UDC: 635.8
DOI: 10.56407/bs.agrarian/1.2024.66

Ukrainian Black Sea Region Agrarian Science
Vol. 28, No. 1

Research of the vacuum low-temperature frying process *Pleurotus eryngii*

Nataliia Bolhova*
PhD in Agriculture, Associate Professor
Sumy National Agrarian University
40000, 160 Gerasym Kondratiev Str., Sumy, Ukraine
http://orcid.org/0000-0002-0201-0769

Lin Fang
Sumy National Agrarian University
40000, 160 Gerasym Kondratiev Str., Sumy, Ukraine
http://orcid.org/0000-0001-8513-6502

Yuliya Nazarenko
PhD in Technical Sciences, Associate Professor
Sumy National Agrarian University
40000, 160 Gerasym Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0003-4870-4667

Tetiana Synenko
Doctor of Philosophy, Associate Professor
Sumy National Agrarian University
40000, 160 Gerasym Kondratiev Str., Sumy, Ukraine
https://orcid.org/0000-0002-5300-5142

Abstract. Mushrooms are consumed because of their nutrients and therapeutic bioactive compounds, historically used in medicine, and representatives of the genus *Pleurotus* are edible species rich in dietary fibre, vitamins, micro- and macroelements, and carbohydrates. The aim is to theoretically substantiate the vacuum frying of oyster mushroom pieces and to obtain a crispy product with optimal consumer characteristics. In the course of the study, the methods of vacuum low-temperature frying, organoleptic study, orthogonal test, single-factor and statistical analysis were used. The factors affecting the quality of vacuum roasting of oyster mushrooms: pre-drying time, temperature and roasting time are analysed. The relationship between oil content and sensory evaluation is described and analysed. The optimal technological parameters of vacuum frying were determined. *Pleurotus eryngii* with a thickness of 2 mm were completely inactivated under boiling conditions for 90 s at 80°C, and for 10 s at 90 and 100°C. If prolonged cooking takes place, the oyster mushroom texture becomes soft and is not amenable to further processing under vacuum at low temperature. Therefore, in order to save production energy and reduce the loss of flavour and nutrients, cooking at 80°C for 90 s was chosen. It has been shown that the treatment of *Pleurotus eryngii* with maltodextrin before vacuum frying reduces the oil content after frying, provides a homogeneous structure, good taste and crispiness of the product. Optimal parameters were obtained: 2 mm slices, mass fraction of maltodextrin 15%, sonication duration 15 min. The influence on the sensory evaluation of the primary and secondary order is described: frying temperature > pre-drying time > frying time. The specific

Article's History:
Received: 10.11.2023
Revised: 20.02.2024
Accepted: 12.03.2024

Suggested Citation:
Bolhova, N., Fang, L., Nazarenko, Yu., & Synenko, T. (2024). Research of the vacuum low-temperature frying process *Pleurotus eryngii*. *Ukrainian Black Sea Region Agrarian Science*, 28(1), 66-78. doi: 10.56407/bs.agrarian/1.2024.66.

*Corresponding author

parameters for which the product will obtain the best sensory characteristics were indicated, namely: frying for 10 min, pre-drying for 20 min, frying temperature of 90°C. The factors influencing the oil content were analysed: pre-drying time > frying time > frying temperature. It was found that the product can obtain the lowest oil content when pre-drying for 30 minutes and frying at 80°C for 10 minutes. The practical value of the study lies in the optimal conditions of the process under investigation: pre-drying time with hot air 20 min, frying temperature 80-90°C, frying time 10 min, frying vacuum 0.08-0.09 MPa

Keywords: oyster mushroom; quality; one-factor test; orthogonal test; sensory evaluation; blanching; oil

INTRODUCTION

Roasting fresh *Pleurotus eryngii* is a new way of eating that further meets the needs of different consumers. At the same time, roasting plays an important role in improving the quality of the food. After frying, the shape shrinks and becomes hard and brittle. A layer of golden yellow gradually forms on the surface, releasing the unique flavour of fried food, which is crispy and tasty.

A. Pérez-Montes *et al.* (2021) noted in their work that the use of edible mushrooms in the food industry is explained by their physicochemical composition and economic availability. *Pleurotus eryngii* is rich in bacteria, crispy and delicate in texture, white in colour, has a unique almond aroma and abalone flavour, which is why it is called the almond abalone mushroom. It is native to Southern Europe, North Africa and Central Asia.

The nutritional value of mushrooms depends on the conditions of their cultivation. According to F. Ayimbila & S. Keawsompong (2023), the protein content ranges from 18 to 37%. In the studies of J. Raman *et al.* (2021), the content of proteins, carbohydrates and dietary fibre was 15.4-28.6, 61.3-84.1, 33.3%, respectively. Scientists H. El-Ramady *et al.* (2022) concluded that every 100 g of dried *Pleurotus eryngii* contains 11.95-35.5% protein, 39.85-63.03% carbohydrates, 36.78 g of total sugar, 1.06-7.50% fat, 6.20-28.29% dietary fibre, 2.97-10.7% ash, which is suitable for diabetics and the elderly.

Pleurotus eryngii is rich in nutrients. It contains a lot of protein, carbohydrates, and many vitamins and minerals. It has a crispy and delicate taste, and has the effects of lowering blood sugar, lowering blood fat, preventing cancer, enhancing immunity, antioxidant, antibacterial and anti-aging effects, as well as anti-fatigue and anti-aging. According to the analysis of A. González *et al.* (2020), *Pleurotus eryngii* protein contains 18 types of amino acids, and the content of 8 types of essential amino acids of the human body is 42.0% of the total amino acids, which is in line with the reference protein model proposed by the Food and Agriculture Organization, World Health Organization. A study on mice conducted by Y. Zhao *et al.* (2020) showed a decrease in animal body weight when eating *Pleurotus eryngii*. A review article by S.K. Dubey *et al.* (2019) analysed the use of mushrooms in the treatment of diabetes and obesity. This opinion was also confirmed in research by J. Ślusarczyk *et al.* (2021). They drew attention to polysaccharides, which exhibit immunoregulatory and antitumour properties by activating the body's immune system. Currently, most mushrooms are fresh foods, and a small portion is processed into dried products (Fang *et al.*, 2021). At the same time, scientists J.-W. Bai *et al.* (2023) pay considerable attention to the study of drying methods and conditions: hot air drying, infrared drying, microwave drying.

