CHAPTER 5

Technological and qualitative aspects of enriching wheat bread with oyster mushroom paste

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Abstract

The article investigates the feasibility of using oyster mushrooms (*Pleurotus ostreatus*) in the form of paste as a functional ingredient in wheat bread produced according to a traditional formulation. The use of by-products from primary mushroom processing (stems and cluster bases) is substantiated as a way to reduce raw material costs and improve the economic efficiency of bread production. Yield coefficients of semi-finished mushroom products obtained by boiling and drying different oyster mushroom strains were determined, and the dry matter content of various parts of fruiting bodies was analyzed. The effect of adding 10%, 20%, and 30% mushroom paste on the physicochemical properties of wheat bread, including moisture content, acidity, porosity, specific volume, baking loss, shrinkage, and crumb water absorption capacity, was evaluated. All experimental bread samples complied with the requirements of State Standard of Ukraine (DSTU 7517:2014 "Wheat Bread"). The results demonstrate that the incorporation of mushroom paste leads to partial changes in the physicochemical characteristics and amino acid profile of bread without exceeding regulatory quality limits. The findings confirm the potential of oyster mushroom paste as a promising ingredient for the development of functional bakery products.

Keywords

Bread, mushroom paste, oyster mushroom, functional foods, semi-finished product yield coefficient, technical characteristics.

5.1 Problem statement

The economic aspect is one of the keys to the success of any industry, and bread production is not an exception. The results of a scientific analysis of the Ukrainian bakery market indicate several needs [1, 2]; among them, the expansion of the

 DOI: 10.21303/978-9908-845-03-6.ch5

product range is particularly noteworthy. This can be achieved, for instance, by improving the assortment in accordance with nutritionists' recommendations and consumer preferences, in response to the growing interest in healthy nutrition [3].

At the same time, researchers note the technological difficulties of such innovations, associated with a decrease in the volume of products, deterioration of organoleptic indicators, as well as additional costs during production. Despite the high scientific interest in this topic, the issue of the optimal combination of functional additives while maintaining high organoleptic indicators and economic feasibility of bread production remains insufficiently studied.

5.2 Analysis of recent research

An analysis of the European bakery market conducted by M. Sychevskyi et al. [4] identified sustained growth in demand for functional bakery products as one of the key long-term trends. Given the structural similarities and integration processes within the European and Ukrainian food markets, this trend may also be considered relevant for the further development of the bread industry in Ukraine. This tendency toward functionalization is further supported by other researchers, who emphasize that current trends in the Ukrainian bread market include growing consumer interest in healthy nutrition, increased demand for high-margin and craft bakery products, and the expansion of assortments with improved health characteristics.

In accordance with current requirements, domestic scientific research is aimed at enriching bread with plant components with a high content of dietary fiber, antioxidants, and biologically active substances. Thus, positive results were obtained in experiments with the addition of various plant-based ingredients and alternative cereal raw materials into bread formulations, including spice plants [5], flaxseed meal [6], amaranth flour [7], hemp seeds [8], asparagus waste [9] and spelt flour [10] to bread.

It should be noted that this research direction represents a global trend. Studies by international authors report numerous examples of incorporating non-traditional plant-based ingredients into bread formulations to improve its properties, including soybeans and sweet potatoes [11, 12], green tea [13], herbs and spices (coriander leaves, ginger) [14, 15], fruits and their by-products (grape seeds) [16], and green coffee beans [17].

Particular scientific interest has been focused on the incorporation of bioactive compounds derived from mushrooms into flour-based products. The addition of oyster mushroom powder to wheat flour has been shown to increase crude protein content [18], while also enhancing the mineral composition by elevating levels of sodium, potassium, calcium, and magnesium [19].

In conclusion, an analysis of recent scientific publications indicates a growing interest in the development of functional bakery products enriched with mushrooms as a valuable source of bioactive compounds. Oyster mushrooms, which represent an accessible raw material in European and Asian countries, as well as the by-products of their primary processing, may be used as an additive in bread with enhanced functional properties.

5.3 Objectives of the study

The aim of this work was to investigate the feasibility of using the common oyster mushroom in the form of minced mass (paste) as an additive capable of improving the functional characteristics of wheat bread produced according to a conventional formulation. In order to reduce raw material costs, the study also assessed the practicality of utilizing by-products from the pre-sale sorting of fresh oyster mushrooms, including trimmed stems and cluster bases.

