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RESEARCH ON THE SENSORY AND ANTIOXIDANT PROPERTIES OF FUNCTIONAL PASTES BASED ON SHIITAKE MUSHROOMS

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Correspondence:

O. Kuzmin,
E-mail: kuzmin_ovl@ukr.net

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O. Kuzmin [1], Doctor of Technical Sciences, Professor
O. Velikanov [2], postgraduate student
O. Melnyk [2], Candidate of Chemical Sciences, Associate Professor,
V. Kiiko [3], Candidate of Technical Sciences, Associate Professor
K. Bakhlukova [4], Candidate of Technical Sciences
A. Kuzmin [5], Master,
[1] Department of Technology of Restaurant and Ayurvedic Products
[2] Department of Foodstuff Expertise
National University of Food Technologies
01033, Ukraine, Kyiv, st. Volodymyrska, 68
[3] State Operator for Non-Lethal Acquisition
04119, Ukraine, Kyiv, st. Degtyarivska, 13/24
[4] Department of Analytical Research and Food Quality
Institute of Food Resources of NAAS
02000, Ukraine, Kyiv, st. Yevhen Sverstyuk, 4A
[5] Individual entrepreneur Kuzmin Anton Olehovych

Abstract. The study is devoted to the assessment of the effect of heat treatment regimes of shiitake mushrooms (Lentinula edodes) on the antioxidant activity of functional pastes with improved organoleptic characteristics.. Low-temperature sous-vide technology (t=50–90 °C, τ=10–60 min) and high-temperature autoclaving technology (t=125 °C, τ=45 min) were used for heat treatment. Antioxidant activity was determined by redoxometry and pH-metry methods with the calculation of reducing capacity hydroalcoholic infusions (REinf) and plant materials (REplant). The results demonstrated that an increase in temperature during the heat treatment of shiitake mushrooms promotes the activation of individual redox components, confirming an increase in the redox potential of Ehact (from 7.0 mV in control to 15.50 mV in autoclaving), however, an increase in temperature leads to the degradation of thermolabile bioactive compounds, reducing the overall redox efficiency. The highest antioxidant activity (REinf=186.98 mV, REplant=141.34 mV) was recorded during sous-vide processing at 50 °C for 60 minutes, which ensured stable pH (7.31) and preservation of taste properties. Autoclaving lowered the pH to 7.18, causing intense Maillard reactions and degradation of antioxidants. Sensory assessment on a 5-point scale (appearance, color, texture, taste, aftertaste, smell) confirmed the superiority of low-temperature modes: sous-vide samples had a light beige color, plastic consistency, pronounced mushroom flavor, and umami and nutty descriptors (4–5 points), while autoclaved samples were characterized by darkening, liver flavor, and less plasticity (3–4 points). It has been established that low-temperature heat treatment of shiitake mushroom pastes contributes to the preservation of an authentic sensory profile and an increase in antioxidant activity, which justifies the use of shiitake mushrooms to create innovative functional products in the restaurant industry and specialized diets.

Keywords: shiitake mushrooms, Lentinula edodes, functional products, paste, sous-vide, autoclaving, quality, sensory properties, antioxidant activity, redox indicators, innovative restaurant technologies.

Introduction. Formulation of the problem

Today, the restaurant industry needs constant dynamic development both in terms of expanding the range and in the aspect of increasing the nutritional and functional value of finished products [1]. Nutrition is one of the basic physiological needs of a person, so food products must meet the individual needs of the body in nutrients. Among the promising areas of innovative development of food technologies, special attention is paid today to the use of biologically active components of natural origin, which can not only enrich the diet with valuable nutrients, but also have a positive effect on the functional state of the body [2].

An important aspect of the introduction of plant and mushroom raw materials into the recipes of new dishes is also the rational use of substandard batches that are not suitable for sale in fresh form, but retain all valuable properties. Such raw materials can be effectively used to create pastes, sauces, dressings, fermented drinks, etc. – products with high taste and functional characteristics that meet modern consumer needs [3, 4].

Shiitake mushrooms (Lentinula edodes) occupy a special place among the most promising ingredients in this area. They are among the most common and valuable cultivated mushrooms in the world due to their high content of vitamins, minerals, polysaccharides, antioxidants and bioactive substances. The combination of nutritional value, therapeutic, prophylactic and sensory properties makes them a universal raw material for the development of functional products of a new generation.

Thus, the relevance of the study lies in the scientific substantiation of the feasibility of using shiitake mushrooms in the composition of food products with increased biological activity, as well as in the study of the influence of technological parameters of their processing on quality, organoleptic characteristics, antioxidant activity and stability during storage.

Analysis of recent research and publications

Tree-destroying shiitake mushrooms (Lentinula edodes) is one of the most cultivated and consumed types of mushrooms in the world. Due to their unique chemical composition, shiitake mushrooms can be a valuable source of proteins, minerals (potassium, magnesium, manganese, iron, phosphorus), vitamins (in particular group B and provitamin D_2), polysaccharides, phenolic compounds, dietary fiber, antioxidants [1] and ergosterol. Due to this composition, shiitake mushrooms are characterized by therapeutic and prophylactic potential manifested in antimicrobial, antiviral, antitumor, hepatoprotective and antidiabetic action [5].

Shiitake mushrooms are traditionally used in oriental medicine to prevent and treat a number of chronic diseases, improve the functioning of the immune system, adapt to stress and recover from physical exertion. As previous studies have shown [2, 6], the use of hydroalcoholic infusion from shiitake helps to increase the antioxidant activity and biological value of foods.

Industrially grown shiitake mushrooms are a promising raw material not only for the general diet, but also for specialized nutrition, in particular as part of vegetarian or vegan menus, as well as rations for military personnel [7]. As a source of protein, they can supplement or partially replace traditional protein products, while significantly outnumbering them in terms of the content of bioactive compounds. On the basis of mushrooms with therapeutic and prophylactic properties, functional food products can be created [3, 4, 8-10].