Vacuum low-temperature frying technology, according to D. Yang *et al.* (2020), mainly refers to using the principle of lowering the boiling point of water in a negative pressure vacuum and using vegetable oil with strong antioxidant ability as the medium to achieve the process of frying and dehydration under low temperature conditions. Compared with conventional pressure frying, it can better retain the original colour, taste and nutrients of the material, and at the same time can reduce the degree of degradation of oil oxidation and carcinogen formation. In addition, it is easy to form a loose and porous structure and crispy taste.

Fresh *Pleurotus eryngii* has an extremely high water content and soft and delicate tissues. After the processes of colour protection, blanching and dipping, the moisture content of the tissues will increase further due to the destruction of some tissue cells. If vacuum frying is carried out directly, the high water content will result in a high oil content in the product; if vacuum frying is carried out after freezing treatment, although it is beneficial for the flatness of the product, it will result in an increase in oil content. A. Ren *et al.* (2018) believe that the ice crystals that form during freezing will make the structure of the vacuum fried product fluffier. During the vacuum frying process, the ice crystals are directly evaporated, so the product will have a certain expansion effect, but the space formed by the expansion will be replaced by the oil phase, causing the product to have a high oil content. A study by J.R. Barbosa *et al.* (2020) found that vacuum frying is carried out directly after freezing. At this time, the temperature difference between the material and the fat is large, and the structure of the material after freezing is more loose, which is conducive to the penetration of the oil phase, which also leads to high oil content in the product.

It is generally believed that there are two ways of fat adsorption in the vacuum frying process: one is the contact and adsorption of fat with the material surface; the other is the replacement of the water phase with the oil phase during the mass transfer process during vacuum frying. The greater the surface tension, the harder it is for the oil to be adsorbed by the product, as confirmed by J. Zhang & L. Fan (2021). For the first method of adsorption, the surface tension of the material can be changed to reduce oil adsorption, for example by adding a surfactant. For the second method, the goal of reducing oil adsorption can be achieved by reducing the aqueous phase space. Typically, the method used to reduce the oil content is to increase the soluble solids content and reduce the moisture content before frying.

The aim of the work was to create a theoretical basis for quality control of vacuum frying of crispy oyster mushroom slices in a vacuum.

MATERIALS AND METHODS

The study used vacuum low-temperature frying technology to process the *Pleurotus eryngii* slices, and hot air impregnation and pre-drying to increase the dry matter content and decrease the moisture content to reduce the oil content of the product. A one-factor test was used to investigate the moisture and oil content of *Pleurotus eryngii* slices during vacuum frying and to determine the appropriate test range for the orthogonal test. The moisture content, oil content and sensory evaluation were used as indicators to determine the optimal frying parameters and degreasing parameters during the vacuum low-temperature frying process of *Pleurotus eryngii* slices.

The following instruments and equipment were used: TP-200D electronic scales (manufacturer: Xiangyi Balance Instrument Equipment Co., Ltd.); VF-40C vacuum fryer (manufacturer: Zhong Shan VK Vacuum Machinery Co, Ltd.); HH-S constant temperature oil bath (manufacturer: Jiangsu Jintan Huanyu Scientific Instrument Factory); SZT-06A fat meter (manufacturer: Suzhou Tianwei Instrument Co., Ltd.); drying cabinet type 101-2 (manufacturer: Shanghai Experimental Instrument Factory); KQ-50B ultrasonic cleaner (manufacturer: Kunshan Ultrasonic Instrument Co, Ltd.).

The sequence of the study was as follows: (1) Fresh *Pleurotus eryngii* without rot and mechanical damage washed in running water is selected. (2) After washing, *Pleurotus eryngii* is cut into pieces and sliced longitudinally, with a thickness of about 2 mm. (3) The sliced *Pleurotus eryngii* pieces are placed in hot water for blanching, and the time of placement is recorded. They are taken out immediately after blanching and quickly cooled with running water. (4) The cooled *Pleurotus eryngii* pieces are placed in a maltodextrin solution of a certain concentration for immersion by ultrasonication. After soaking, the *Pleurotus eryngii* pieces are taken out and the surface moisture is dried. (5) The processed *Pleurotus eryngii* pieces are placed in a drying oven for pre-drying at a certain temperature. (6) The pre-dried *Pleurotus eryngii* slices are placed in an airtight container and placed in a sealed place. (7) The vacuum frying device is switched on and the frying temperature, frying time and oil removal time are set. The palm oil is heated to the set temperature, the slices of *Pleurotus eryngii* are placed on the frying grid, the frying container is closed, which is placed in the frying chamber, the frying chamber door is closed, and then the vacuum pump is switched on for vacuuming. When the vacuum degree reaches approximately 0.08-0.09 MPa, the vacuum frying container is lowered. (8) After the frying process is complete, the oil level in the frying container rises. The frying container is degreased under vacuum. After degreasing, the motor and vacuum pump are turned off, the vacuum valve is opened to blow out the air, and the experimental product is taken out. (9) Crispy whole slices of *Pleurotus eryngii* with uniform texture are selected for packaging in a nitrogen environment.

In order to prevent the darkening reaction of *Pleurotus eryngii* slices, bleaching and enzymatic treatment were performed during the preliminary hot air drying and vacuum roasting process. The presence of peroxidase activity is used as an indicator of whether the enzyme is completely destroyed. In order to determine the relationship between temperature and blanching time and peroxidase activity, *Pleurotus eryngii* was cut into slices of about 2 mm thickness and blanched in water at 60, 70, 80, 90, 100°C. The mushroom slices were taken out after 2, 5, 10 and 15 s and tested with 2-methoxyphenol test solution. If the colour of the *Pleurotus eryngii* slices did not change, it meant that they were completely inactivated.

The dipping treatment of *Pleurotus eryngii* pieces was carried out before vacuum low-temperature frying. Ultrasonically assisted impregnation was used to promote the impregnation. Using ultrasonic impregnation with a slice thickness of 2 mm as a fixed parameter, the effect of maltodextrin concentration and material-liquid ratio on the solid content of *Pleurotus eryngii* slices was studied. In each group, pieces of *Pleurotus eryngii* were selected after blanching, and two factors, maltodextrin concentration and material-to-liquid ratio, were used to study the change in solid content of

2 mm pieces of *Pleurotus eryngii* after blanching. The impregnation concentration was 10, 15, 20, 25%; the material-to-liquid ratio was 5, 10, 15, 20 ml/g for a one-factor experiment. The difference in quality was used to determine the solid content of *Pleurotus eryngii* pieces after immersion and to determine the optimal parameters of the immersion process.