During the study, the following objectives were established:

1. To determine the compliance of bread samples containing 10%, 20%, and 30% paste prepared from boiled oyster mushrooms with the requirements of DSTU 7517:2014 "Wheat Flour Bread".

2. To identify changes in the physicochemical properties of mushroom-enriched bread, including moisture content, titratable acidity, porosity, water absorption capacity, baking loss, shrinkage during storage, and specific volume.

3. To investigate changes in the composition of essential amino acids in the produced samples.

5.4 Materials and methods

Experiments aimed at assessing the quality of the raw materials (mushrooms) were conducted in the laboratory of ESMASh-3 LLC (Kyiv, Ukraine). Semi-finished product yield coefficients were calculated as the ratio of the mass of the obtained product to the mass of the initial raw material.

The investigation of bread samples enriched with mushroom paste was carried out in the laboratory of the Department of Bakery and Confectionery Technology, National University of Food Technologies (Kyiv, Ukraine). The experimental design involved the production of four variants of wheat bread made from premium-grade wheat flour with the addition of mushroom paste prepared from common oyster mushrooms of unsatisfactory market appearance (cracked caps, separated parts of fruiting bodies) as well as by-products of primary processing (cluster bases and stems). The first sample served as the control and was prepared according to a conventional formulation. The experimental variants contained 10%, 20%, and 30% mushroom paste, with a corresponding replacement of part of the water in the bread formulation by the water contained in the mushroom paste.

Mushroom paste was prepared from mushroom raw material boiled for 5 minutes and partially cooled on a metal sieve to remove excess water. The prepared mushrooms were ground using a blender to obtain a homogeneous paste.

Dough mixing for the experimental variants was performed using a dough mixer. Baking was carried out in a convection oven for 30 minutes at 200°C. The bread was cooled under ambient conditions by placing it on racks. Product quality parameters were determined in accordance with DSTU 7517:2014 "Wheat Flour Bread". All experiments were conducted in triplicate.

Moisture content, specific volume, porosity (using the Zhuravlev apparatus), water absorption capacity of the bread crumb, baking loss, and shrinkage coefficients were determined according to standard methods.

Bread acidity was determined in accordance with State Standard of Ukraine (DSTU 7045:2009 "Bakery Products. Methods for Determining Physicochemical Parameters", including amendments). Amino acid composition was analyzed using standardized methods at the Experimental and Biological Center of the Palladin Institute of Biochemistry of the National Academy of Sciences of Ukraine.

Statistical analysis was performed using Microsoft Office Excel 2016 MSO (16.0.4266.1001). The obtained data were analyzed using both one-way ANOVA and two-way ANOVA with replication via the QI Macros 2020 add-in for Excel 2016. Mean values were compared using Duncan's multiple range test. Differences were considered statistically significant at $p < 0.05$. All experiments were conducted in triplicate.

5.5 Discussion of results

The nutritional and technological value of mushroom raw materials is primarily determined by their dry matter content; therefore, it is advisable to analyze the yield of semi-finished products not only after boiling followed by grinding into a paste, but also after complete moisture removal through drying. Such an approach allows for an objective assessment of raw material losses associated with its structural and chemical characteristics and enables a more accurate interpretation of the results obtained from the use of paste-like semi-finished products in wheat bread technology.

The yield coefficients of semi-finished products (Y_{SP}) of four strains of the common oyster mushroom were compared using two raw material processing methods: boiling and drying (**Fig. 5.1**).

The lowest losses (2.6%) were observed after boiling mushrooms of Strain 433 (Y_{SP} = 0.9737 ± 0.0219), whereas for the other strains this parameter was close to 10%: Strain 16 – 0.9018 ± 0.0424; Strain 62 – 0.8997 ± 0.0597; Strain 1004 – 0.8973 ± 0.0203 (the highest losses). However, no statistically significant differences in Y_{SP} after boiling were found among the tested strains.

A significantly higher Y_{SP} after drying ($p < 0.05$) was determined for raw material obtained from oyster mushroom Strain 433 (0.1149 ± 0.0055), whereas Strain 16 demonstrated the lowest value (0.0910 ± 0.0045). That is, Strain 433 had the lowest raw material losses (88.5%), while Strain 16 had the highest (90.9%), with a difference of 2.4%.

The lower mass losses during boiling observed for Strain 433 may be attributed to its higher dry matter content.

