Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

Journal of Chemistry and Technologies

pISSN 2663-2934 (Print), ISSN 2663-2942 (Online).

journal homepage: http://chemistry.dnu.dp.ua
editorial e-mail: chem.dnu@gmail.com

UDC 664.64.014

SPLINE MODEL OPTIMIZATION OF THE BIOTECHNOLOGICAL PROCESS OF OBTAINING SOURDOUGH FOR BAKERY NEEDS USING FUNCTIONAL COMPONENTS

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Received 16 July 2024; accepted 25 October 2024; available online 25 January 2025

Abstract

Aim. An improved biotechnology for producing bread sourdough was developed based on pure cultures of lactic acid bacteria and functional components – hydrated flax and milk thistle seeds, lactulose prebiotic, and ethanol extract of propolis. Methods. To assess the qua lity of the bread sourdough standard physicochemical methods (titrated acidity, dough ball rising power) and microbiological methods (viable cell count of lactic acid bacteria) were used at fermentation temperatures of the flour component 22 °C and 40 °C, respectively. Results. A spline model was developed to optimize the process, specifying the optimal content of the added functional components in the bread sourdough formulation. Therefore, it is recommended to add prebiotic components to the sourdough – lactulose (4 %), hydrated flax and milk thistle seeds (4.4 %), and ethanol extract of propolis (no more than 1 %) — to increase the titer of lactic acid bacteria, reduce fermentation time, regulate the acid accumulation process (no more than 14°T), and improve the fermentation processes. The fermentation temperature of 40 °C leads to the thinning of the sourdough, an increase in titrated acidity, and a deterioration in the quality indicators of the fermentation process, such as the dough ball rising power, which should not exceed 25 minutes. While analysed samples with the addition of functional components have a stable pasty consistency with an acidity 10–14°T and a dough ball rising power of no more than 25 minutes. Conclusions. The mathematical processing of the experimental data allowed to determine the minimum fermentation time of the flour component, which ranges from 66 hours 27 minutes to 72 hours 40 minutes. Additionally, the results of the research prove that the inclusion of functional components in the bread sourdough significantly increases the number of lactic acid bacteria, intensifying the fermentation process and improving the quality of bread products.
Keywords: symbiosis of lactic acid bacteria; sourdough; functional components; bread; spline approximation

МОДЕЛЬ СПЛАЙН ОПТИМІЗАЦІЇ БІОТЕХНОЛОГІЧНОГО ПРОЦЕСУ ОТРИМАННЯ ЗАКВАСКИ ДЛЯ ХЛІБОПЕКАРСЬКИХ ПОТРЕБ З ВИКОРИСТАННЯМ ФУНКЦІОНАЛЬНИХ КОМПОНЕНТІВ

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Анотація

Мета. Розроблено покращену біотехнологію отримання хлібної закваски на основі чистих культур молочнокислих бактерій та функціональних компонентів – гідратованого насіння льону та розторопші, пребіотику лактулози, а також етанольного екстракту прополісу. Методи. Для оцінки якості хлібної закваски використано загальноприйняті фізико-хімічні (титрована кислотність, підйомна сила за кулькою) та мікробіологічні методи досліджень (кількість життєздатних клітин молочнокислих бактерій) за температур ферментації борошняної складової 22 ⁰С та 40 ⁰С відповідно. Результати. Побудована сплайн-модель оптимізації процесу із зазначенням оптимального вмісту доданих функціональних компонентів до рецептури хлібної закваски. Для інтенсифікації процесу ферментації борошняної суміші рекомендовано додавати до складу закваски пребіотичні компоненти – лактулозу (4 %), гідратоване насіння льону та розторопші (4.4 %) та спиртовий екстракт прополісу (не більше 1 %) – задля підвищення титру молочнокислих бактерій та скорочення часу ферментації, урегулювання процесу кислотонакопичення (не більше 14 ⁰Т) та покращення бродильних процесів. Обговорення. Ферментація за 40 ⁰С призводить до розрідження закваски, зростання титрованої кислотності та погіршення показників якості бродильних процесів. Досліджені зразки хлібних заквасок за якісними показниками мають стабільну форму пастоподібної консистенції з кислотністю 10–14 ⁰Т, підйомну силу за кулькою не більше 25 хв. Висновки. Математична обробка експериментальних даних дозволила встановити мінімальний час ферментації борошняної складової (від 66 год 27 хв до 72 год 40 хв).
Ключові слова: симбіоз молочнокислих бактерій; закваска; функціональні компоненти; хліб; сплайн-апроксимація.

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 doi: 10.15421/jchemtech.v32i4.308639

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

Introduction

Scientifically based rational nutrition in ecologically adverse conditions of today contributes to the preservation of human health, high physical and mental activity. The quality of nutrition plays a role as the most crucial factor in the adaptation of the human body to modern conditions of existence and increasing external stress. As a result of an unbalanced diet among all segments of the population (an increase in the number of simple carbohydrates in the daily diet), the number of patients with diabetes is increasing. Functional food products, with daily use, have high nutritional value, can support physiological functions, biochemical reactions, and improve physical and mental health of a person. Biotechnology for the production of functional food products is one of the priority branches of food biotechnology production. The problem of increasing the number of overweight people is relevant for the whole world, which confirms the need to introduce into the daily diet functional food products, especially products of daily use, which include bread that is made under conditions of full fermentation, without the use of artificial components such as improvers, preservatives, etc.

Due to the regular consumption of functional products, stimulation and activation of immune reactions occurs in the human body, thanks to which the development of many diseases is prevented.

The main functional components with which food products with increased therapeutic and preventive properties are additionally enriched include:

– dietary fibers (soluble and insoluble, in this case – hydrated flax and thistle seeds;

– vitamins and minerals (due to the addition of useful types of flour such as whole-grain spelled and chickpea flour to the recipe of bread products);

– polyunsaturated fats (vegetable oils, fish oil, omega-3 and omega-6 – fatty acids contained in flax and thistle seeds);

– antioxidants (β-carotene, vitamins E, C);

– probiotics (live cultures of lactic acid bacteria);

– prebiotics (non-digestible components of food that selectively stimulate the activity of the protective microflora of the human intestine and thereby improve its health, they are insoluble in the stomach, examples of prebiotics include lactulose, propolis extract).

The analysis of the highlighted issue indicates the relevance of the chosen research direction regarding the necessity for the development and implementation of an improved biotechnology for bread production based on sourdough with enhanced functional properties.

Literature Review. In Europe and the USA, the concept of functional nutrition, which is based on aspects of modern biotechnology, is becoming widespread [1]. Scientific research in the field of functional nutrition is aimed at maintaining human health and creating conditions for reducing the risk of diseases, especially of the gastrointestinal tract [2; 3]. Unfortunately, according to the data of the State Statistical Service of Ukraine regarding the assessment of the state of health of adolescents, in recent years there has been an increase in the total number of diseases of the gastrointestinal tract, the number of which has increased every year [4]. Also, the state of health of the population is influenced by negative environmental factors [5; 6], which are very difficult to avoid.

One of the most useful types of bread is considered to be bread made on the basis of sourdough, which includes a symbiosis of pure cultures of lactic acid bacteria (*Bifidobacterium longum*, *Lactobacillus acidophilus*), with the addition of useful types of flour, seeds, meal, plant extracts, lactulose, etc. [1; 3; 7; 8]. The authors proved that sourdough bread with a high titer of lactic acid bacteria inhibited the growth of yeast cultures that were added to the dough. A positive factor is that the bread obtained with the introduction of 30, 50 and 100 % sourdough to the dough did not differ significantly in terms of organoleptic, physico-chemical indicators, but the shelf life of such bread (without mold formation) was increased from 3 to 6 days [7]. The difference between this work and the analyzed one is that in the proposed technology, a gluten-free type of flour, namely soy flour (soy flour is successfully used as part of a nutrient medium for the cultivation of lactic acid bacteria) and finely ground low-gluten spelled flour are added to wheat flour in a ratio of 1 : 1 : 2 at the stage of making sourdough for the further fermentation process at the stage of fermentation of the dough in order to obtain a product of complete fermentation with improved organoleptic indicators, and the recipe itself proposed for bread in this scientific work does not involve the introduction of baker's yeast at any stage, because for people with the disease gastrointestinal tract is not recommended by doctors to use yeast bread products. The addition of soybean flour to the sourdough is a justified technological decision from the point of view of nutritional value and the needs of lactic acid bacteria in valuable amino acids.

The works show the role of functional components that contribute to the improvement of the quality of the nutrient medium in the flour mixture and stimulate the growth of the number of lactic acid bacteria in bread-making technology [8–14].

Scientists conducted a study on the feasibility of using non-standard raw materials such as vegetable meal, prebiotic lactulose and hydrolyzed flaxseed in the technology of enriching bread with functional components and improving its quality according to the main indicators [15–22]. The authors show that the introduction of flax seed meal into the recipe of bakery products allows to obtain a functional product, which is enriched with such physiologically functional ingredients as lignans, proteins, vitamins, micro- and macro elements, polyunsaturated fatty acids, as well as dietary fibers. Experiments have proven that plant components in the composition of the recipe contribute to the intensification of fermentation processes and the formation of corresponding structural and mechanical properties of bread products [20; 21]. The difference between the proposed biotechnological approaches of this work and those presented by the authors [20; 21] is that the authors suggest using a fairly wide temperature range of 40–60 °C for water for seed hydration, which, in our opinion, can negatively affect the enzymatic activity of plant enzymes and biologically active substances. Also, in the presented work, the stage of grinding the seeds before hydration is proposed, which allows to accelerate the mucilage process of flax and thistle seeds, as well as to avoid the inhomogeneity of the sourdough at the stage of its maturation, activation and storage.