Before vacuum low-temperature frying, *Pleurotus eryngii* slices undergo a certain pre-drying process, which can appropriately reduce the moisture content of mushroom slices and reduce the replacement of water phase with oil phase during the vacuum frying process, which can effectively reduce the oil content of products after rapid vacuum frying. In order to study the effect of the pre-drying process on the quality of *Pleurotus eryngii* pieces, *Pleurotus eryngii* pieces with a thickness of about 2 mm after blanching and dipping were subjected to hot air drying at 60, 70 and 80°C, respectively. After evaluation, the moisture content, colour and deformation of the *Pleurotus eryngii* pieces were evaluated as indicators and measured every 10 minutes to determine the optimal parameters of the pre-drying process. In order to study the effect of frying temperature on product oil content and sensory quality, the pre-drying conditions were set to dry at 60°C for 20 minutes, vacuum frying time was 10 minutes, vacuum degree was 0.08-0.09 MPa, frying temperature was 70°C, frying was performed at 80, 90, 100 and 110°C, degreasing speed was 350 rpm, and degreasing time was 10 minutes. Each time 100 g of *Pleurotus eryngii* pieces were sampled for the one-factor test, the oil and water content of the final product was determined and the product was sensory evaluated.

Vacuum frying conditions have a great impact on the colour, crispness, fat content, flavour, appearance and other qualities of *Pleurotus eryngii* (Table 1). Taking the hot air pre-drying time, vacuum frying temperature and vacuum frying time as factors, the corresponding level of each factor determined according to the single-factor test is taken as the level of the orthogonal test, and the L9 orthogonal test is designed to determine the final vacuum oil frying process.

Table 1. *Sensory assessment criteria and methods*

Assessment	Colour	Crispness	Fat content	Taste characteristics	Shape	General perception
0-2	Yellowish brown, strong browning	Harder or softer	High oil content, oily taste	No *Pleurotus eryngii* scent or *Pleurotus eryngii* scent is very strong, difficult to to perceive	The whole is twisted, severely broken, and the burning phenomenon is serious	Very poor
3-4	Yellow with strong browning at the edges	General	High oil content, oily surface	The smell of *Pleurotus eryngii* is not obvious	Sections of *Pleurotus eryngii* are more degenerated and slightly burnt	Not enough
5-6	Yellow, with a slight browning	Crispy crust	Slightly higher oil content	General	Slices of *Pleurotus eryngii* rolled up all around	Common
7-8	Light yellow	Relatively crispy	Moderate oil content	*Pleurotus eryngii* has an obvious aroma	*Pleurotus eryngii* slices are slightly twisted	Good
9-10	Light yellow, uniform colour	Very crunchy	Low oil content, no greasy feeling	*Pleurotus eryngii* has a distinct and moderate flavour and is easy to digest	Slices of *Pleurotus eryngii* are whole, without curling	Excellent

Source: *authors' own development*

In order to study the effect of degreasing time after vacuum frying on the oil content of *Pleurotus eryngii* slices, a test was conducted to degrease *Pleurotus eryngii* slices fried under optimal vacuum frying conditions using the centrifugal rotation method. The speed of degreasing by centrifugal rotation of the vacuum frying equipment was set at 350 rpm. After vacuum frying, centrifugal rotational degreasing was carried out for 2, 4, 6, 8, 10 and 12 min, and the effect of degreasing time on the oil content of *Pleurotus eryngii* was determined and analysed. Excel 2010 was used to organise and analyse the test data, and a line graph was drawn using Origin 9.0.

RESULTS AND DISCUSSION

Table 2 shows the effect of different blanching temperatures and times on peroxidase activity in *Pleurotus eryngii* slices. It can be seen that the peroxidase is inactivated by scalding at 60°C for 60 s and 70°C for 30 s after 30 s in the middle of the mushroom slices, but there is still activity on the marginal epidermis. This may be due to the fact that the peroxidase in the mushroom epidermis is active, which in turn may be due to the distribution of polyphenolic substrates in different parts of *Pleurotus eryngii* and different polyphenol oxidase activities. The peroxidase of *Pleurotus eryngii* was completely inactivated by scalding at 80°C for 90 s, 90 and 100°C for 10 s. However, if the blanching time is too long, the texture of *Pleurotus eryngii* becomes soft. Considering the need to save energy in production and reduce the loss of flavour nutrients, the blanching process parameter was set at 80°C and blanching for 90 s. The results of this experiment are consistent with those of A. Ren *et al.* (2022). The authors proposed blanching in boiling water at 100°C for 3 min. In P. Piyalungka *et al.* (2019), it was practically established that with an increase in temperature (90-110°C) and roasting time (10-30 min), the oil content, hardness, and darkening of the samples increased.

Table 2. *Effect of different blanching temperature and time on peroxidase activity Pleurotus eryngii*

Time (s)/ Temperature	10	20	30	40	50	60	70	80	90	100	110	120
60	++	++	++	++	++	+	+	+	+	+	+	+
70	++	++	+	+	+	+	+	+	+	+	+	+
80	+	+	+	+	+	+	+	+	-	-	-	-
90	-	-	-	-	-	-		-	-	-	-	-
100	-	-	-	-	-	-	-	-	-	-	-	-

Notes: *"++" – general colour change; "+" – edge colour change; "-" – colour change*
Source: *authors' own development*

Impregnating *Pleurotus eryngii* flakes before vacuum frying can not only increase the dry matter content of *Pleurotus eryngii*, but also reduce the moisture content before vacuum frying to reduce the oil content of the final product by reducing the water phase. At the same time, it is also conducive to maintaining the flatness of the product, and can increase the crispiness of *Pleurotus eryngii* slices and obtain better sensory quality. In addition, by improving the taste, it also improves the quality of *Pleurotus eryngii* slices, effectively reducing costs, which is consistent with the opinions of M. Kidoń & J. Grabowska (2021) and J. Zhu *et al.* (2022).

To determine the effect of maltodextrin concentration on the dry matter content of *Pleurotus eryngii*, slices (2 mm thick, blanched at 80°C for 90 s), weighing 30 g, were selected and immersed for 15 min at a material to liquid ratio of 1:5. The dry matter content of *Pleurotus eryngii* slices varies with malt. The same phenomena were observed by T.-V.-L. Nguyen *et al.* (2023), studying the effect of different maltodextrin contents (0, 6, 7, 5, 9 and 10,5 g/100 g of pulp) on the drying rate of avocado pulp, and J.W. Siccama *et al.* (2021), demonstrating the drying technology of asparagus concentrate. The dependence of the change in the mass fraction of dextrin is shown in Figure 1.

