CHAPTER 8

Development of sauce technology from fermented plant-based materials for the food industry and HoReCa

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Abstract

The research is aimed at developing a sauce technology from fermented plant-based materials of various origins for use in the food industry and the HoReCa segment. The objects of the research were fermented legume, grain, pseudo-grain, and vegetable crops, as well as sauces prepared on their basis according to three experimental formulations. The control was a sauce prepared using traditional technology based on boiled chickpeas. Lactic acid bacteria of the species *Lactiplantibacillus plantarum* were used as biocatalysts during the fermentation of all types of plant substrates. An assessment of physicochemical changes in plant-based materials before and after fermentation was carried out with an emphasis on determining the pH, redox potential, titrated acidity, content of proteins, fats, total carbohydrates, and sugars. A significant decrease in pH was established, indicating the active accumulation of organic acids. At the same time, a shift in the redox potential towards a reducing environment was recorded, which is typical for anaerobic fermentation conditions, especially in samples with a high sugar content. A substantial decrease in the total content of carbohydrates, in particular sugars, was observed due to their utilization by microorganisms. The changes obtained indicate an improvement in the functional properties of plant-based materials after fermentation. The energy value of ready-made sauces based on the selected formulations was determined. It was established that samples from fermented plant-based materials have a lower energy

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value compared to the control, which is associated with the biochemical degradation of part of the sugars and partial cleavage of organic compounds under the effect of the enzymatic activity of microorganisms. Organoleptic evaluation showed a clear formation of new flavor profiles in sauces from fermented plant-based materials. All variants demonstrated a highly stable and homogeneous consistency. Based on the results of experimental studies, a functional sauce technology from fermented plant-based materials for the food industry and HoReCa was developed. According to the results of economic calculations, all samples of sauces prepared according to the experimental formulation had a higher level of profitability compared to the control. The results obtained confirm the feasibility of producing sauces using the developed technology based on the use of fermented plant-based materials in the food industry and the HoReCa segment, both from the standpoint of technological and functional advantages and economic efficiency.

Keywords

Sauces, fermentation, chickpea, carrot, oat, lentil, quinoa, tomato, zucchini, barley, green pea.

8.1 Introduction

Modern trends in the development of innovative technologies for the food industry and the HoReCa segment are aimed at constantly increasing the requirements for organoleptic indicators, nutritional and biological value, as well as functional properties of the product. In modern conditions, the global market for food products with new qualities that contribute to improving human health and well-being is rapidly developing. Consumer demand for high-quality natural products that do not contain synthetic food additives, but instead have improved functional properties due to the introduction of natural enriching ingredients, is increasing [1]. According to the leading nutritionists worldwide, sauces play the most important role in human nutrition. They provide unique taste accents, enrich the aroma, increase nutritional and biological value, and, due to the stimulation of the digestive glands, improve food digestibility. Sauces ensure the juiciness of dishes, increase calorie content, and diversify the diet, making products with a bland taste more attractive and in high demand among consumers [2].

However, traditional technologies for making sauces involve deep heat treatment of the raw materials, which significantly reduces the biological value. Their formulations contain increased concentrations of salt, sugar, and fat. Synthetic preservatives are added to sauces to increase their shelf life, and structure stabilizers are added to ensure rheological properties. This approach does not align with modern theories of healthy eating, which have gained particular popularity all over the world [2, 3].

Fermentation is one of the most promising ways to increase the functional properties of sauces based on natural plant-based materials. Thanks to the use of beneficial microorganisms, plant-based materials are transformed into valuable food products during fermentation. Such products have an extended shelf life, improved consistency, a unique taste and aroma, as well as an increased nutritional value created by probiotics [3]. Modern scientific literature presents the results of studies that explain the mechanisms of fermentation processes in food systems [4, 5]; however, the issue of using fermented plant-based materials for the preparation of sauces remains almost unexplored.

Another problem is the development of a universal technological process adapted to the conditions of modern restaurants, catering services, and craft food production. For modern establishments of the HoReCa segment, a special requirement is a short production cycle and high quality of the finished product, which must be standardized. For food industry enterprises, in addition to the above, the reproducibility of technological parameters, scalability, and economic indicators of production are no less important.

From this point of view, there is a lack of a scientifically substantiated technology for the production of sauces for the food industry and the HoReCa segment, which would meet all modern trends and ensure the production of sauces with improved functional and sensory properties, high production, and economic attractiveness. Solving this problem requires a detailed experimental study of the mechanisms influencing fermentation on the properties of plant substrates, as well as scientifically based modeling of formulations of sauces from fermented plant-based materials.

8.2 Scientific and theoretical fundamentals for the development of functional sauces from fermented plant-based materials

Modern prospects for the development of the food product range are aimed at meeting the specific needs of different population groups. In this regard, dishes for vegans and vegetarians, low-sugar, gluten-free, lactose-free, and high-protein complete diets are becoming increasingly popular. Such trends determine the expansion of the specific line of sauces based on natural plant-based materials. They will contribute to the enrichment of the diet with valuable biologically active substances, in particular vitamins, phenolic substances, natural dietary fibers, and minerals [4, 6].

The most promising plant-based materials for the production of sauces are legume, grain, pseudo-grain and vegetable crops. The complementarity of the functional and technological properties of these crops and a possible synergistic effect of their combination in the formulations are of special scientific interest.

Legume crops are traditionally considered the most complete source of vegetable protein, as well as soluble and insoluble dietary fiber. Protein of legume crops is complete and characterized by a high content of amino acids. It is very well absorbed by the human body. In addition, protein fractions of legumes exhibit high moisture-retaining and fat-retaining capacity, which ensures the ability of raw materials to swell. Dietary fiber also has pronounced structure-forming properties. Soluble dietary fiber, such as pectin and hemicellulose, increases the viscosity of food systems, insoluble fiber forms the structural basis of the product and determines its consistency. Thus, dietary fiber performs the functions of natural stabilizers of dispersed food systems. It should also be noted that soluble dietary fiber is directly involved in the processes of regulating blood glucose levels and lipid metabolism [7]. Therefore, the use of legume crops will contribute to the formation of a stable, homogeneous consistency of sauces without the use of synthetic stabilizers.

A well-known drawback of legumes is the presence of antinutrients that reduce the bioavailability of essential minerals. They contain phytic acid, tannins, and raffinose oligosaccharides [8, 9]. Phytic acid has the ability to create chelate complexes with calcium, iron, and zinc, which complicates their absorption. Raffinose and stachyose induce gas formation in the intestine during fermentation. In view of this, when developing the processing technology, it is advisable to provide methods of pre-treatment of legume crops that will help reduce the content of these substances or convert them into more accessible forms.

Cereals and pseudocereals can be considered as a functional supplement to the protein fraction of legumes. The correct combination of these crops ensures the formation of a complementary amino acid composition, as well as the supply of useful complex carbohydrates, starch, β-glucans, phenolic substances, and vitamins. In the presence of moisture, polysaccharides of cereals and pseudocereals are intensively hydrated and form viscous colloidal systems. This has a positive effect on the consistency and rheological properties of sauce systems. The most useful high-molecular soluble polysaccharides of cereals are β-glucans. They form stable hydrocolloid structures, significantly increase the moisture-binding and moisture-retaining capacity of the product, and strengthen its structural stability. In addition, β-glucans are characterized by a high ability to reduce blood cholesterol levels [10–12]. As for the phenolic substances of cereals and pseudocereals, most of them are in a bound form, but they can be considered as a promising source of substances with antioxidant activity [13].

Plant-based materials determine organoleptic properties and micronutrient composition of sauces. The high content of β-carotene, lycopene, polyphenols, ascorbic acid, and mineral elements, compared to other plant-based materials, forms the functional properties and attractive natural color of the product [12, 14]. Pectic substances, starch, cellulose, hemicellulose, and other structural polysaccharides of vegetables take an active part in creating a stable consistency, as they are able to form gels and ensure the stability of emulsions.

Microbiological fermentation contributes to a more complete use of the functional properties of plant-based materials in the production of food products [15]. During fermentation, deep transformations of proteins, carbohydrates, and phenolic substances of plant-based materials occur. Active forms of microorganisms transform complex compounds into simpler and more accessible forms, reduce the concentration of antinutrients, and stimulate the synthesis of biologically active substances [16, 17].