In the context of the development of sous-vide technologies, which involve different combinations of temperature (55–65 °C) [11], (60–80 °C) [12] and time (6–24 h) [12], there is a need to optimize the parameters of heat treatment specifically for mushroom pastes. Existing studies mainly focus on vegetable, meat dishes and hydrobionts [11-14], leaving out the specifics of mushroom products.

Heat treatment is a key step in mushroom paste technology, as it simultaneously affects the safety, microbiological stability and organoleptic properties of the finished product. High temperatures (>100 °C) enhance the intensity of aroma and color due to Maillard reactions, but at the same time destroy some bioactive compounds, including antioxidants, and lead to dryness and the appearance of bitter or «livery» tones. Low temperatures (<60 °C) better preserve the natural taste of mushrooms and biologically active substances, but do not always provide sufficient expression of the flavor profile and can affect the texture.

Thus, it is the optimization of temperature regimes that is critically important to achieve a double goal: the preservation of bioactive components and antioxidant capacity, on the one hand, and the formation of attractive organoleptic characteristics, on the other. Despite the availability of separate works covering the effect of heat treatment on vegetable and meat products, there are no systematic studies in the modern scientific literature on shiitake-based mushroom pastes. This creates a scientific and practical gap, since the lack of optimized technological solutions makes it difficult to produce competitive products with pronounced functional properties. Therefore, the study of the influence of heat treatment regimes on the sensory and antioxidant characteristics of mushroom pastes is becoming relevant both for the development of innovative technologies in the restaurant industry and for expanding the range of healthy food products.

The purpose of the study is to evaluate the effect of heat treatment regimens of shiitake mushrooms (Lentinula edodes) on the antioxidant activity of functional pastes with improved organoleptic characteristics.

Research objectives:

1. To determine the antioxidant activity of pastes based on shiitake mushrooms after applying various heat treatment regimens;
2. To analyze the influence of temperature, duration and method of heat treatment on organoleptic indicators, functional properties and quality characteristics of mushroom pastes;
3. To conduct a sensory analysis of pastes using a point scale and to assess the intensity of descriptors that form the flavor profile.

Research materials and methods

For the formation of mushroom paste, the following were used as raw materials: shiitake mushrooms (Lentinula edodes), artificially enriched with trace elements (Cr, Se); carrots; onions; vegetable oil; water; starch; sugar; salt; nuts. A parameter-technological block diagram of the preparation of mushroom paste using sous-vide technology and autoclaving is presented in Fig. 1.

The antioxidant ability of hydroalcoholic infusions of shiitake mushrooms (Lentinus edodes) was determined by the methods of redoxometry and pH-metry with a volume fraction of ethyl alcohol of 40%.

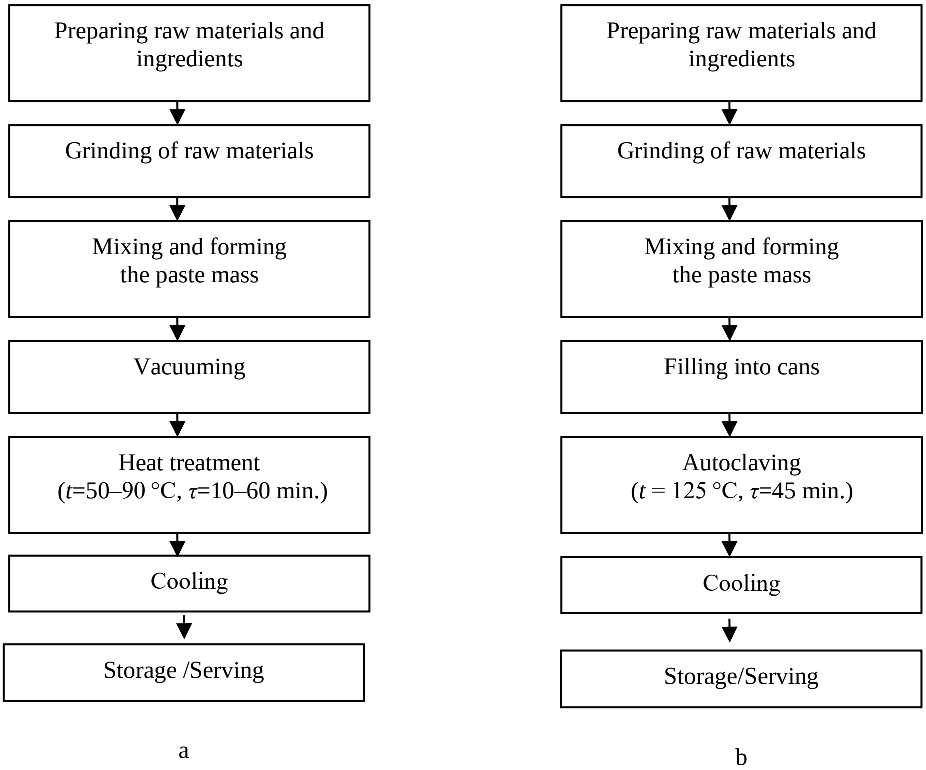

Fig. 1. Parameter-technological block diagram for the preparation of mushroom paste: a – sous-vide technology at t=50–90 °C, τ=10–60 minutes; b – autoclaving technology at t=125 °C, τ=45 min.

The theoretical redox potential (Eh_{min}) was calculated according to equation [15]:

$$Eh_{min}=502-42\cdot pH, \text{ mV}.$$

The actual redox potential (Eh_{act}) was measured on a platinum electrode.

The infusion recovery energy (RE_{inf}) was calculated as the difference between the theoretical (Eh_{min}) and actual (Eh_{act}) potential [15, 16]:

$$RE_{inf}=Eh_{min}-Eh_{act}, \text{ mV}.$$

The recovery energy of plant raw materials (RE_{plant}) was determined taking into account the control hydroalcoholic solvent (RE_{sol}) [15]:

$$REplant=RE_{inf}-RE_{sol}, \text{ mV}.$$

Organoleptic indicators (appearance, color, consistency, taste, aftertaste, smell) were evaluated by the sensory method on a 5-point scale.

