade and homogeneity; with the optimal quality characteristics, is loose, homogenous, without lumps

It should be noted that at a drying temperature of 45 ° C, the process of binding of volatile components (alcohols and ketones: L-hexanol, 3-heptanol, 3-octanol, 3-octanone, L-octene) presumably occurs, which impart a specific mushroom aroma to dried champignons and products prepared with their use (Zhang et al., 2022).

An important task is to ensure the microbiological safety of dried champignon powder both immediately after their production and during storage. The microbiological analysises were performed directly after obtaining the dried champignon powder and every three months throughout a year. The results are presented in Table 5.

Table 5

Microbiological characteristics of dried champignon powder during storage

Microorganisms	Hygienic norms	Time of storage, months				
		0	3	6	9	12
MAFAnM, CFU/g	$5.0 \cdot 10^4$	$2.2 \cdot 10^2$	$2.2 \cdot 10_2$	$4.6 \cdot 10^2$	$8.3 \cdot 10^2$	$5.8 \cdot 10^3$
Escherichia coli in 0.1 g	N/A	N/D	N/D	N/D	N/D	N/D
Moulds, CFU/g	$5.0 \cdot 10^2$	N/D	N/D	N/D	N/D	N/D
Yeast CFU/g	$2.0 \cdot 10^2$	N/D	N/D	N/D	N/D	$1.0 \cdot 10^1$

Note: MAFAnM, mesophilic aerobic and facultative anaerobic microorganisms; CFU, Colony Forming Units; N/A, not allowed; N/D, not detected.

The results of microbiological analysis show that the pathogenic bacteria of *Salmonella* genus (in 25 g of the product) were not detected in dried champignon powder; the bacteria of *Escherichia coli* group were not found, as well as moulds. Yeast were detected only in the sample stored for 12 months, otherwise their amount is sufficiently less than the hygienic norm. Thus, the highlighted method to prepare the dried champignon powders, which includes their drying with a temperature of 45 °C for 340 min, provides the level of the product's general microbial contamination by MAFAnM within the limitations and alongside oppresses the activity of harmful microorganisms.

Conclusions

The deficiency of protein foods is dramatically progressing; the animal proteins, as well as those obtained by microbiological methods, cannot provide their necessary amounts in diets. Therefore, the role of natural plant-origin proteins, as well as knowledge on their chemical nature, is sharply increased, which would create the preconditions to development of scientifically intensified technologies to process the protein containing raw materials and widely include them into the food technology. In this viewpoint, typical for many countries are the increasing scales of growing and using the cultivated mushrooms, regarding the high amounts of their biologically active substances to express the various pharmacological impacts. Among the cultivated mushrooms, champignons (*Agaricus bisporus*) occupy the priority place.

The most important factors to define the selection of mushroom raw materials for obtaining the high-quality semi-finished products are the proteins, particularly their ratio, biological value, amino acid balance, compliance of essential amino acids with the WHO reference protein, and also sensory characteristics that satisfy both the requirements to main technological processes and the consumer's needs.

The results of theoretical and experimental researches presented in this work are believed to expand the knowledge about the protein components and the biological value of

champignons, to prove the expedience to process them into powdered products to fortify different food mediums in order to increase the protein ratio. These fortified foodstuffs would become an efficient remedy for both the correction of diets and prevention or additional treatment of alimentary-originated diseases. Henceforth, the studies of mushroom cultivation, improving the technologies of their procession and application as food supplements or healthy foodstuffs remain relevant for nowadays and for the years to come.

References

Asao T., Md. Asaduzzaman (2017), *Amino Acid – New Insights and Roles in Plant and Animal*, IntechOpen, DOI: 10.5772/66064.

Avdieva L., Zhukotskyi E., Dekusha H., Ivanov S.(2021), Analysis of the existing methods and specific features of drying shiitake mushrooms, *Food Science and Technology*, 3, pp. 94–107, DOI:10.15673/fst.v15i3.2118.