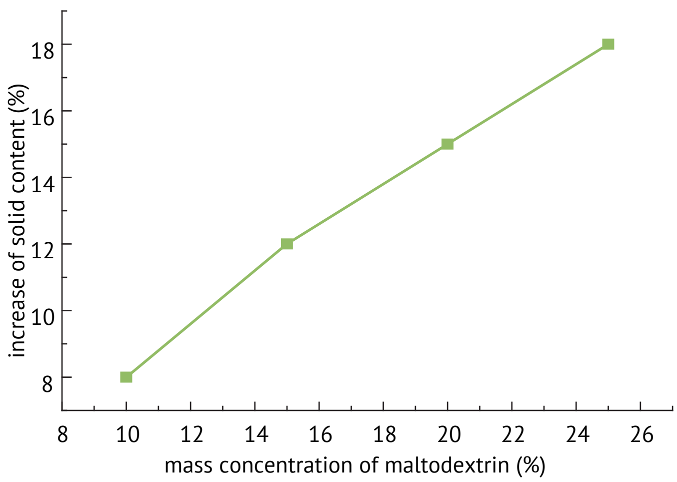

Figure 1. *Effect of maltodextrin concentration on dry matter content*
Source: *authors' own development*

The figure above shows that within a certain range, the concentration of maltodextrin can increase the solid content of *Pleurotus eryngii* slices. The higher the mass fraction of the impregnating solution, the more the dry matter content increases, but when the mass fraction of the impregnating solution exceeds 15%. At that time, the sweetness of maltodextrin is relatively high, which masks the original flavour of *Pleurotus eryngii,* so it is ideal to choose maltodextrin with a mass fraction of 15% as an impregnating solution. S. Lachowicz *et al.* (2020) confirmed the positive effect of adding maltodextrin at 15% in preparation for vacuum drying of Saskatoon fruit, juice and berry pomace.

To determine the effect of the material-liquid ratio on the solid phase content of *Pleurotus eryngii*, sliced and blanched slices (2 mm thick, blanched at 80°C for 90 s) weighing 30 g were selected, immersed in maltodextrin with a concentration of 15% for 15 minutes, after which the dry matter content of the *Pleurotus eryngii* slices would change. The dependence of the change in the liquid ratio is shown in Figure 2.

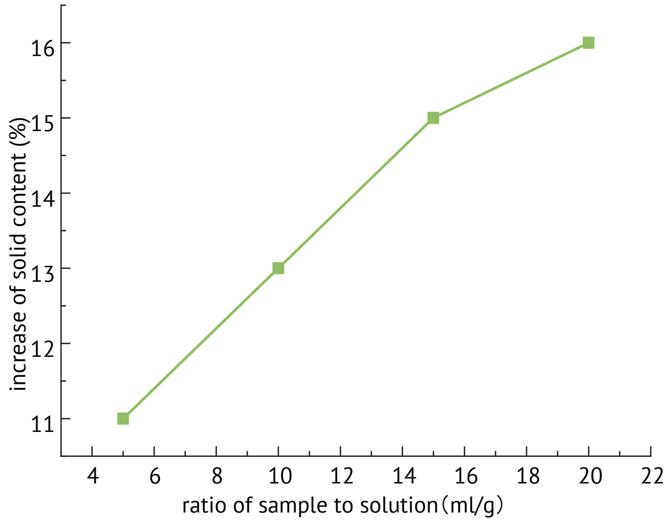

Figure 2. *Effect of sample to solution ratio on solid phase content*

Source: *authors' own development*

Figure 2 shows that the greater the mass ratio of *Pleurotus eryngii* flakes to the impregnating liquid, the higher the impregnation efficiency, and when the ratio of impregnating liquid exceeds 15 ml/g, the dry matter content increases slowly. Therefore, the mass ratio of *Pleurotus eryngii* pieces to malt dextrin impregnating solution was determined to be 15 ml/g. A. Ren *et al.* (2018) reported that shiikate mushroom chips cut into 6 mm thickness and soaked in a 50% maltodextrin solution resulted in a vacuum-fried product with the highest dehydration efficiency index, lowest oil content, and higher sensory performance.

Comprehensively taking into account the above test results, the optimal parameters of the process of dipping *Pleurotus eryngii* slices before vacuum low-temperature roasting were determined, which are as follows: thickness of *Pleurotus eryngii* slices – 2 mm, mass fraction of maltodextrin - 15%, ultrasonic impregnation for 15 minutes, at which the material-liquid ratio is 15 ml/g. The developed algorithm is consistent with the result reported by J. Zhang *et al.* (2021). The *Pleurotus eryngii* pieces after blanching and immersion are removed and dried to dry the surface moisture, and then subjected to the hot air pre-drying test (Table 3).

Table 3. *Effect of different drying temperatures and times on moisture content and appearance Pleurotus eryngii*

Drying time, min	Drying temperature 60°C		Drying temperature 70°C		Drying temperature 80°C	
	Moisture content, %	Exterior	Moisture content, %	Exterior	Moisture content, %	Exterior
10	80.9	No discolouration, no shrinkage	79.2	No discolouration, no shrinkage	79.0	No discolouration, no shrinkage
20	77.9	No discolouration, no shrinkage	77.2	Colour does not change, slightly shrinks	75.4	Does not change colour, does not shrink
30	72.7	Colour hardly changes, slightly shrinks	68.0	Slight discolouration and shrinkage	64.5	Some colours change, shrinkage is more severe

Table 3, Continued

Drying time, min	Drying temperature 60°C		Drying temperature 70°C		Drying temperature 80°C	
	Moisture content, %	Exterior	Moisture content, %	Exterior	Moisture content, %	Exterior
40	/	Colour hardly changes, shrinks	/	Some colours change and shrink	/	Colour changes strongly and serious shrinkage occurs

Notes: *since the colour and shape of the Pleurotus eryngii slices have undergone obvious changes after drying for 40 minutes, it is not suitable for frying and the moisture content was not measured*
Source: *authors' own development*

Table 3 shows that as the drying time increases, the moisture content of *Pleurotus eryngii* slices gradually decreases. The *Pleurotus eryngii* slices pre-dried by hot air at 60°C can effectively delay the deformation and discolouration of *Pleurotus eryngii* slices during the pre-drying process, while ensuring the dehydration rate, which can minimise the vacuum roasting process. The *Pleurotus eryngii* slices are highly deformable, shrinkable and hardenable. The *Pleurotus eryngii* slices dried at 60°C cannot shrink, and there is no obvious discolouration. The effect of hot air pre-drying is the best.