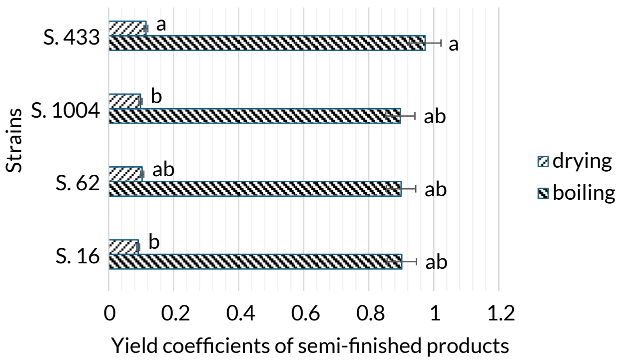

Fig. 5.1 Yield coefficient of semi-finished products after boiling and drying of Pleurotus ostreatus (Strains 16, 62, 433, and 1004). Statistically significant differences between the results ($p < 0.05$) are indicated by different letters of the Latin alphabet

A comparison of dry matter (DM) content in the fruiting bodies, caps, and stems with trimmed cluster bases of the aforementioned strains demonstrated the consistency of this parameter for raw material obtained from stems and cluster base trimmings (**Fig. 5.2**).

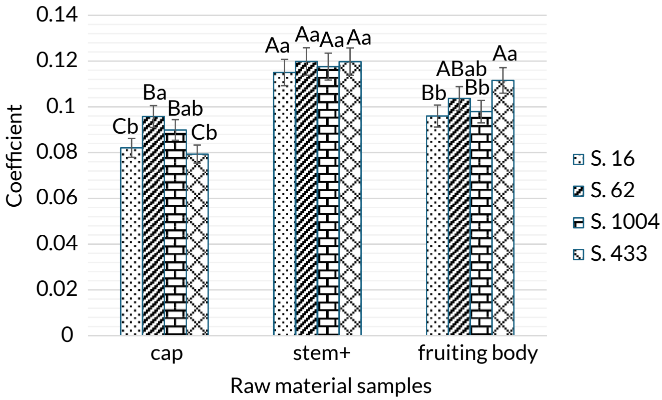

Fig. 5.2 Dry matter content in different raw material types obtained from Pleurotus ostreatus Strains 16, 62, 433, and 1004. Statistically significant differences between the results ($p < 0.05$) are indicated by different letters of the Latin alphabet: factor A (raw material type) is denoted by uppercase letters, and factor B (strain) by lowercase letters
*Note: *stem+ — designation for the mixture of stem waste and trimmings of cluster bases*

The highest Y_{SP} were observed when stems and cluster bases of Strains 433 and 62 were used (0.1198 ± 0.0022 and 0.1198 ± 0.0034, respectively). However, no statistically significant differences ($p > 0.05$) were found compared with Strains 16 and 1004, which showed Y_{SP} values of 0.1150 ± 0.0018 and 0.1176 ± 0.0025, respectively.

According to the results of the two-way ANOVA with replication, a statistically significant difference between the means was found for raw material types (factor B; i.e., caps, stems + trimmings, and whole fruiting bodies), whereas no significant differences were detected among the strains (factor A). However, the calculated mean dry matter (DM) content of caps and whole fruiting bodies showed greater variability compared with stems + trimmings when analyzed by strain (factor A). Specifically, the highest DM content was observed in the caps of Strain 62 (0.0958 ± 0.0002), whereas the lowest value was recorded for Strain 433 (0.0794 ± 0.0009), corresponding to a difference of 1.91%.

Whole fruiting bodies of Strain 433 were characterized by a significantly higher DM content (0.1116 ± 0.0087) compared with Strains 16 (lowest value, 0.0960 ± 0.0011) and 1004 (0.0979 ± 0.0034). In contrast, Strain 62 did not differ significantly from the other experimental results in this parameter (0.1037 ± 0.0021). Thus, the smallest difference in mean dry matter content between caps and stems + trimmings was 1.93%, whereas the largest reached 4.4%. These findings support the feasibility of using stems and cluster base trimmings as raw material for mushroom paste production. The technological advantages of this approach include: (1) reduced dependence of the process on raw material variability; (2) production of a semi-finished product with higher dry matter content; and (3) reduced raw material costs, since stems and trimmings constitute by-products of cleaning and sorting prior to fresh sale or processing into canned products. The obtained results are consistent with previous publications investigating the processing of other *Pleurotus ostreatus* strains, confirming the stability of the technological parameters of boiling and drying processes across different strains of this species [20, 21].