Thus, the research results [18] showed that during the fermentation of legume crops by lactic acid bacteria of the genus *Lactobacillus*, hydrolysis of phytic acid occurs, and the content of raffinose oligosaccharides decreases [18]. During the fermentation of grain raw materials, the enzyme systems of both grains and microorganisms that take a direct part in the process are activated. This results in partial cleavage of polysaccharides and the release of bound phenolic compounds, increasing antioxidant properties [19]. During the fermentation of plant-based materials, the main result is the formation of organic acids – primarily lactic and acetic. This is accompanied by a decrease in pH, inhibition of the development of pathogenic microorganisms, extension of the shelf life of the product, and improvement of its functional properties [20, 21].

In this regard, lactic acid fermentation can be an effective technological method for improving the functional properties of natural sauces based on plant-based materials. Lactic acid bacteria are the main biocatalysts of fermentation processes. In the process of metabolic activity during growth and development, they convert sugars into lactic acid. This provides a decrease in pH, which inhibits the development of pathogenic microorganisms and extends the shelf life of products [22].

The products of the metabolic activity of lactic acid bacteria during fermentation are not only organic acids. As a result of the synthesis, volatile aromatic compounds are also formed. They ensure the formation of a complex, pleasant aroma of the product [23]. Depending on the ingredients of the formulation, pleasant creamy, spicy, sour, or umami tastes can dominate in the finished fermented sauces. This is crucially important, since the taste and aroma profile is the most important indicator of the organoleptic assessment of sauce products.

Exopolysaccharides are the metabolic products of certain strains of lactic acid bacteria. They are high-molecular compounds that are responsible for the density of the product, improve moisture-binding and moisture-retaining properties, and prevent emulsion delamination. This naturally ensures a stable, homogeneous consistency of sauces [24, 25].

The fermentation also results in a change in the composition of proteins and phenolic substances. Peptides and free amino acids are formed through proteolysis. They take an active part in the formation of the taste and aroma profile of food systems, and some even exhibit antioxidant activity. Along with this, the availability of micronutrients increases, and the synthesis of B vitamins also occurs [26]. This significantly increases the functional properties of ready-made sauces.

The efficiency of microbiological fermentation is determined by a set of technological parameters. The most important of them are the temperature, process duration, physicochemical properties of the substrate, and the type of strain of microorganisms [27]. By controlling and changing technological parameters, the intensity of metabolic development of microorganisms can be regulated, and the properties of finished sauces can be optimized.

Controlled fermentation using pure starter cultures of lactic acid bacteria provides predictable acidity, reproducibility of organoleptic properties, and stability of quality indicators compared to spontaneous fermentation [28]. This is of fundamental importance for the food industry and the HoReCa segment, where standardization of formulations, stability of indicators, and the possibility of scaling production are necessary.

Thus, the combination of complementary plant-based materials with controlled lactic acid fermentation forms a holistic technological concept for creating functional sauces. This approach allows for a simultaneous increase in biological value, ensures structural stability, forms a complex natural sensory profile, and adapts the product to the requirements of the food industry and the HoReCa segment. The set of the presented modern scientific data confirms the scientific validity of this direction and its prospects for expanding the range of new generation sauces.

8.3 Modeling of formulations of functional sauces from fermented plant-based materials

The aim of the research was to develop a technology for the production of functional sauces from fermented plant-based materials of various natures for use in the food industry and the HoReCa segment.

To achieve this aim, the following tasks were set: to investigate the kinetics of physicochemical changes in plant-based materials during the fermentation process; to analyze the content of mass fractions of macronutrients in experimental samples of sauces and determine their energy value; to conduct an organoleptic assessment of sauces from fermented plant-based materials and compare it with the control option; to develop a technology for the production of sauces from fermented plant-based materials taking into account the requirements of the food industry and HoReCa, determining rational technological parameters and stages of the process.

Three variants of formulations from fermented plant-based materials were developed for the research (**Table 8.1**).

A traditional sauce based on boiled, unfermented chickpeas, olive oil, lemon juice, garlic, and spices was used as a control (**Table 8.1**). Fermented plant-based materials were not included in the formulation of the control sample, which allowed to carry out an objective assessment of the effect of fermentation on the organoleptic properties, physicochemical parameters, content of basic macronutrients, and energy value of experimental sauce samples.

The main raw materials selected were legumes, including chickpeas, green peas, lentil; vegetables, including carrots, zucchini, tomatoes; cereals, including oats, barley; and a pseudocereal crop, quinoa. All industrial raw materials were purchased from the SILPO retail chain. Legumes and cereals were produced by "Arnika Organic" Agroindustrial Group, and vegetable crops were produced by "Ovochevy Svit" LLC, Ukraine.

Four experimental sauce samples were prepared under laboratory conditions, according to the given formulation (**Table 8.1**), each in five replicates.

The manufacturing process was carried out using the equipment of the Educational and Scientific Laboratory of Food Technology of the National University of Life and Environmental Sciences of Ukraine (Kyiv), in particular a washing bath, a grinder, an incubation chamber with adjustable temperature and humidity parameters, a homogenizer with adjustable rotations, a thermostatic cabinet for processing liquid components, sterile containers for fermentation and a pH meter for monitoring acidity during the fermentation process.

To prepare the control sample, chickpeas were pre-filled with drinking water in a ratio of 1:3 and kept for 12 hours. After the end of the holding period, the swollen grains were separated from the water and washed 2 more times. Such careful preparation of chickpea grains contributes to the leaching of a significant proportion of antinutrients. Next, the chickpeas had been boiling until fully cooked at a temperature of 100°C for 45 minutes. After cooking, they were cooled to a temperature of 18 ± 2°C. The sauce was prepared by mixing all the recipe ingredients (**Table 8.1**) in a laboratory homogenizer. The rotation speed of the homogenizer shaft was

3000 rpm, and the mixing duration was 3 min. As a result, a sauce of a homogeneous pasty consistency was obtained. The finished control samples were packed in sterile, sealed plastic containers, labeled, and stored in a refrigerator at a temperature of 4 ± 1°C until experimental studies were conducted, but no longer than for 5 days.

Table 8.1 Formulations of sauces from fermented plant-based materials

Control formulation (Cf)		Fermented Chickpea – Carrot – Oat (FCCO)	
Ingredients	**Mass, g**	**Ingredients**	**Mass, g**
Boiled chickpea	60.0	Fermented chickpea	30.0
Water	25.0	Fermented carrot	18.0
Olive oil	8.0	Fermented oats	12.0
Table salt	1.2	Vegetable broth	25.0
Lemon juice	2.0	Olive oil	8.0
Fresh garlic	1.0	Table salt	1.2
Smoked paprika	0.8	Lemon juice	2.0
Cumin	0.6	Roasted garlic	1.0
Turmeric	0.5	Smoked paprika	0.8
Black pepper	0.9	Cumin	0.6
–	–	Turmeric	0.5
–	–	Black pepper	0.9
Total	**100**	**Total**	**100**
Fermented Green Pea – Zucchini – Barley (FGZB)		**Fermented Tomato – Lentil – Quinoa (FTLQ)**	
Ingredients	**Mass, g**	**Ingredients**	**Mass, g**
Fermented green peas	23.2	Fermented tomato	31.0
Fermented zucchini	20.3	Fermented lentils	18.6
Fermented barley	14.5	Fermented quinoa	12.4
Vegetable broth	27.7	Vegetable broth	22.2
Pumpkin seed oil	7.0	Red basil oil	7.0
Table salt	1.0	Table salt	1.2
Apple vinegar	2.0	Balsamic vinegar	2.0
Fermented garlic	1.0	Roasted garlic	1.0
Ground coriander	1.0	Smoked paprika	0.8
Dried mint	0.5	Chili pepper	0.6
Fresh dill	1.0	Cloves	0.2
Fresh green onion	0.8	Inulin	3.0
Total	**100**	**Total**	**100**

Before preparing experimental samples of sauces, fermentation of plant-based materials was carried out. Plant-based materials were ground in a universal laboratory blender to particles ≤ 5 mm in size. Chickpeas, red lentils, oats, and quinoa were moistened to 68 ± 2%. After that, fermentation was carried out.