One of the main problems faced by food biotechnology is the deterioration of products during their storage. In the biotechnology of bread production, a fundamental problem consists in bread insemination by various types of pathogenic and conditionally pathogenic microflora, which most often enters with flour as a result of its improper storage. The present microorganisms cause various "bread diseases", which was investigated in previous works [23; 24]. Molding of bread products is most often caused by molds of the genus *Aspergillus* (*A. flavus*, *A. fumigatus*, A. niger, *A. ochraceus*), *Mucor* (*M. mucedo*, *M. pusillus*, *M. spinosus*), *Penicillium* (*P. crustosum*, *P. expansum*). "Potato disease" is the most widespread and dangerous phenomenon, which is caused by a spore-forming bacterium *Bacillus subtilis*. "Bloody bread disease" is a disease caused by the bacterium "wonderful stick" - *Serratia marcescens*. "Chalk disease" is caused by yeast-like fungi of the genus *Endomyces*, which are brought in with flour. It is possible to prevent these diseases and improve the quality of the product by using a sourdough based on lactic acid bacteria that produce lactic acid and bacteriocins, as well as by acidifying the dough due to the additional introduction of organic acids or by using such a functional ingredient as alcohol extract of propolis [25–28], which is used successfully in the medical field, food and agricultural industry, as well as veterinary medicine. Propolis is a bioproduct of beekeeping.

Studies have proven that propolis has antibacterial, anti-inflammatory, antioxidant, and even oncocidal effects. The value of propolis is that it contains more than 300 different chemical compounds (esters, phenolic acids, resins, plant balsam, essential and aromatic oils, pollen, etc.). The effectiveness of propolis extract application for prevention and comprehensive treatment of coronavirus disease has been demonstrated. Its efficacy has also been shown in the therapy of type 2 diabetes, which is highly relevant nowadays and relates to modern biotechnologies for expanding the range of functional food products [28–30]. Incidentally, magniferonic acid, which was isolated from the propolis of *H. fimbriata*, exhibits anticancer properties in relation to the colon cancer cell line. Also, propolis contains coumaric compounds that have antimicrobial and antioxidant properties [31–35]. Considering the above, the authors classify propolis as a functional food product [31–35], which contains quercetin, benzoin, caffeine, ferulic and coumaric acid in sufficient quantities, as well as in small concentrations such compounds as vanillic and chlorogenic acid, epiatecin, rutin, syringic and o-coumaric acid. Also, the use of prebiotic lactulose in food technologies is relevant [20]. Many authors have proven the high efficiency of using propolis extract against various fungi [36]. Currently, propolis extracts (water- and alcohol-based) are actively used in the food industry. Its effectiveness in the technology of storing freshwater shibuti (*Barbus grypus*) fish fillets in vacuum packaging at dosages of propolis extract of 0.1 (P1), 0.3 (P3) and 0.5 (P5) % (vol./wt.) is proved [37]. In modern studies, it is proposed to use the alcohol extract of propolis in the amount of 0.1–0.5 % (relative to the mass of flour) in the technology of

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

bread production, it is also added to milk, yogurt and cheese, juice-containing drinks (the amount of the extract was 30 mg/l), beer, cookies, as well as ice cream. Experiments have proven the effectiveness of its use in terms of chemical, microbiological and organoleptic quality indicators of the products listed above [36–44].

Also, the results of research have proven the need to add propolis to sweets, for example, sherbet. The authors recommended adding propolis for storing fish, chicken shashlik in the amount of 4, 8, 12 % vol./mass and veal cutlets in the amount of 2 %, which led to a decrease in the content of microbes and a slowdown in lipid oxidation, as well as a prejudice against a rapid decrease in the pH indicator, that is, an acidifying environment. In these works, it is noted that the antioxidant activity is due to the content of phenols, and their effectiveness is higher than that of such a preservative as potassium sorbate. Experiments have confirmed that the alcohol extract of propolis in the amount of 0.9 % prevents the oxidation of vegetable oil, which was added to cookies, which confirms its powerful antioxidant properties, which were studied by many authors in works [43–49]. Technologies of using different types of propolis extracts (ethanol, water and glycerin) are considered. Among these, ethanol extract is considered the best option, as it contains the maximum number of biologically active substances, which are about 300 in propolis [43–45]. Also, the recipes of various bakery products include alcoholic beverages, which help the dough to rise faster, thanks to which such products bake better, do not become stale during a certain storage time, and have an attractive crust.

It is stated in the works that a study was conducted regarding the effectiveness of using propolis in concentrations of 0.1–0.5 % in the recipe of toasted bread made with the addition of baker's yeast, which made it possible to avoid staleness of bread by 22 % and avoid mold growth for 5 days, at the same time, a change in color was recorded, namely, bread products become darker than the control sample [45; 46]. In contrast to the mentioned works, in the presented work a study of the technology of using propolis extract in the technology of obtaining sourdough with the aim of activating the fermentation microflora (increasing the titer of lactic acid bacteria), and correcting acid formation during the preparation of sourdough, activation and its storage was carried out. In the proposed technology, it is recommended to add propolis alcohol extract at the stage of obtaining the sourdough, as it acts as a leavening agent, promotes more intensive gas formation, and intensifies the fermentation process due to the content of biologically active substances, which is confirmed by such an indicator as the rising power. Given that the presented technology does not use baker's yeast, which produces ethanol, the addition of ethanol extract of propolis to the sourdough is a reasonable solution.

Given that propolis is included in the GRAS list (Generally recognized as safe: substances that are included in this list are recognized as completely safe for humans - this designation is proposed by Food and Drug Administration, and ingredients that have the designation GRAS are exempt from the requirements of the Federal Law (FDA) to register them as food additives, drugs or cosmetics, so food products containing this mark are automatically considered "generally recognized and safe"; the list of substances recognized by the FDA as "generally recognized and safe" is updated monthly starting in 2021), it is classified as a non-toxic compound, and even, according to many scientists, is considered as a functional component that has antimicrobial and antioxidant preservative properties (How U.S. FDA's GRAS Notification Program Works (original January 2006; updated); US Food and Drug Administration; Generally Recognized as Safe (GRAS); US Food and Drug Administration; FDA's Approach to the GRAS Provision: A History of Processes; US Food and Drug Administration; List of GRAS Notices).

The works show that propolis extract increases the nutritional value of food products and this allows it to be attributed to functional components [44–49], which is relevant, in our opinion, in the technology of baking bread. Scientists have proven that propolis, like other bee products, contains many functional components, such as prebiotics, fibers, biologically active and phytochemical substances (vitamins, peptides, minerals, phenols, flavonoids, carotenoids) and organic acids, which proves the feasibility and the necessity of its use in food technology, especially in the technology of production of functional bread.

Experimental part

Object and tasks of the study. The object of research is the technology of obtaining sourdough for bread baking with an increased titer of lactic acid bacteria and functional components.

The aim of the work is to develop a spline model for optimizing the biotechnological process of obtaining sourdough for bread, enriched with functional components (seeds of oil crops such as flax and milk thistle, lactulose and alcohol extract of propolis), which have a prebiotic effect in relation to the fermenting microflora. The tasks of the research include the construction of a spline model of the optimal technological parameters of the biotechnology of obtaining sourdough based on a flour mixture (wheat, soybean and spelled flour) by optimizing the quantitative ratios of such functional components as lactulose, flax and milk thistle (hydrated) seeds, and propolis extract.

To achieve the set aim, it was necessary to solve the following tasks:

- to study the effect of prebiotics added to sourdough on physicochemical parameters (titrated acidity, rising power according to dough ball float test;
- to establish the optimal concentrations of the added functional components in the composition of the sourdough using the method of mathematical modulation of the process in order to implement the accelerated fermentation process of the nutritious flour mixture;
- to determine the effect of addition of hydrated flax seeds, milk thistle seeds, and propolis extract on the titer of lactic acid bacteria;
- to optimize the technology of obtaining sourdough by building a spline model based on experimental data and to determine the optimal number of functional components.

Materials and Methods. The main materials used for conducting the research included: liquid lactulose (Lekhim, Ukraine), finely ground wheat, soybean and spelled flour, thistle and flax seeds (Ekorod, OrganicEcoProduct, Ukraine), propolis extract ("Dim medu", Ukraine), sourdough starter of the consortium of lactic acid bacteria of the trademark Vivo (Ukraine, ISO 9001:2008, ISO 22000:2005), methylene blue (DSTU 8056:2015), distilled water (DSTU ISO 3696:2003), sodium hydroxide (DSTU 7258:2012), phenolphthalein (DSTU 8056:2015), Lactoagar and Bifidoagar ("Pharmaktiv", Ukraine, TU U 24.4-37219230-001:2011).

Main equipment: analytical scales, electronic Radwag series AS 310, R2 (Poland), dry-air thermostat TS-20, mercury thermometer TL, dough kneading machine, electric oven.