The technological quality parameters of bread samples containing different levels of mushroom paste were evaluated. According to DSTU 7517:2014, the maximum moisture content of wheat bread may range from 45% to 50%, depending on the product category. The obtained results indicate a significant increase in relative moisture content in the variants enriched with mushroom paste compared with the control sample (**Fig. 5.3**).

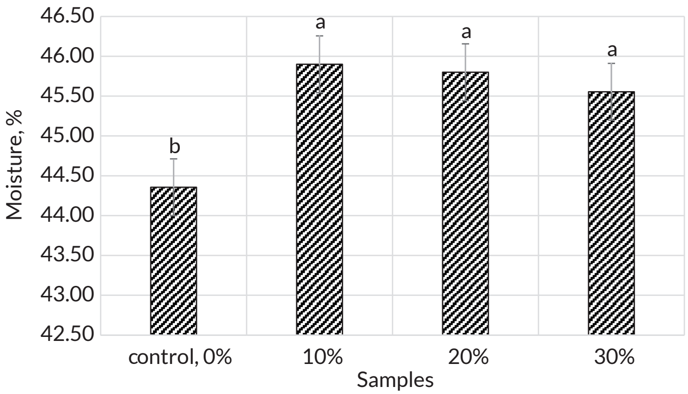

Fig. 5.3 Moisture content of bread with different levels of mushroom paste

The highest moisture content was observed in samples containing 10% mushroom addition (45.90 ± 3.36%), while the control samples exhibited 44.36 ± 2.22%. As the content of mushroom raw materials increased, the relative humidity of the product decreased, although no statistically significant difference between the experimental variants was found. This fact may be related to the presence of fungal polysaccharides, which are characterized by their ability to bind moisture with heat-resistant protein-glycan complexes, which, according to previous studies, have a high moisture retention coefficient. Nevertheless, all experimental variants remained within the permissible moisture limits defined by the standard, which specifies a maximum of 46% for pan bread made from premium wheat flour.

Statistical analysis revealed an inverse linear correlation between baking yield and the increasing proportion of mushroom raw material (**Fig. 5.4**).

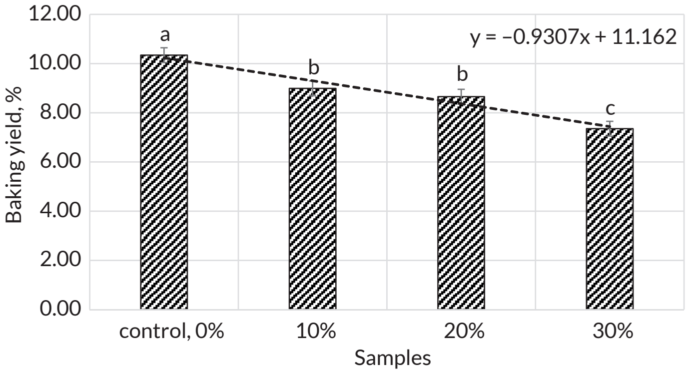

Fig. 5.4 Baking yield of bread with varying mushroom paste content

The highest baking yield (10.34 ± 1.76%) was observed in the control samples, while the lowest (7.35 ± 0.25%) was found in samples containing 30% mushroom paste, supporting the hypothesis of water retention by complex compounds formed between mushroom and flour components.

No clear trends were identified in the dynamics of the bread shrinkage coefficient; significant differences were observed only for samples with 10% mushroom addition (5.92 ± 0.47), whereas the other samples did not differ significantly from each other (**Fig. 5.5**). The results of the conducted experiments do not allow a definitive explanation of the observed effect, indicating that further studies are required.

All investigated variants complied with the requirements of the national standard DSTU 7517:2014 regarding porosity (not less than 70%). The highest porosity was observed in the samples containing 20% mushroom addition (77.34 ± 1.33%), whereas the lowest value was recorded for bread with 30% mushroom addition (**Fig. 5.6**).

No clear trends were identified in the changes of this parameter with increasing mushroom content. The observed results may have been influenced by technological aspects of sample preparation and specific testing conditions.