To investigate the effect of frying temperature on the oil and water content and sensory quality of the product, 100 g of 2 mm thick slices of *Pleurotus eryngii* were blanched and dipped, and the pre-drying conditions were set to 60°C for 20 min and vacuumed. After vacuum frying, centrifugal degreasing was performed at 350 rpm, the oil and water content of the product was measured, and a sensory evaluation of the product was performed based on an overall score of 60 points. The standard sensory score, as well as the results of the moisture and oil content of the product, are given in Table 4 and shown in Figure 3.

Table 4. *Results of sensory evaluation of Pleurotus eryngii pieces with different roasting temperatures*

Temperature	Colour	Texture	Greasy feeling	Taste	Shape	Acceptance	Assessment
70	8	4	7	5	8	5	37
80	9	8	8	7	8	8	48
90	7	8	7	7	7	8	44
100	7	8	7	7	7	8	44
110	6	8	6	6	7	7	40

Source: *authors' own development*

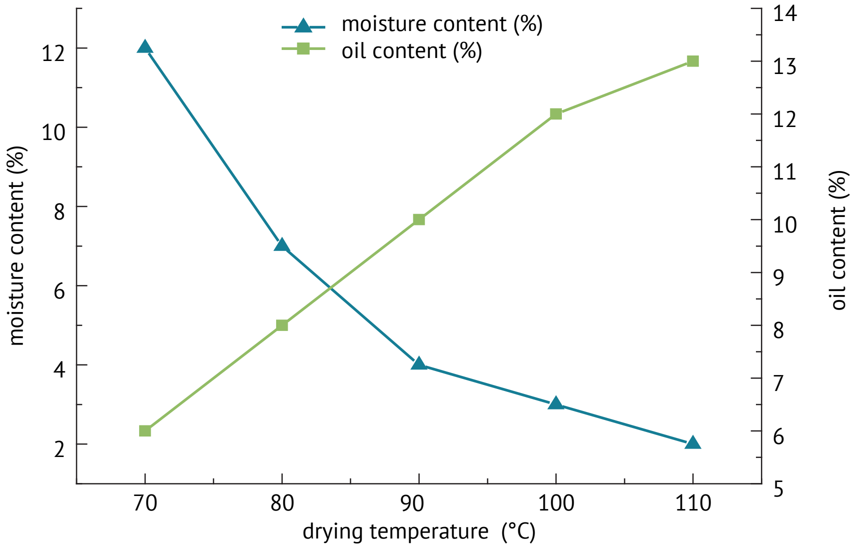

Figure 3. *Effect of frying temperature on moisture and oil content in Pleurotus eryngii*
Source: *authors' own development*

It can be seen that under the same conditions of hot air pre-drying time, degree of vacuum and vacuum roasting time, the roasting temperature affects the water and oil content of *Pleurotus eryngii*. The higher the roasting temperature, the lower the final moisture content of the product, and the higher the oil content, these two values are inversely proportional. At a frying temperature below 90°C, the moisture content of the product exceeds 7%; at a frying temperature of 100°C, the oil content of the product is 43.23%, and at a temperature of 110°C, the oil content is 44.86%. No significant changes in oil content are observed. In addition, Table 4 shows that at frying temperatures between 80 and 100°C, the sensory scores of the products exceed 44 points, and better sensory quality can be obtained at oil temperatures between 80 and 100°C. The importance of organoleptic characteristics was noted in their work by M.R. Hilapad *et al.* (2020) noted that fried oyster mushroom pieces for 20-35 minutes are characterised by higher scores (6.85-7.79). Similar findings were obtained by A. Shah *et al.* (2020), analysing the effect of vacuum frying on onion slices. The authors established the dependence of temperature and duration of vacuum frying: 30, 25 and 20 minutes at 80, 90 and 100°C, respectively. This study showed that the colour and texture of the chips were optimal at 90°C. And as a result of research by I. Izham *et al.* (2022) it is stated that the optimal process variables for processing mushrooms were 110 minutes of hot air drying at 75°C. The highest desirability index of 0.648 was achieved.

In order to investigate the effect of frying time on the oil and water content and sensory quality of the product, 100 g of 2 mm thick slices of *Pleurotus eryngii* were blanched and dipped, and the hot air pre-drying temperature was 60°C. The sensory evaluation is based on a total score of 60 points. The sensory evaluation criteria and the results of the moisture and oil content of the product are shown in Table 5 and Figure 4.

Table 5. *Results of sensory evaluation of Pleurotus eryngii pieces with different roasting times*

Frying time	Colour	Texture	Greasy feeling	Taste	Shape	Acceptance	Assessment
5	8	2	8	3	8	3	32
10	7	8	7	7	7	8	44
15	7	8	7	7	7	8	44
20	6	9	6	8	6	7	42
25	4	9	4	6	4	5	32

Source: *authors' own development*

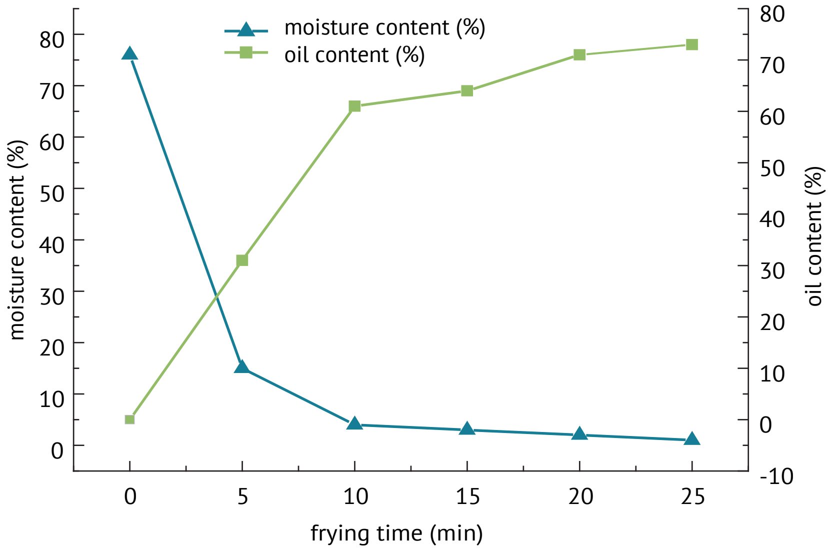

Figure 4. *Effect of frying time on moisture and oil content in Pleurotus eryngii*
Source: *authors' own development*

In order to maintain the crispness and shelf life of the product after frying, it is usually necessary to keep the moisture content below 8%. Figure 4 shows that the oil content increases more rapidly before frying for 10 minutes (from 1.88 to 35.8%), and after 10 minutes the oil content increases more slowly, and the oil content tends to stabilise after 20 minutes. At the same time, the water content decreased sharply before 5 minutes (from 77.9 to 13.6%), and the water content decreased to 3.93% within 5 minutes. After 10 minutes, the decrease became stable. It can be seen that the moisture content dropped below 7% when fried for 15 minutes. Therefore, in order to achieve a safe moisture content, the oil content is the lowest. Confirmation of this can be found in A. Ren *et al.* (2018), where the researchers statistically confirmed that pretreatment significantly affected the colour of shiitake mushroom chips ($p < 0.05$).

