CHAPTER 3

THEORETICAL AND PRACTICAL ASPECTS OF FERMENTED HUMMUS PRODUCTION WITH STARTER CULTURES

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INTRODUCTION

Over the past decade, food systems have shown a sustained trend towards an increasing share of plant-based, ready-to-eat products, as well as products positioned as "natural", "minimally processed", and with a "short ingredient list". In this context, legume-based spreadable products – particularly hummus – occupy a distinctive place, as they combine high nutritional value, convenience of consumption, and culinary versatility (sauces, spreads, components of dishes, etc.).[1]

At the same time, growing demand for "chilled" products with a short ingredient list intensifies a technological challenge: consumers expect the absence of preservatives while simultaneously requiring an extended shelf life, a stable consistency, and predictable sensory characteristics[2]. This creates a need for technologies that ensure natural stabilization of the product and reproducibility of parameters from batch to batch[3].

The Ukrainian market is characterized mostly by conventional, non-fermented hummus, whereas the segment of legume pastes, produced using starter cultures, remains underdeveloped. Therefore, the scientific and practical development of fermented hummus technology may be of both technological and commercial significance.

The aim of the research is to provide a scientific rationale for, and to develop, a technology for a fermented legume paste (fermented hummus) using

[1] Alajaji S. A., El-Adawy T. A. Nutritional composition of chickpea (*Cicer arietinum* L.) as affected by microwave cooking and other traditional cooking methods. *Journal of Food Composition and Analysis*. 2006. Vol. 19. P. 806–812. DOI: 10.1016/j.jfca.2006.03.015.

[2] Ipekesen S., Basdemir F., Tunc M., Bicer B. T. Minerals, vitamins, protein and amino acids in wild *Cicer* species and pure line chickpea genotypes selected from a local population. *Journal of Elementology*. 2022. Vol. 27. P. 127–140.

[3] Bintsis T. Lactic acid bacteria: Their applications in foods. *Journal of Bacteriology & Mycology*. 2018. Vol. 6. No. 2. P. 89–92.

starter cultures, which ensures improved microbiological stability, an enhanced flavor–aroma profile, and stable functional and technological properties of the product without the use of chemical preservatives[4], [5].

The object of the research is the technological process for producing fermented chickpea paste.

The subject of the research is the effect of starter cultures and fermentation regimes on the quality and safety indicators of fermented hummus (physic-chemical, rheological, microbiological, and sensory), as well as their changes during storage

1. Factors determining the quality of fermented legume products

Chickpea (Cicer arietinum) is a source of plant protein, complex carbohydrates, dietary fiber, and micro- and macronutrients. Its use in paste-like products is justified by its ability to form a dense dispersed structure after heat treatment and comminution, as well as by its technological compatibility with the fat phase (oil) and with the emulsifying/structuring components of sesame raw materials[6, 7].

The quality of the final paste is determined by the following groups of factors:

– the properties of the protein–carbohydrate complex after heat treatment (degree of swelling, starch gelatinization, protein denaturation);

– the dispersity after comminution and the extent of disruption of cellular structures;

– the ratio of the aqueous and fat phases, which affects viscosity, plasticity, and spreadability;

– the balance of flavor components (saltiness, acidity, sesame “nutty” notes, spices) and the presence/absence of a “raw legume” aftertaste.

From a technological standpoint, water-binding capacity and the stability of the dispersed system are also essential indicators. For products with a paste-like structure, consumers are particularly sensitive to defects such as syneresis (water separation) and phase separation, which directly affect perceived quality.

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[4] Loutfi S., Hamdi M. Lactic fermentation of chickpea: Microbial dynamics and biochemical changes. *Journal of Food Processing and Preservation*. 2016. Vol. 40. P. 129–138.

[5] Vogel R. F., Knorr R., Müller M. R. A., Steudel U., Gänzle M. G., Ehrmann M. A. Non-dairy lactic fermentations: A review. *International Journal of Food Microbiology*. 1999. Vol. 46. P. 181–196.

[6] Papalamprou E. M., Doxastakis G. I., Biliaderis C. G., Kiosseoglou V. Influence of preparation methods on physicochemical and emulsifying properties of chickpea protein isolates. *Food Hydrocolloids*. 2010. Vol. 24. P. 50–58.

[7] da Silva M., Neves V., Lourenço E. Protein fractions and major globulin from chickpea (*Cicer arietinum* L.). *Alimentos e Nutrição*. 2001. Vol. 12. P. 131–149.