The research methodology consisted of the main stages: production of sourdough for bakery needs with the addition of prebiotics, which are stimulators of the growth of lactic acid bacteria - lactulose, seeds of thistle and flax and alcohol extract of propolis.

Biotechnology of bread production on the basis of examined sourdough samples consisted of the following stages: dough kneading, fermentation, division into dough blanks, proofing, baking, cooling. Evaluation of the examined samples of bread was carried out according to DSTU P-4588-2006 "Bakery products for special dietary consumption". The following standards were chosen to evaluate baked bread samples, due to the lack of a standard for bread made with the proposed flour mixture. Trial baking of sourdough-based bread was performed according to the standard GOST 27669-88; determination of organoleptic indicators of bread was carried out according to GOST – 65 "Bread and bakery products. Acceptance rules, methods of sampling, methods of determining organoleptic indicators and mass of products"; optimization of the parameters of the fermentation process was carried out using mathematical modeling. During obtaining the sourdough, such technological parameters of the process as titrated acidity (GOST 5670-96 "Bakery products, methods of determining acidity") and rising power according to dough ball float test were regularly monitored according to the generally accepted method [16; 18–20]. Moisture was determined by the weight method according to the generally accepted method [16; 18–20]. The number of lactobacilli and bifidobacteria was determined according to GOST 26670-91 "Food products, methods of cultivation". In order to obtain reliable research results, experimental data were subject to optimization by the method of mathematical modeling using splines. Mathematical processing of research results was carried out using Microsoft Excel. Experimental studies were carried out in triplicate. The error of experimental studies was within and did not exceed 5 %.

In order to obtain sourdough for baking bread with a stable consortium of lactic acid bacteria, it is suggested to use a commercial preparation of pure cultures of the Vivo (Ukraine) trademark, the quality of which is confirmed by certificates of the International Organization that meets European quality standards. Biological preparation Vivo is a symbiotic complex of pure cultures: *Streptococcus thermophilus*, *Lactobacillus delbrueckii ssp. Bulgaricus*, *Lactobacillus acidophilus*, *Bifidobacterium lactis*, *Lactobacillus casei*, *Lactobacillus rhamnosus*, *Lactobacillus paracasei*, *Bifidobacterium infantis*. The peculiarity of the course of the first phase of dilution of the sourdough is the introduction of the biopreparation of pure cultures of lactic acid bacteria of the Vivo sourdough starter in the amount of 1.0 g

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

per 3 kg of flour mixture in dry form without prior dilution in milk and cultivation in thermostatic conditions for growing up biomass, which made it possible to reduce the time spent on this an additional stage. To obtain the sourdough, a sifted nutritious flour mixture was used, namely, a blend of soy, spelt flour of fine milling, and wheat flour in a ratio of 1 : 1 : 2. Using the method of detailed calculations, the necessary ratio of flour mixture and water was established so that the sourdough corresponded to a moisture content of 48–50 %. Additional components (lactulose, flax and thistle seeds, propolis alcohol extract) were added to the sourdough by pre-dilution in water in predetermined proportion to the mass of flour used.

The technology for producing thick sourdough with a moisture content of 48–50 % was implemented according to the generally accepted methodology which consists of 5 cycles of dilution [16–20]. Sourdough production technology is based on the fermentation of a nutrient mixture by a stable consortium of lactic acid bacteria. Sourdough was renewed every 12 hours, and technological parameters of the process were measured once a day. In order to determine the influence of pure cultures of lactic acid bacteria on the fermentation process, acid accumulation and rising power, a parallel cultivation of sourdough without the use of additional growth stimulants (control sample) was carried out. The sourdough was divided into a dough-making part and a part for renewal. According to the classic technology of fermentation, a temperature regime of 28–32 °C is used. In the presented work, the influence of two temperature regimes for the cultivation of sourdough microflora was investigated: in the first regime, the temperature was maintained at 22 °C, and in the second, accelerated regime, the temperature was 40 °C. Additional components were introduced at the beginning of each dilution cycle according to the added mass of the flour mixture. At the end of the dilution stage, the obtained sourdough had a stable pasty consistency with an acidity of 10–14 degrees, a moisture content of 48–50 %, and a content of lactic acid bacteria of at least $1 \cdot 10^6$ CFU/cm^3 in all samples, except for the control one. The obtained sourdough in the amount of 35 % was added to the dough relative to the total weight of the highest-grade wheat flour.

In order to optimize the process of obtaining sourdough and increase of mucous substances content, it is proposed to carry out the process of hydration of flax and thistle seeds. Before hydration, the seeds were ground to a powdery state to speed up the process. Hydration of the used seeds was carried out with water, which is taken into account in the recipe for the preparation of sourdough with a moisture content of 48–50 %. The seed hydration process took place under the following conditions: the temperature of the prepared water for soaking the crushed seeds corresponded to the limits of 22–25 °C, the hydration duration was 30–40 minutes. During this time, there is an intensive swelling of the added functional components and the transition to the liquid phase of the sourdough of biologically active substances (especially mucilage-forming substances such as polysaccharides, which contribute to an increase in the titer of the fermenting microflora, in this case - an increase in the number of lactic acid bacteria). Taking into account the results of the studies, it is recommended to carry out the hydration process of powdered oilseeds at a ratio of 1 : 3 to prepared water (pre-purified tap water). It is not advisable to increase the hydration duration of crushed seeds, since the added and prepared functional components will be additionally fermented by the fermenting microflora of the sourdough even at the stage of fermentation of the dough. It is not recommended to increase the water temperature for soaking and mucilage formation, since the oilseeds contain plant enzymes that can be inactivated at temperatures above 40 °C. Wetting of crushed seeds affects the quality of bread products, as it improves the moisture retention of the dough, which means its shape stability. Similar approaches were considered in works [22; 50]. At the same time, there is an increase in the volume of bread and an improvement in its shape stability. Due to the development of the volume of the products and the loosening of the structure of the crumb, the flax seeds are more evenly distributed in the crumb. It is worth noting that the process of soaking the seeds of oil crops will contribute to the removal of phytic acid, which is also contained in wheat grains and grain products. An excess of phytic acid, according to nutritionists, leads to a violation of the process of the human digestive system and the absorption of vitamins. At the same time, the additional process of fermentation in an acidic medium at the stage of obtaining sourdough will contribute to its decomposition, and it will not harm a person, as well as such bread will not cause a feeling of heaviness in the stomach.

Results and their discussion

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

Assessment of the quality of sourdough for bakery needs. In order to establish optimal parameters of the process of obtaining sourdough with increased nutritional value, made on the basis of a fermented nutritious flour mixture from wheat, soybean and spelled types of flour with improved baking properties, the influence of functional components (crushed (hydrated) flax and thistle seeds, lactulose, and propolis alcohol extract) on the quality characteristics of the sourdough was investigated.

Today, flaxseed is one of the best dietary products of high biological value, which is used both for medicinal purposes and in cooking. This product is increasingly beginning to appear in the diet of people who are concerned about their health, because flax seeds belong to functional food products. All thanks to the composition of flax seeds, rich in such nutrients as vitamins E, D, B_2, B_3, B_4, B_5, B_6, B_9, beta-carotene, minerals, tocopherols, macro- and trace elements such as calcium, potassium, iron, magnesium, zinc, selenium, aluminum, manganese, chromium, nickel, copper, boron, iodine. The seeds contain carbohydrates in the amount of 12–26 %, essential oils 35–45 %, mucous substances – 12 %, protein – 20–33 %, are rich in unsaturated fatty acids, organic acids, enzymes [16; 18–20]. Spotted milk thistle seeds are a valuable functional component, as they contain fatty oils (30–40 %), essential oils (up to 0.1 %), resins, mucus, vitamins A, D, E, F, K, trace and macro elements (potassium, calcium, iron, magnesium, aluminum, vanadium and chromium) [16; 18–20].

Lactulose ($C_2H_{22}O_{11}$) is a synthetic oligosaccharide (4-O-β-galactopyranosyl-D-fructose, not found in nature), having a melting point of 169 °C, a glycemic index of 0 and a calorie content of 4 cal/g. Only lactic acid bacteria have enzymes capable of breaking down lactulose [20].

Propolis is a very valuable and unique beekeeping product that has natural antibiotic properties, contains pollen, which includes pure cultures of lactic acid bacteria (5–11 %), calcium, potassium, manganese, zinc, aluminum, sodium, phosphorus, iron, magnesium, copper, cobalt, vanadium, silicon, nitrogenous substances such as proteins, amides, amines, amino acids such as aspartic, glutamic, tryptophan, and phenylalanine, leucine, cystine, methionine, valine, serine, glycocol, histidine, arginine, proline, tyrosine, threonine, alanine and lysine [8; 40]. All bee products (propolis, honey, perga, pollen) are classified as fermented products, because they are fermented by lactic acid bacteria belonging to the genus *Lactobacillus*, which are representatives of the microflora of bee saliva, therefore, the use of propolis extract and metabolic products of lactic acid bacteria gives enhanced a synergistic effect on inhibiting the growth of fungi and other associated pathogenic and conditionally pathogenic microflora, which is confirmed by research by other authors [41–44; 48–49]. Taking into account the biological value of such prebiotic components (content of polysaccharides, mucus, trace and macro elements, vitamins and amino acids) as hydrated flax seeds, milk thistle seeds, lactulose and alcohol extract of propolis, the use of these functional components will contribute to the stimulation of the growth of lactic acid bacteria in the sourdough, which confirms the feasibility of their use in baking technology.