Furthermore, as can be seen from Figure 4, the dehydration process of *Pleurotus eryngii* slices fried in a vacuum at low temperature can be divided into three stages. The first stage lasts from 0 to 5 min. During this time, accelerated drying takes place. The water inside the *Pleurotus eryngii* pieces boils rapidly under the influence of negative pressure and high temperature, and flows out of the internal tissues of *Pleurotus eryngii* as steam. The moisture content in the pieces of *Pleurotus eryngii* decreases significantly, and the water that evaporates at this time is mainly free water in the outer layer. The second stage is the stage of uniform dehydration. This stage occurs in about 5-10 minutes. At this time, the overflowing water is mainly free water that diffuses from the inner layer to the outer layer. The rate of dehydration is affected by the rate of water diffusion, so the dehydration rate remains basically stable. The third stage occurs after 15 minutes, and the water content of the *Pleurotus eryngii* pieces remains almost unchanged at this stage. At this stage, only a small amount of bound water continues to evaporate, so the change in water content is very small. In the third stage, the moisture content changes very little. Continuing to fry will only result in a deterioration of the colour and taste of the product and wasted energy.

The change in oil content with frying time is basically divided into two stages. The first stage is the period from 0 to 10 minutes. During this time, the oil content increases from 1.88 to 35.8%. After 15 minutes, most of the free water has evaporated, the dehydration rate becomes slow, and all the oil phases replace the water phase. The rate also becomes slower, so the oil content basically stabilises and reaches equilibrium. The decrease in oil content was consistent with the studies of A. Ren *et al.* (2022). The authors confirmed that the mechanism to reduce oil absorption by ultrasonic osmosis was the pre-treatment with ultrasound before vacuum frying. This created a high vapour pressure in the sample structure reducing the oil absorption during frying.

In the process of vacuum low-temperature frying, the frying temperature, frying time and the degree of vacuum have a great influence on the product quality. In this test, the fixed vacuum degree is in the range of 0.08-0.09 MPa, and the orthogonal test is designed according to the three factors that affect the quality of vacuum-fried *Pleurotus eryngii* pieces, frying temperature and frying time. Vacuum low-temperature roasting is orthogonal. The level selected for the test is shown in Table 6.

The oil content and sensory quality of *Pleurotus eryngii* slices produced by vacuum low-temperature frying are related to consumer perception.According to the sensory evaluation criteria in Table 1, nine groups of orthogonal tests were evaluated to determine the oil content of each group, and the range of sensory evaluation and oil content was analysed. The results of the orthogonal test and the vacuum frying process are shown in Table 7.

Table 6. *Factors in the vacuum frying process conditions*

Level	Factor		
	Drying time, min	Frying temperature, °C	Frying time, min
1	10	80	10
2	20	90	15
3	30	100	20

Source: *authors' own development*

Table 7. *Orthogonal experimental design of vacuum frying process conditions*

No.	Factor				Overall sensory score	Oil content, %
	A Zero column	B Drying time	C Frying temperature	D Time frying		
1	1	1	1	1	43	45.2
2	1	2	2	2	47	43.8
3	1	3	3	3	37	40.1
4	2	1	2	3	42	46.6

Table 7, Continued

No.	Factor				Overall sensory score	Oil content, %
	A Zero column	B Drying time	C Frying temperature	D Time frying		
5	2	2	3	1	40	34.8
6	2	3	1	2	39	24.5
7	3	1	3	2	41	53.5
8	3	2	1	3	44	45.3
9	3	3	2	1	45	30.6
K Sensor 1	42.3	42.0	42.0	42.7		
K Sensor 2	40.3	43.7	44.7	42.3		
K Sensor 3	43.3	40.3	39.3	41.0		
R Sensor	3.0	3.3	5.3	1.7		
K Oil 1	43.0	48.4	38.3	36.9		
K Oil 2	35.3	41.3	40.3	40.6		
K Oil 3	43.1	31.7	42.8	44.0		
R Oil	7.833	16.700	4.467	7.133		

Source: *authors' own development*

The range analysis shows that the primary and secondary order factors affecting the sensory evaluation are as follows: roasting temperature > pre-drying time > roasting time, roasting for 10 min under the conditions of pre-drying with hot air for 20 min and roasting temperature of 90°C. The best sensory quality was obtained. The analysis of the oil content range shows that the order of factors affecting the oil content is: pre-drying time > frying time > frying temperature. When the pre-drying time is 30 min and the frying temperature is 80°C, the product can be obtained after frying for 10 min. The lowest oil content is obtained. However, when the pre-drying time was 30 minutes, the *Pleurotus eryngii* slices deformed more severely than the *Pleurotus eryngii* slices dried for 20 minutes during the dehydration process, and the sensory evaluation was slightly worse. These findings were consistent with the opinion reported by C. Wang *et al*. (2019).

Comprehensively considering the two factors of reducing the oil content in the final product and improving the sensory quality of the product, the optimal process conditions were obtained: hot air pre-drying time 20 min, roasting temperature 80-90°C, roasting time 10 min, and vacuum degree 0.08-0.09 MPa. Figure 5 shows the appearance of *Pleurotus eryngii* slices after vacuum roasting. It can be seen that the slices of *Pleurotus eryngii* are light yellow, with small pores formed on the surface as a result of air drying.

Figure 5. *Appearance of Pleurotus eryngii pieces after vacuum roasting*

Source: *authors' own development*

Thus, using the combined vacuum frying process, mushrooms with a crispy texture were obtained, which can be considered an appropriate attribute for the manufacture of a snack-type product. It should be noted that oyster mushrooms have high nutritional and health benefits, good antioxidant properties due to biologically active compounds (phenol) and are a source of vegetable protein.