Legumes may contain antinutritional components, including protease inhibitors, oligosaccharides that may cause discomfort, phytates, and phenolic compounds[8]. In hummus technologies, operations capable of reducing undesirable effects play a significant role: soaking, rinsing, heat treatment, and fermentation[9, 10].

Fermentation, particularly under controlled conditions, may contribute to:

– modification of available carbohydrates and a reduction in the intensity of the "beany" aroma;

– development of a milder flavor profile;

– changes in functional and technological properties due to enzymatic processes within the matrix[11].

Within the present study, these effects are considered elements of a technological solution that enhances stability, process controllability, and consumer attractiveness of the product.

Paste-like products with relatively high moisture content provide a favourable environment for microbial growth in cases of non-compliance with process discipline or unstable storage conditions. For chilled ready-to-eat products, the following are critical:

– primary contamination (raw materials, water, equipment);

– secondary contamination after heat treatment during comminution/mixing/fillin;

– temperature fluctuations along the "production–logistics–storage" chain[12].

A practically significant marker of instability in pastes and sauces is yeast growth, which may manifest as gas formation, changes in aroma, surface defects, and an increased risk of organoleptic faults. This is particularly relevant for products where intensive thermal sterilization of the final packaged product is not envisaged.

Therefore, the technological solution must simultaneously reduce the risk of growth of undesirable microflora and ensure the stability of organoleptic

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8 Santos M. I., Lima Á., Borges O., Carvalho A. P., Guiné R. P. F. Effect of processing on oligosaccharides content in chickpeas and lentils. *Journal of Food Science and Technology*. 2018. Vol. 55. P. 2195–2202.

9 Åman P. Carbohydrates in raw and germinated seeds from mung bean and chick pea. *Journal of the Science of Food and Agriculture*. 1979. Vol. 30. P. 869–875. DOI: 10.1002/jsfa.2740300907.

10 Loutfi S., Hamdi M. Lactic fermentation of chickpea: Microbial dynamics and biochemical changes. *Journal of Food Processing and Preservation*. 2016. Vol. 40. P. 129–138.

11 Limón R. I., Peñas E., Torino M. I., Martínez-Villaluenga C., Dueñas M., Frias J. Fermentation enhances the content of bioactive compounds in kidney bean flour. *Food Chemistry*. 2015. Vol. 172. P. 343–352.

12 Vogel R. F., Knorr R., Müller M. R. A., Steudel U., Gänzle M. G., Ehrmann M. A. Non-dairy lactic fermentations: A review. *International Journal of Food Microbiology*. 1999. Vol. 46. P. 181–196.

characteristics, while remaining compatible with the "preservative-free" concept.

Lactic acid fermentation is widely used in food technologies as a means of improving microbiological stability and developing a characteristic flavor. The use of lactic acid bacteria (LAB) as starter cultures is technologically justified in view of the following mechanisms:

– reduction of pH because of organic acid formation, which inhibits part of the competing/undesirable microflora;

– competitive exclusion due to the rapid growth of a dominant beneficial culture.

– formation of metabolites with antimicrobial properties (including bacteriocins–depending on the species/strain);

– development of a flavor–aroma profile perceived as "fresh" and "clean", if cultures and regimes are appropriately selected[13, 14].

For legume pastes, fermentation has an additional technological dimension: it can affect structural and mechanical properties. Since the paste is a multiphase system (chickpea particles + moisture + fat phase), even moderate changes in acidity and enzymatic modification of components can alter the degree of water binding, dispersity, and the perception of texture.

Controlled fermentation involves the addition of starter cultures, which should be:

– capable of active growth in the relevant matrix (chickpea paste);
– technologically stable and compatible with the production regime.
– predictable in their effect on flavor and aroma.
– safe for food use[15].

In the practice of assessing the safety of microorganisms intentionally added to food, systematic approaches such as QPS are applied, in which correct identification, a history of safe use, and control of potential risk factors are important. For fermented hummus technology, this is of dual value: it substantiates the selection of cultures and supports the evidence base of technological decisions when preparing technical documentation[16].

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[13] Bintsis T. Lactic acid bacteria: Their applications in foods. *Journal of Bacteriology & Mycology*. 2018. Vol. 6. No. 2. P. 89–92.