Results of the research and their discussion

Antioxidant capacity. The value of the antioxidant capacity of the hydroalcoholic infusion of shiitake (Lentinus edodes) was: active acidity (pH) – 7.38 pH; redox potential (Eh_{act}) – 7.0 mV; infusion recovery energy (RE_{inf}) – 185.04 mV; minimum theoretical value of redox potential (Eh_{min}) – 192.04 mV; reduction energy of plant raw materials (RE_{plant}) – 139.40 mV [2] (Fig. 2). RE $value_{sol}$ (solvent reduction energy) is 45.64 mV. Hydroalcoholic infusion of shiitake is characterized by the following organoleptic indicators: color and transparency – beige, transparent; aroma - mushroom, rich, sweet, honey, alcoholic; taste - earthy, mushroom, moss, medicinal, alcoholic. The prospects for using shiitake infusion in the development of new recipes for sauces and drinks in restaurant technology. This approach can be widely used in the industry and contribute to the development of innovative products, in accordance with modern trends and requests of the food industry.

In the course of the study, the effect of temperature and time regimes of heat treatment (from 50 °C to 125 °C, duration 10–60 minutes) on changes in redox potential (Eh), redox efficiency (reduction energy) (RE) and pH level of hydroalcoholic infusions of shiitake mushrooms was analyzed.

pH level. The control sample that was not subjected to heat treatment had the highest pH (7.38), which corresponds to a slightly alkaline environment. With an increase in temperature and processing time, a natural decrease in pH to a minimum value of 7.18 is observed at t=125 °C, τ=45 min. This decrease may be due to the formation of organic acids or Maillard reaction products, which cause the «acidification» of the medium. The dynamics of pH indicates that intensive heat treatment leads to changes in the chemical composition of the infusion, which is important in the formation of its biological activity and taste properties.

Indicators of redox potential (Eh_{min}, Eh_{act}). The minimum value of Eh (Eh_{min}) was recorded in the control sample (192.04 mV), and the maximum value was recorded after treatment at t=125 °C, τ=45 min. (200.44 mV).

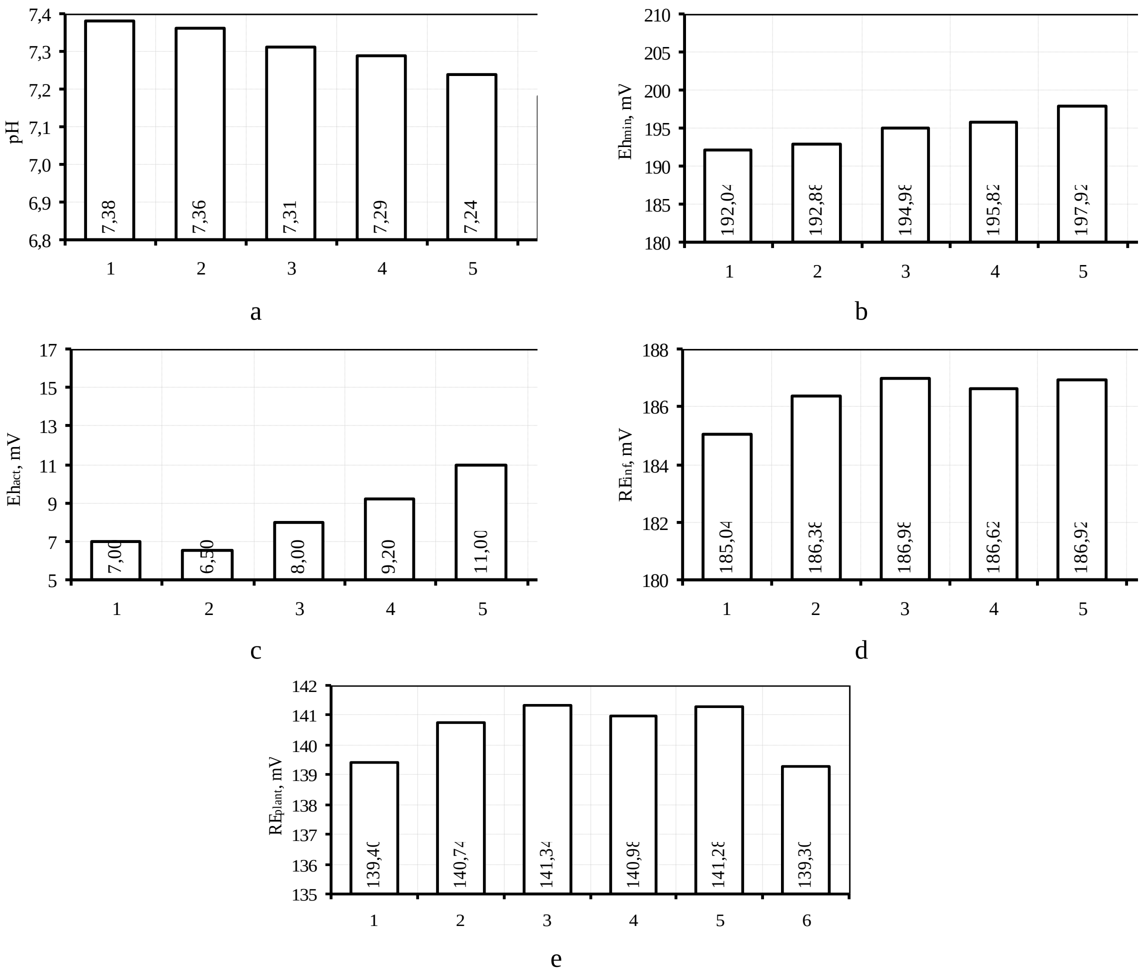

Fig. 2. Assessment of the antioxidant activity of the hydroalcoholic infusion of shiitake mushrooms according to redox efficacy indicators: a – active acidity (pH); b – the minimum theoretical value of the redox potential (Eh_{min}); c – the redox potential (Eh_{act}); d – infusion recovery energy (RE_{inf}); e – the energy of plant regeneration (RE_{plant}); under the following conditions: 1 – hydroalcoholic infusion of shiitake (control); 2 – hydroalcoholic infusion of shiitake (t=50 °C; τ=10 min.); 3 - hydroalcoholic infusion of shiitake (t=50 °C; τ=60 min.); 4 - hydroalcoholic infusion of shiitake (t=90 °C; τ=10 min.); 5 – hydroalcoholic infusion of shiitake (t=90 °C; τ=60 min.); 6 – hydroalcoholic infusion of shiitake (t=125 °C; τ=45 min.)