Lactic acid bacteria of the species *Lactiplantibacillus plantarum* were used as biocatalysts during the fermentation of all types of plant substrates at a concentration of 10^6–10^7 CFU/g. Fermentation was carried out in a thermostat at 30 ± 1°C. The process was stopped after 24 hours of fermentation and reaching the substrate pH at the level of 4.1–4.3 by cooling to 1 ± 1°C. Creating the same fermentation conditions for all experimental samples of plant-based materials eliminated them as an influencing factor and ensured a correct scientific comparison of changes in the properties of sauces under the influence of the recipe ingredients.

Fermented plant ingredients were stored in the refrigerator at 1 ± 1°C in airtight containers for further experimental research and preparation of sauces, but no longer than 7 days.

To prepare experimental samples of sauces, a certain amount of recipe ingredients was mixed in a laboratory homogenizer at a shaft rotation frequency of 3000 rpm for 3–5 minutes until a homogeneous consistency was formed, packed in sterile airtight plastic containers, labeled, cooled, and stored at 4 ± 1°C until experimental research was conducted, but no longer than for 5 days.

Organoleptic and physicochemical indicators of the fermented plant-based materials and experimental samples of sauces were evaluated, the content of essential nutrients was determined, and the energy value was calculated.

Organoleptic characteristics were evaluated by the method of profile analysis with the involvement of a tasting commission using a descriptor approach. Appearance, color, aroma, consistency, and flavor profile were evaluated.

Physicochemical parameters of the raw materials before and after fermentation were determined by generally accepted methods. Active acidity (pH) was measured by the potentiometric method using a calibrated pH meter at a temperature of 20 ± 2°C. Redox potential (ROP) was determined electrochemically using a platinum electrode [29]. Titrated acidity was determined by the method of neutralization titration with 0.1 N NaOH solution, with the results expressed in terms of lactic acid [30].

The mass fraction of sugars was determined by the ferricyanide method. This analytical method is based on the ability of reducing sugars to convert potassium ferricyanide ($K_3[Fe(CN)_6]$) to potassium ferricyanide ($K_4[Fe(CN)_6]$) under alkaline conditions. The reaction occurs by reducing ferricyanide ions with monosaccharides present in the sample. Methylene blue was used as a redox indicator. During the reaction, the characteristic blue color gradually disappears as the ferricyanide is reduced, resulting in a color change to a pale yellow or almost colorless solution, indicating the titration end point [31].

Protein content was determined by the Kjeldahl method using a conversion factor of 6.25. Fat mass fraction was determined by extraction in a Soxhlet apparatus. Total carbohydrates were determined by laboratory method after acid hydrolysis of samples with subsequent quantitative determination of the carbohydrate fraction by the spectrophotometric method. Dietary fiber mass fraction was determined by the gravimetric method with enzymatic treatment [29]. Energy value was calculated based on the obtained data on the content of proteins, fats, and carbohydrates using generally accepted conversion factors [32].

All determinations were performed in at least five replicates. The results were processed using mathematical statistics methods, using mean values and standard deviation.

8.4 Changes in the physicochemical parameters of plant-based materials under the influence of fermentation

The most important condition for ensuring the predicted quality of functional sauces and the controllability of the technological process of their production is scientific monitoring of the physicochemical parameters of raw materials at the stage of lactic acid fermentation. The degree of metabolic activity of lactic acid bacteria is characterized by changes in the hydrogen index (pH), redox potential (Eh), titrated acidity (TA), and basic macronutrients.

The active acidity of the environment, which is characterized by the value of the hydrogen index, is of primary importance for ensuring the metabolic activity of lactic acid bacteria during fermentation. Achieving the required pH level ensures the formation of product taste qualities and extends its shelf life.

The results of experimental studies, presented in **Fig. 8.1**, show that the initial pH values mainly ranged within 6.11…6.44 depending on the type of plant-based materials, with the exception of tomatoes with an initial pH of 4.32, which are typical values for fresh plant substrates. After fermentation, the pH decreased to the range of 3.78…4.56 depending on the type of raw materials.

After 24 hours of fermentation, the pH of most plant substrates, in particular carrots, zucchini, green peas, barley, decreased to the range of 4.1…4.3, which contributed to the formation of excellent organoleptic indicators and high preservation.

In dry legume extracts (chickpeas, lentils) and quinoa, the value of the hydrogen index after 24 hours of fermentation exceeded the limit of 4.3, but its decrease was significant and was within 1.7–1.8 units. Such dynamics are associated with the peculiarity of the chemical composition of these crops, in particular, a higher content of proteins, which provides an increase in buffer capacity.

During the fermentation of tomatoes, the decrease in the hydrogen index pH was minimal and amounted to only 0.54 units. However, the low initial value and its corresponding decrease characterize a sufficient level of fermentation and contribute to the formation of a stable acidic environment.

It should be noted that, depending on the type of substrate, the decrease in pH ranged from 1.71 to 2.18 units. Such a change in the hydrogen value fully corresponds to the typical dynamics of lactic acid fermentation of plant substrates. Achieving a pH value ranging from 4.1 to 4.3 has high technological significance. At the same time, the development of most types of pathogenic microflora is inhibited, and prerequisites for the production of sauces with an extended shelf life are formed.

The metabolic activity of lactic acid bacteria during fermentation is affected not only by a change in the pH value. Under their action, profound changes in biochemical substrates occur, which significantly affect the redox balance of the environment (**Fig. 8.2**).

Before the start of fermentation, almost all plant substrates were characterized by a negative redox potential with fluctuations ranging within –40…–65 mV.

This may be due to the high content of proteins and amino acids, phenolic substances, and active enzymes. The only exception was tomatoes, for which the ORP value was positive and amounted to 120 mV. This is due to higher natural acidity, low protein content, and, accordingly, lower buffer capacity. It should also be noted that tomato tissues are characterized by a higher proportion of dissolved oxygen, as a result of which a more oxidative environment was formed, compared to other crops.

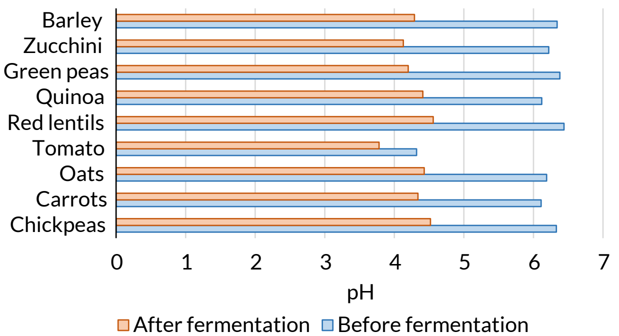

Fig. 8.1 Changes in pH of plant materials during fermentation

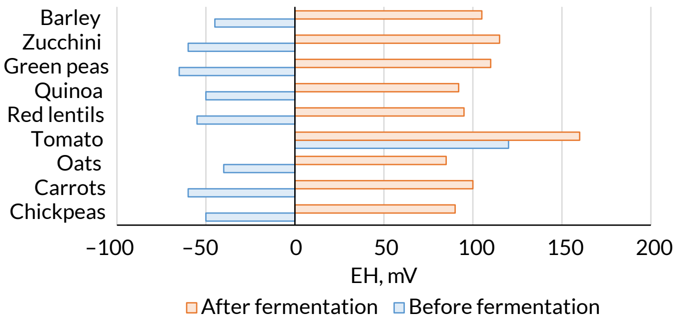

Fig. 8.2 Changes in the redox potential (Eh) of plant-based materials during fermentation, mV

After fermentation, the redox potential increased in all plant substrates without exception to the limits of +85...+160 mV. This increase is fully correlated with the increase in pH and indicates changes in the physicochemical parameters of plant substrates and the formation of a stable acidic environment, which will provide unique organoleptic indicators of future sauces and contribute to the extension of their shelf life.

Titrated acidity (TA) is considered the main indicator characterizing the intensity of lactic acid fermentation. It enables the estimation of the total amount of acids in the fermented system. It is generally known that the metabolic activity of lactic acid bacteria may result in the accumulation of secondary metabolites of fermentation, i.e. organic acids. The main acid formed during the fermentation of plant substrates is lactic acid. The formation of acetic acid is also possible. The level of TA growth characterizes the intensity of their accumulation.

The results of experimental studies (**Fig. 8.3**) indicate a statistically significant increase in titrated acidity (TA) in all plant substrates after lactic acid fermentation.

The initial content of titrated acids was typical for fresh plant-based materials and ranged from 0.035 to 0.16%. This indicator was minimal in grain and pseudo-grain substrates, and it was maximal in tomatoes.

