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A multiplicative approach to optimize the consumer properties of quick-frozen semifinished products from cultivated champignons

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ABSTRACT

It is possible to maximise the consumer properties of grown fruit and vegetable products, significantly reduce their losses during the life cycle, and satisfy the public demand for products ready for consumption by using different preservation methods, particularly freezing. It has been found that the freezing of mushrooms without pretreatment does not provide a high-quality finished product. It justifies the expediency of mushroom pretreatment before freezing to stabilize their consumer properties. The inhibition effect of high temperatures on the oxidoreductase activity has been confirmed, ensuring the high preservation of cultivated champignons' natural color and consistency. A quasimetric assessment of the quality of quick-frozen cultivated mushrooms was performed, and the optimal heat treatment parameters were determined. Before freezing, blanched mushrooms' efficiency with polysaccharides has been scientifically proved. Rational concentrations and types of polysaccharides for mushroom processing have been determined. It has been established that blanching champignons in 0.1% citric acid solution followed by xanthan gum (0.2%), guar gum (0.1%), and lamidan (0.1%) processing ensure stability of consumer properties of quick-frozen semifinished products made of cultured champignons. After defrosting, they have an attractive appearance, natural light brown colour, elastic consistency, well-expressed mushroom flavour, and harmonious taste.

Keywords: mushrooms, semifinished product, cultivated champignons, quality models, consumer properties

INTRODUCTION

The production of quick-frozen vegetable raw materials is the first step toward rational nutrition that saves maximum consumer properties, significantly reduces losses of cultured products, and meets consumer demand for products ready for consumption. The works of **[1], [2]**, **[3]**, **[4]**, **[5]**, **[6]**, **[7]**, **[8]**, etc., are devoted to the impact of freezing on the quality of fruit and vegetable products. Scientists studied and analyzed the components of the biological value of broccoli, the variety of Parthenon cultivated in the regions of Ukraine. The research results are reported, the changes in the content of ascorbic acid and isothiocyanates were analyzed, as well as a pigment composition: chlorophyll and β-carotene in the freshly harvested broccoli, as well as after its pretreatment before freezing: by blanching and aging in a solution of food salt **[1]**. In freshly harvested cabbage, pre-frozen in different ways before freezing, the mass fraction of moisture and the form of its connection with dry matter were determined **[2]**. Dubinina A. et al. studied the effect of thermal treatment on the degree of chlorophyll destruction in rhubarb and gooseberry. We established the effect of stabilizing additives on the transformation of chlorophylls and a change in the colour of rhubarb and gooseberry **[3]**. Zamorska I.et al. proposed the technology of production of strawberry jam from strawberries with the replacement of pectin solution with apple puree **[4]**. The problems of the formation of assortment and quality of frozen fruit and vegetable products are investigated in work **[5]**. A complex of organoleptic, commercial, physical, and thermophysical indicators of eggplant, sweet pepper, and tomato fruits was developed to determine their harvesting time **[6]**. Scientists' influence of cryomechanodestruction is examined on the activation and destruction of heteropolysaccharides when developing the nanotechnologies of plant supplements, in particular, frozen nanopuree from carrot, sweet pepper, pumpkin, tomato, apricot, buckthorn **[7]**. Scientists have proved that there are colour changes and loss of cell sap in plant raw materials after defrosting because of high enzymatic activity, which negatively affects the nutritional value of products. Among cultivated mushrooms, champignons are subjected to freezing. Still, there are almost no data in the scientific literature on the study of their nutritional value after freezing and long-term low-temperature storage. Unfortunately, the traditional technology of mushroom freezing does not provide a high quality of the finished products, so the development of methods of mushroom pretreatment before freezing to stabilize their consumer properties is an important issue.

Scientific Hypothesis

The hypothesis of the scientific work lies in the supposition about the possibility of pretreatment of semifinished products made of cultivated champignons before freezing. Based on the established trends of changes in the quality of quick-frozen semifinished products from cultivated mushrooms, the mechanism of stabilization of their consumer properties by treatment of xanthan gum, guar gum, and lamidan pre-blanched mushrooms in citric acid solution has been scientifically substantiated. In-depth scientific ideas about the patterns of color stabilization and consistency of quick-frozen semi-finished products from cultivated mushrooms.

MATERIAL AND METHODOLOGY

Samples

The object of the study was quick-frozen semifinished products made of cultivated champignons (*Agaricus bisporus*) of the brown race, strain No. 117, with a closed cap of the first collection wave.