This indicates a decrease in the reduction potential of samples after heat treatment, i.e. the medium becomes less capable of reduction (less antioxidant) under standard conditions.

At the same time, the actual redox potential (Eh_{act}), which is an integral indicator of the total redox activity of the infusion, increases almost 2.2 times – from 7.00 mV (control) to 15.50 mV (t=125 °C, τ=45 min.). This increase indicates an increase in the activity of antioxidant compounds that are activated or formed by thermal reactions.

Redox efficiency (RE_{inf}, RE_{plant}). The RE_{inf} index, demonstrating the internal efficiency of the redox system in hydroalcoholic infusions, varied from 184.94 to 186.98 mV. The highest value was recorded at t=50 °C; τ=60 min., which allows us to conclude that the antioxidant potential is preserved and even potentially enhanced under mild processing conditions. This indicates the feasibility of using low-temperature technologies to preserve the natural bioactivity of fungi.

The RE_{plant}, which can be interpreted as the total biological value of fungi in relation to solvent (RE_{sol}=45.64 mV) (in terms of electrochemical activity), remained relatively stable in all samples (139.30–141.34 mV). The lowest value was recorded at t=125 °C; τ=45 min., indicating potential losses of some thermolabile components, despite the high activity of Eh_{act}.

The results obtained indicate a complex effect of heat treatment on the antioxidant activity of shiitake mushroom infusions. An increase in temperature activates certain redox components, which is demonstrated by an increase in Eh_{act}, but can reduce the overall redox efficacy and lead to the degradation of some bioactive substances. The optimal mode, which ensures balanced antioxidant activity and preservation of bioactive compounds, is heat treatment at t=50 °C; τ=60 min. provided maximum redox efficiency (RE_{inf}=186.98 mV) at a relatively stable pH and moderate redox potential.

2. Organoleptic indicators. Organoleptic parameters of mushroom pate were studied by the sensory method with specified modes - processing temperature (t, °C), processing time (τ, min.): t=50 °C; τ=10 min. (Table 1); t=50 °C; τ=60 υβ. (Table 2); t=90 °C; τ=10 min. (Table 3); t=90 °C; τ=60 min. (Table 4); t=125 °C; τ=45 min. (Table 5) by indicators: appearance, color, consistency, taste, aftertaste, smell.

Table 1 – Results of tasting evaluation of mushroom pastes at heat treating t=50 °C, processing time τ=10 min

Indicator name	Characteristic
Appearance	Homogeneous paste mass with the inclusion of recipe ingredients
Color	Light beige, heterogeneous, with inclusions of prescription ingredients
Consistency	Homogeneous, moderately dense, ointment-like, heterogeneous, plastic, with inclusions of pieces of mushrooms and nuts
Taste	Pleasant, sweetish, nutty, delicate, harmonious, balanced, umami taste is felt
Aftertaste	Mushroom
Smell	Pleasant, not pronounced, with a subtle nutty tint

Table 2 – Results of tasting evaluation of mushroom pastes at heat treating t=50 °C, processing time τ=60 min

Indicator name	Characteristic
Appearance	Homogeneous paste mass with the inclusion of recipe ingredients
Color	Beige, heterogeneous, with inclusions of recipe ingredients
Consistency	Homogeneous, moderately dense, ointment-like, heterogeneous, plastic, with inclusions of pieces of mushrooms and nuts
Taste	Pleasant, sweetish, nutty, fresh, harmonious, balanced, the taste of mushrooms is felt
Aftertaste	Pronounced mushroom
Smell	Pleasant, pronounced, with a subtle nutty shade

Table 3 – Results of tasting evaluation of mushroom pastes at heat treating t=90 °C, processing time τ=10 min

Indicator name	Characteristic
Appearance	Homogeneous pate mass with the inclusion of recipe ingredients
Color	Rich beige, heterogeneous, with inclusions of recipe ingredients
Consistency	Homogeneous, moderately dense, ointment-like, heterogeneous, plastic, with inclusions of pieces of mushrooms and nuts
Taste	Pleasant, sweetish, harmonious, balanced, pronounced mushroom and umami flavor
Aftertaste	Pronounced mushroom
Smell	Pleasant, pronounced, nutty

Table 4 – Results of tasting assessment of mushroom pastes at heat treating t=90 °C, processing time τ=60 min

Indicator name	Characteristic
Appearance	Homogeneous pate mass with the inclusion of recipe ingredients
Color	Intense beige, heterogeneous, with inclusions of recipe ingredients
Consistency	Homogeneous, dense, ointment-like, heterogeneous, plastic, with inclusions of pieces of mushrooms and nuts
Taste	Pleasant, balanced, rich, pronounced mushroom, nutty, oily content is felt
Aftertaste	Sun-dried tomatoes
Smell	Pleasant, pronounced, nutty, notes of sun-dried tomatoes

Table 5 – Results of tasting evaluation of mushroom pastes at heat treating t=125 °C, processing time τ=45 min

Indicator name	Characteristic
Appearance	Homogeneous pate mass with the inclusion of prescription ingredients (characteristic of liver pate)
Color	Rich brown, not typical for this type of raw material (characteristic of liver pate), heterogeneous, with inclusions of prescription ingredients
Consistency	Homogeneous, dense, ointment-like, heterogeneous, less plastic, similar in liver pate
Taste	Pleasant, rich, meat (liver, beef), fat content is felt
Aftertaste	Pronounced sun-dried tomatoes and liver pate
Smell	Pleasant, pronounced, nutty, sun-dried tomatoes

Appearance and color. Low heat treatment temperature (t=50 °C) does not cause significant darkening of the mushroom paste (Fig. 3, a, b). In this mode, the finished product has a light beige color, close to the color of raw mushroom mass, which changes towards a more saturated beige depending on the duration of heating. The appearance remains uniform, while maintaining the typical texture of mushroom raw materials, which indicates minimal changes in polyphenolic compounds and protein structures under the influence of moderate heating.