CONCLUSIONS

In order to inactivate the peroxidase of *Pleurotus eryngii*, taking into account the need for energy saving in production and reducing the loss of flavour nutrients, the blanching process parameter was set at 80°C for 90 s. In order to reduce moisture in the product and increase dry matter, oyster mushroom impregnation with maltodextrin (15%) in a ratio of 1:5 for 15 min was used. Taking into account the test results, the ideal parameters for forming *Pleurotus eryngii* slices by dipping before vacuum frying at low temperature were determined, which included: thickness of 2 mm, mass fraction of maltodextrin of 15% and 15-minute ultrasonic impregnation. Subsequent studies have shown that during the pre-drying process, it is possible to delay the deformation and discolouration of *Pleurotus eryngii* by using hot air (60°C) for pre-drying while maintaining the same dehydration rate, which minimises the vacuum frying process. When the frying temperature remains below 90°C, the moisture content of the product exceeds 7%. However, when the temperature rises to 100°C, the oil content of the product reaches 43.23%, and at 110°C it increases even further to 44.86%. It should be noted that there are no significant fluctuations in the oil content. In addition, when the frying temperature falls between 80 and 100°C, the product's sensory scores exceed 44 points. It can therefore be concluded that maintaining the oil temperature between 80 and 100°C results in excellent sensory performance. Temperature, frying time and the degree of vacuum have a significant impact on the quality of the product during the low-temperature vacuum frying process. These are the three factors that determine the design of the orthogonal dough, which has a fixed vacuum degree in the range of 0.08-0.09 MPa. The ideal process conditions were achieved by taking full account of two factors to reduce the oil content of the final product and improve the sensory qualities of the product: pre-drying time with hot air 20 minutes, frying temperature 80-90°C, frying time 10 minutes, and vacuum degree 0.08-0.09 MPa. The appearance of the *Pleurotus eryngii* pieces after vacuum frying has light yellow surface sections with small pores. Therefore, future research may be aimed at producing safe snacks from different types of edible mushrooms.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Ayimbila, F., & Keawsompong, S. (2023). Nutritional quality and biological application of mushroom protein as a novel protein alternative. *Current Nutrition Report*, 12(2), 290-307. doi: 10.1007/s13668-023-00468-x.

[2] Bai, J.-W., Wang, Y.-C., Cai, J.-R., Zhang, L., Dai, Y., Tian, X.-Y., & Xiao, H.-W. (2023). Three-dimensional appearance and physicochemical properties of *Pleurotus eryngii* under different drying methods. *Foods*, 12(10), article number 1999. doi: 10.3390/foods12101999.

[3] Barbosa, J.R., dos Santos Freitas, M.M., da Silva Martins, L.H., & de Carvalho Junior, R.N. (2020). Polysaccharides of mushroom *Pleurotus* spp.: New extraction techniques, biological activities and development of new technologies. *Carbohydrate Polymers*, 229, article number 115550. doi: 10.1016/j.carbpol.2019.115550.

[4] Dubey, S.K., Chaturvedi, V.K., Mishra, D., Bajpeyee, A., Tiwari, A., & Singh, M.P. (2019). Role of edible mushroom as a potent therapeutics for the diabetes and obesity. *3 Biotech*, 9, article number 450. doi: 10.1007/s13205-019-1982-3.

[5] El-Ramady, H., Abdalla, N., Badgar, K., Llanaj, X., Törős, G., Hajdú, P., Eid, Y., & Prokisch, J. (2022). Edible mushrooms for sustainable and healthy human food: Nutritional and medicinal attributes. *Sustainability*, 14(9), article number 4941. doi: 10.3390/su14094941.

[6] Fang, L., Ren, A., Bolgova, N., Samilyk, M., & Sokolenko, V. (2021). Quality changes of *Pleurotus eryngii* during vacuum frying. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies. Series: Food Technologies*, 23(95), 91-97. doi: 10.32718/nvlvet-f9515.

[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), 7400-7414. doi: 10.1039/d0fo01746a.

[8] Hilapad, M.R., Esguerra, E.B., & Castillo-Israel, K.A.T. (2020). Optimization of processing parameters for vacuum fried oyster mushroom (*Pleurotus ostreatus* (Jacquin) P. kummer). *Food Research*, 4(4), 1371-1382. doi: 10.26656/fr.2017.4(4).065.

[9] Izham, I., Avin, F., & Raseetha, S. (2022). Systematic review: Heat treatments on phenolic content, antioxidant activity, and sensory quality of malaysian mushroom: Oyster (*Pleurotus* spp.) and Black Jelly (*Auricularia* spp.). *Frontiers in Sustainable Food Systems*, 6, article number 882939. doi: 10.3389/fsufs.2022.882939.

[10] Kidoń, M., & Grabowska, J. (2021). Bioactive compounds, antioxidant activity, and sensory qualities of red-fleshed apples dried by different methods. *LWT – Food Science and Technology*, 136(2), article number 110302. doi: 10.1016/j.lwt.2020.110302.

[11] Lachowicz, S., Michalska-Ciechanowska, A., & Oszmiański, J. (2020). The impact of maltodextrin and inulin on the protection of natural antioxidants in powders made of saskatoon berry fruit, juice, and pomace as functional food ingredients. *Molecules*, 25(8), article number 1805. doi: 10.3390/molecules25081805.

[12] Nguyen, T.-V.-L., Nguyen, T.-T.-D., Huynh, Q.-T., & Nguyen, P.-B.-D. (2023). Effect of maltodextrin on drying rate of avocado (*Persea Americana* Mill.) pulp by refractance window technique, and on color and functional properties of powder. *Polish Journal of Food and Nutrition Sciences*, 73(2), 187-195. doi: 10.31883/pjfns/163982.

[13] Pérez-Montes, A., Rangel-Vargas, E., Lorenzo, J.M., Romero, L., & M Santos, E. (2021). Edible mushrooms as a novel trend in the development of healthier meat products. *Current Opinion in Food Science*, 37, 118-124. doi: 10.1016/j.cofs.2020.10.004.

[14] Piyalungka, P., Sadiq, M.B., Assavarachan, R., & Nguyen, L.T. (2019). Effects of osmotic pretreatment and frying conditions on quality and storage stability of vacuum-fried pumpkin chips. *International Journal of Food Science & Technology*, 54(10), 2963-2972. doi: 10.1111/ijfs.14209.

[15] Raman, J., Jang, K.-Y., Oh, Y.-L., Oh, M., Im, J.-H., Lakshmanan, H., & Sabaratnam, V. (2021). Cultivation and nutritional value of prominent *Pleurotus* spp.: An overview. *Mycobiology*, 49(1), 1-14. doi: 10.1080/12298093.2020.1835142.