After fermentation, the titrated acidity increased by 5–9 times depending on the nature of the plant substrate. The maximum growth of this indicator was established for green peas, zucchini, and tomatoes, which indicates a high metabolic activity of lactic acid microflora in these plant substrates. The increase was somewhat lower for barley, quinoa, and carrots. The different dynamics of this indicator may be associated with the peculiarities of the chemical nature of plant substrates, as well as the varying degree and speed of involvement of polysaccharide complexes in the fermentation processes. The obtained values of titrated acidity after fermentation indicate the accumulation of a sufficient amount of organic acids in all plant substrates to ensure the necessary taste characteristics of future sauces.

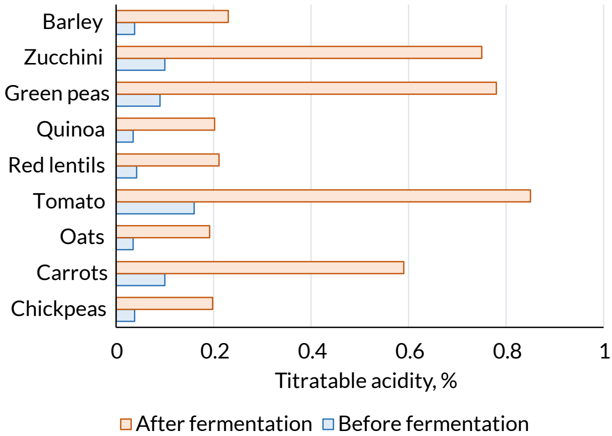

Fig. 8.3 Titrated acidity (TA) of plant substrates after fermentation, %

Another criterion that allows for establishing the nature and intensity of the course of fermentation processes is the quantitative assessment of changes in the carbohydrate complex (**Table 8.2**) and the content of total sugars (**Fig. 8.4**). In all studied samples, a decrease in the total content of carbohydrates is observed, indicating their active involvement in fermentation metabolism.

In legume crops, the decrease in carbohydrate content occurred at different rates. Thus, for chickpeas, the carbohydrate content after fermentation decreased by 10.3%, for red lentils by 9.7%. For green peas, the grains of which were characterized by the minimum initial value among legumes, it decreased by 15.4%.

In cereal and pseudocereal substrates, the decrease in carbohydrate content after fermentation was relatively stable and fluctuated within 1.73–1.95 g/100 g, which corresponds to the range of 7.4–9.2%.

In vegetable substrates, the decrease in carbohydrate content in absolute values was less pronounced and amounted to 0.55–1.04 g/100 g. However, the percentage comparison regarding the initial value indicated significant changes. In carrots, the level of carbohydrates became lower by 10.9%, in zucchini by 17.7%, and in tomatoes by 19.5%.

Table 8.2 Changes in the content of macronutrients in plant-based materials during fermentation

Plant-based material	Carbohydrates, g/100 g		Proteins, g/100 g		Fats, g/100 g	
	before fermentation	after fermentation	before fermentation	after fermentation	before fermentation	after fermentation
Chickpeas	19.66 ± 1.44	17.64 ± 1.58	6.56 ± 0.32	6.73 ± 0.58	1.93 ± 0.12	2.02 ± 0.04
Carrots	9.58 ± 0.69	8.54 ± 0.05	0.93 ± 0.02	1.00 ± 0.06	0.24 ± 0.03	0.25 ± 0.02
Oats	21.22 ± 2.64	19.27 ± 1.24	5.41 ± 0.06	5.51 ± 0.30	2.21 ± 0.05	2.25 ± 0.14
Tomatoes	3.89 ± 0.25	3.13 ± 0.03	0.88 ± 0.02	0.93 ± 0.02	0.20 ± 0.03	0.21 ± 0.01
Red lentils	19.23 ± 2.42	17.37 ± 1.46	8.26 ± 0.05	8.38 ± 0.34	0.36 ± 0.19	0.39 ± 0.01
Quinoa	20.54 ± 1.61	18.77 ± 1.41	4.51 ± 0.16	4.64 ± 0.43	1.96 ± 0.07	2.01 ± 0.05
Green peas	14.45 ± 1.07	12.23 ± 0.77	5.42 ± 0.03	5.63 ± 0.18	0.39 ± 0.05	0.49 ± 0.03
Zucchini	3.11 ± 0.17	2.56 ± 0.21	1.21 ± 0.08	1.28 ± 0.12	0.32 ± 0.02	0.35 ± 0.01
Barley	23.53 ± 2.08	21.80 ± 1.64	3.17 ± 0.24	3.28 ± 0.47	0.39 ± 0.04	0.42 ± 0.06

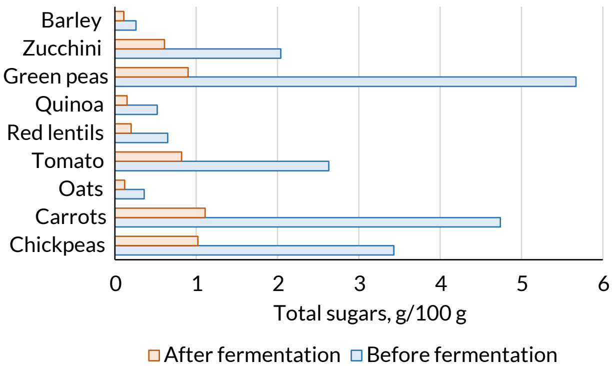

Fig. 8.4 Content of total sugars in plant substrates after fermentation, g/100 g

Analysis of the content of total sugars (**Fig. 8.4**) confirms their decrease after fermentation in all groups of plant substrates by 58–84%. It was most pronounced in green peas (84%), carrots (77%), quinoa (71%), chickpeas, zucchini (70%), and red lentils (69%). Minimal loss of sugars was observed during barley fermentation (58%). The results obtained indicate the direct involvement of mono- and disaccharides in metabolic processes during lactic acid fermentation, regardless of the species characteristics of the substrates. Along with this, it should be noted that in grain substrates (barley, oats) there is a significantly higher preservation of total sugars, which indicates a more active involvement in metabolic processes of starch and other reserve polysaccharides.

Thus, the change in the carbohydrate complex during fermentation has several important technological values. On the one hand, it forms the sugar profile of future sauces and provides the necessary balanced taste properties, and on the other hand, it takes a direct part in the formation of their consistency and provides a viscous, homogeneous structure.

In order to establish the influence of fermentation on the nature of the restructuring of the protein complex of plant substrates during lactic acid fermentation, the content of total protein was determined. The results of experimental studies indicate an insignificant increase in the mass fraction of protein in all plant substrates. In substrates characterized by a higher natural protein content before fermentation, the increase in the indicator after fermentation was also more substantial. In particular, in chickpeas, the content of total protein increased by 0.17 g/100 g, quinoa by 0.13 g/100 g, red lentils by 0.12 g/100 g, barley by 0.11 g/100 g, and green peas by 0.21 g/100 g. At the same time, in vegetable substrates, the changes were minimal and did not exceed the level of statistical error.

Protein increase may be associated with the accumulation of microbial biomass, which increases the total content of nitrogenous substances. According to the chosen methodology, protein was determined by total nitrogen, the content of which characterizes the total content of nitrogenous substances, which takes into account both the content of partial proteolysis products and proteins of microbial origin involved in the fermentation process. In addition, during fermentation, structural rearrangement of proteins occurs. Under the action of proteases of lactic acid bacteria, partial hydrolysis of proteins occurs, and peptides and free amino acids are formed. This is accompanied by an increase in the bioavailability of amino acids and the formation of a specific umami taste component. At the same time, no decrease in the mass fraction of total protein is observed.

The results of the experimental study also established minimal changes in the mass fraction of fats in all plant substrates after fermentation. The increase in this indicator, recorded within 0.01–0.09 g/100 g, is within the statistical error and confirms its stability. Thus, it can be concluded that there is no lipolytic activity of lactic acid microorganisms during the fermentation of selected plant substrates. Preservation of lipid structural stability is an important condition for ensuring a homogeneous consistency of future sauces.

Therefore, based on the obtained results of experimental studies, it is concluded that a decrease in the proportion of carbohydrates is accompanied by an increase in the content of organic acids and a structural transformation of the protein-lipid complex of plant substrates without the loss of their quantity. This increases the technological suitability of fermented plant substrates for the production of functional sauces with a predicted consistency, as well as taste and aroma characteristics.