[14] Mokoena M. P. Lactic acid bacteria and their bacteriocins: Classification, biosynthesis and applications against uropathogens: A mini-review. *Molecules*. 2017. Vol. 22. No. 8. 1255.

[15] Turpin W., Humblot C., Guyot J.-P. Genetic screening of lactic acid bacteria from fermented foods: Starter selection. *Food Microbiology*. 2011. Vol. 28. P. 150–159.

[16] European Food Safety Authority. Introduction of a Qualified Presumption of Safety (QPS) approach for assessment of selected microorganisms referred to EFSA – Opinion of the Scientific Committee. *EFSA Journal*. 2007. Vol. 5. No. 12. 587.

The use of mixed LAB cultures is often technologically advantageous, since different cultures can complement one another in terms of acidification rate, spectrum of metabolites, and impact on sensory properties. For paste-like plant-based products, such synergy may manifest as:

– faster attainment of a technologically appropriate acidity level;
– a milder, more “rounded” taste without harsh notes;
– better stability during storage.

Within the present work, experimental data confirmed the expediency of using a combination of Lactococcus lactis and Lactobacillus rhamnosus as appropriate solution[17].

2. Technology of fermented hummus

Based on a series of preliminary experiments and taking into account data from the scientific and technical literature, a process flow for producing a fermented legume paste using starter cultures of lactic acid bacteria was developed. The proposed technology – use of semi-prepared legume raw material and the inoculation with starter preparations containing lactic acid bacteria[18].

The raw material was cooked, comminuted legumes (namely chickpeas), standardized in terms of total solids by adding a plant protein concentrate. As the starter culture, a combination of microbial strains was used comprising a mixture of lactic acid bacteria, in particular Lactobacillus rhamnosus and Lactococcus lactis subsp. lactis.

Preliminary studies established that the use of Lactobacillus rhamnosus and Lactococcus lactis starter cultures is appropriate for fermenting hummus under a low-temperature regime, ensuring stable progression of the microbiological process and improved sensory characteristics of the product. It was shown that varying the starter dose within $1 \times 10^6 \ldots 1 \times 10^9$CFU/g does not lead to substantial differences in the final pH values; however, it affects the intensity of the initial stage of fermentation. The concentration of $1 \times 10^7 \ldots 1 \times 10^8$CFU/g was identified as rational.

It was determined that hummus fermentation at 2…6 °C is characterized by a slow decrease in acidity and the formation of a pH plateau after 21 days, due to the properties of the legume raw material, the limited amount of fermentable carbohydrates, and the buffering capacity of the product. It was demonstrated

[17] Гніцевич В. А., Доронін К. А. Дослідження парамерів ферментації хумусу старовими культурами. *Праці Таврійського державного агротехнологічного університету*, 2026. (1). https://doi.org/10.32782/2078-0877-2026-26-1-28

[18] EFFCA: European Food & Fermentation Cultures Association. About EFFCA [Electronic resource]. URL: https://effca.org/ (Last accessed: 20.05.2026).

that fermentation temperature affects diacetyl accumulation: its most intensive formation is observed at 2…6 °C which is associated with higher metabolic activity of lactic acid bacteria compared with conditions of 2…4 °C. It was established that the main accumulation of diacetyl occurs during the first 7 days of fermentation, after which its concentration stabilises due to substrate depletion and the transition of microorganisms to the stationary growth phase.

The fermentation parameters for hummus using starter cultures were optimized. In order to determine the optimal parameters of the fermentation process, a multivariate experimental design method was employed using the orthogonal symmetric Box–Wilson design[19]. Table 1 presents the conditions for conducting a full three-factor experiment[20].

Table 1

Levels and Intervals of the Factors Varied

Levels	Factors		
	Starter culture dose (X1), $\log_{10}$ (CFU/g)	Fermentation duration (X2), days	Fermentation temperature (X3), °C
	x1	x2	x3
Base (xi 0)	7	21	4
Variation interval (Dxi)	1	7	2
Lower (xi min)	6	14	2
Upper (xi max)	8	28	6

As the response function Y, the diacetyl content (μg/kg) was adopted. Based on the results of three series of measurements determining diacetyl content for the multifactor experimental designs, its mean value was established (Table 2).