Bakratsas G., Polydera A., Katapodis P., Stamatis H. (2021), Recent trends in submerged cultivation of mushrooms and their application as a source of nutraceuticals and food additives, *Future Foods*, 4, p. 100086, DOI: 10.1016/j.fufo.2021.100086.

Calvo M.S., Mehrotra A., Beelman R.B. (2016), A retrospective study in adults with metabolic syndrome: diabetic risk factor response to daily consumption of *Agaricus bisporus* (white button mushrooms), *Plant Foods for Human Nutrition*, 71(3), pp. 245–251, DOI: 10.1007/s11130-016-0552-7.

González A., Cruz M., Losoya C., Nobre C., Loredo A., Rodríguez R., Contreras J., Belmares R. (2020), Edible mushrooms as a novel protein source for functional foods, *Food & Function*, 11(9), pp. 7400–7414, DOI: 10.1039/d0fo01746a.

Dietary Protein Quality Evaluation in Human Nutrition (2011), *FAO Food and Nutrition Paper*, 31 March-2 April, 2011, Auckland, New Zealand, 92.

Ferdousi J., Al-Riyadh Z., Ikbal H.(2020), Mushroom production: benefits, status, challenges and opportunities in Bangladesh: A review, *Annual Research & Review in Biology*, 34(6), pp. 1–13, DOI: 10.9734/arrb/2019/v34i630169.

Garidel P. (2013), Protein solubility from a biochemical, physicochemical and colloidal perspective, American Pharmaceutical Review, Available at: https://www.americanpharmaceuticalreview.com/Featured-Articles/152568-Protein-Solubility-from-a-Biochemical-Physicochemical-and-Colloidal-Perspective.

Haeney M. (1994), Intravenous immune globulin in primary immunodeficiency, *Clinical & Experimental Immunology*, 97, pp. 11–15.

Ivanov V., Shevchenko O., Marynin A., Stabnikov V., Gubenia O., Stabnikova O., Shevchenko A., Gavva O., Saliuk A. Trends and expected benefits of the breaking edge food technologies in 2021–2030. *Ukrainian Food Journal*, 2021, 10(1), pp. 7-36. DOI: 10.24263/2304-974X-2021-10-1-3

Joye I. (2019), Protein digestibility of cereal products, *Foods*, 8(6), pp. 199–213, DOI: 10.3390/foods8060199.

Kumar M., Turner S. (2015), Protocol: a medium-throughput determination of cellulose content from single stem pieces of *Arabidopsis thaliana*, *Plant Methods*, 11, DOI: 10.1186/s13007-015-0090-6.

Martinez-Medina G.A., Chávez-González M.L., Kumar V.D. (2021), Bio-funcional components in mushrooms, a health opportunity: Ergothionine and huitlacohe as recent trends, *Journal of Functional Foods*, 77, p. 104326, DOI: 10.1016/j.jff.2020.104326.

Meera Ch.R., Smina Th.P., Nitha B. (2009), Antiarthritic activity of a polysaccharide-protein complex isolated from *Phellinus rimosus* (Berk.) Pilat (Aphyllophoromycetideae) in

Freund's complete adjuvant Induced arthritic rats, *International Journal of Medicinal Mushrooms*, 11(1), pp. 21–28, DOI: 10.1615/IntJMedMushr.v11.i1.30.

Metrohm IC. (2023), Determination of carbohydrates by means of ion chromatography, Available at: https://www.metrohm.com/en-th/company/news/news-determination-of-carbohydrates-by-means-of-ion-chromatography.

Nelson D.L., Cox M.M. (2017), *Lehninger Principles of Biochemistry*, Springer.

Ramos M., Burgos N., Barnard A., Evans G., Preece J., Graz M., Ruthes A.C., Quero A.J., Martínez-Abad A., Vilaplana F., Pham L., Brouwer A. (2019), *Agaricus bisporus* and its by-products as a source of valuable extracts and bioactive compounds, *Food Chemistry*, 292, pp. 176–187, DOI: 10.1016/j.foodchem.2019.04.035.