Chemicals

Potassiumiodate, KJO_3 (Energostroyinvest Trading House LLC, Ukraine); sodium hydroxide, NaOH (Khimlaborreaktyv LLC, Ukraine); ascorbic acid, vitamin C (Khimlaborreaktyv LLC, Ukraine); Metaphosphoric acid, HPO_3 (Khimlaborreaktyv LLC, Ukraine); Pyrocatechin, $C_6H_4(OH)_2$ (Khimlaborreaktyv LLC, Ukraine); citric acid, $C_6H_8O_7$ (Ecotechnics LLC, Ukraine) **[9]**; xanthan gum, E 415 (Criamo LLC, Ukraine) **[10]**; guar gum, E 412 (SOSA Ingredients, Spail) **[11]**; lamidan (Lamidan LLC, Ukraine) **[12]**.

Biological Material

The quick-frozen semifinished product made of cultivated champignons (*Agaricus bisporus*) included raw materials that met the requirements of regulatory documents and had the conclusions of the state sanitary and epidemiological expertise: cultivated champignons **[13]**, **[14]**. Cultivated champignons were grown in the commercial firm and purchased to produce semi-finished products.

Instruments

Titration unit (Labor-Technik LLC, Ukraine).

Analytical electronic scales KERN ABS 120-4 (Khimtex SE, Ukraine).

Termia electric cooker EPCH-1.5/200 (Mayak Vinnytsia plant PJSC, Ukraine).

Laboratory Methods

Experimental studies were conducted using modern standard, conventional and special organoleptic, physicochemical, biochemical methods, and mathematical modeling using modern computer programs (Microsoft Excel and Origin 8). The frozen product mass determined mass loss during storage; water holding capacity was determined by the difference in the frozen and unfrozen product mass; oxidoreductase activity-ascorbinatoxidase, polyphenoloxidase was determined by the quantity of ascorbic acid converted to dehydrator 1 g of tissue per unit time. The experimental data were processed by multicriteria optimization.

Description of the Experiment

Sample preparation: Brown race cultivated champignons of strain 117 with the closed cap of the first collection wave were used for the experiments. To produce a test batch of quick-frozen semifinished products, the mushrooms were cleaned of dust, soil, and other foreign impurities and inspected for quality, sorted, washed, and cut into 0.5 cm thick slices. The mushrooms were blanched in hot water at 85 °C ±2°C for 30, 60, and 90 s with the addition of citric acid concentration 0.05; 0.1 and 0.15% in stainless steel boilers, cooled with cold running water (4 – 5 °C), placed on a colander to remove excess moisture. Pre-blanched mushrooms were treated with xanthan gum, guar gum, carrageenan, and lamidan concentrations of 0.1 and 0.2% and their combinations, thoroughly mixed for uniform distribution of polysaccharides, and kept for 1 hour at plus 18 ±2 ºC for polysaccharides swelling. Mushrooms were frozen in a freezer at minus 27 ±2 °C and stored in a freezer at minus 20 ±2 °C.

Number of samples analyzed: test samples were quick-frozen semifinished products of brown race, cultivated mushrooms of strain No. 117 with the closed cap of the first collection wave. Mushrooms were pre-blanched in different concentrations of citric acid for a different time, and treated before freezing with different types and concentrations of natural polysaccharides. Cultured champignons without pre-blanching and pre-treatment with natural polysaccharides, frozen under similar temperature regimes, served as a control sample.

Number of repeated analyses: average samples were used to determine all quality indicators in five-fold repeatability. The indices were determined, taking a mass loss during freezing and low-temperature storage into account.

Number of experiment replication: each trial was carried out five-fold replication for the test and the control sample.

Design of the experiment:

- mushroom stored in a freezer at minus 20 ±2 °C;
- mushroom preparation: the mushrooms were cleaned of dust, soil, and other foreign impurities and inspected for quality, sorted, washed, and cut into 0.5 cm thick slices;
- mushroom blanching in hot water at 85 °C ±2 °C for 30, 60, and 90 s with the addition of citric acid concentration 0.05; 0.1 and 0.15% in stainless steel boilers;
- treatment with polysaccharides of natural origin: the mushrooms were treated with xanthan gum, guar gum, carrageenan, and lasmiditan concentration of 0.1 and 0.2% and their combination;
- measurement of the organoleptic parameters, mass loss during blanching, weight loss during freezing, moisture-holding capacity, and enzyme activity;
- Microsoft Excel and Origin 8 produced statistical analyses.

Statistical Analysis

Microsoft Excel and Origin 8 produced the statistical analysis data. The accuracy of the obtained experimental data was determined using the Student's test for confident probability ≤0.05 based on the number of parallel determinations of at least 5.