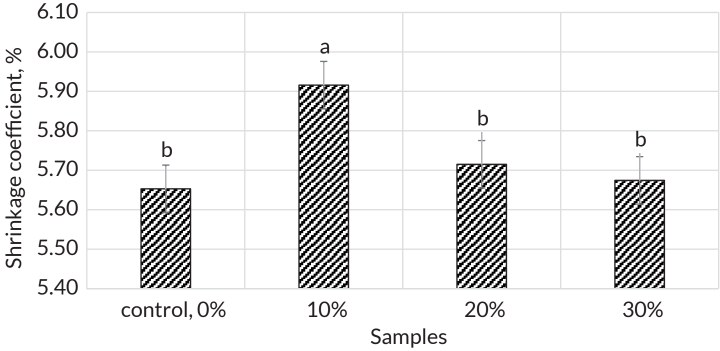

Fig. 5.5 Shrinkage of bread with varying mushroom paste content

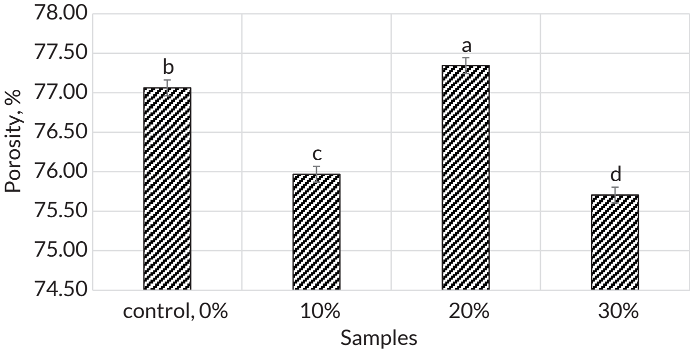

Fig. 5.6 Porosity of bread with varying mushroom paste content

No significant differences in specific volume were found between the control sample (262.7 cm^3/100 g) and the sample containing 10% mushroom paste (262.9 cm^3/100 g). In contrast, the other variants exhibited a substantial decrease in this parameter, reaching 209.7 cm^3/100 g in the sample with 30% mushroom paste, which represented the lowest value recorded in the study (**Fig. 5.7**).

Accordingly, an overall decreasing trend in specific volume was observed with increasing proportions of mushroom raw material in the bread formulation. Thus, additional incorporation of mushroom paste may adversely affect the overall appearance of the products.

Comparison of titratable acidity among the experimental variants demonstrated that the addition of mushroom paste to the dough had a noticeable effect on this parameter. However, the control sample and the variant containing 10% mushroom paste exhibited identical acidity values (1.2°). Therefore, at this concentration, the mushroom ingredient did not affect bread acidity. Increasing the proportion of mushroom paste to 20% and 30% resulted in an increase in acidity to 1.3°, i.e., by 0.1 units (**Fig. 5.8**).

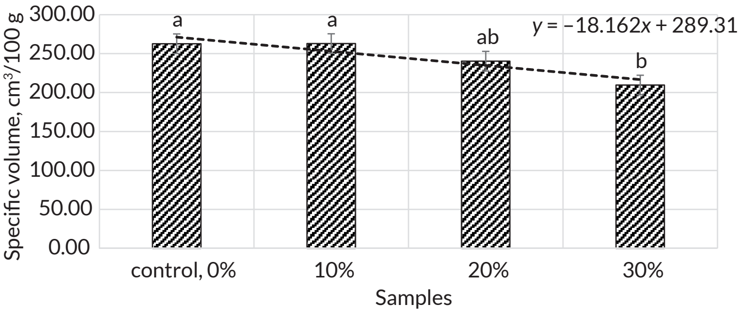

Fig. 5.7 Specific volume of bread with varying mushroom paste content

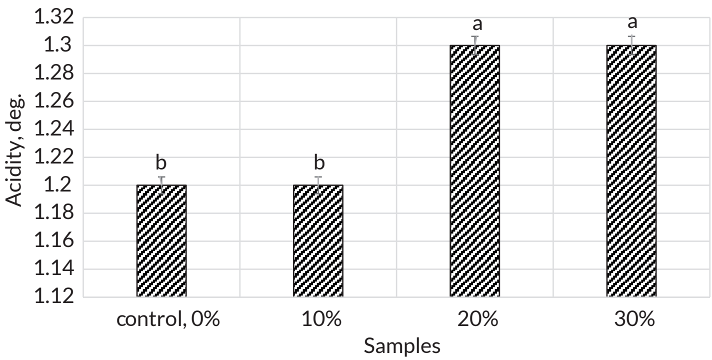

Fig. 5.8 Titratable acidity of bread with varying mushroom paste content

Despite the slight increase, the acidity of all obtained samples remained relatively low and fully complied with the requirements of DSTU 7517:2014, which specifies a maximum permissible value of 3.5°.