Redweik S., Xu Y., Wätzig H. (2012), Precise, fast and flexible determination of protein interactions by affinity capillary electrophoresis, *Electrophoresis*, 33(22), pp. 3316–3322, DOI: 10.1002/elps.201200181.

Ribeiro B., de Pinhoa P., Andrade P., Baptista P., Valentão P.(2009), Fatty acid composition of wild edible mushrooms species: A comparative study, *Microchemical Journal*, 93(1), pp. 29–35, DOI: 10.1016/j.microc.2009.04.005.

Shelke S., Badhe P. (2021), In-silico study of *Agaricus bisporus* on DNA damaging protein, *Preprints 2021*, 2021090138, DOI: 10.20944/preprints202109.0138.v1.

Schill S., Stessl B., Meier N., Tichy A., Wagner M., Ludewig M. (2021), Microbiological safety and sensory quality of cultivated mushrooms (*Pleurotus eryngii*, *Pleurotus ostreatus* and *Lentinula edodes*) at retail level and post-retail storage, *Foods*, 10(4), pp. DOI: 10.3390/foods10040816.

Stabnikova O., Wang J.Y., Ivanov V. (2010), Value-added biotechnological products from organic wastes, In: Wang L.K., Ivanov V., Tay J.H., Hung Y.T. eds., Handbook of environmental engineering, Vol.10, Environmental biotechnology, Humana Press, NJ, pp. 343– 394. DOI: 10.1007/978-1-60327-140-0_8.

Stojković D., Reis F.S., Glamočlija J. et al. (2014), Cultivated strains of *Agaricus bisporus* and *A. brasiliensis*: chemical characterization and evaluation of antioxidant and antimicrobial properties for the final healthy product-natural preservatives in yoghurt, *Food & Function*, 5(7), pp. 1602–1612, DOI: 10.1039/c4fo00054d.

Tarabees R.Z., Hassanin Z.H., El Bagoury A.M. (2015), Polymerase chain reaction (PCR): an alternative rapid method for detection of some microbial contamination of meat products, *Alexandria Journal of Veterinary Sciences*, 45, pp. 91–98, DOI: 10.5455/ajvs.177446.

Vetter J. (2019), Biological values of cultivated mushrooms – a review, *Acta Alimentaria*, 48(2), pp.229–240, DOI: 10.1556/066.2019.48.2.11.

Walde S.G., Velu V., Jyothirmayi T., Math R.G. (2006), Effects of pretreatments and drying methods on dehydration of mushroom, *Journal of Food Engineering*,74(1), pp. 108–115, DOI: 10.1016/j.jfoodeng.2005.02.008.

Wasser S.P., Sokolov D., Reshetnikov S., Timor-Tismenetsky M. (2000), *International Journal of Medicinal Mushrooms*, 1, pp. 1–19, DOI: 10.1615/IntJMedMushr.v2.i1.10.

Yastreba Yu., Pasichny V. (2010), Doslidzhennya biologichnoyi tsinnosti poroshkopodibnoho napivfabrykatu z hrybiv hlyva zvychayna, *Naukovyi Visnyk Lvivskoyi Derzhavnoyi Akademiyi Veterynarnoyi Medycyny im. S.Z. Gzhytskoho*, 2, pp. 124–129.

Yurchak V., Sharkova N. (2023), Development of dietary additive of shiitake mushrooms enhanced with active polysaccharides for pasta production, In: Paredes-López O., Shevchenko O., Stabnikov V., Ivanov V., eds., *Bioenhancement and fortification of foods for a healthy diet,* pp. 221-236, CRC Press, Boca Raton, London, DOI: 10.1201/9781003225287-6.

Zhang M., Xing S., Fu C. et al. (2022), Effects of drying methods on taste components and flavor characterization of *Cordyceps militaris*, *Foods*, 11(3933), pp. 1–18, DOI: 10.3390/foods11233933.