RESULTS AND DISCUSSION

The problem of insufficient protein in the diet of the world's population is currently acute. Fish and fish products play an important role in solving the problem of supplying the world's population with animal protein **[15]**, **[16]**, **[17]**. Cultivated mushrooms are one of the most accessible plants protein sources with high digestibility. However, mushrooms have low storability in fresh form, which is confirmed by the results of scientific research by domestic and foreign scientists and indicates the urgent need to find effective ways of storage, timely processing, and quality control in the distribution process **[18]**, **[19]**, **[20]**, **[21]**, **[22]**. Various processing methods are widely used to reduce the losses of mushrooms and expand the range of mushroom products, such as salting, canning, drying, and freezing. The authors studied the effect of blanching on the stabilization of the consumer properties of cultivated brown race champignons. Citric acid was added to the blanching water to preserve the mushrooms' tissue structure, and natural colourand reduce the enzymatic activity that causes the mushrooms to darken more intensively. The results of the studies were used to calculate (CQI) of the cultivated brown race champignons depending on the blanching time and the amount of citric acid (Table 1).

Table 1 Comprehensive assessment of the quality of fresh-frozen cultivated champignons of the brown strain No.117.

Experiment options		**Organoleptic parameters**					**CQI**
Duration of blanching, s	**Citricacidcon centra-tion,%**	**Appearance, ball**	**Color, ball**	**Scent, ball**	**Taste, ball**	**Consistence, ball**	
Control (without blanching)		3.70 ±0.19	3.50 ±0.17	4.50 ±0.22	3.90 ±0.19	3.60 ±0.18	0.40
Experiment							
	0.05	3.80 ±0.19	3.57 ±0.17	4.54 ±0.22	3.96 ±0.19	3.70 ±0.18	0.61
30	**0.10**	3.85 ±0.19	3.59 ±0,17	4.56 ±0.22	3.96 ±0.19	3.72 ±0.18	0.61
	0.15	3.87 ±0.19	3.60 ±0.18	4.57 ±0.22	3.98 ±0.19	3.73 ±0.18	0.62
	0.05	3.90 ±0.19	3.60 ±0.18	4.59 ±0.23	4.00 ±0.2	3.78 ±0.18	0.62
60	**0.10**	3.90 ±0.19	3.60 ±0.18	4.60 ±0.23	4.00 ±0.2	3.80 ±0.19	0.63
	0.15	3.90 ±0.19	3.60 ±0.18	4.60 ±0.23	4.00 ±0.2	3.81 ±0.19	0.62
	0.05	3.87 ±0.19	3.59 ±0.17	4.50 ±0.22	4.10 ±0.2	3.65 ±0.18	0.60
90	**0.10**	3.80 ±0.19	3.60 ±0.18	4.50 ±0.22	4.10 ±0.2	3.67 ±0.18	0.60
	0.15	3.84 ±0.19	3.59 ±0.17	4.50 ±0.22	4.10 ±0.2	3.65 ±0.18	0.60
Coefficient of weight		0.10	0.10	0.10	0.10	0.11	

Table 1 Cont.

		Physico-chemical parameters				
		Mass loss during blanching, %	**Moisture holding capacity, %**	**Enzyme activity, conventional units**		
				ascorbate-oxidase	**polyphenol-oxidase**	
Control (without blanching)		0	63.0 ±3.15	0.30 ±0.01	8.62 ±0.43	0.40
Experiment						
	0.05	3.50 ±0.17	65.88 ±3.29	0.27 ±0.01	6.81 ±0.34	0.61
30	**0.10**	3.80 ±0.19	65.90 ±3.29	0.26 ±0.01	6.80 ±0.34	0.61
	0.15	3.70 ±0.18	66.03 ±3.30	0.25 ±0.01	6.78 ±0.33	0.62
	0.05	6.21 ±0.31	68.25 ±3.41	0.20 ±0.01	5.10 ±0.25	0.62
60	**0.10**	6.12 ±0.31	70.94 ±3.54	0.15 ±0.01	4.92 ±0.24	0.63
	0.15	6.17 ±0.31	69.15 ±3.45	0.13 ±0.01	4.91 ±0.24	0.62
	0.05	7.67 ±0.38	68.25 ±3.41	0.07 ±0.003	4.65 ±0.23	0.60
90	**0.10**	7.50 ±0.37	69.00 ±3.45	0.08 ±0.004	4.63 ±0.23	0.60
	0.15	7.57 ±0.31	69.96 ±3.49	0.09 ±0.004	4.61 ±0.23	0.60
Coefficient of weight		0.15	0.15	0.09	0.10	