The water absorption capacity of the crumb was evaluated, revealing a significant increase with the addition of 10% mushroom paste, whereas increasing the mushroom content to 20% and 30% resulted in a decrease in this parameter (**Fig. 5.9**).

The lowest value was recorded in the sample containing 30% mushroom paste. This finding may be explained by the increased content of hydrophilic mushroom polysaccharides, which retain water even after baking. However, at higher inclusion levels, they contribute to an increase in the overall moisture content of the product (**Fig. 5.3**), which in turn reduces the water absorption capacity of the bread.

Analysis of the amino acid composition of bread samples with varying mushroom paste content did not reveal a consistent trend in the levels of essential amino acids compared to the control sample (**Fig. 5.10**).

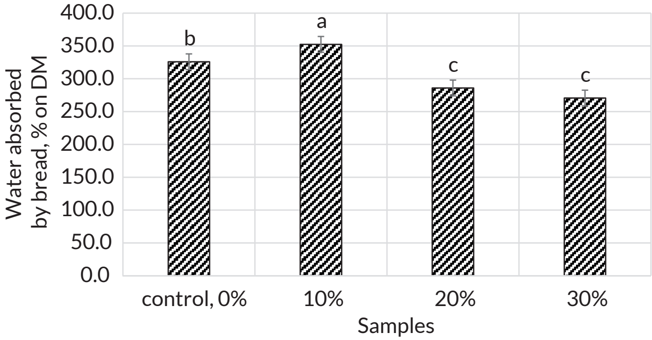

Fig. 5.9 Water absorption coefficient of bread with varying mushroom paste content

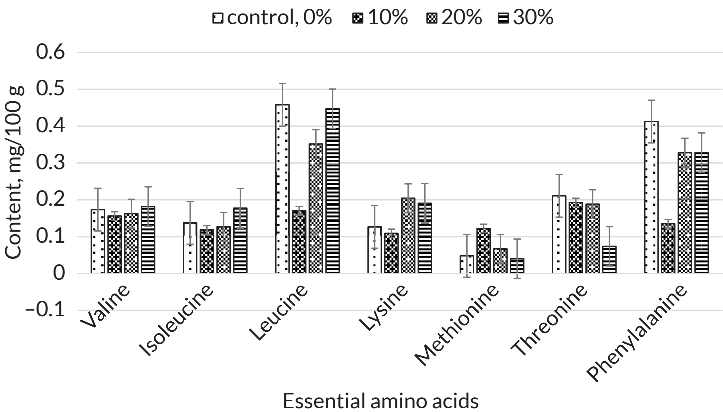

Fig. 5.10 Results of essential amino acid determination in bread with varying mushroom paste content

All bread variants exhibited high levels of leucine and phenylalanine (except for the sample containing 10% mushroom paste). The lowest values among the variants were recorded for methionine, ranging from 0.0401 mg/100 g (30%) to 0.1223 mg/100 g (10%). It was also determined that the addition of 20% and 30% mushroom paste increased the levels of isoleucine and lysine, while significantly decreasing the contents of threonine and methionine.

The obtained data do not provide a definitive conclusion regarding the effect of mushroom paste incorporation on the content of essential amino acids in bread, indicating the need for further research.

5.6 Conclusions

The results of the study demonstrate the technological stability of mushroom paste obtained from different strains of *Pleurotus ostreatus*. The use of stems and trimming residues for the production of the mushroom semi-finished product may offer certain economic advantages. The incorporation of mushroom paste at levels ranging from 10% to 30% (flour basis) does not violate the requirements of DSTU 7517:2014 for wheat bread quality; however, it partially alters the physico-chemical properties of the products, which should be considered when determining storage conditions and commercialization parameters.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

Financing

The study was performed without financial support.

Use of artificial intelligence statement

The author confirm that he did not use artificial intelligence technologies when creating the current work.

Acknowledgments

The author gratefully acknowledges ESMASh-3 LLC (Kyiv, Ukraine) for laboratory support in raw material analysis, the National University of Food Technologies (Kyiv, Ukraine) for laboratory support in bread sample investigation, and the Palladin Institute of Biochemistry of the National Academy of Sciences of Ukraine for conducting amino acid analysis. The author also expresses sincere gratitude to the laboratory staff and assistants for their valuable support.

Authors' contributions

Oleksandr Sokot: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review and editing.

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