8.5 Nutrient profile and energy value of sauces from fermented plant-based materials

Assessment of the nutrient profile (**Table 8.3**) is an important stage in substantiating the formulations of functional sauces, since proteins, fats, and carbohydrates determine not only the energy value of the product, but also form its consistency, taste profile, and emulsion stability. The obtained results demonstrate clear differences between the control sample and variants from fermented plant-based materials, confirming the influence of both the formulation composition and the preliminary biotechnological treatment.

Table 8.3 Content of essential macronutrients and chemical components in sauces from fermented plant-based materials

Indicator	Cf	FCCO	FGZB	FTLQ
Proteins, g/100 g	4.65 ± 0.08	3.39 ± 0.03	2.48 ± 0.03	2.79 ± 0.04
Fats, g/100 g	9.51 ± 0.10	9.20 ± 0.09	7.45 ± 0.03	7.60 ± 0.02
Carbohydrates, g/100 g	15.26 ± 0.05	11.89 ± 0.11	8.44 ± 0.37	11.67 ± 0.11
Sugars, g/100 g	2.50 ± 0.03	1.23 ± 0.13	0.99 ± 0.03	1.32 ± 0.03
Fiber, g	3.46 ± 0.03	3.58 ± 0.09	3.15 ± 0.10	5.03 ± 0.17
Titratable acids, %	0.36 ± 0.02	0.64 ± 0.03	0.67 ± 0.02	0.73 ± 0.04

In terms of total protein content, the control variant of the sauce exceeded all the experimental variants by an average of 1.4…1.9. The decrease in the mass fraction of protein in the samples of the experimental variants of the sauces is associated with the peculiarities of their formulation. Thus, the formulation of the control variant of the sauce includes 60% of boiled chickpeas, which is considered a high-protein plant ingredient. In contrast, the formulation of the experimental samples includes other fermented plant ingredients, the protein content of which is significantly lower. However, this difference does not affect the functional properties of the sauces, since they are not considered the main source of protein in the diet. It should also be noted that the complete or partial replacement of chickpeas in the experimental formulations has a positive effect on the digestive processes and facilitates the digestibility of ready-made dishes. A smaller mass fraction of the protein fraction in the experimental samples of the sauces contributes to the formation of a more uniform consistency and reduces the risk of protein coagulation during their storage.

The fat content in all samples of sauces prepared according to the experimental formulations was lower compared to the control sample. Depending on the variant, the decrease amounted to 3.3…21.7% compared to the control variant. This had a positive effect on the functional properties of the sauces. In the experimental samples, the proportion of saturated fatty acids decreased, the lipid profile improved, and the energy value significantly decreased. It should also be noted that the improvement of the functional properties of sauces is facilitated not only by the quantitative composition of the fat fraction, but also by its qualitative composition. In the experimental sauce formulations, it is proposed to use various types of cold-pressed plant oils, which have undeniable nutritional advantages. Thus, olive oil is characterized by a high content of monounsaturated fatty acids, contains polyphenols and tocopherols, providing a high antioxidant potential. It is stable in cold emulsions and has high emulsifying compatibility with vegetable proteins. Pumpkin seed oil contains a lot of linoleic acid, tocopherols, and phytosterols. It has a natural nutty aroma, deep, rich taste, and color, and increases the viscosity of emulsions. Red basil oil contains volatile terpene compounds, enhances the aroma of sauces, and improves their color range.

Sauce samples prepared according to the control formulation exceeded all experimental samples both by carbohydrate content (by 1.3…1.8 times) and by total mono- and disaccharides content (by 1.9–2.5 times). Among the experimental samples, FCCO sauce samples had the maximum carbohydrate content, and FTLQ samples had the highest sugar content. FGZB sauce samples had the minimum content of total carbohydrates as well as mono- and disaccharides. The reduced mass fraction of carbohydrates, including readily available sugars, contributes to the formation of food products with a reduced glycemic load and limits the possibility of undesirable carbonyl stress.

A special advantage of sauces prepared according to the experimental FCCO and FTLQ formulations is the increased content of dietary fiber. In the FCCO sauce samples, their content exceeded the control variant by 1.1 times, and in the FTLQ sauce samples by 1.5 times. High level of fiber in these sauces is associated with the use of cereals, pseudocereals, and legumes, as well as the addition of inulin. This increases the functional properties of the sauces and makes it possible to consider the experimental samples of sauces as a source of prebiotic components. From a technological point of view, this ensures the formation of a thick, stable, homogeneous consistency of sauces.

The indicators of titrated acidity additionally confirm the functional orientation of the experimental samples. In the control variant, it was 0.36%, while in sauces from fermented plant-based materials, it increased to 0.64–0.73%. The highest level of acidity was recorded in FTLQ (0.73%), which is associated with the use of fermented tomatoes and lentils. The increase in acidity, combined with a reduced sugar content, forms a more pronounced, balanced flavor profile and contributes to the microbiological stability of the product.

Thus, the comparative analysis indicates that FCCO and FTLQ sauces based on fermented vegetable raw materials are characterized by a higher content of dietary fiber, a reduced level of fats, carbohydrates, and simple sugars. The combination of these indicators indicates the possibility of manufacturing products with improved functional properties.

The energy value of the developed sauces is presented in **Fig. 8.5**.

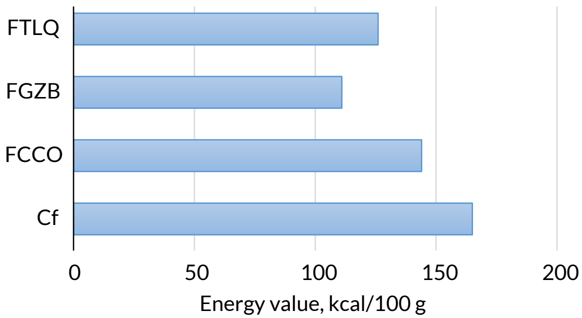

Fig. 8.5 Energy value of sauces formulated from fermented plant-based materials (kcal/100 g)

Assessment of the energy value of sauces (**Fig. 8.5**) reveals a consistent decrease in calorie content in all variants from fermented plant-based materials compared to the control sample. The maximum energy value was observed in the samples of sauces prepared according to the control formulations. The determined value of this indicator was 165 kcal/100 g of finished sauce. This is due to the high content of both boiled chickpeas and the liquid fat fraction – olive oil – in the formulation composition. According to the results of the studies (**Table 8.3**), the control samples of Cf sauces exceeded all samples of the experimental variants in terms of the content of proteins, fats, and carbohydrates. Therefore, the maximum energy value is quite expected.

The energy value of sauces prepared according to the experimental FCCO formulation was 144 kcal/100 g, i.e., it was 13% lower than the samples of the control variant, but at the same time it exceeded all samples of other experimental variants. Such dynamics are due to the fact that in the FCCO formulation, chickpeas are partially replaced by lower-calorie products, e.g., carrots and oats. In addition, all the main plant ingredients are used in the fermented form, which results in a decrease in the content of easily accessible carbohydrates and, accordingly, a decrease in their contribution to the overall energy balance.

The minimum energy value was observed in the samples of sauces prepared according to the FGZB formulation. In this variant, the value was 111 kcal/100 g of the finished sauce, which is 33% lower than in the control variant. The calorie content of this sauce sample, as well as all other experimental variants, is provided by fermented ingredients of the formulations. In addition, the use of pumpkin oil in a smaller amount compared to the control also contributed to a decrease in energy value.

In the FTLQ variant, the energy value was 126 kcal/100 g. Despite the presence of lentils and quinoa as sources of protein and complex carbohydrates, the reduction in the content of simple sugars due to fermentation and a moderate proportion of fat provided a decrease in calorie content compared to the control by 24%. In addition, the low intrinsic energy value of fermented tomatoes, which are the basis of the formulation and contribute to a decrease in the overall energy load, should be taken into account.

Thus, the results obtained indicate that the introduction of fermented plant components into sauce formulations allows for a reduction in the energy value by 21–54 kcal/100 g compared to the control sample, while maintaining an increased content of protein and dietary fiber.

8.6 Organoleptic evaluation of sauces based on fermented plant-based materials

Organoleptic evaluation of sauces from fermented plant-based materials and the control sample was carried out using a nine-point scale, determining such indicators as appearance, color, consistency, aroma, and taste (**Table 8.4**). The results of the sensory evaluation indicate significant differences between the samples of sauces prepared according to the control formulation (Cf) and all experimental formulations.