The proposed functional components – hydrated flaxseed and milk thistle seeds, as well as propolis alcohol extract are of great importance in bread biotechnology, as they possess various biologically active substances that help increase the titer of lactic acid bacteria (LAB) in sourdough and dough during fermentation. And also, they have functional features, showing a therapeutic and preventive effect.

Currently, among general practitioners, nutritionists, functional and integrative medicine doctors, there is a tendency to prescribe flaxseed (*Linum usitatissimum*) and milk thistle seeds (*Silybum marianum*) in the daily diet in the long term, as they are a valuable source not only of fats and proteins, as well as many vitamins and trace elements. These beneficial properties can be useful to many consumers who have not been diagnosed with an "allergy to flaxseed and milk thistle seeds", but the number of such patients, fortunately, in the whole world is insignificant. Experts in the field of allergy studies (according to WHO data) found that 1–3 % of adults and 4–6 % of children in the world suffer from food allergies, so the number of patients is not large, so this bread can be consumed by a sufficient number of people who are not included to this list [50].

According to the WHO, 8 food allergens have been established that most often cause allergies in people, namely cereal products (containing gluten), molluscs and crustaceans, eggs, fish, peanuts, soy, dairy products, nuts [50].

Among consumers of flaxseed, a more pronounced allergy is observed in those who are allergic to the 2S albumin protein, which has also been detected (using mass spectrometry) not only in flax seeds but also in foods such as pistachios, sunflower seeds, almonds, walnuts, peanuts,

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

buckwheat, and chickpeas. Allergy to flaxseed is a rare type of allergic reaction, which is especially manifested in individuals who work in the textile industry or have close contact in the agricultural fields with this culture, which is confirmed in scientific works [52].

Given that the amount of added functional food ingredients (hydrated flaxseed and milk thistle seeds) is moderate in the recipe, and they undergo enzymatic processing thanks to the symbiosis of pure lactic acid bacteria cultures, the functional bread can be consumed by those segments of the population who do not have cross-allergies to the aforementioned products, without additional laboratory testing for flaxseed. This is because this category of products contains the same allergenic 2S albumin protein, which is included in the WHO/IUIS allergen nomenclature. In the scientific work [53], it is mentioned regarding this claim, but in relation to the study of peanut protein (2S albumin). Considering that flaxseed contains the identical allergenic protein 2S albumin, this information is relevant to the presented work: the conformation of the epitope can be altered by various types of thermal processing, which may reduce, increase, or have no effect on binding.

Other types of processing, such as acid or enzymatic hydrolysis of the allergenic protein, affect the degree of reduction of the IgE-binding capacity of some peanut proteins. The development of new approaches to the production of food products containing peanuts is of great importance for public health and therefore requires further research, according to the authors [51; 54].

Milk thistle is a valuable medicinal plant (contains the hepatoprotector silymarin), which is widely used in medical practice, it does not contain the allergenic protein 2S-albumin, unlike flaxseed, so doctors do not recommend its use only in case of individual intolerance. Milk thistle seeds are generally considered non-allergenic, as no allergies have been found in the world. Therefore, scientists believe that people who suffer from individual food intolerance and at the same time have diseases of internal organs, the impetus for the development of an allergic reaction is various diseases of the gastrointestinal tract, nervous and endocrine systems. Also, the development of allergies is influenced by environmental factors - due to the "achievements" of modern civilization, as well as poor-quality food products, most of which contain hormones, antibiotics and preservatives [55–57].

Alcohol extract of propolis (propolisi tinctura) has been used for medicinal purposes for several millennia. It is effective against viruses and bacteria, as well as fungi. But beekeeping products are prohibited for people who are allergic to these components. Compound LB-1 is recognized as the most important allergen contained in propolis. Its composition includes three pentylin esters of caffeic acid, which come from poplar. The second significant contact allergen in propolis is phenylethyl ether of caffeic acid. It is present in it in a smaller amount than LB-1. The third main contact allergen is benzyl salicylate. This substance is less aggressive, but in the composition of cosmetic products it can lead to cross-reactivity in patients allergic to propolis. The fourth main contact allergen is benzyl cinnamate. It also has allergenic properties. In European studies, it is reported that the number of positive results in patch testing of hypersensitivity to propolis extract ranges from 1.2 to 6.6 %. Considering that the number of people who are allergic to propolis ranges from 1.2–6.6 % (depending on the country in the world), most people can consume bread products with the addition of 1 % alcohol extract of propolis [58–60].

According to scientific publications [61–63], people who are professionally related to propolis and beekeeping products are primarily at risk of developing an allergy to propolis. In case of the overdose or individual sensitivity, people most often experience headache, swelling, itching, heartburn and weakness.

According to scientists, people sensitive to propolis are most often affected by biocosmetics and biotherapy products containing it in significant concentrations [64].

As for food, propolis is primarily present in honey: some beekeepers leave a portion of bee glue in it to enhance the therapeutic properties of the product. Propolis is also used in the food industry to give shine to fresh fruits, candies, chewable vitamins, and gums [65].

According to the authors [64; 66], not all components of propolis exhibit allergic effects; some even reduce allergic reactions. The active components of propolis with anti-allergic properties are flavonoids such as chrysin, kaempferol, galangin, and pinocembrin. Among the studies conducted, green propolis is the most commonly researched type for its anti-allergic activity.

According to experiments [67; 68], propolis is considered non-toxic, non-genotoxic and safe at

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

doses of 1.4 mg/kg or about 70 mg/day. In particular, a dose of 1400 mg/kg/day in mice for 90 days did not cause histomorphological changes and was proposed as a level of no side effects. It was also confirmed that administration of ethanolic extracts of Brazilian and Chinese propolis to 5-week-old mice at a dose of 2230 to 4000 mg/kg for 2 weeks did not affect animal mortality, body weight, or histological abnormalities in tissues. Propolis and its flavonoids are widely used in traditional medicine as anti-inflammatory agents, as well as ingredients in antifungal antibiotics, anticoagulants, antiretroviral, antiallergic, and anticancer drugs. The anti-inflammatory effect of propolis is based on inhibition of platelet aggregation, rat paw edema and adjuvant-induced arthritis, eicosanoid synthesis, production of cytokines and other mediators important for the control of allergic diseases.

In the proposed bread sourdough recipe for obtaining yeast-free bread, the amount of propolis alcohol extract is insignificant (1 %). Bread with the addition of propolis alcohol extract is recommended for use by people who do not have a pronounced allergy to propolis.

Taking into account the above, it can be concluded that plant components (hydrated flaxseed and milk thistle seeds, as well as alcohol extract of propolis), which are proposed for use in the technology of obtaining functional sourdough bread with an increased LAB titer, can be added to the recipe of bakery products, taking into account the obtained technological and functional effect, because according to the WHO, only up to 6.6 % of people worldwide have allergic reactions to the food allergens listed above, so most people will be able to use these bakery products. But, on the package with the bread product there should be a marking regarding the presence of special functional components in order to avoid possible dangerous effects.

In order to evaluate the process of fermentation of the flour component by the fermenting microflora during 5 cycles of dilution of the sourdough, a preliminary determination of the acidity of the types of flour used by the titrometric method was performed. The acidity of spelled flour, wheat flour, and soybean flour was 4.1 degrees, 3.6 degrees and 10.5 degrees, respectively. After preparing the sourdough according to the above-mentioned technology, the initial acidity of the flour mixture for all samples was 5.8 degrees, the rising power according to dough ball float test for all samples of the sourdough before the start of fermentation was absent. Tables 1, 2, 3 show the results of studies of the influence of functional components (hydrated flax and milk thistle seeds, lactulose and ethanol extract of propolis) on the course of homo- and heterofermentative fermentation by lactic acid bacteria, which were previously added to the composition of sourdough for bakery needs according to the above-mentioned methodology. The process of fermentation of the flour mixture was evaluated according to the following main parameters: rising power according to dough ball float test and titrated acidity at two fermentation temperature regimes of 22 °C /40 °C. The control sample of sourdough, obtained on the basis of a flour mixture and symbiosis of pure cultures of lactic acid bacteria, did not contain functional components. Taking into account previously published research results [3], according to which the expediency of using lactulose prebiotic in the practice of obtaining sourdough for bakery needs was established, lactulose is recommended to be used in the presented technology, as it has a moisture-retaining ability, and is also an excellent substrate for the development and reproduction of lactic acid bacteria. The specified indicators make it possible to assess the depth of fermentation processes, which indicate the possibility of the end of the fermentation process and the readiness of the sourdough for baking needs, while the titrated acidity of the sourdough should not exceed 14 degrees according to Turner (better within the range of 10–14 °T), and the rising power according to dough ball float test should not exceed 25 minutes.