The control samples were champignons without blanching. Brown race champignons pre-blanched in a 0.1% citric acid solution for 60 seconds proved to be the best organoleptic and physicochemical properties. After freezing and defrosting, the experimental samples had a slightly less attractive appearance than the fresh ones but significantly better than the control ones. The addition of citric acid helped preserve the natural colour of the mushrooms compared to the control ones. A more elastic consistency was also found in brown race mushrooms pre-blanched in a 0.1% aqueous citric acid solution for 60 seconds. Increasing the blanching time to 90 seconds harms the consistency of the mushrooms, softening the tissues due to their structure changes. The highest mass loss was observed in mushrooms irrespective of race, subjected to heat treatment for 90 seconds. Preliminary heat treatment of mushrooms before freezing positively affected the water holding capacity (compared to control ones). However, champignons were still characterized by a significant loss of cell sap, confirming the need to find additional ways to pre-treat mushrooms before freezing. As a result of these studies, thein inhibitory effect of blanching on the activity of oxidoreductases in experimental samples was determined compared to the control ones (without blanching), characterized by high activity of polyphenoloxidase, which caused the change in colour of mushrooms during defrosting. Experimental studies to determine the optimal blanching time, citric acid concentration, type, and rational concentration of natural polysaccharides require a long time and significant material costs. Therefore, the use of mathematical apparatus and the development of mathematical models of quality allows us to determine the optimal parameters for the effective preservation of product quality. Mathematical processing of the experimental results using Origin 8 software was carried out using the method of multi-criteria optimization. The initial variables (Table 2) were selected as blanching time (s) – x1 and citric acid concentration (%) – x2. The optimization criteria were: organoleptic parameters, mass loss during blanching, water holding capacity, and polyphenoloxidase enzyme activity.

Table 2 Parameters of cultivated champignon pretreatment.

Experiment options	x_1	x_2
1 (control without processing)	0	0
2	30	0.05
3	30	0.1
4	30	1.5
5	60	0.05
6	60	0.1
7	60	1.5
8	90	0.05
9	90	0.1
10	90	1.5

Mathematical models of dependence of consumer properties of cultivated brown champignons of strain No. 117 ($z_1 - z_4$) from the duration of blanching (x_1) and citric acid concentration (x_2):

1) organoleptic quality assessment (z_1):

$$z_1 = -4.35 \cdot x_1^2 + 1.45 \cdot x_2^2 + 2.83 \cdot x_1 \cdot x_2 - 4.27 \quad (1)$$

2) mass loss during blanching (z_2):

$$z_2 = -3.13 \cdot x_1^2 + 3.04 \cdot x_2^2 + 1.89 \cdot x_1 \cdot x_2 - 2.0 \quad (2)$$

3) water holding capacity (z_3):

$$z_3 = 2.03 \cdot x_1^2 - 2.36 \cdot x_2^2 - 3.16 \cdot x_1 \cdot x_2 + 1.43 \quad (3)$$

4) polyphenoloxidase activity (z_4):

$$z_4 = 6.47 \cdot x_1^2 + 2.08 \cdot x_2^2 - 5.92 \cdot x_1 \cdot x_2 - 7.59 \quad (4)$$

The mathematical models obtained make it possible to proceed to the nextstage of the study, which is to determine the optimum duration of blanching and concentration of citric acid. The optimal blanching parameters for cultivated brown champignons of strain No. 117 were determined graphically (Figure 1).

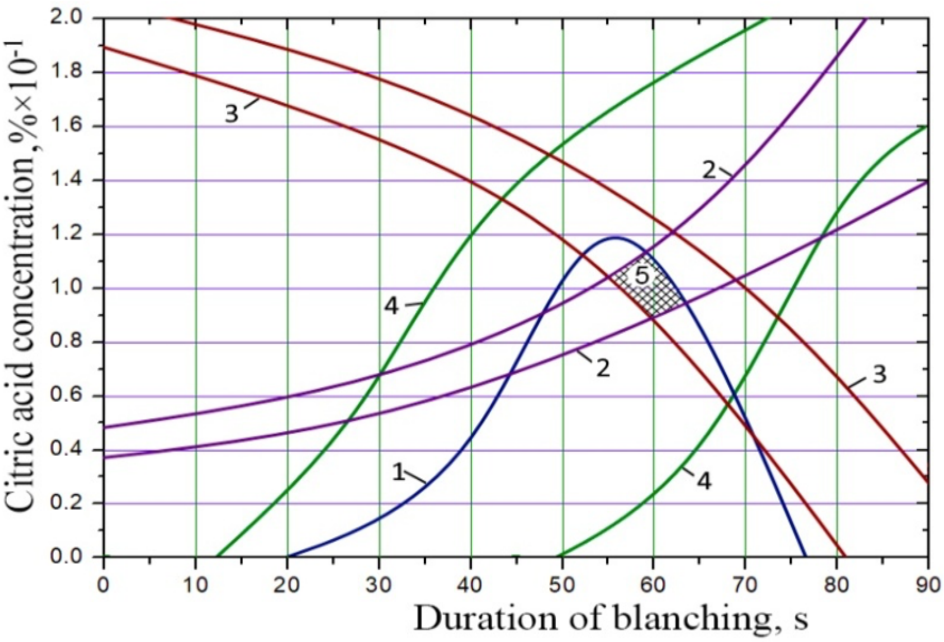

Figure 1 The optimal blanching parameters for cultivated brown champignons of strain No. 117. Note*:* Range of parameters: 1 – organoleptic assessment; 2 – mass loss during blanching; 3 – water holding capacity; 4 – polyphenol oxidase activity; 5 – the range of optimal compromise values of blanching parameters.