The mean score of the sauce samples prepared according to the control formulation was 6.56 points. According to the tasters, the control samples were characterized by a mild neutral taste and aroma, which was reflected in the tasting score for these criteria – 6.49 and 6.42 points, respectively. The consistency of the sauces was paste-like, but not completely homogeneous, with a slight graininess and, according to some experts, too thick for the sauce system. The color was uniform, light beige, but too neutral and insufficiently expressive. Thus, the scores for these criteria were also not maximum – 6.81 points for consistency and 6.5 points for color.

Table 8.4 Sensory indicators of sauces from fermented plant-based materials, scores

Sample	Appearance	Color	Consistency	Aroma	Taste	Mean score
Cf	7.03 ± 0.41	6.50 ± 0.04	6.81 ± 0.19	6.42 ± 0.06	6.49 ± 0.09	6.56 ± 0.41
FCCO	8.73 ± 0.19	8.52 ± 0.28	8.59 ± 0.25	8.38 ± 0.14	8.43 ± 0.13	8.48 ± 0.19
FGZB	8.44 ± 0.11	8.03 ± 0.14	8.32 ± 0.14	8.24 ± 0.15	8.30 ± 0.08	8.22 ± 0.11
FTLQ	8.90 ± 0.10	8.98 ± 0.05	8.82 ± 0.20	8.83 ± 0.12	8.90 ± 0.14	8.88 ± 0.10

The experts rated the sauce samples prepared according to the experimental FCCO formulation significantly higher. Their average score was 8.48 points. The maximum scores were given to the attractive appearance and homogeneous, moderately viscous, and stable consistency of the sauces (**Table 8.4**). The color of the sauces was natural with a light orange tint provided by the fermented carrot included in the formulation. The taste and aroma were balanced, sweet and sour, with light spicy notes.

The mean score of the sauce samples prepared according to the FGZB formulation was 8.22 points. That was the minimum score among all sauce samples prepared using the experimental formulations. However, it also exceeded the organoleptic evaluation of the control samples by 1.3 times (**Table 8.4**). The experts noted that the consistency of these sauces was homogeneous, delicate, and moderately thick. The color was light green, but less intense than other variants. Nevertheless, this did not have a significant impact on the appearance, and it remained quite attractive and was rated 8.44 points. The taste and aroma were inherent in the plant-based materials included in the formulation and characterized by freshness and a slightly sour taste.

The maximum scores were given to the sensory indicators of sauces prepared according to the experimental FTLQ formulation. The mean score of these samples was 8.88 points. The experts awarded the highest scores (**Table 8.4**) to the intense ruby color provided by the combination of fermented tomatoes and red lentils. This bright color resulted in an attractive appearance, which was rated at 8.9 points. High scores were also given to the pronounced taste and aroma profile of the sauces of the FTLQ variant, characterized by a successful combination of sweet-and-sour and spicy notes. Their consistency was thick, homogeneous, and without delamination.

Thus, the presented results of the organoleptic evaluation indicate that all samples prepared according to the experimental formulations exceed the samples prepared according to the control formulation by an average of 1.4–2.5 times for each organoleptic indicator. The greatest impact of the plant-based material fermentation was observed in the taste and aroma characteristics of functional sauces.

A comparative assessment of organoleptic indicators of both the control and experimental variants showed that each sample made according to a unique formulation is characterized by a characteristic sensory identity. Thus, FCCO sauces had a balanced taste and aroma profile with light smoky-spicy notes. The taste and aroma profile of FGZB sauces was characterized by freshness, with a slight "green" plant-dominant tone and delicate sourness. The FTLQ sauces demonstrated the brightest taste and aroma profile with deep umami undertones and sweet-and-sour notes. The formation of these properties of sauces is directly related to the influence of lactic acid fermentation on the functional and sensory characteristics of the plant base of sauces.

Thus, changes in plant-based materials that occur as a result of the metabolic activity of lactic acid microflora during fermentation significantly change the sensory characteristics of sauces, contribute to the formation of a brighter and more expressive aroma, as well as a pleasant, balanced, and harmonious taste. An increase in the organic acid content, as well as the accumulation of other products of lactic acid fermentation, contributes to the formation of natural sweet-creamy, sour, spicy, and umami flavors, which improve the culinary appeal of finished sauces. At the same time, changes in the structural components of fermented plant-based materials form a stable and homogeneous consistency. The results obtained confirm the feasibility of using fermented plant-based materials as an effective tool for increasing the sensory and functional attractiveness of sauces for the food industry and the HoReCa segment.

8.7 Biochemical mechanisms of quality formation and practical aspects of implementing the technology of sauces from fermented plant-based materials

The scientific research is aimed at systematically substantiating the formulation and production technology of functional sauces, in which lactic acid fermentation of plant-based materials is used as a key biotechnological tool for forming the quality and stability of the product for the restaurant segment and the food industry. The research is based on the scientific hypothesis that the use of lactic acid fermentation of vegetable, legume, and grain substrates as a functional basis for sauces will simultaneously improve their organoleptic characteristics, increase nutritional and biological value, and form a technologically stable system without the use of synthetic additives.

The obtained results confirm the internal logic of this hypothesis.

During lactic acid fermentation, due to the increased metabolic activity of microorganisms, complex biochemical processes occur, which are characterized by an interconnected set of changes in the pH value, titrated acidity, redox potential, and carbohydrate complex. The degree of intensity of these changes characterizes the kinetics of the fermentation process. In view of this, it is proposed to control the fermentation processes in studies by the level of pH decrease and the increase in the content of titrated acids, with simultaneous comparison with the decrease in the content of total sugars and carbohydrates in general. This approach is consistent with the results of modern studies, in which these criterion indicators were selected to monitor the course of fermentation [33].

The indicator of active acidity pH has been selected as the main control criterion in our studies, as well as in scientific publications [7, 34]. During fermentation of plant substrates, in particular legumes, cereals, pseudocereals, and vegetable crops, the increase in pH is primarily caused by the lactic acid accumulation. When the level of active acidity pH $\leq$ 4.6 is reached, the growth of pathogenic microorganisms is significantly inhibited, they lose the ability to reproduce, and the products acquire higher microbiological resistance. Lactic acid bacteria are characterized by higher acid resistance; therefore, after reaching this acid barrier, they continue to participate in metabolic processes with the formation of lactic acid. However, as the content of the latter increases, their activity is gradually inhibited.

A comparative analysis of the obtained changes in titrated acidity with the data from other scientific studies [7] shows that the values are typical for fermented plant substrates. Thus, it is well known that the most pleasant and balanced taste is inherent in fermented vegetables with a content of titrated acids in the range of 0.6–0.8%. The results of our studies are fully consistent with such values and are within this range. According to the research [7], the intensity of lactic acid formation is determined by the preliminary preparation of plant substrates for fermentation, in particular, the degree of grinding and moistening if necessary. In view of this, all plant substrates used in our studies were ground to particles $\leq$ 5 mm in size, and dry ones were moistened to $68 \pm 2\%$. Such technological techniques contributed to the intensification of fermentation processes and the achievement of the required acidity levels within 24 hours.

Simultaneously with changes in the acidity of the medium during lactic acid fermentation, changes in its redox potential occur. Due to increased metabolic activity, lactic acid bacteria consume certain types of reducing compounds, use the energy generated in this process, and form new substances. This leads to a gradual change in the redox state of the system. Reviews on the fermentation of plant substrates emphasize that the state of the redox system and the availability of oxygen determine both the intensity of the fermentation process and the subsequent stability of the product during storage [35].

The study of the carbohydrate component of plant substrate is a logical continuation of the changes in acidity and redox potential. The decrease in the mass fraction of sugars after fermentation is fully consistent with the generally accepted scheme: mono- and disaccharides are the main substrates for lactic acid bacteria and determine the rate of acid accumulation. For legumes, the literature separately emphasizes a significant reduction in readily available sugars with a parallel improvement in their technological and nutritional characteristics. For cereals and pseudocereals, a scenario of partial starch hydrolysis is described, which may temporarily modify the proportion of low-molecular sugars and affect the rheology of the system [35].

It is these biochemical transformations in fermented plant-based materials that create the prerequisites for the formation of a qualitatively new profile of ready-made sauce systems.