Table 2

Trial results

X_1	6	8	6	8	6	8	6	8	5,8	8,2	7	7	7	7	7
X_2	14	14	28	28	14	14	28	28	21	21	12,5	29,5	21	21	21
X_3	2	2	2	2	6	6	6	6	4	4	4	4	1,6	6,4	4
Y_{mean}	2480	2520	3660	3720	4067	4133	4146	4214	3664	3736	3699	3687	3624	4293	3700

[19] Box G. E. P., Wilson K. B. On the experimental attainment of optimum conditions. *Journal of the Royal Statistical Society. Series B (Methodological)*. 1951. Vol. 13. No. 1. P. 1–45.

[20] Box G. E. P., Hunter J. S., Hunter W. G. Statistics for experimenters: design, innovation, and discovery. 2nd ed. Hoboken : Wiley, 2005.

The experimental were designed considering the orthogonality criteria. With a total number of 15 runs for the orthogonal central composite design, the value of $\alpha = 1.2153$.

Because the object of study exhibits significant non-linear properties, a first-order design did not allow an adequate regression model to be obtained. When investigating the region of the optimum and sections of the response surface with pronounced curvature, a third-degree polynomial was used for the mathematical description. In addition to the main effects b_i, it includes all pairwise interactions b_{ij}, quadratic effects b_{ii}, and also accounts for the interaction of all three factors b_{123}. After normalising the factor levels, the least-squares method was used to obtain mutually uncorrelated estimates of the regression coefficients. When converted to natural (uncoded) variables, the constructed response-surface regression model takes the following form:

$$Y1 = -6513{,}98 + 1747{,}86x1 + 216{,}42x2 + 505{,}37x3 + 1{,}01x1x2 + 5{,}50x1x3 - 18{,}70x2x3 - 0{,}16x1x2x3 - 124{,}86x12 - 2{,}65x22 + 12{,}53x32 \quad (1)$$

The validation check confirmed the homogeneity of the reproducibility variance for the experimental mean values Y_{avg} (Table 2) and the theoretical levels Y calculated using mathematical model (1). According to Fisher's criterion, $F = 0.33529 \leq 8.72868$, which indicates the adequacy of the obtained regression.

Construction of mathematical model (1) made it possible to formulate an optimisation problem. The diacetyl content, which should be maximised, was selected as the objective function; the limiting values of the fermentation parameters were adopted as the constraint functions characterising the processing conditions. The calculations yielded the following results: for the most pronounced flavour, the starter culture dose should be $6.0 \times 10^6 \ldots 3.1 \times 10^7$ CFU/g, the fermentation duration 19…21 days, and the fermentation temperature 6 °C.

The production process for the new fermented product (Fig. 1) includes the following stages: the legume raw material is soaked, boiled until soft, comminuted to a paste-like state, portioned into packets, and frozen.

During paste preparation, oil, salt, and other ingredients are added to the main raw material, followed by homogenization for 3–5 minutes until the required consistency is obtained and the temperature reaches 6 °C. After completion of the cutter-mixing process, the product is packaged on the line, cooled to 4±2 °C and stored at 0…6 °C. Over the course of 3 days, cold fermentation of the mass occurs with the formation of aromatic compounds.