An increase in temperature to t=90 °C leads to the activation of Maillard reactions. As a result, the paste mass acquires from a rich beige to an intense beige shade (Fig. 3, c, d). With an increase in the heat treatment time (from τ=10 min to τ=60 min), there is a further darkening of the color, which is a consequence of the increasing formation of melanoidins – the end products of Maillard reactions [17], responsible for the color change and the formation of the characteristic aroma of the product.

At t=125 °C, shiitake mushroom paste acquires a rich brown color (Fig. 3, e). Such an intense tone is not typical for mushroom raw materials, but is more consistent with the color of liver pates, which may indicate deep thermal changes in the protein-carbohydrate matrix. This effect is explained by the intensive course of melanoid formation - the reaction of the interaction of amino acids with reducing sugars under the influence of high temperature, accompanied by the synthesis of melanoidins and volatile aromatic compounds. As a result, there is a significant change in the color of the product: from a light and natural shade for mushroom raw materials to a darker and denser one, which can affect both consumer perception and nutritional value of the product.

Therefore, the temperature and duration of heat treatment significantly affect the color change, and low-temperature cooking allows you to preserve as much as possible the typical appearance of mushroom raw materials, which is consistent with the results [18, 19]: with an increase in processing temperature, a significant darkening of mushroom raw materials occurs, while at lower temperatures, a lighter color characteristic of fresh mushrooms is preserved. A temperature of 60 °C allows you to maintain a higher concentration of umami flavors and aromatic compounds compared to higher temperatures [18]. This indicates that low-temperature cooking allows you to preserve the typical appearance of mushroom raw materials as much as possible.

Consistency. At a low temperature of heat treatment (t=50 °C), even with an extension of the heating time from τ=10 min. to τ=60 min., the consistency of mushroom pate remains stable. The structure of the product is quite homogeneous, moderately dense, flesh-like in sensations, plastic, with characteristic heterogeneity due to the presence of pieces of shiitake mushrooms and nuts in the mass. This texture contributes to a pleasant perception of the product and preserves the authenticity of raw materials.

Increasing the heat treatment temperature to t=90 °C moderately thickens the texture of the pate. At the same time, a balance is maintained between tenderness and density of the structure, which has a positive effect on the sensory perception of the product.

The maximum processing temperature (t=125 °C) leads to significant changes in the consistency of the pate. The product becomes less plastic, resembling a traditional liver pate in structure. These changes are due to more intense moisture loss during high-temperature autoclaving (sterilization at t=125 °C for τ=45 min.). Significant dehydration causes dryness and a decrease in the juiciness of the product, which can negatively affect its consumer characteristics.

a b c d e

Fig. 3. Appearance of samples of mushroom pastes under the following conditions: a – t=50 °C; τ=10 min.; b – t=50 °C; τ=60 min.; c – t=90 °C; τ=10 min.; d – t=90 °C; τ=60 min.; e – t=125 °C; τ=45 υβ

Therefore, the use of "gentle" heat treatment modes, such as sous-vide technology at t=50-90 °C, allows you to retain more moisture in the product, providing high juiciness, tenderness and plasticity of the pate mass. The use of such modes helps to increase the organoleptic parameters of the final product and preserve the natural properties of the raw materials. These data are consistent with studies [20]: that cooking mushrooms using sous-vide technology at temperatures of 70–90 °C allows more moisture and bioactive compounds such as β-glucans [1, 10] and polyphenols to be retained compared to traditional processing methods. This confirms that low-temperature treatment [21] helps to retain moisture and improve the textural properties of the mushroom mass [22].

Taste and aftertaste. At a processing temperature of t=50 °C and a short heating time (τ=10 minutes), the taste of the pate is characterized as pleasant, sweetish, nutty, delicate, harmonious and balanced, with a noticeable umami effect [22]. At the same time, the aftertaste remains mushroom, delicate and unobtrusive.

Extension of processing time to τ=60 min. at the same temperature (t=50 °C) leads to an increase in freshness and mushroom shade of taste: the nutty and sweetish taste is preserved, but a clearer sense of mushroom note appears. The aftertaste becomes pronounced mushroom, which indicates a deepening of the aroma due to longer exposure to temperature.

When the temperature rises to t=90 °C and a short processing time (τ=10 minutes), the taste of the paste becomes more pronounced mushroom, sweet and balanced, with a clearer expression of umami. The aftertaste remains pronounced mushroom, but acquires greater depth compared to products processed at 50 °C.

Increasing the duration of heat treatment to τ=60 minutes. at t=90 °C, it significantly changes the flavor palette. The paste has a rich, pronounced mushroom and nutty taste, with a slight feeling of oiliness, which gives the impression of greater juiciness and fullness. The aftertaste turns into a note of sun-dried tomatoes, which indicates the development of secondary aromatic components due to prolonged heating.

Finally, at a temperature of t=125 °C (τ=45 minutes), the most significant changes in taste and aftertaste occur. The taste of the paste becomes rich, meaty, with liver and beef nuances, which is no longer typical for mushroom raw materials. High fat content is felt. This is consistent with the results [23]: an increase in the processing temperature of the mushroom hydrolyzate to 125 °C leads to significant changes in the flavor profile of the product. In particular, the formation of a meaty taste and aftertaste is observed, which is due to the intensive development of Maillard reactions and the formation of melanoidins [17, 23]. These reactions promote the emergence of new aromatic compounds such as 2-thiophenecarbaldehyde, 2,5-thiophendicarbaldehyde, and 3-methylbutanal, which are associated with meat flavor [23]. In addition, the increased temperature contributes to the formation of compounds with caramel and liver hues, which changes the typical mushroom flavor profile of the product [23]. These changes may be undesirable if the goal is to preserve the authentic flavor of the mushroom raw material.