Comparison of control and fermented sauces demonstrates the effect that is typical for plant-based fermented products: a decrease in carbohydrate content and an increase in dietary fiber content in formulations that combine legumes and cereal or pseudocereal fermented ingredients. Modern reviews confirm that lactic acid fermentation can increase nutritional value, technological quality, and functional properties by changing the availability of nutrients, reducing the proportion of antinutrients, and restructuring protein fractions [36].

The introduction of fermented legumes into the composition of sauce formulations significantly changes the protein complex. During fermentation in legumes, protein proteolysis occurs. The result of this process is the formation of peptides and amino acids. At the same time, the total amount of protein remains stable, but its structure becomes completely different. These changes improve the properties of the protein component, in particular, increase solubility, moisture retention capacity, improve emulsifying ability, change taste qualities, making them more saturated and harmonious [37]. These data are fully consistent with the higher scores of organoleptic evaluation of experimental sauce samples.

Crops such as oats, barley, and quinoa are characterized by a high content of starch, polysaccharides, and dietary fiber. As a result of fermentation, this carbohydrate complex is partially changed and restructured. The introduction of fermented grain and pseudo-grain raw materials into formulations increases the viscosity of sauces and provides a stable, homogeneous structure without delamination [38].

A completely predictable consequence of the obtained experimental research results, and primarily a decrease in the sugar content, is a decrease in the energy value of the experimental sauce samples compared to the control variant.

Thus, summarizing the obtained results, it can be concluded that lactic acid fermentation of plant-based materials can be an effective technological stage in the process of producing sauces with improved functional properties. The main advantages of these sauces are the regulated formation of organic acids and the creation of the necessary acidic environment, improvement of organoleptic indicators, and reduction of energy value.

Along with this, a detailed analysis of the results has identified a number of issues that remained unresolved and determined the prospects for further research. Thus, the issue of protein proteolysis and its consequences, as one of the main factors in the formation of the umami taste of functional sauces, requires further research. A more in-depth study of the influence of the oxygen environment on changes in the redox potential of plant-based materials during fermentation and the preservation of their stable natural color is also of great scientific interest. The microbiological stability of sauces and, accordingly, their food safety, both when manufactured in restaurant establishments and in food industry enterprises, requires experimental verification as well.

In general, the obtained results of experimental research demonstrate the possible high efficiency of the proposed technology for the production of sauces, both when implemented in the HoReCa segment and the food industry, taking into account all modern requirements of regulatory documentation and consumer preferences.

The proposed technology for the production of sauces for the HoReCa segment and food industry enterprises will be based on the process of preliminary lactic acid fermentation of plant-based materials, which, according to our research, is decisive in the formation of taste and quality characteristics of the finished product. The main difference of the developed technology is the biochemical mechanisms of formation of the necessary technological and organoleptic properties, in contrast to traditional technologies, which require stabilizers, flavor enhancers, aroma, dyes, and preservatives. In view of this, the finished product will meet the modern requirements of catering establishments and food enterprises to reduce the amount of synthetic food additives and comply with the Clean Label concept.

The technological scheme of the developed process is presented in **Fig. 8.6**.

Sauce production begins with raw material reception. It must meet all normative technological and sanitary requirements. Before the start of fermentation, plant-based materials at food industry enterprises are stored in refrigeration chambers or warehouses in compliance with the regime parameters listed in **Table 8.5**.

In the conditions of enterprises of the HoReCa segment, wet plant-based materials are stored in hermetically sealed containers with proper labeling in refrigerators according to the regime parameters given in **Table 8.6**. Dry raw materials are stored in clean, dry warehouses in hermetically sealed production packaging or in hermetically sealed containers. Storage conditions and terms are shown in **Table 8.6**.

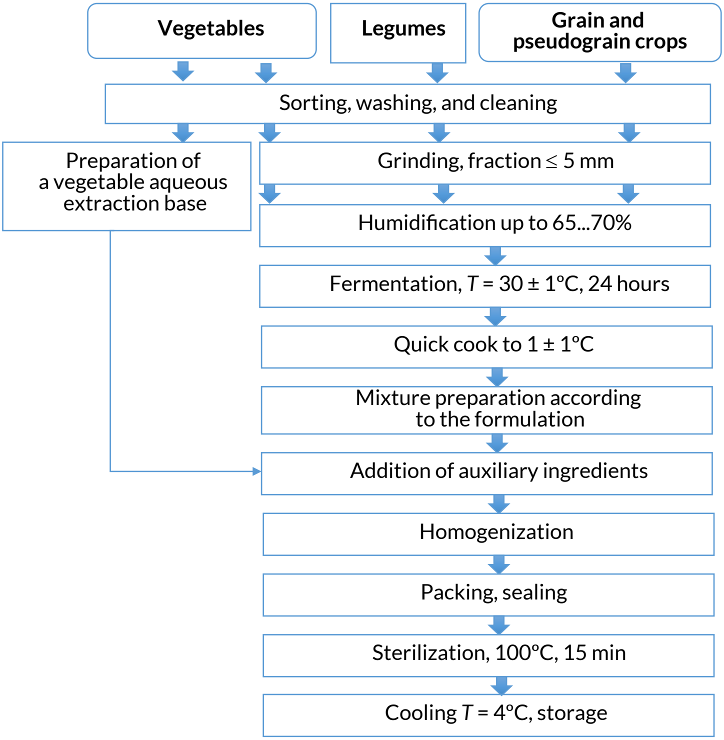

Fig. 8.6 Technological scheme for the production of functional sauces using fermented plant-based materials

The first stage of sauce production is the inspection and sorting of plant-based materials. At the same time, they remove raw materials that do not meet technological requirements, i.e. with signs of microbiological and physiological deterioration, mechanically injured, etc. In addition, various impurities are removed. Then the vegetables are washed. Water for washing raw materials must meet all sanitary requirements for drinking water.

Next, all plant-based materials are crushed to a fraction size of ≤ 5 mm. Grinding is carried out in the conditions of food industry enterprises using hammer crushers or roller or disk mills, in the conditions of catering establishments, on universal kitchen grinders, mills, blenders, and cutters. The purpose of grinding is to increase the availability of nutrients of plant substrates for lactic acid microflora.

Table 8.5 Storage conditions and terms for plant-based materials in the conditions of food industry enterprises

Plant-based material	Storage conditions		Shelf life
	temperature, °C	relative air humidity, %	
Carrots	0…2	90…95	2…4 months
Tomatoes	8…12	90…95	5…10 days
Zucchini	4…8	90…95	7…10 days
Green peas	0…2	95…98	2…5 days
Chickpeas	5…15	≤ 70	12…24 months
Red lentils	5…15	≤ 70	12…18 months
Quinoa	5…15	≤ 65	12…18 months
Spelt wheat	5…15	≤ 70	12…24 months
Oat	5…15	≤ 70	8…12 months
Barley	5…15	≤ 70	12…18 months

Table 8.6 Storage conditions and terms for plant-based materials in the conditions of HoReCa establishments

Plant-based material	Temperature of storage, °C	Shelf life
Carrots	2…4	5…10 days
Tomatoes	6…10	3…7 days
Zucchini	4…6	3…5 days
Green peas	2…4	1…2 days
Chickpeas	10…18	6…12 months
Red lentils	10…18	6…12 months
Quinoa	10…18	6…12 months
Spelt wheat	10…18	6…12 months
Oat	10…18	4…6 months
Barley	10…18	6…12 months

After grinding, the dry raw material was moistened with water at a temperature of 30–40°C to a moisture content of 65–70%. The purpose of this technological operation was to activate plant enzymes and create more favorable conditions for the intensive development of lactic acid microflora.

The prepared plant substrates were sent for fermentation. Fermentation was carried out with pure cultures of lactic acid bacteria of the species Lactiplantibacillus plantarum, which were added at a concentration of 10^6–10^7 CFU/g. The temperature during fermentation in thermal chambers or thermostats was maintained within 30 ± 1°C. Such temperature conditions are optimal for the development of this type of lactic acid bacteria and maximally reduce the risk of the development of foreign microflora. The process was stopped after 24 hours when the pH of the substrates decreased to ≤ 4.6 by rapid cooling to a temperature of 1 ± 1°C in intensive cooling chambers – in production conditions, or in shockers – in food establishments. A sharp drop in temperature to the limit of 0...1°C causes the inactivation of vegetative forms of microorganisms and stops the process of lactic acid fermentation. It should also be noted that the absence of heat treatment and the use of particularly low positive temperatures for the inactivation of microflora ensures significantly higher preservation of natural biologically active substances of plant-based materials and increases their functional properties.