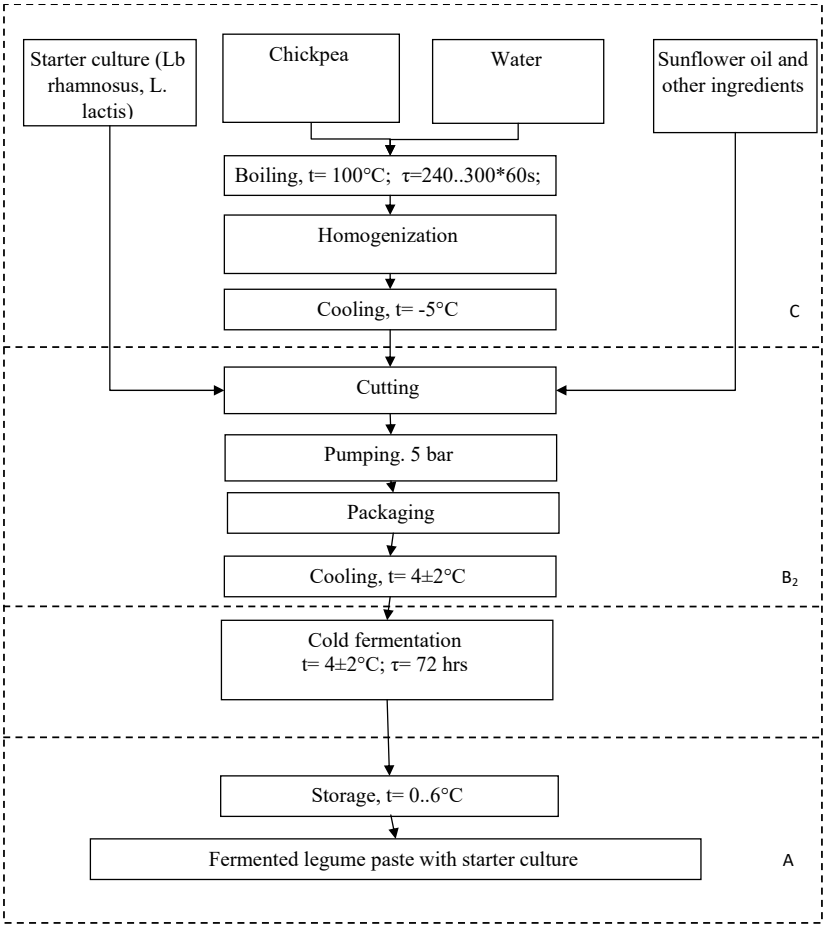

Fig. 1. Fermented hummus production scheme

The resulting product has a uniform paste-like consistency, a pleasant aroma, a mild taste with a characteristic tangy note, a light beige color, and a stable texture without phase separation.

The studies conducted made it possible to develop the formulation composition (Table 3) of the fermented hummus.

After pouring the packaging product is stored 0…+6 °C.

Table 3

Recipe

№	Name	Quantity, kg	
		Control	Trial
1	Prepared chickpea	54.0	54.0
2	Water	12.0	12.0
3	Sunflower oil	14.0	14.0
4	Takhini	12.0	12.0
5	Starter culture	–	5×10^6
6	Citric acid (45%)	1.24	1.24
7	Salt	1.0	1.0
8	Garlic	0.6	0.6
9	Potassium sorbate	0.1	–
10	Sodium benzoate	0.1	–

3. Study of the fermented hummus quality

Within the scope of the study, particular attention was paid to evaluating the quality of fermented hummus as a multicomponent food system whose properties are shaped by the fermentation process. An analysis of the organoleptic, physicochemical, and microbiological indicators of the finished product was carried out to determine the effect of fermentation on its consumer properties, stability, and safety during storage[21]. The organoleptic indicators used to assess the fermented hummus are presented in Table 4.

Table 4

Sensory evaluation criteria

Parameter	Description
Appearance	Creamy mass ranging in color from light cream to dark cream
Taste	Neutral, slightly pea-like taste with a subtle acidic note from lemon juice
Flavor	Delicate nutty aroma with creamy notes
Texture	Paste-like, homogeneous mass without lumps

To provide a comprehensive assessment of the nutritional value of the standard hummus sample, the amino acid composition of the product was investigated. Determining the amino acid content makes it possible to evaluate the biological quality of the protein fraction and to establish the

[21] ISO 8589:2010+A1:2014. Sensory analysis – General guidance for the design of test rooms [Online]. Geneva : International Organization for Standardization, 2014. URL: https://www.iso.org/standard/36385.html (Last accessed: 21 May 2026).

product's potential nutritional value. The results of the study are presented in Table 5[22].

Table 5

Study of the relative amino acid composition of fermented hummus

Amino acid	Hummus (control)		Hummus (trial)	
	Amount, mg/100 g	Content, %	Amount, mg/100 g	Content, %
Lysine	0.205	6.49	0.119	7.79
Histidine	0.084	2.66	0.035	2.30
Arginine	0.194	6.13	0.083	5.44
Aspartic acid	0.441	13.93	0.216	14.17
Threonine	0.127	4.01	0.072	4.75
Serine	0.186	5.89	0.072	4.69
Glutamic acid	0.719	22.72	0.319	20.94
Proline	0.168	5.30	0.101	6.60
Glycine	0.160	5.05	0.088	5.74
Alanine	0.126	3.97	0.106	6.92
Cystine	0.057	1.81	0.038	2.50
Valine	0.083	2.61	0.032	2.10
Methionine	0.013	0.41	0.013	0.85
Isoleucine	0.076	2.42	0.033	2.15
Leucine	0.193	6.10	0.060	3.96
Tyrosine	0.161	3.66	0.072	4.70
Phenylalanine	0.171	4.25	0.067	4.40
Total	3.163	100.00	1.525	100.00

The obtained results of the comparative analysis of the amino acid composition of the control (standard) and experimental samples indicate a substantial shift in both the quantitative and structural characteristics of the amino acid profile under the influence of the investigated technological factor (fermentation/use of starter cultures).