The first conclusions can be drawn: low temperature (t=50 °C) retains a delicate, fresh mushroom taste; moderate temperature (t=90 °C) helps to reveal a rich mushroom and nutty taste while maintaining juiciness; high temperature (t=125 °C) changes the flavor profile of the product towards meat and liver notes, which is atypical for mushroom pate.

Smell (aroma). At a low processing temperature (t=50 °C), the smell of pâtés remains pleasant, delicate, slightly pronounced, with a subtle nutty tint, which indicates minimal aromatic changes in the raw materials. Extending the processing time (up to τ=60 minutes) enhances the aroma: it becomes brighter, mushroom, but at the same time retains a nutty tone. When the temperature rises to t=90 °C, the smell of the paste becomes rich, pronounced with nutty notes and the appearance of a characteristic mushroom aroma, which is enhanced by longer processing. Under conditions of high temperature (t=125 °C), the smell changes: it becomes deep, saturated, with bright notes of sun-dried tomatoes and liver pate, which indicates intense reactions of the aromatic profile inherent in products of deep heat treatment.

Thus, the higher the temperature and the longer the processing, the more pronounced, complex and intense the aroma of mushroom pastes becomes: from delicate, nutty-mushroom at t=50 °C to deep, liver-tomato profile at t=125 °C, this is confirmed by the deep transformation of aromatic compounds and the effect of Maillard reactions and caramelization on odor formation. These reactions promote the emergence of new aromatic compounds such as 2-thiophenecarbaldehyde, 2,5-thiophendicarbaldehyde, and 3-methylbutanal, which are associated with meat flavor [23].

3. Sensory profile. The sensory profile of mushroom paste was examined using the sensory method according to 13 descriptors (pleasant; sweetish; harmonious; balanced; delicate; characteristic of ingredients; nutty; umami; mushroom; liver; beef; sun-dried tomatoes; fatty) with specified modes - processing temperature (t, °C), processing duration (τ, υβ.): t=50 °C; τ=10 min. (Fig. 4, a); t=50 °C; τ=60 min. (Fig. 4, b); t=90 °C; τ=10 min. (Fig. 4, c); t=90 °C; τ=60 min. (Fig. 4, d); t=125 °C; τ=45 min. (Fig. 4, e), according to a 5-point rating scale, by intensity: 1 – not felt; 2 - barely felt; 3 – moderately felt; 4 - felt; 5 - intensely felt.

The assessment of shiitake mushroom pastes showed that the descriptor of taste «pleasantness» remains consistently high (score of 5 points) in all heat treatment modes – both at low temperatures (t=50°; τ=10-60 minutes) and at intensive modes (t=90-125°C). This indicates a good basic taste appeal of the product, regardless of the method of preparation.