The studies and mathematical modeling results confirmed the positive effect of blanching on organoleptic parameters, water holding capacity, and enzymatic activity of cultivated champignons. The developed mathematical models determined the optimal blanching parameters for mushrooms in 0.1% aqueous citric acid solution for 60 seconds (taking into account CQI).

The next step was the pretreatment of cultivated champignons before freezing with natural polysaccharides: xanthan gum, guar gum, carrageenan, and lamidan at 0.1% concentration (Experiment). Samples of champignons without adding natural polysaccharides served as a control one. The main criteria for selecting polysaccharides were the organoleptic properties, mass loss after defrosting, and the water holding capacity of the raw mushroom material. Before freezing, the cultivated brown champignons of both the control and experimental variants were characterized by an attractive appearance, a well-defined natural colour, a clean, pleasant, harmonious, inherent taste without a foreign taste and flavour, and a dense, elastic consistency. The average organoleptic score was 5.0.

The studies showed that the most noticeable deterioration of sensory indicators was observed in the control sample (without treatment) after defrosting, 3.84 points (Table 3). Thus, defrosted mushrooms of control variants had a less attractive appearance (compared with the experimental ones), dark brown colour, deterioration of taste, and significant deterioration of consistency, which, in our opinion, is associated with significant physical, chemical, and biochemical changes of the product. Among the experimental variants of mushrooms, the mushrooms pretreated with xanthan gum, guar gum, and lamidan were the best in organoleptic indicators. After defrosting, the mushroom samples were characterized by an attractive appearance and uniform, nearly natural colour.

Table 3 Organoleptic assessment of the quality of frozen cultivated brown champignons of strain No. 117 depending on the type of natural polysaccharides.

Organoleptic parameters	Control (without processing)	Experiment (concentration 0.1 %)			
		Xanthan gum	Guar gum	Carrageenan	Lamidan
Appearance	3.7 ±0.18	4.2 ±0.21	4.2 ±0.21	4.0 ±0.20	4.3 ±0.21
Color	3.5 ±0.17	4.0 ±0.20	4.0 ±0.20	3.7 ±0.18	4.0 ±0.20
Taste	3.9 ±0.19	4.3 ±0.21	4.3 ±0.21	4.0 ±0.20	4.5 ±0.22
Scent	4.5 ±0.22	4.8 ±0.23	4.5 ±0.22	4.7 ±0.23	4.6 ±0.23
Consistence	3.6 ±0.18	4.1 ±0.20	4.2 ±0.21	3.8 ±0.19	4.1 ±0.20
Secondary ball	3.84	4.29	4.24	4.04	4.30

The testing samples' taste and flavour of the frozen mushroom semifinished products were pleasant, rich, and normal, without foreign tastes and flavours. However, it should be noted that the flavour of mushrooms, which were pretreated with lamidan, was somewhat different from the other samples and had a pleasant seaweed flavour. A high level of consistent preservation of the experimental mushroom samples compared to the control ones was also noted, which is due to the ability of the natural polysaccharides to bind moisture. Testing samples of champignons treated with carrageenan had slightly lower quality indicators (compared to other types of natural polysaccharides). After defrosting, the mushrooms had significant changes in colour and consistency.

Mass loss during freezing and the water holding capacity of mushrooms had a significant impact on preserving the quantitative and qualitative characteristics of the products. Brown mushrooms (0.179%), pretreated with xanthan gum, had the lowest mass loss during freezing. This indicator was 1.64% higher for champignons of the brown race, which were treated with guar gum. The highest mass loss (0.245%) was observed in the mushrooms of the control samples (with no treatment). The cultivated brown mushrooms of the control samples were characterized by the lowest water holding capacity (63%). The highest moisture-retaining ability was characterized by samples of brown mushrooms, which were pretreated with xanthan gum (81.07%).

This indicator was lightly lower for guar gum (76.49%). This can be explained by the high content of dietary fibers in polysaccharides, which can form colloidal solutions and thus bind free water and participate in the formation of additional intermolecular bonds. Carrageenan-treated mushrooms had the lowest water holding capacity (66.92%).

The research results confirm the practicality of using natural polysaccharides to stabilize the consumer properties of quick-frozen mushroom semifinished products. Preservation of the appearance, taste, and aroma of mushrooms, their elastic consistency, reducing weight loss, and increasing the moisture-retaining capacity of semifinished products is due to the formation of a film on the surface of mushrooms during pre-treatment with natural polysaccharides.

The experiment to determine the optimal types and concentrations of natural polysaccharides is shown in Table 4. Champignons without added polysaccharides – variants No.1 were control samples, and No. 2 – 10 –pretreated with polysaccharides were experimental samples.