Table 1

Comparative characteristics of the quality assessment of experimental samples of sourdough with the addition of lactulose according to the main indicators - titrated acidity and the rising power according to dough ball float test [3]

Technological indicators	Types of sourdough cultures at 2 temperature regimes of cultivation 22 ^{0}C/40 ^{0}C								
Dilution cycle/ temperature, ^{0}C	Sourdough (flour mixture, lactulose)				Sourdough (flour mixture, lactulose, ethanol extract of propolis)				Sourdough, control sample (flour mixture)
1	2	3	4	5	6	7	8	9	10
Lactulose content, %	2	4	6	8	2	4	6	8	-

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

Continue the Table 1

Content of propolis extract, %	-	-	-	-	0.5	1.0	1.5	2.0	-
The first cycle of dilution (24 hours.)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	6.8/ 9.2	7.2/ 11.0	7.4/ 12.1	7.6/ 12.5	6,6/ 9.0	6.8/ 10.8	7.2/ 12.0	7.4/ 12.2	6.0/ 7.1
22 ^{0}C/40 ^{0}C Rising power, min.	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-
The second cycle of dilution (48 hours.)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	7.4/ 11.4	9.0/ 13.2	9.6/ 15.2	9.8/ 16.0	7.2/ 11.1	8.8/ 13.0	9.2/ 14.9	9.5/ 15.7	7.3/ 10.2
22 ^{0}C/40 ^{0}C Rising power, min.	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-
The third cycle of dilution (72 hours)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	9.0/ 14.0	12.7/ 16.9	13.1/ 18.3	13.4/ 19.1	8.6/ 13.8	11.1/ 16.7	12.4/ 18.0	13.0/ 18.9	8.2/ 12.5
22 ^{0}C/40 ^{0}C Rising power, min.	46/60	31/50	39/53	44/60	34/55	20/40	30/47	33/ 50	60/-
The fourth cycle of dilution (96 hours.)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	11.5/ 17.7	14.0/ 19.5	14.4/ 21.9	14.7/ 22.3	10.7/ 17.0	12.8/1 8.6	13.6/ 20.9	13.8/ 21.4	9.2/ 13.7
22 ^{0}C/40 ^{0}C Rising power, min.	39 / 43	20/ 38	23/ 43	35/ 48	31/ 37	17/ 31	21/ 37	30/ 41	49/ 58
The fifth cycle of dilution (120 hours)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	11.5/ 17.7	14.0/ 19.5	14.4/ 21.9	14.7/ 22.3	10.7/ 16.9	12.6/ 18.6	13.6/ 21.0	13.8/ 21.5	9.3/ 13.8
22 ^{0}C/40 ^{0}C Rising power, deg.	39 / 43	20/ 38	23/ 43	35/ 48	31/ 37	17/ 31	21/ 37	30/ 41	48/ 57

Note: "-" ball does not float to the surface

Table 2

Comparative characteristics of the evaluation of the quality of experimental samples of sourdough with the addition of flax seeds according to the main indicators - titrated acidity and rising power according to dough ball float test

Technological indicators	Types of sourdough at 2 temperature regimes of cultivation 22 ^{0}C/40 ^{0}C								
Dilution cycle/ temperature, ^{0}C	Sourdough (flour mixture, lactulose, propolis extract, crushed flax seeds)				Sourdough (flour mixture, lactulose, crushed flax seeds)				Sourdough, control sample (flour mixture)
Content of lactulose, %	2	4	6	8	2	4	6	8	-
Content of propolis extract, %	0.5	1.0	1.5	2.0	-	-	-	-	-
The content of crushed flax seeds, %	2.5	5.0	7.5	10.0	2.5	5.0	7.5	10.0	-
The first cycle of dilution (24 hours)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	6.5/ 9.1	7.2/ 10.6	7.7/ 11.4	7.8/ 12.0	7.0/ 11.0	7.7/ 13.2	8.0/ 14.1	8.2/ 14.2	6.0/ 7.1
22 ^{0}C/40 ^{0}C Rising power, min.	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-
The second cycle of dilution (48 hours)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	7.5/ 11.0	8.3/ 12.6	9.9/ 14.5	10.0 / 15.0	8.1/ 14.5	9.2/ 16.0	10.4/ 17.8	10.5/ 18.2	7.3/ 10.2
22 ^{0}C/40 ^{0}C Rising power, min..	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-
The third cycle of dilution (72 hours)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	9.0/ 13.5	10.5/ 16.0	12.7/ 17.5	12.8 / 18.0	10.0 /17. 3	13.1/ 18.7	14.0/ 19.2	14.5/ 19.4	8.2/ 12.5
22 ^{0}C/40 ^{0}C Rising power, min..	42/ 56	26/ 45	33/ 49	44/ 56	-/-	-/-	-/-	-/-	60/-
The fourth cycle of dilution (96 hours.)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	11.2/ 17.1	13.1/ 19.1	14.2/ 21.0	14.8 / 21.4	11.7 / 18.0	16.1/ 22.0	16.2/ 22.5	16.5/ 22.7	9.2/ 13.7

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

Continuation of Table 2

22 ⁰C/40 ⁰C Rising power, min.	34/ 41	21/ 36	24/ 41	35/ 47	58/-	32/ 50	35/-	-/-	49/ 58
The fifth cycle of dilution (120 hours)									
22 ⁰C/ 40 ⁰C Acidity, deg.	11.2/ 17.0	13.2/ 18.9	14.2/ 20.6	15.0 / 21.2	11.7 / 19.5	15.9/ 22.2	16.1/ 22.5	16.5/ 23.0	9.3/ 13.8
22 ⁰C/40 ⁰C Rising power, min.	33/ 41	22/ 36	24/ 41	35/ 44	37/ 50	23/ 38	27/ 47	40/ -	48/ 57

Note: "-" ball does not float to the surface

Analyzing the research results (Tables 1–3), it was established that at elevated temperature (the fermentation temperature of the flour component is 40 °C) the cultivation of lactic acid bacteria on a nutritional mixture of wheat, soybean and spelled types of flour is impractical, taking into account the results of acidity and rising power values. Despite the acceleration of the fermentation process of the flour component at a cultivation temperature of 40 °C, which is evidenced by the results of increasing acidity in all the tested samples, the time of rising power according to dough ball float test increases compared to fermentation at a temperature of 22 °C. From the point of view of the energy efficiency of this technology, it is advisable to carry out fermentation at a temperature of 22 °C. This temperature will promote full fermentation with moderate acid accumulation. Analyzing the given results of experimental studies on the expediency of using lactulose in the practice of obtaining sourdough, it is possible to assert the expediency of its use in bread baking. If it is added to the sourdough, the fermentation duration of the flour mixture is accelerated with a directly proportional increase in the number of viable cells of lactic acid bacteria, but an increase in its concentration (according to data in Tables 1–3) leads to inhibition of the fermentation process. The essence of the fermentation process of the flour mixture under the influence of the enzymes of lactic acid bacteria is that sugars, carbohydrates, starch, and fiber are transformed into alcohol, carbon dioxide, and organic acids. First, simple carbohydrates are assimilated such as glucose and fructose, and then complex ones like sucrose, maltose and lactulose are transformed. We noted that lactulose causes intense gas formation in the sourdough, which is stably preserved for several days when the sourdough is kept in the refrigerator. This is explained by the fact that lactulose is assimilated by the fermenting microflora, which leads to the intensity of gas formation as a result of fermentation processes, since lactic acid bacteria have an enzyme for breaking down lactulose, so its use can be considered appropriate in this technology for obtaining sourdough.

Table 3

Comparative characteristics of the evaluation of the quality of experimental samples of sourdough with the addition of thistle seeds according to the main indicators - titrated acidity and rising power according to dough ball float test

Technological indicators	Types of sourdough at 2 temperature regimes of cultivation 22 ⁰C/40 ⁰C								
Dilution cycle/ temperature, ⁰C	Sourdough (flour mixture, lactulose, propolis extract, crushed thistle seeds)				Sourdough (flour mixture, lactulose, crushed thistle seeds)				Sourdough, control sample (flour mixture)
Content of lactulose, %	2	4	6	8	2	4	6	8	-
Content of propolis extract, %	0.5	1.0	1.5	2.0	-	-	-	-	-
Content of crushed thistle seeds, %	2.5	5.0	7.5	10.0	2.5	5.0	7.5	10.0	-
The first cycle of dilution (24 hours)									
Continuation of Table 3									
22 ⁰C/ 40 ⁰C Acidity, deg.	6.6/ 9.1	7.0/ 10.6	7.5/ 11.4	7.9/ 12.0	6.8/ 11.0	7.5/ 13.2	7.9/ 14.1	8.2/ 14.2	6.0/ 7.1
22 ⁰C/40 ⁰C Rising power, min.	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-
The second cycle of dilution (48 hours)									
22 ⁰C/ 40 ⁰C Acidity, deg.	7.3/ 11.0	8.2/ 12.6	9.6/ 14.5	9.7/ 15.0	7.8/ 14.5	9.0/ 16.0	10.1/ 17.8	10.3/ 19.0	7.3/ 10.2
22 ⁰C/40 ⁰C Rising power, min.	-/57	-/53	-/57	-/60	-/-	-/-	-/-	-/-	-/-
The third cycle of dilution (72 hours)									