When fermentation is stopped, plant ingredients in sealed containers should be stored at 1 ± 1°C in refrigeration chambers or refrigerated wall cabinets until they are used to prepare sauces, but no more than 7 days.

The formulation of functional sauces from fermented plant-based materials includes a liquid base, i.e., vegetable broth, which is prepared in advance. Carrots, onions, and celery root are used for their preparation. Vegetables are inspected, washed, cleaned, chopped into pieces 10...15 mm in size, and poured with drinking water in the ratio: 3 parts of water are added to 1 part of vegetables. Next, the mixture is brought to a boil and cooked at a slow boil for 30 minutes. After cooking, the liquid part is separated from the cooked vegetables and filtered. The obtained vegetable broth is cooled to a temperature of 18–20°C in the case of immediate use for preparing sauces, or to 1 ± 1°C for storage in refrigeration conditions for no more than 24 hours.

Sauces are prepared by mixing all the ingredients provided by the developed formulations in the homogenizer following a specific sequence: first, vegetable broth is introduced into the homogenizer, then fermented plant-based materials are added. The mixture is homogenized at a shaft rotation speed of at least 3000 rpm for 3–5 minutes until a stable, homogeneous consistency is formed. Inulin is introduced (for the FTLQ variant) and homogenized for 2 minutes. The fat phase is introduced and homogenize to form a stable homogeneous emulsion. The acidity is adjusted by adding lemon juice or the specified types of vinegar. Then, it is necessary to homogenize for 2 minutes. Salt, spices, garlic, and herbs are added. Then, homogenize to form a uniform stable consistency. The preparation of the sauce is finished by checking the organoleptic properties. The finished product is packaged in a prepared sterile container and sealed.

When preparing sauces in HoReCa establishments, the finished product is cooled to 4 ± 1°C and stored in a refrigerator at 1 ± 1°C for up to 5 days.

When preparing sauces in the conditions of food industry enterprises, after sealing, they are sterilized at 100°C for 15 minutes. During sterilization, pathogenic microflora is destroyed, which helps to extend the shelf life of ready-made sauces without the use of a cold chain. Sterilized sauces have a lower content of biologically active substances compared to fresh ones that have not undergone heat treatment, but retain a stable consistency, high functional properties, and excellent organoleptic indicators.

Therefore, implementing the developed technology will ensure the production of premium-quality sauces for HoReCa establishments, as well as sauces with an extended shelf life and high functional properties for mass industrial production and sale in the retail network.

The technological and functional advantages of the developed sauce production technology are confirmed by economic calculations (**Table 8.7**).

Table 8.7 The main economic indicators of the developed sauce technology from fermented plant-based materials

Indicators	Implementation	Cf	FCCO	FGZB	FTLQ
Cost price, UAH/kg	HoReCa	189	152	163	223
	industrial production	246	224	235	301
Sales price, UAH/kg	HoReCa	833	1000	1000	1333
	industrial production	500	500	500	650
Profit, UAH/kg	HoReCa	644	848	837	1110
	industrial production	254	276	265	349
Level of profitability, %	HoReCa	341	558	515	498
	industrial production	103	123	112	116

The results of the calculations (**Table 8.7**) show that the cost of the sauce, which is made according to the control formulation based on boiled chickpeas (Cf) in the HoReCa segment, was UAH 189 per kg and was higher than the cost of the experimental variants. This is due to the use of a larger amount of fairly valuable chickpeas and the higher energy intensity of the process of its preparation. Partial or complete replacement of chickpeas with cheaper local raw materials for Ukraine, as well as the replacement of cooking with fermentation, helps to reduce the cost of experimental samples. The maximum cost of FTLQ sauce is associated with the use of raw materials (quinoa, red lentil, red basil oil, inulin) of a higher price segment.

A comparative analysis of the cost price reveals a higher level of this indicator in industrially produced sauces compared to similar sauces in the HoReCa segment by 31–46%, depending on their type. Such an excess is explained by additional costs for heat treatment, packaging, labeling, quality control, logistics, wages, etc. At the same time, the ratio between the experimental samples fully corresponds to HoReCa sauces.

Better organoleptic properties of the sauce samples, prepared according to the experimental FCCO and FGZB formulations, made it possible to set higher sales prices in the menu of establishments, which, in turn, ensured a higher level of profit (**Table 8.7**). Cf, FCCO, FGZB industrially produced sauces had a similar selling price. However, the lower cost of the experimental FCCO and FGZB samples made it possible to obtain higher profits compared to Cf sauce. As for FTLQ sauce, it is positioned as a premium quality product in terms of functional and sensory properties. This made it possible to set a higher selling price and, therefore, to obtain a higher profit compared to all other options.

The evaluation of the level of profitability (**Table 8.7**) reflects the cost-effectiveness and characterizes the economic advantages of each sauce sample. All sauce samples, which were made according to experimental formulation, had a higher level of profitability compared to the control. The maximum level of profitability was determined in FCCO sauce, which provides it with better resistance to fluctuations in the purchase prices of raw materials and production costs.

Thus, the obtained results confirm the expediency of the production of sauces according to the developed technology based on the use of fermented plant-based materials in the conditions of the food industry and the HoReCa segment, both from the standpoint of technological and functional advantages, as well as economic effectiveness.

An important direction of further research can be the assessment of the bioavailability of mineral substances, antioxidant activity and prebiotic potential of products during the fermentation of plant-based materials, the study of microbiological stability and shelf life during the storage of ready-made sauces, as well as the approbation of the technology in the conditions of scaling and practical implementation in the conditions of craft productions of the food industry and institutions of the HoReCa segment.

The results obtained in the research process constitute an essential scientific and practical basis for the creation of innovative products, in particular in the field of sauce production, and provide opportunities for expanding their assortment.

8.8 Conclusions

As a result of the simulation of three formulations of fermented sauces using chickpeas, carrots, oats, lentils, quinoa, tomatoes, zucchini, barley, and green peas, functional products with a balanced composition were created. The choice of raw materials is based on both nutritional value and the ability to undergo enzymatic transformation.

An assessment of physicochemical changes in plant-based materials before and after fermentation was carried out, with an emphasis on determining pH, redox potential, titrated acidity, protein, fat, total carbohydrates, and sugars. A significant decrease in pH was established, which indicates an active accumulation of organic acids. At the same time, a shift of the redox potential towards a reducing environment was recorded, which is typical for anaerobic fermentation conditions, especially in samples with a high sugar content. A substantial decrease in the total content of carbohydrates, in particular sugars, was observed as a result of their utilization by microorganisms. The obtained changes indicate an improvement in the functional properties of raw materials after fermentation.

The energy value of ready-made sauces based on selected formulations was determined. It was established that samples from fermented plant-based materials have a lower energy value compared to the control, which is associated with the biochemical degradation of part of the sugars and the partial splitting of organic compounds under the action of the enzymatic activity of microorganisms.

The organoleptic evaluation confirmed the clear formation of new taste profiles in sauces from fermented plant-based materials: a balanced taste with smoky-spicy notes (FCCO), a fresh green profile with a light texture (FGZB), and a pronounced umami taste with sweet-sour tones (FTLQ). All variants showed a highly stable and homogeneous consistency.

Based on the results of experimental research, a technology for the production of functional sauces from fermented plant-based materials for the food industry and HoReCa was developed.

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.

Data availability

The data that support the findings of this study will be made available by the authors on reasonable request.

Use of artificial intelligence statement

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Authors' contributions

Marina Serdyuk: Supervision, Conceptualization, Methodology, Writing – original draft, Investigation, Project administration.

Valentyna Bandura: Conceptualization, Methodology, Writing – original draft, Investigation.

Tetiana Kolisnychenko: Methodology, Writing – original draft, Writing – review & editing, Investigation, Visualization, Validation.

Karina Palamarek: Writing – original draft, Writing – review & editing, Visualization, Formal analysis, Validation.

Olha Romanovska: Writing – original draft, Visualization, Formal analysis, Validation.

Tetiana Brykova: Writing – review & editing, Investigation, Visualization.

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