Table 4 Types and concentrations of natural polysaccharides.

Experiment options	Carrageenan	Xanthan gum	Guargum	Lamidan
1	0	0	0	0
2	0.1	0	0	0
3	0.2	0	0	0
4	0	0.1	0	0
5	0	0.2	0	0
6	0	0	0.1	0
7	0	0	0	0.1
8	0	0.2	0.1	0.1
9	0	0.2	0	0.1
10	0	0.2	0.1	0

The criteria for choosing the optimal concentration and type of natural polysaccharides were organoleptic properties of quick-frozen cultivated brown champignons of strain No. 117, mass loss during freezing, water holding capacity, and polyphenol oxidase activity (Table 5).

This study indicates that cultivated brown champignons of variant No. 8 (xanthan gum 0.2%, guar gum 0.1%, lamidan 0.1%) had the highest average organoleptic score (4.5 points) compared with the other variants. The control variant of brown champignons (No. 1) had the lowest averages core (3.84).

Table 5 Quality parameters of quick-frozen cultivated champignons depend on natural polysaccharides' type and concentration.

Quality parameters	Experiment variant number									
	1	2	3	4	5	6	7	8	9	10
Organoleptic parameters , ball										
Appearance	3.7 ±0.18	4.0 ±0.20	4.0 ±0.20	4.2 ±0.21	4.2 ±0.21	4.2 ±0.21	4.3 ±0.21	4.5 ±0.22	4.2 ±0.21	4.3 ±0.21
Color	3.5 ±0.17	3.7 ±0.18	3.9 ±0.19	4.0 ±0.20	4.1 ±0.20	3.5 ±0.17	3.7 ±0.18	3.9 ±0.19	4.0 ±0.20	4.1 ±0.20
Taste	3.9 ±0.19	4.0 ±0.20	4.0 ±0.20	4.3 ±0.21	4.3 ±0.21	4.3 ±0.21	4.5 ±0.22	4.5 ±0.22	4.4 ±0.22	4.5 ±0.22
Scent	4.5 ±0.22	4.7 ±0.23	4.7 ±0.23	4.8 ±0.24	4.8 ±0.24	4.9 ±0.24	4.8 ±0.24	4.7 ±0.23	4.9 ±0.24	4.8 ±0.24
Consistence	3.6 ±0.18	3.8 ±0.19	4.0 ±0.20	4.1 ±0.20	4.1 ±0.20	4.2 ±0.21	4.1 ±0.20	4.3 ±0.21	4.2 ±0.21	4.2 ±0.21
Secondary ball	3.84	4.04	4.12	4.29	4.30	4.24	4.30	4.50	4.36	4.38
Quality parameters	**Experiment variant number**									
	1	2	3	4	5	6	7	8	9	10
Physical and biochemical parameters										
Weight loss during freezing,%	0.245 ±0.01	0.231 ±0.01	0.216 ±0.01	0.179 ±0.008	0.170 ±0.008	0.182 ±0.009	0.181 ±0.009	0.144 ±0.007	0.185 ±0.009	0.160 ±0.008
Moisture retention capacity,%	63.0 ±3.15	66.92 ±3.34	68.03 ±3.40	81.07 ±4.05	81.45 ±4.07	76.49 ±3.82	75.10 ±3.75	83.60 ±4.18	81.50 ±4.07	81.70 ±4.08
The activity of polyphenol-oxidase, c.u.	8.62 ±0.43	8.63 ±0.43	8.63 ±0.43	8.61 ±0.43	8.61 ±0.43	8.61 ±0.43	8.60 ±0.43	8.59 ±0.43	8.60 ±0.43	8.60 ±0.43

The dependence of organoleptic properties, mass loss, water holding capacity, and polyphenol oxidase activity on the types and concentrations of natural polysaccharides can be described mathematically.

Based on the experimental data, we obtained the following mathematical descriptions:

5) organoleptic quality assessment (z_1):

$$z_1 = -0.04 \cdot x_1 + 4.67 \cdot x_2 - 1.06 \cdot x_3 + 0.16 \cdot x_4 + 0.11 \cdot x_1 \cdot x_3 - 0.38 \cdot x_2 \cdot x_3 + 1.26 \cdot x_2 \cdot x_4 - 0.83 \cdot x_2 \cdot x_4 - 0.47 \quad (5)$$

6) mass loss during freezing (z_2):

$$z_2 = 0.21 \cdot x_1 - 0.12 \cdot x_2 + 3.07 \cdot x_3 - 2.67 \cdot x_4 + 0,19 \cdot x_1 \cdot x_3 + 2.08 \cdot x_2 \cdot x_3 - 1.46 \cdot x_2 \cdot x_4 - 1.84 \cdot x_2 \cdot x_4 + 1.22 \quad (6)$$