First, a significant decrease in the total amino acid content was observed in the experimental sample from 3.163 to 1.525 mg (≈ −51.8%). This finding suggests an overall reduction in the concentration of free (or analytically detectable) amino acids in the product, which may be attributable to their active involvement in microbial metabolism, conversion into secondary nitrogen-containing compounds, or the transition of a portion of amino acids into bound forms/fractions that are less accessible to determination by the method applied.

[22] Alajaji S. A., El-Adawy T. A. Nutritional composition of chickpea (*Cicer arietinum* L.) as affected by microwave cooking and other traditional cooking methods. *Journal of Food Composition and Analysis*. 2006. Vol. 19. P. 806–812. DOI: 10.1016/j.jfca.2006.03.015.

Along with the general decline in absolute values, a redistribution of the relative contributions of individual amino acids within the total pool was recorded. In the experimental sample, the relative share of alanine (3.97% → 6.92%), glycine (5.05% → 5.74%), proline (5.3% → 6.6%), and lysine (6.49% → 7.79%) increased, resulting in a profile with a higher proportion of amino acids associated with microbial stress responses and adaptive mechanisms and/or with intensified proteolysis. In contrast, the proportions of leucine (6.10% → 3.96%), serine (5.89% → 4.69%), arginine (6.13% → 5.44%), and glutamic acid (22.7% → 20.94%) decreased, which may reflect their preferential utilization by the microbial community as sources of nitrogen and carbon or as precursors for the synthesis of fermentation metabolites.

Overall, the experimental sample was characterized by lower amino acid levels in both mass- and molar-based terms, but by a different component ratio, indicating directed biochemical transformations within the substrate. To conclusively substantiate the observed differences, it is advisable to complement these findings with a statistical assessment of the significance of differences between means and to account for the potential contribution of moisture/dry matter when interpreting absolute values.

To assess the nutritional and biological value of fermented hummus, the contents of key vitamins were determined in the experimental samples. Analysis of the vitamin profile made it possible to evaluate the effects of the raw materials used and the fermentation process on the development of the functional properties of the final product. The results are presented in Table 6.

Table 6

Level of vitamins, mg%/100g

№	Parameter	Hummus (control)	Hummus (trial)
1	Vitamin B_1	0.32 ± 0.02	0.26 ± 0.01
2	Vitamin B_2	0.07 ± 0.01	0.12 ± 0.03
3	Vitamin B_3	1.06 ± 0.06	0.86 ± 0.01
4	Carotenoids	1.34 ± 0.03	1.55 ± 0.05

A comparative assessment of two batches of hummus – a standard (control) product and a product manufactured using starter cultures – indicates a targeted modification of its biochemical profile with respect to B-group vitamins and carotenoids. In the starter-culture sample, the riboflavin (vitamin B_2) concentration increased from 0.07 ± 0.01 to 0.12 ± 0.03 mg% (mg per 100 g), corresponding to an approximately 71% increase relative to the control. This trend is consistent with the presumed ability of certain members of starter

consortia to biosynthesize riboflavin, as well as with the release of bound vitamin forms due to enzymatic activity during fermentation.

In contrast, thiamine (vitamin B_1) and niacin (vitamin B_3) decreased in the starter-culture variant: B_1 from 0.32 ± 0.02 to 0.26 ± 0.01 mg%, and B_3 from 1.06 ± 0.06 to 0.86 ± 0.01 mg%. These changes may be attributable to the involvement of thiamine and niacin in microbial metabolism as cofactors of enzymatic systems, as well as to possible oxidation and/or transformation of these compounds during processing. Notably, carotenoid content increased in the starter-culture sample from 1.34 ± 0.03 to 1.55 ± 0.05 mg%, which may indicate improved pigment stabilization within the fermented matrix or altered conditions affecting their retention and analytical determination.

Overall, the results demonstrate that the use of starter cultures exerts a differentiated (selective) effect on the levels of bioactive components in hummus: increases in vitamin B_2 and carotenoids occur alongside decreases in vitamins B_1 and B_3. This supports the need for further optimization of starter-culture composition and fermentation parameters with consideration of target quality attributes, as well as confirmation of the observed differences using mathematical statistical methods (i.e., significance testing of differences between means given a sufficient sample size).