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

Continuation of Table 3

22 ^{0}C/ 40 ^{0}C Acidity, deg.	9.1. 13.5	10.4/ 16.0	12.7/ 17.5	13.3/ 18.0	9.7/ 17.3	13.1/ 18.7	13.6/ 19.2	14.1/ 19.4	8.2/ 12.5
22 ^{0}C/40 ^{0}C Rising power, min.	38/ 56	25/ 45	35/ 49	47/ 56	58/ 55	35/ 47	36/-	62/ -	60/-
The fourth cycle of dilution (96 hours.)									
22 ^{0}C/ 40 ^{0}C Acidity, deg..	10.7/ 17.1	13.8/ 19.1	14.3/ 21.0	14.6/ 21.4	11.7/ 19.5	15.3/ 22.2	15,7/ 22,5	16.2/ 23.0	9.2/ 13.7
22 ^{0}C/40 ^{0}C Rising power, min.	34/ 41	21/ 36	25/ 41	37/ 47	36/ 47	26/ 38	29/ 49	42/ -	49/ 58
The fifth cycle of dilution (120 hours)									
22 ^{0}C/ 40 ^{0}C Acidity, deg.	10.7/ 17.0	13.9/ 18.9	14.3/ 20.6	14.6/ 21.2	11.6/ 19.5	15.3/ 22.2	15.8/ 22.5	16.2/ 23.0	9.3/ 13.8
22 ^{0}C/40 ^{0}C Rising power, min.	34/ 41	21/ 36	25/ 40	37/ 44	36/ 47	26/ 38	29/ 49	42/ -	48/ 57

Note: "-" ball does not float to the surface

Increasing the acidity of sourdough, provided lactulose is added, according to the results of research by well-known scientists, occurs due to the intensification of the biosynthesis of organic acids by the fermenting microflora [17; 20; 69; 70]. The authors noted that in the dough with the addition of lactulose, an increase in the amount of lactic acid by 2.6 % was recorded, compared to the dough to which sugar was added, although the content of citric and tartaric acids remained practically the same as in the dough with the addition of sugar, while malic and of succinic acids was synthesized less by 2.5 %. Therefore, the addition of lactulose promotes the biosynthesis of lactic acid, which is a powerful preservative and inhibits the growth of pathogenic and conditionally pathogenic cultures.

The results of the research, which are shown in Tables 2 and 3, show that the addition of functional components such as hydrated flax seeds and milk thistle seeds contribute to more intensive acid accumulation, which indicates the activation of fermentation processes at a temperature of 22 °C. Although, the indicator such as rising power according to dough ball float test is somewhat higher than in the samples to which only lactulose and ethanol extract of propolis were added, which indicates an increase in the amount of the substrate (Tables 2, 3).

The introduction of propolis alcohol extract led to a decrease in acid accumulation by 8–10 % in all experimental samples, which are presented in Tables 1–3. Also, the indicator of rising power according to dough ball float test is better in all experimental samples to which propolis extract was added. The research results show that increasing the content of lactulose and oilseeds by much more than 4 % is impractical, because the excess of this substrate is not used by lactic acid bacteria during the specified fermentation duration, which is confirmed by the insignificant increase in acidity in the samples when functional components are added by more than 4 %. With regard to the indicator of rising power according to dough ball float test, an increase in the content of functional components leads to inhibition of fermentation processes, therefore, in excess, these components act as an inhibitor of enzymatic reactions of fermentation.

It was established that the addition of functional components to the dough leads to a decrease in the elasticity of gluten, and an improvement in the elasticity of the dough, which allows obtaining a sufficient volume of the products having a soft state and ensuring good taste properties. Due to the high hydration capacity of lactulose, as well as seeds that contain mucilaginous substances, products containing these components keep freshness longer than products with sugar for 5 days. The results of the research prove the feasibility of using these functional compositions in the production technology of diabetic bakery products, as well as diabetic products with prebiotic properties. As a result of the use of the proposed functional prebiotic components, due to the greater hydration capacity of saccharides and polysaccharides, which leads to an increase in free water amount in the dough, better swelling of proteins occurs, which makes it possible to obtain bread products with the appropriate specific volume and porosity. Lactulose, as well as mucilaginous and pectin substances of oilseeds, bind and retain water, which prevents the stratification of the sourdough, which has a moisture content of 48–50 %. The presence of lipids and fats in the raw material used (oilseeds) contributes to the reduction of surface tension in a multiphase system, which is the dough, which leads to an increase in the size and stabilization (stability) of gas bubbles. If there are no fat-soluble components in the raw materials, or their amount is small, the surface tension in the dough will increase, which leads to the formation of a larger number of smaller bubbles.

When the fermentation temperature increases, the number of gas bubbles on the surface of the dough and, accordingly, its porosity, can decrease due to the increase of the desorption process that is the removal of CO_2 bubbles from the dough into the environment. We noted that the addition of lactulose to the composition of the sourdough leads to faster freezing of dough blanks.

Additional introduction of crushed seeds of oil crops contributes to the saturation of the dough with lipids. In the case of hydrolysis, they form hydroperoxides, which in turn also oxidize proteins, forming a bridge, thereby increasing protein strength. Actually, the very process of protein denaturation leads to an increase in hydrophobicity, increasing emulsification. Mucilage in crushed seeds contains water-soluble pentosans, which also affect dough rheological properties and dough strength. Due to the increased protein content, oxidation-reduction reactions are more active. Thanks to the proteins, there is a disturbance of the balance in the direction of the reduction processes and the flour proteinase enzymes are activated, thus the protein structure is fixed and the strength of the flour increases. Strong flour holds air and determines the bread's specific volume, structure and porosity. But if the flour is too strong, then its volume becomes smaller. The resistance of the dough increases, and as a result its stretching worsens under the influence of the pressure of the growing bubbles of carbon dioxide. As a result of this phenomenon, the gas-forming capacity of the dough and its volume decrease. That is why it is very important to optimize the content of the main components of sourdough in order to obtain high-quality bread products. The role of lactic acid is significant, it peptizes flour proteins, reduces the content of crude fiber, the process of proteolysis of proteins and gluten occurs, proteolytic enzymes are activated, and they split proteins by their peptide bonds. Under the action of proteinase, peptides and polypeptides are formed, and amino acids are released. An increase in acidity leads to protein strengthening. In the presented technology, with the proposed composition of sourdough, such indicators as flour strength and dough stretchability are balanced.

Mathematical processing of research results by the spline method. Splines are the basis of the mathematical apparatus used in this article. Splines are a fairly popular way of solving problems of approximation and interpolation of experimental data. Most often, they are used as a tool for intermediate geometric constructions in the tasks of constructing topologies or optimizing the shapes of geometric objects. In this article, the processing of experimental data is carried out using spline surface interpolation.

This work presents spline surfaces on the example of a sample of sourdough with the addition of flax seeds, lactulose and propolis extract at a fermentation temperature of 22 °C (Figures 1, 2), which are similar to other samples of sourdough, so they are not given in this article. Analyzing the obtained research results, which are given in Tables 1, 2, 3, it becomes clear that conducting a mathematical analysis at the fermentation temperature of the flour component, which is 40 °C, is not advisable, since all samples of sourdough do not meet the established requirements for sourdough for bakery needs according to such indicators as rising power and titrated acidity. In order to reproduce intermediate points, the data discretization interval was reduced. This can be achieved by constructing a continuous function of approximation or interpolation, after which, for further calculations, the resulting function is discretized with an interval of a smaller value.

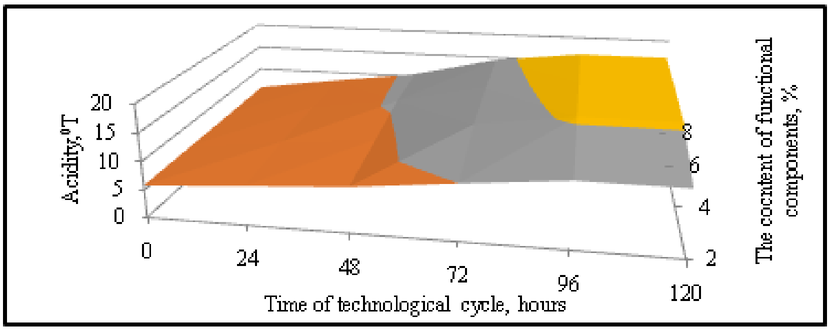

Fig. 1. Dependence of titrated acidity on the duration of the technological cycle of obtaining sourdough with the addition of lactulose and hydrated flax seeds

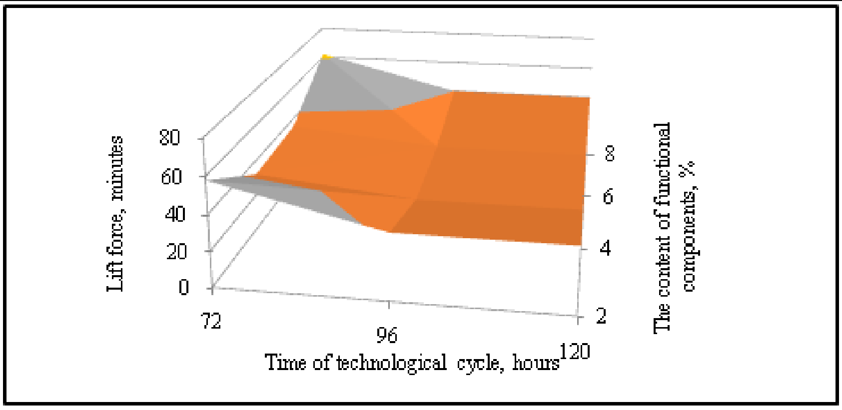

Fig. 2. Dependence of the rising power of sourdough on the time of the technological cycle of obtaining sourdough with the addition of lactulose and hydrated flax seeds

Both approximation and interpolation have their advantages. In the case of approximation, the resulting model curve does not pass exactly through the points of the given curve, but the curve levels out the measurement error and has a smoother shape.