7) water-holding capacity (z_3):

$$z_3 = -0.76 \cdot x_1 + 2.41 \cdot x_2 - 1.47 \cdot x_3 + 0.26 \cdot x_4 + 2.18 \cdot x_1 \cdot x_3 + 0.27 \cdot x_2 \cdot x_3 + 1.48 \cdot x_2 \cdot x_4 - 1.21 \cdot x_2 \cdot x_4 - 2.04 \quad (7)$$

8) polyphenoloxidase activity (z_4):

$$z_4 = 0.46 \cdot x_1 - 1.25 \cdot x_2 + 2.04 \cdot x_3 - 1.27 \cdot x_4 + 0.66 \cdot x_1 \cdot x_3 + 0.94 \cdot x_2 \cdot x_3 - 0.06 \cdot x_2 \cdot x_4 - 2.73 \cdot x_2 \cdot x_4 + 2.07, : \quad (8)$$

where x_1 is carrageenan content, x_2 is xanthan gum content, x_3 is guar gum content, x_4 is lamidane content, %):

Xanthan gum and lamidan content were the most important for organoleptic assessment, guar gum, and xanthan gum – for mass loss during freezing, guar gum, and xanthan gum – for water-holding capacity, and guar gum – for polyphenol oxidase activity. The effect of carrageenan on organoleptic parameters and water-holding capacity was inversely proportional. Organoleptic parameters and water holding capacity decreased significantly with increasing carrageenan content.

The mathematical models were a prerequisite for the next stage of the study, the task of which was to validate the polysaccharide treatment parameters (Figure 2) mathematically.

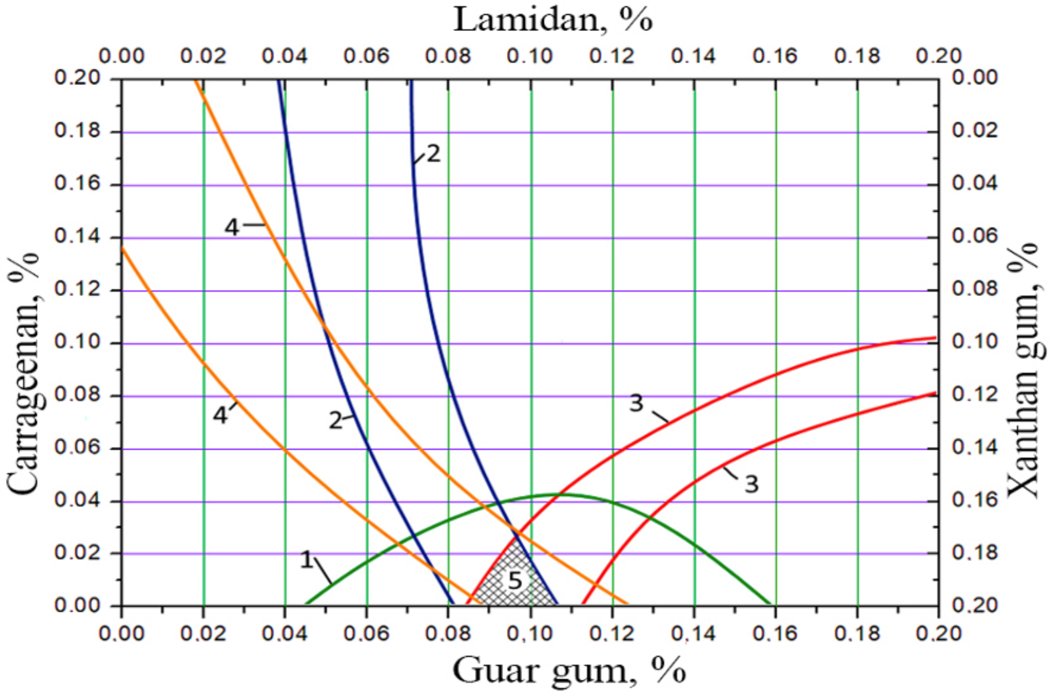

Figure 2 Optimal range of concentrations of natural polysaccharides for cultivated brown champignons of strain No. 117. Note: range of parameters: 1 – organoleptic assessment; 2 – mass loss during frosting; 3 – water holding capacity; 4 – polyphenol oxidase activity; 5 – the range of optimal compromise values of natural polysaccharide concentrations.

Optimal types and concentrations of natural polysaccharides are mathematically proved: 0.2% xanthan gum; 0.1% guar gum; 0.1% lamidan.

Quick-frozen mushroom semi-finished products treated with natural polysaccharides had an attractive appearance, natural light brown colour, elastic consistency, and well-defined taste and smell (Figure 3).

Figure 3 Quick-frozen semifinished product made of cultivated brown champignons of strain No. 117.