A comparative analysis of relative changes in volatile aroma-forming compounds in the experimental sample versus the control (Table 7) indicates that the investigated processing regimes/variants induce multidirectional and multi-scale restructuring of the aroma profile, manifested both in the overall magnitude of shifts and in the dominance patterns of individual marker metabolites. The experimental sample exhibited the most pronounced deviations from the control, primarily due to an anomalously large increase in acetoin and diacetyl. This result may be interpreted as an indicator of substantial intensification of enzymatic conversions toward the formation of carbonyl compounds (in particular, via pyruvate metabolism and associated redox transformations), which can generate a creamy-buttery sensory dominant and markedly shape the overall aromatic impression of the product.

Concurrently, moderate decreases in certain components – specifically ethyl acetate and selected disulfides – were observed in the experimental sample, which may be associated with shifts in the balance between esterification and hydrolysis reactions and with transformations of sulfur-containing compounds within the matrix.

In between, these findings indicate that the experimental sample provides a high degree of controlled aroma modulation; however, it may also increase the risk of sensory imbalance due to excessive accumulation of 1–2 key compounds

with high odor activity. By contrast, the control sample is characterized by a more moderate, multicomponent pattern of changes without the formation of extreme peaks. The observed increases in a range of volatile compounds – particularly alcohols, terpene constituents, and selected heterocyclic compounds – are generally limited in magnitude, which is consistent with the development of a more balanced, polycomponent aroma profile.

Table 7

Comprehensive analysis of aroma compounds

Aromatic compound		Hummus (control)	Hummus (trial)
Misc	1,8-Cineole	5	2
Alcohol	1-Hexanol	10	27
Aromatic	3-Carene	22	2
Ketone	Acetoin	195	15
Sulfur	Allyl methyl sulfide	25	25
Aromatic	α-Pinene	5	-5
Misc	Cubebene	5	-5
Aldehyde	Decanal	2	2
Ketone	Diacetyl	136	-10
Aromatic	Limonene	9	-2
Aromatic	o-Cymene	4	4
Pyrazine	2,5-Dimethylpyrazine	-3	2
Sulfur	2-Acetylthiazole	-2	15
Ketone	2-Butanone	-3	-7
Pyrazine	2-Ethyl-3,5-dimethylpyrazine	-2	-2
Furan	2-Hexanoylfuran	-2	15
Aldehyde	2-Methylbutanal	-2	10
Furan	3-Methylfuran	-18	-5
Sulfur	Diallyl disulfide	-20	2
Sulfur	Dimethyl disulfide	-3	-3
Alcohol	Ethanol	-37	-3
Ester	Ethyl acetate	-2	-2
Misc	Indole	-5	-2
Pyrazine	Trimethylpyrazine	3	-2

During the study, changes in the principal microbiological indicators were determined as a function of product storage duration, enabling assessment of fermentation efficiency and the product's ability to maintain stable consumer properties throughout the established shelf life. In evaluating the quality of fermented products, a key criterion is the composition and dynamics of the

microflora, as it determines both product stability and the potential evolution of sensory properties during storage.

The microbiological results (Table 8) demonstrate a sustained positive trend in the development of lactic acid microflora and confirm that microbiological safety indicators complied with the requirements of ТУ У10.8-37146938-002:2023 over the investigated period.

Table 8

Microbiological study of fermented hummus

Parameter	TU U 10.8-37146938-002:2023	Results					
		0 day	7 days	14 days	25 days	30 days	35 days
MAFAM, CFU/g	not more 1.0·103	8.0·101	9.0·101	3.1·102	5.5·102	9.0·102	1.0·103
LAB (Lactobacillus curvatus & Lactococcus lactis spp lactis), CFU/g	–	5.5·106	1.1·107	1.7·107	5.2·107	1.3·108	5.3·108
Coliforms), per 1,0 g	not allowed	not detected					
Salmonella, per 25 g	not allowed	not detected					
Staphylococcus aureus, per 1,0 g	not allowed	not detected					
Yeast, CFU/g	not allowed	not detected					5.5·101
Mold, CFU/g	not allowed	not detected					
L. monocytogenes	not allowed	not detected					

In the freshly produced product (day 0), the count of lactic acid bacteria (Lactobacillus curvatus and Lactococcus lactis ssp. lactis) was 5.5×10^{6} CFU/g. Subsequently, their abundance increased: on day 7 to 1.1×10^{7} CFU/g; on day 14 to 1.7×10^{7} CFU/g; on day 25 to 5.2×10^{7} CFU/g; on day 30 to 1.3×10^{8} CFU/g and on day 35 to 5.3×10^{9} CFU/g. This trend is typical of fermented food systems and reflects the sustained metabolic activity of the starter microflora during storage. At the same time, increasing LAB counts may correlate with changes in acidity and, consequently, with shifts in the sensory profile during extended storage, underscoring the need for an integrated assessment of physicochemical and organoleptic parameters.