The advantage of interpolation is obvious - model data during interpolation exactly coincide with points that are known from experimental measurements, giving a zero error of the model on known data. However, artifacts of interpolation, such as curve inflections that were not present in the experimental data, may occur at intermediate points.

In the course of the research, an approximation model was developed to select the most appropriate approach.

An interval of 10–14 degrees is considered to be an acceptable range of sourdough acidity, and the rising power according to dough ball float test should ensure a time of no more than 25 minutes for lifting the ball. The following parameters are considered optimal, in which the acceptable range of acidity and rising power is achieved with the minimum duration of the technological cycle.

The data given in Tables 1–3 form a matrix of technological parameters, which shows the dependence of rising power and acidity on the number of introduced components and process duration. The type of dependence is shown on the example of sourdough with the introduction of flax seeds, lactulose and propolis extract in Figure 2.

In the work, the optimization of the technological parameters of the biotechnology of obtaining sourdough was carried out by determining the optimal quantitative ratios of additionally introduced stimulating components in order to minimize the duration of the technological cycle of diluting the sourdough. The task is to find the minimum duration of the technological process of sourdough production, at which the organoleptic and physico-chemical indicators of the bread will be acceptable according to the standard. Qualitative characteristics of sourdough should be as follows: acidity in the range of 10–14 degrees, rising power according to dough ball float test is less than 25 minutes. According to the data given in the Tables 1–3, a matrix of technological parameters was built, and mathematical modeling based on it was carried out. Modeling allows to obtain functions of the influence of the concentration of lactulose, oilseeds and propolis extract on the duration of the technological cycle of fermentation of the flour component. This will make it possible to find the specified amount of improvers that must be added to the sourdough (lactulose, propolis extract and flax and thistle seeds) so that the duration of the technological cycle will be minimal, and at the same time the values of acidity (optimal interval 10–14 degrees) and rising power according to dough ball float test (no more than 25 min.) were within the acceptable range.

As a result of the measurements carried out, obtained experimental data are presented in the form of matrices of dependence of acidity and rising power on the number of proposed components and process duration. To perform optimization, it is necessary to reproduce continuous two-dimensional functions from experimental data. Interpolation splines, equations (1–6) were used as a means of reproduction in the work:

$$f(x) = (1-t(x))z_1 + t(x)z_2 + t(x)(1-t(x))(1-t(x)a + t(x)b), \quad (1)$$

$$t(x) = \frac{x - x_1}{x_2 - x_1}, \quad (2)$$

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

$$a = k_1(x_2 - x_1) - (z_2 - z_1), \quad (3)$$

$$b = -k_2(x_2 - x_1) + (z_2 - z_1), \quad (4)$$

$$k_1 = q'(x_1), \quad (5)$$

$$k_2 = q'(x_2). \quad (6)$$

As a result of mathematical processing of experimental data (Tables 1–3), spline models were built for sourdough with the addition of flax and thistle seeds, lactulose, and propolis extract (Figures 3, 4).

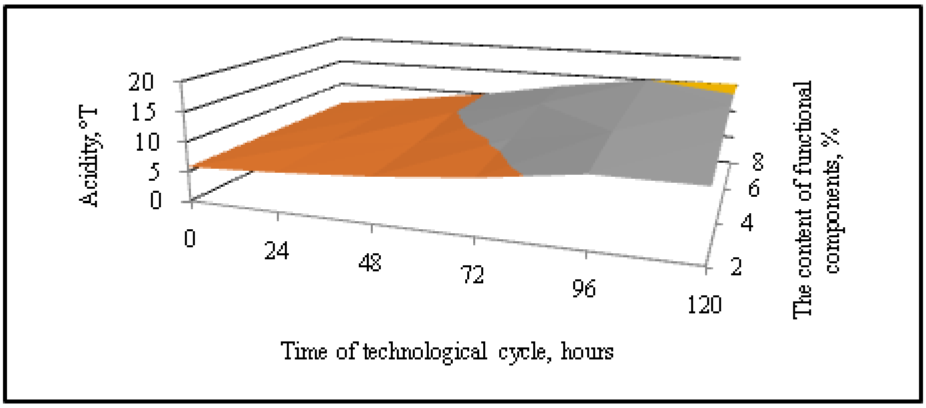

Fig. 3. Dependence of titrated acidity on the time of the technological cycle of obtaining sourdough with the addition of lactulose, hydrated flax seeds and propolis extract

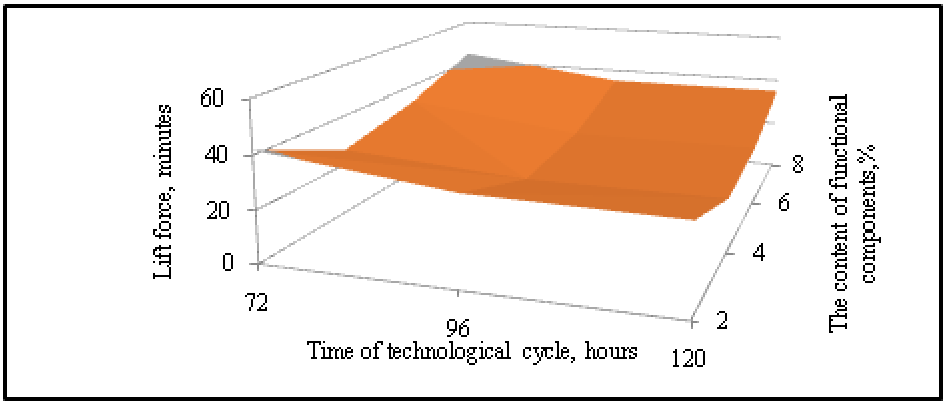

Fig. 4. The dependence of the rising power of sourdough on the time of the technological cycle of obtaining sourdough with the addition of lactulose, hydrated flax seeds and propolis extract

Thanks to the processing of experimental data, the optimal parameters of the technological process of obtaining sourdough with an increased content of pure cultures of lactic acid bacteria were obtained, the titer of lactic acid bacteria was increased due to the introduction of additional substrates such as lactulose, hydrated seeds of oil crops, as well as ethanol extract of propolis (Table 4).

Through mathematical processing of research results (Tables 1–3), the concentrations of lactulose, flax seeds, milk thistle seeds, and propolis extract were determined in the production technology of sourdough based on a flour mixture (soybean, spelled and wheat flour) with the determination of the duration of the technological cycle (Table 4). As a result of modeling the process, it was established that the sourdough samples with the addition of hydrated flax seeds and milk thistle seeds (without addition of propolis extract) are not able to reach parameters within the optimal range, as the acidity in them exceeds the limit of 14 degrees before the rising power reaches the value of 25 minutes. The titrated acidity of 14.53 and 15.19 ^{0}T are the minimum achievable values for the considered sourdoughs.

Since acidity is an obvious "bottleneck" of the technological process, simulations were carried out with the aim of finding the minimum value of acidity at a rising power not slower than 25 minutes for all samples, except for the sample of sourdough with the addition of lactulose and thistle seeds (Table 5).

Table 4

Optimal parameters of the technological process of obtaining sourdough with the addition of functional components with the minimum possible duration of the technological cycle (fermentation)

Indicators	Sourdough (flour mixture, lactulose, flax seeds)	Sourdough (flour mixture, lactulose, thistle seeds)	Sourdough (flour mixture, lactulose)
Acidity, ^{0}T	14.53	15.19	13.56
Content of functional components, %	3.7	4.38	4.34
Rising power according to dough ball float test, min.	25	26	25
Duration of the technological process of obtaining sourdough, hours	88 hours	86 hours	76 hours

As a possible solution to the problem, the addition of propolis alcohol extract is suggested. This component reduces the value of acidity, which can be seen from Tables 1–3. The results of the optimization of technological parameters for sourdough with the addition of propolis extract are shown in Table 5. Table 5 shows the parameters at which the acidity is minimal under the condition that the rising power according to dough ball float test is 25 min.

Table 5

Optimal parameters of the technological process of obtaining sourdough with the addition of functional components with the minimum possible duration of the technological cycle (fermentation) with the addition of propolis extract

Indicators	Sourdough (flour mixture, lactulose, flax seeds, propolis extract)	Sourdough (flour mixture, lactulose, thistle seeds, propolis extract)	Sourdough (flour mixture, lactulose, propolis extract)
Acidity, ^{0}T	10.76	10.45	10.34
Content of functional components, %	4.11	4.02	4.03
Content of propolis extract, %	1.03	1.01	1.01
Rising power according to dough ball float test, min..	25	25	25
Duration of the technological process of obtaining sourdough, hours	72 hours 40 min.	71 hours 43 min.	66 hours 27 min.