[16] Ren, A., Cao, Z., Tang, X., Duan, Z., Duan, X., & Meng, X. (2022). Reduction of oil uptake in vacuum fried *Pleurotus eryngii* chips via ultrasound assisted pretreatment. *Frontiers in Nutrition*, 9, article number 1037652. doi: 10.3389/fnut.2022.1037652.

[17] Ren, A., Pan, S., Li, W., Chen, G., & Duan, X. (2018). Effect of various pretreatments on quality attributes of vacuum-fried shiitake mushroom chips. *Journal of Food Quality*, 2018, article number 4510126. doi: 10.1155/2018/4510126.

[18] Shah, A., Patel, D., Rathod, J., Joshi, R., & Ramani, B. (2020). Effect of temperature, pressure and fryng time in vacuum frying: A review. *International Research Journal of Engineering and Technology (IRJET)*, 7(4), 4617-4621.

[19] Siccama, J.W., Pegiou, E., Eijkelboom, N.M., Zhang, L., Mumm, R., Hall, R.D., & Schutyser, M.A.I. (2021). The effect of partial replacement of maltodextrin with vegetable fibres in spray-dried white asparagus powder on its physical and aroma properties. *Food Chemistry*, 356, article number 129567. doi: 10.1016/j.foodchem.2021.129567.

[20] Ślusarczyk, J., Adamska, E., & Czerwik-Marcinkowska, J. (2021). Fungi and algae as sources of medicinal and other biologically active compounds: A review. *Nutrients*, 13(9), article number 3178. doi: 10.3390/nu13093178.

[21] Wang, C., Su, G., Wang, X., & Nie, S. (2019). Rapid assessment of deep frying oil quality as well as water and fat contents in French fries by low-field nuclear magnetic resonance. *Journal of Agricultural and Food Chemistry*, 67(8), 2361-2368. doi: 10.1021/acs.jafc.8b05639.

[22] Yang, D., Wu, G., Li, P., Qi, X., Zhang, H., Wang, X., & Jin, Q. (2020). Effect of microwave heating and vacuum oven drying of potato strips on oil uptake during deep-fat frying. *Food Research International*, 137, article number 109338. doi: 10.1016/j.foodres.2020.109338.

[23] Zhang, J., & Fan, L. (2021). Effects of preliminary treatment by ultrasonic and convective air drying on the properties and oil absorption of potato chips. *Ultrasonics Sonochemistry*, 74, article number 105548. doi: 10.1016/j.ultsonch.2021.105548.

[24] Zhang, J., Yu, P., Fan, L., & Sun, Y. (2021). Effects of ultrasound treatment on the starch properties and oil absorption of potato chips. *Ultrasonics Sonochemistry*, 70, article number 105347. doi: 10.1016/j.ultsonch.2020.105347.

[25] Zhao, Y., Chen, X., Zhao, Y., Jia, W., Chang, X., Liu, H., & Liu, N. (2020). Optimization of extraction parameters of *Pleurotus eryngii* polysaccharides and evaluation of the hypolipidemic effect. *RSC Advances*, 10(20), 11918-11928. doi: 10.1039/c9ra10991a.

[26] Zhu, J., Liu, Y., Zhu, C., & Wei, M. (2022). Effects of different drying methods on the physical properties and sensory characteristics of apple chip snacks. *LWT – Food Science and Technology*, 154, article number 112829. doi: 10.1016/j.lwt.2021.112829.

Дослідження процесу вакуумного низькотемпературного смаження *Pleurotus eryngii*

Наталія Вікторівна Болгова
Кандидат сільськогосподарських наук, доцент
Сумський національний аграрний університет
40000, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0002-0201-0769
Лін Фанг
Сумський національний аграрний університет
40000, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0001-8513-6502
Юлія Валентинівна Назаренко
Кандидат технічних наук, доцент
Сумський національний аграрний університет
40000, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0003-4870-4667
Тетяна Павлівна Синенко
Доктор філософії, доцент
Сумський національний аграрний університет
40000, вул. Герасима Кондратьєва, 160, м. Суми, Україна
https://orcid.org/0000-0002-5300-5142

Анотація. Гриби споживаються через їх поживні речовини та терапевтичні біологічно активні сполуки, історично використовувалися в медицині, а представники роду *Pleurotus* є їстівними видами які багаті харчовими волокнами, вітамінами, мікро- та макроелементами, вуглеводами. Мета – теоретично обґрунтувати вакуумне смаження шматочків гливи, отримати хрусткий продукт з оптимальними споживчими характеристиками. В процесі дослідження використано методи вакуумного низькотемпературного смаження, органолептичного дослідження, ортогонального тесту, однофакторного та статистичного аналізу. Проаналізовано чинники, що впливають на якість вакуумного смаження гливи: час попереднього сушіння, температуру та час смаження. Описано та проаналізовано зв'язок показників вмісту олії та сенсорної оцінки. Були визначені оптимальні технологічні параметри смаження у вакуумі. *Pleurotus eryngii* товщиною 2 мм були повністю інактивовані в умовах проварювання протягом 90 с при 80 °C, і протягом 10 с при 90 °C і 100 °C. Якщо відбувається тривале варіння, текстура гливи стає м'якою, погано піддається подальшій обробці під вакуумом при низькій температурі. Тому, з метою економії виробничої енергії та зменшення втрати смаку і поживних речовин, було обрано приготування при 80 °C протягом 90 с. Зазначено, що обробка *Pleurotus eryngii* мальтодекстрином перед смаженням у вакуумі, зменшує вміст олії після смаження, забезпечує однорідну структуру, гарний смак і хрусткість продукту. Було отримано оптимальні параметри: зрізи по 2 мм, масова частка мальтодекстрину 15 %, тривалість ультразвукової обробки 15 хв. Описано вплив на сенсорну оцінку основного і вторинного порядку: температура смаження > час попереднього сушіння > час смаження. Було зазначено конкретні параметри, за яких продукт отримає найкращі сенсорні показники, а саме: смаження 10 хв, попереднє сушіння 20 хв, температура смаження 90 °C. Було проаналізовано фактори впливу на вміст олії: час попереднього сушіння > час смаження > температура смаження. Було встановлено, що продукт може отримати найменший вміст олії за умови попереднього сушіння 30 хв, температури смаження 80 °C протягом 10 хв. Практична цінність дослідження полягає у визначених оптимальних умов досліджуваного процесу: час попереднього сушіння гарячим повітрям 20 хв, температура смаження 80-90 °C, час смаження 10 хв, ступінь вакууму смаження 0,08-0,09 МПа

Ключові слова: глива; якість; однофакторний тест; ортогональний тест; сенсорна оцінка; бланшування; олія