Scientists **[23]** proposed a method to control the relative humidity of shiitake mushrooms and found that mushrooms should be dried in an environment with low relative humidity. The use of ultrasound as a method of pretreatment of mushrooms before drying to improve their quality has been studied by foreign scientists. Scientists analyzed the effect of ultrasound and pre-blanching on the drying of mushrooms using a logarithmic model according to given criteria and parameters. It was found that pretreatment of mushrooms reduces the drying time by 9.5% compared to untreated samples **[24]**. Farahnak R. et al. investigated the effect of different ultrasound modes on the defrosting rate and the quality of champignons compared to conventional defrosting methods. They found that using probe-type ultrasound at 250 W could increase the defrosting rate and reduce protein denaturation without significant structural changes **[25]**. The works of Islam et al. **[26]** are devoted to the effect of ultrasound on the quality and rate of mushroom freezing. Aday M. investigated the effectiveness of electrolyzed water on the storage life of mushrooms and found that electrolyzed water at concentrations of 25 mg/l and 50 mg/l preserve the quality of mushrooms better than other treatments **[27]**. The Isfahan University of Technology studied the effect of static electric field on freezing parameters and microstructure of mushrooms (*Agaricus bisporus*). The experimental mushroom samples were frozen at minus 30 °C in an electrostatic field with 0; 4.5; 9.0, and 13.5 kV voltages. It was found that freezing in an electric field increases the generation temperature and reduces the ice crystal size, improving the mushroom microstructure. The smallest ice crystals were formed at voltages of 4.5 and 9.0 KV **[28]**, **[29]**. Scientists **[30]** analyzed the water holding capacity, loss of cell membrane integrity, and changes in the state of structural polymers of the cell wall of *Agaricus bisporus*. Marcal Sarah et al. reflected the effect of canning methods on mushrooms' nutritional and biological value **[31]**. The effect of different combinations of freezing and defrosting on preserving the quality of *Pleurotus eryngii* and the fruit bodies of shiitake mushrooms (*Lentinula edodes*) was studied **[32]** in the works **[33]**. Octavian Baston et al. investigated the quality of *Agaricus* and *Pleurotus* mushrooms during freezing and low-temperature storage **[34]**. Scientists **[35]** investigated the effect of different cooking and canning methods on the *Amanita Zambian* mushroom's nutritional value and phytochemical composition. The work **[36]** analyzed and conducted a comparative assessment of sensory indicators of *Cantharellus cibarius*, *Craterellus tubaeformis*, *Boletus edulis*, and *Lactarius camphoratus* wild mushrooms with *Agaricus bisporus* cultivated mushrooms. Scientists from Ukraine proposed the expansion of the range of sausages with increased biological value by combining meat and mushroom raw materials and found that the mass fraction of fat decreases, the proportion of carbohydrates increases, and the composition of the protein is closer to the "ideal" one in the finished products**[37]**. Egyptian scientists proposed to add fresh or dried mushrooms of the *Pleurotus ostreatus* genus to processed cheese. Organoleptic, physicochemical, and microbiological parameters were studied, and it was found that the finished product is characterized by increased nutritional value and improved sensory properties **[38]**. Scientists **[39]** analyzed cream and Enoki (*Flammulina velutipes*) mushroom extract combinations. They found a slowing of ice crystal growth in whipped cream by adding 0.1% of Enoki mushroom extract, which provides a reduction in quality changes during low-temperature storage. Scientists **[40]** proposed the use of microperforated packaging material to extend the shelf life of fresh-sliced mushrooms. The proposed design of the micro-perforation process, which will be used in passive modified atmosphere packaging, was based on the diameter and number of microholes, and the shelf life of fresh-sliced mushrooms was determined. The empirical equation used in this research can be determined to be applied to microperforated packaging design for fresh-sliced mushrooms. The fresh-sliced mushrooms' shelf life was 8 days, while it was less than 7 days (4, 5, or 6 days) when packaged with non-microperforated packaging material.

CONCLUSION

We determined the positive effect of blanching on organoleptic and physico-chemical parameters. Based on the complex index of quality calculation quality index, the rational parameters of the heat treatment process, namely blanching raw material in 0.1% solution of citric acid for 60 seconds, were determined. Based on the determined changes of consumer properties of quick-frozen semifinished products of cultivated champignons, the rational methods of pretreatment are scientifically proved: blanching of champignons in citric acid solution (0.1%) with the subsequent treatment with xanthan gum (0.2%), guar gum (0.1%) and lamidan (0.1%). It has been scientifically proven and experimentally confirmed that fast-supply semi-finished products with cultivated ovens, treated with certain types and concentrations of polysaccharides of natural origin after thawing, have a small attractive appearance, light brown color, elastic consistency, well-defined mushroom smell, and harmonious nature. Previous moisture-retaining political strength and lower phenol oxidase activity provided less weight loss during freezing.

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