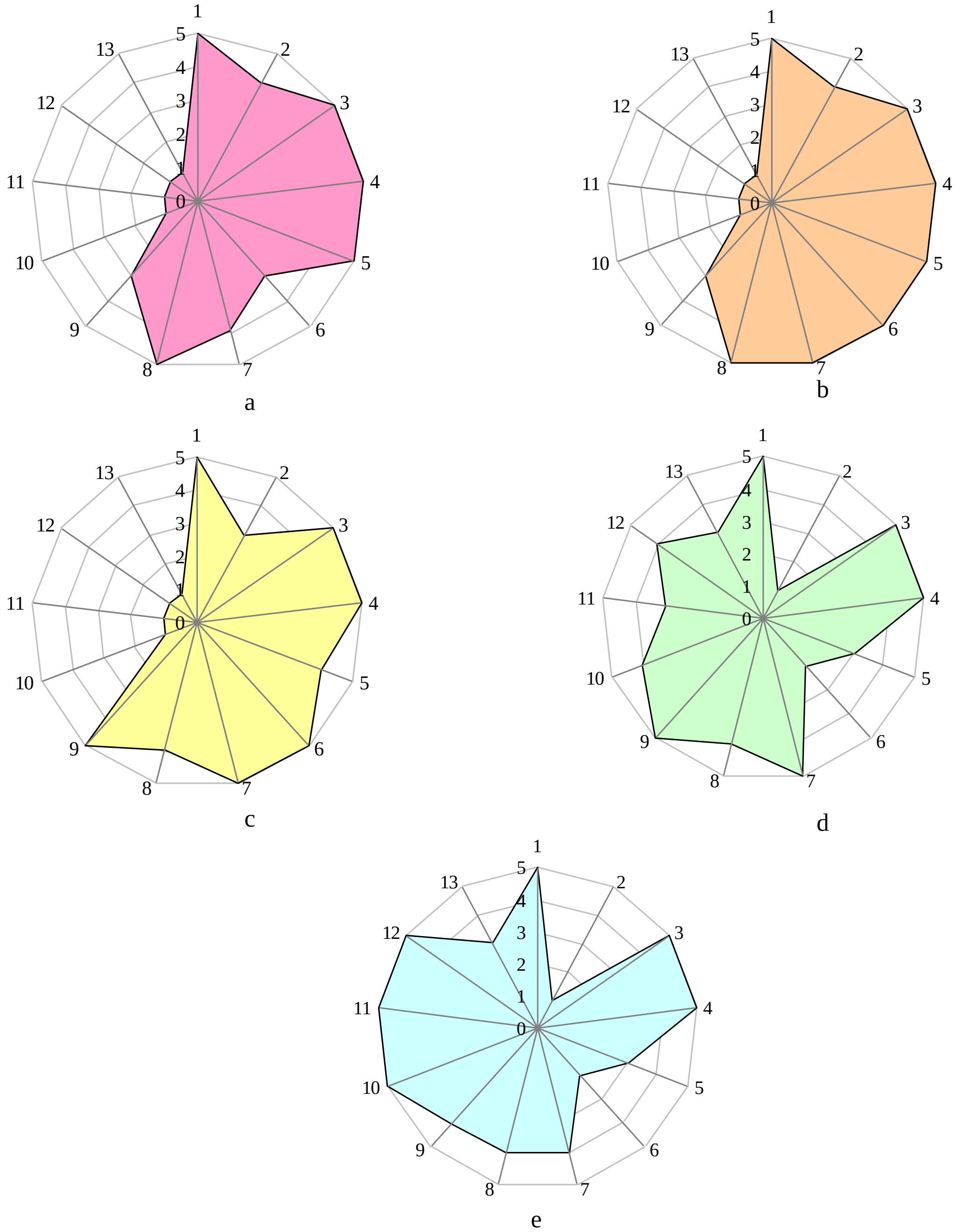

Fig. 4. Sensory profile of mushroom pastes under the following conditions: a – t=50 °C; τ=10 min.; b – t=50 °C; τ=60 min.; c – t=90 °C; τ=10 min.; d – t=90 °C; τ=60 min.; e – t=125 °C; τ=45 min.; 1 – pleasant; 2 – sweetish; 3 – harmonious; 4 – balanced; 5 – tender; 6 – characteristic of ingredients; 7 – nutty; 8 – umami; 9 – mushroom; 10 – liver; 11 – beef; 12 – sun-dried tomatoes; 13 – fatty

At the same time, the «sweetish» descriptor undergoes significant changes: if at a temperature of t=50°C it remains at the level of 4 points, then when the temperature rises to t=90°C or more, its intensity sharply decreases to the minimum values (1 point). This is due to the thermal degradation of natural sugars of mushroom raw materials.

The descriptors «harmonious» and «balanced» remain consistently high regardless of the heat treatment mode (all scores are 5 points), which indicates the stability of the overall composition of the product's taste even with an increase in temperature.

The descriptor «tenderness» of taste is much better revealed during delicate processing (t=50°C) - a score of 5 points. When the temperature rises to t=90°C or more, tenderness decreases (up to 3 points), which indicates structural changes in the protein part of the mushrooms and general coagulation of the texture.

The descriptor «inherent in the ingredients» aroma is most pronounced at t=50°C (especially at τ=60 min.

processing) - a score of 5 points. At high temperatures, the intensity of this descriptor decreases to 2 points, which is due to the thermal destruction of volatile aromatic compounds.

The «nutty» flavor descriptor remains at a high level in all processing modes, but peaks at t=50°C in τ=60 minutes. and at t=90°C for τ=10 min. (scores 5 points). A slightly weaker «nutty» tone appears at t=125°C.

The «umami» descriptor remains intense at all stages of processing (4-5 points). A slight decrease in score is observed after prolonged heating at t=90°C and above, indicating a partial loss of some flavor enhancers naturally present in mushrooms.

The «mushroom» descriptor, on the contrary, is strengthened after processing at t=90°C: from 3 points at t=50°C to 5 points at t=90°C for τ=10-60 minutes. This may be due to the formation of new aromatic compounds during the thermal decomposition of proteins.

The appearance of «liver», «beef» descriptors and shades of «sun-dried tomatoes» is observed only at high temperatures (t=90-125°C). Thus, the «liver» descriptor rises from 1 point at t=50°C to 5 points at t=125°C. «Beef» aroma similarly manifests itself only during intensive heat treatment, which indicates the development of Maillard reactions and caramelization of amino acids and sugars.

The descriptor «fat content» also increases after treatment at t=90-125°C (up to 3 points), which may be due to the release of intracellular lipids of fungal tissue.

Thus, to preserve tenderness, sweetness and inherent aroma, it is advisable to use delicate heat treatment regimes (t=50°C). To obtain pastes with a rich mushroom, liver, beef flavor and pronounced fat content, it is advisable to use higher temperatures (t=90-125°C). The sensory profile of taste and aroma can vary depending on the technological process, which allows you to flexibly shape the consumer properties of the product.

Organoleptic studies have shown that the temperature, duration and method of heat treatment significantly affect the consumer properties of mushroom paste. The use of sous-vide technology at low temperatures (50-90 °C) helps to preserve the traditional appearance and flavor profile of the product - natural light or rich beige color, uniform plastic consistency interspersed with ingredients, pronounced mushroom taste with umami notes and a pleasant nutty aroma. An increase in temperature to 90 °C (for a duration of 10-60 minutes) provides the most balanced sensory profile, enhancing color, aroma and taste expressiveness without loss of authenticity. On the other hand, autoclaving at a temperature of 125 °C causes darkening of the color to a brown tint unusual for mushroom paste, thickening of the texture and the appearance of a meat (liver) taste and aftertaste, which reduces the identification of the product as mushroom. Thus, gentle sous-vide heat treatment regimes are more appropriate for the production of mushroom paste with high sensory performance and maintaining its culinary appeal. This is consistent with the results of other researchers [18-21, 23-27], which confirms the negative effect of high-temperature treatment of mushrooms on organoleptic properties (color, texture, and taste) [23, 25, 27] and affects the nutritional value and antioxidant properties of mushrooms [24, 26].

4. Recommendations on the prospect of using shiitake mushrooms in innovative restaurant technologies. Taking into account the biochemical composition of shiitake mushrooms, as well as the ability to preserve antioxidant activity under mild thermal conditions (50–90 °C), it is advisable to recommend their use on the market [28] – in modern restaurant technologies as an ingredient in functional dishes. The following areas of development are promising: mushroom, vegetable and mushroom [29], meat pastes with the addition of mushrooms [30]; sauces [2-4]; cream soups; cheesecakes [8]; snacks [31]; fermented drinks [9], etc., which can be combined with fermented components [32, 33] to enhance biological action [34, 35, 36]. Due to the rich flavor profile, shiitake is able to replace meat components in recipes [30] for vegetarian and vegan concepts [29]. In the restaurant business, shiitake mushrooms can serve not only as a source of unique umami taste, but also as a platform for creating healthy dishes with targeted properties [37] – antioxidant, immunostimulating and adaptogenic effects.