Microbiological safety indicators remained within regulatory limits throughout the entire observation period: coliform bacteria, pathogenic

microorganisms (including Salmonella), Staphylococcus aureus, and Listeria monocytogenes were not detected. Mould fungi were likewise not detected during storage, indicating the absence of conditions conducive to their growth under the adopted storage regime and confirming the product's microbiological stability with respect to this parameter.

Yeasts were not detected over 0…30 days of storage; however, on day 35 they were detected at a level of 5.5×10^1 CFU/g. The emergence of yeast microflora at this late storage stage may be considered a marker of the onset of undesirable microbiological changes that could potentially lead to deterioration in quality attributes (in particular, the development of off-odours/off-flavours and gas formation) during further storage.

Thus, the data confirm that the fermented hummus, over the study period, was characterized by a high level of lactic acid microflora and complied with microbiological safety requirements regarding coliforms, pathogenic microorganisms, S. aureus, and L. monocytogenes. The detection of yeasts on day 35 substantiates the advisability of setting the maximum storage life at 30 days under the specified storage and packaging conditions

CONCLUSIONS

As a result of the conducted research, a scientifically substantiated technology for fermented hummus was developed using starter cultures of lactic acid bacteria, ensuring stable quality and safety parameters of the finished product without the use of chemical preservatives. It was established that the combined use of Lactococcus lactis subsp. lactis and Lactobacillus rhamnosus is appropriate for the controlled fermentation of chickpea paste and supports the stable progression of fermentation processes during storage.

Fermentation was shown to positively affect the sensory characteristics of the product, promoting a milder flavour–aroma profile and ensuring the stabilization of a homogeneous paste-like structure. Changes in the amino acid composition of fermented hummus indicate the occurrence of biochemical transformations within the protein matrix driven by microbial fermentation. The experimental sample was characterized by increased levels of certain amino acids, notably alanine, proline, glycine, and lysine, which may be associated with proteolysis and the metabolic activity of lactic acid bacteria.

The vitamin profile analysis demonstrated that fermentation contributes to the modification of the product's biochemical profile, in particular to an increase in riboflavin and carotenoid contents in the experimental sample compared with the control. These results confirm the potential of lactic acid fermentation as a tool for imparting functional properties to fermented legume-based pastes.

Microbiological testing established that throughout the entire storage period the safety indicators complied with regulatory requirements: coliform bacteria and pathogenic microorganisms, including Salmonella spp., as well as Staphylococcus aureus and Listeria monocytogenes, were not detected. At the same time, active development of lactic acid microflora during storage was observed, confirming the stability of the fermentation process. The detection of yeasts on day 35 indicates the onset of undesirable microbiological changes and substantiates the advisability of setting the maximum shelf life at 30 days at a storage temperature of 4..6°C.

SUMMARY

Current trends in food technology are driving increased demand for ready-to-eat (RTE) products with enhanced nutritional value and minimal use of synthetic preservatives.

One promising approach is the application of lactic acid fermentation in the processing of legume-based foods, particularly hummus. This section investigates the effect of controlled fermentation on the quality formation of fermented hummus using the starter cultures Lactococcus lactis subsp. Lactis and Lactobacillus rhamnosus. The finished product was evaluated in terms of sensory properties, amino acid profile, vitamin composition, and microbiological parameters.

Fermentation was found to improve the product's flavor and aroma and to stabilize the texture of hummus. Positive changes in the amino acid profile and increased levels of selected vitamins were observed in experimental samples compared with the control. The use of lactic acid bacteria was shown to ensure the microbiological stability of the product without the addition of chemical preservatives. During storage, fermented hummus complied with the relevant regulatory requirements for safety and quality.

The feasibility of applying lactic acid fermentation in the development of functional chickpea-based products is substantiated, and a rational shelf-life for fermented hummus is defined.

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