The results obtained confirm the feasibility of using shiitake mushrooms as an ingredient with high functional potential in restaurant technology. The proposed parameter-technological solutions can be used to develop technological maps of new functional dishes in the field of HoReCa.

Approbation of research results.

The results of the study were tested in the production conditions of «ESMASH-3» LLC (Ukraine), specializing in the cultivation of vegetables and mushrooms, within the framework of an agreement on scientific and technical consulting with the National University of Food Technologies (2021–2026). The introduction of the technology of Asian mushroom pastes was confirmed by the act of completion (2024), which testified to the social and economic effect, in particular, improving the quality of products and optimizing technological processes.

Conclusion

1. Studies have shown that heat treatment of shiitake mushrooms significantly affects the redox parameters of water-alcohol infusions. The highest antioxidant capacity was recorded at a temperature of 50 °C for 60 minutes, where the redox efficiency (RE_{inf}) was 186.98 mV at Eh_{act}=8.0 mV and pH=7.31. Higher temperatures activate individual redox components, but cause degradation of sensitive bioactive substances.

2. The most favorable for preserving the natural appearance, taste and aroma of mushroom paste turned

out to be sous-vide modes at 50–90 °C (10–60 minutes). They provided a traditional light beige color, a plastic consistency and a rich mushroom aroma. In contrast, autoclaving at 125 °C caused color darkening, structural compaction, unwanted meat notes, and reduced product authenticity.

3. On a 5-point scale, samples processed sous-vide at 90 °C received the highest overall rating, characterized by a harmonious flavor profile with pronounced umami descriptors and nutty notes. Samples after autoclaving received lower ratings due to changes in color, texture and flavor characteristics.

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ДОСЛІДЖЕННЯ СЕНСОРНИХ ТА АНТИОКСИДАНТНИХ ВЛАСТИВОСТЕЙ ФУНКЦІОНАЛЬНИХ ПАШТЕТІВ НА ОСНОВІ ГРИБІВ ШИЇТАКЕ

О.В. Кузьмін [1], доктор технічних наук, професор, *E-mail:* kuzmin_ovl@ukr.net
О.О. Веліканов [2], аспірант, *E-mail:* aiexvelikanov777@gmail.com
О.П. Мельник [2], кандидат хімічних наук, доцент, *E-mail:* ksaname@gmail.com
В.В. Кійко [3], кандидат технічних наук, доцент, *E-mail:* victoriya_kiyko@ukr.net
К.В. Бахлукова [4], кандидат технічних наук, *E-mail:* xenia.bakhlukova@gmail.com
А.О. Кузьмін [5], магістр, *E-mail:* kuzminaolmrfox@gmail.com
[1] Кафедра технології ресторанної і аюрведичної продукції
[2] Кафедра експертизи харчових продуктів
Національний університет харчових технологій
01033, Україна, м. Київ, вул. Володимирська, 68
[3] Державний оператор тилу
04119, Україна, м. Київ, вул. Дегтярівська, 13/24
Контактний телефон: 080 010 1101
[4] Відділ аналітичних досліджень та якості харчової продукції
Інститут продовольчих ресурсів НААН
02000, Україна, м. Київ, вул. Євгена Сверстюка, 4А
Контактний телефон: 044 517 1737
[5] ФОП Кузьмін Антон Олегович

Анотація. Дослідження присвячено оцінці впливу режимів термічного оброблення грибів шиїтаке (Lentinula edodes) на антиоксидантну активність функціональних паштетів із покращеними органолептичними характеристиками. Для термічної обробки застосовано низькотемпературну технологію sous-vide (t=50–90 °C, τ=10–60 хв.) та високотемпературну технологію автоклавування (t=125 °C, τ=45 хв.). Антиоксидантну активність визначали методами редоксметрії та pH-метрії з розрахунком відновлювальної здатності водно-спиртових настоїв (RE_{inf}) та рослинної сировини (RE_{plant}). Результати продемонстрували, що підвищення температури у процесі термічного оброблення грибів шиїтаке сприяє активації окремих редокс-компонентів, підтверджуючи зростання окисно-відновного потенціалу Eh_{act} (з 7,0 мВ у контролі до 15,50 мВ при автоклавуванні), однак збільшення температури приводить до деградації термолабільних біоактивних сполук, знижуючи загальну редокс-ефективність. Найвищу антиоксидантну активність (RE_{inf}=186,98 мВ, RE_{plant}=141,34 мВ) зафіксовано при обробці sous-vide за режимом 50 °C протягом 60 хв., що забезпечувало стабільні показники pH (7,31) та збереження смакових властивостей. Автоклавування знижувало pH до 7,18, спричиняючи інтенсивні реакції Майяра та деградацію антиоксидантів. Сенсорна оцінка за 5-баловою шкалою (зовнішній вигляд, колір, консистенція, смак, післясмак, запах) підтвердила перевагу низькотемпературних режимів: зразки sous-vide мали світло-бежевий колір, пластичну консистенцію, виражений грибний смак і дескриптори «умамі» та «горіховий» (4–5 балів), тоді як автоклавовані зразки характеризувалися потемнінням, печінковим присмаком і меншою пластичністю (3–4 бали). Встановлено, що низькотемпературна термообробка паштетів з грибів шиїтаке сприяє збереженню автентичного сенсорного профілю та підвищенню антиоксидантної активності, що обґрунтовує використання грибів шиїтаке для створення інноваційних функціональних продуктів у ресторанному господарстві та спеціалізованих раціонах харчування.

Ключові слова: гриби шиїтаке, Lentinula edodes, функціональні продукти, паштет, sous-vide, автоклавування, якість, сенсорні властивості, антиоксидантна активність, редокс-показники, інноваційні ресторанні технології.