Evaluating the data presented in Tables 4 and 5, it can be seen that due to the addition of propolis extract in the amount of 1.01 %, it is possible to reduce the content of lactulose from 4.34 % to 4.03 %. Regarding the sourdough samples with the addition of flax seeds, thistle seeds and propolis extract, the following can be noted: when adding lactulose in the amount of 4.03 %, it is necessary to add flax seeds and thistle seeds in the amount of 4.11 % and 4.02 %, respectively, and the fermentation duration will be 72 hours 40 min. and 71 hours 43 min., respectively.

In order to establish the prebiotic effect of the functional components added to the composition of the sourdough intended for bakery needs, the titer of lactic acid bacteria was determined. The number of lactobacilli in experimental sourdough samples was determined on Lactoagar nutrient medium, and the number of bifidobacteria was determined on Bifidoagar (Figures 5, 6).

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

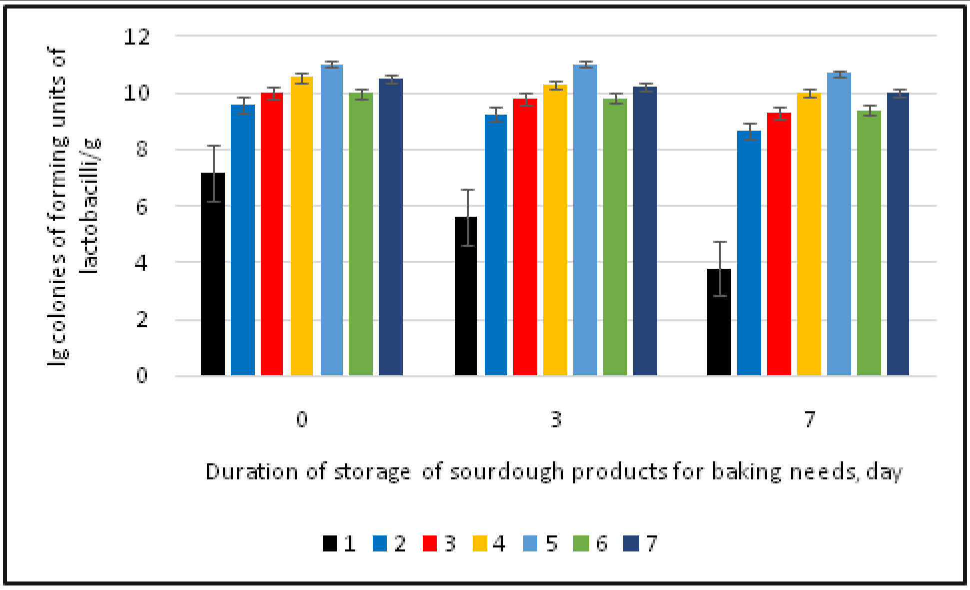

Figure.5. The result of determining the titer of lactobacilli on the 1st, 3rd and 7th day of storage of sourdough in the refrigerator at a temperature of 4 °C in test samples of sourdough: 1 – sourdough (control sample), 2 – sourdough with lactulose, 3 – sourdough with lactulose and propolis extract, 4 – sourdough with lactulose and flax seeds, 5 – sourdough with lactulose, flax seeds and propolis extract, 6 – sourdough with lactulose and thistle seeds, 7 – sourdough with lactulose, thistle seeds and propolis extract

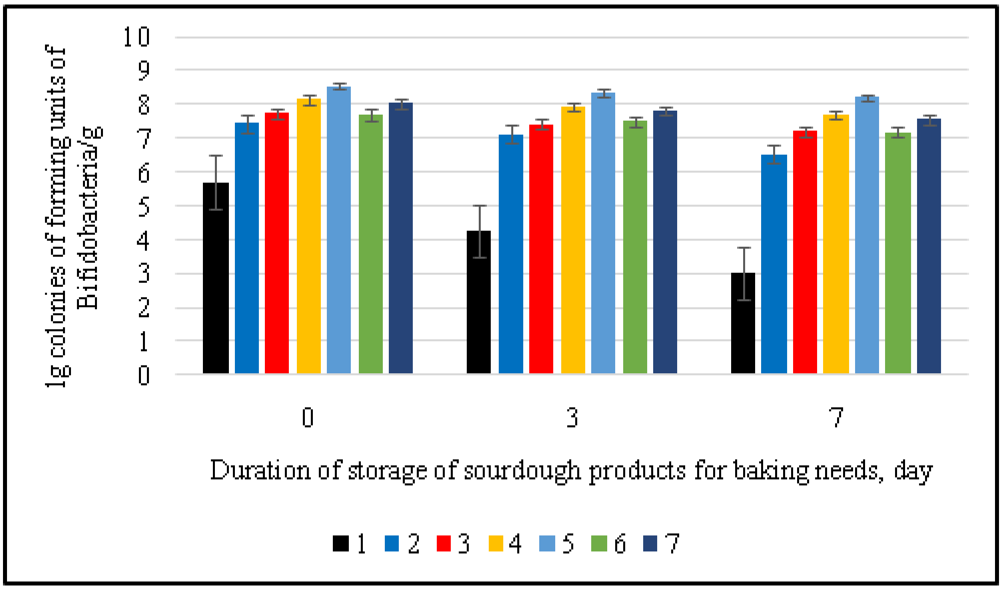

Fig.6. The result of determining the titer of bifidobacteria on the 1st, 3rd and 7th day of storage of sourdough in a refrigerator at a temperature of 4 °C in test samples of sourdough: 1 – sourdough (control sample), 2 – sourdough with lactulose, 3 – sourdough with lactulose and propolis extract, 4 – sourdough with lactulose and flax seeds, 5 – sourdough with lactulose, flax seeds and propolis extract, 6 – sourdough with lactulose and thistle seeds, 7 – sourdough with lactulose, thistle seeds and propolis extract

The presented research results (Figures 5, 6) show that the addition of functional components helps to increase the titer of lacto- and fidiobacteria, especially this applies to the prebiotic lactulose, the addition of which led to an increase in the titer of probiotic cultures compared to the control sample for lacto- and bifidobacteria by 33.5 and 30.4 %, respectively. Analyzing the presented results, it can be seen that due to the addition of propolis extract in the amount of 1.01 %, the titer of lactic acid bacteria increases by 4.5 % and 4.1 % for lacto- and bifidobacteria, respectively, which can be explained by the presence of a large number of biologically active substances in it. When oilseeds and lactulose are added to sourdours, the titer of lacto- and bifidobacteria increases by 9.8 and 9.5 % relative to flax seeds and by 4.1 and 3.3 % relative to thistle seeds. The research results show that flax seeds are the better substrate compared to thistle seeds, which can be explained by the higher content of mucous substances needed by lactic acid bacteria. When the ethanol extract of propolis is added to sourdours 3, 5, 7, there is a synergistic effect of increasing the titer of lactic acid bacteria, which allows to use these components in a complex manner according to the calculation data given in Table 5, and not individually in the technology of obtaining sourdough. Thanks to the addition of propolis extract, we note the inhibition of the titrated acidity of the sourdours, which allows maintaining a sufficiently high titer of the fermenting microflora during 3 days of storage (the number of lactic acid bacteria in sourdours 2–7 was reduced on the 3rd day by only 2.1–4.1 %, which is an insignificant loss, therefore, in our opinion, renewal and activation of sourdough for baking needs can be carried out on day 7 of storage in the refrigerator. However, this does not apply to sourdough 1 (control sample), since the loss of biological activity is noted on day 3; a decrease in the number of lactic acid bacteria (lacto- and bifido-) is about 50 %, which is caused by acidification of the environment and a decrease in the content of nutrients. Samples of sourdoughs 2-7 do not delaminate during the specified storage period in the refrigerator, which cannot be said about the control sample (sourdough starter 1). This fact allows to express the opinion that the seeds of oil crops and lactulose have a stabilizing effect during the storage of sourdough, because they have an increased moisture-retaining capacity. On the 7th day of storage of sourdours 2–7, the loss of lactobacilli and bifidobacteria is: for lactobacilli from 3 to 10 %, for bifidobacteria from 3.5 to 12 %, respectively. That is, bifidobacteria are pickier about the storage conditions of sourdough and the amount of additional functional components compared to lactobacteria, which is explained by their pronounced sensitivity to acidification of the environment. Regarding the feasibility of adding flax and thistle seeds to the sourdough recipe, it can be noted that the presence of mucous substances, polysaccharides, vitamins, macro- and microelements leads to an increase in the titer of lacto- / bifidobacteria.

The improved technology for obtaining sourdough for the needs of bread-making became possible thanks to the introduction of a consortium of lactic acid bacteria with the biological preparation of the trademark "Vivo", the use of which is due to the possibility of direct introduction of the consortium of microorganisms into the nutrient medium, which consists of the proposed types of flour (wheat, soybean and spelled) and prepared water , without prior activation of the symbiosis of pure cultures of lactic acid bacteria in thermostatic conditions, which differs from the approaches of classical technology.

Using the proposed approach allows:

- to simplify and speed up the preparation of sourdough for bread in the dilution cycle;
- ensure the stability of the properties of the obtained sourdough by creating favorable conditions for the development of lactic acid bacteria;
- to contribute to the significant spread in the industry of promising technological processes for the preparation of bakery products based on pure cultures of lactic acid bacteria without the addition of baker's yeast.

Hydration of oilseeds helps to improve fermentation processes, as flax and thistle seeds contain vegetable proteins, sugars, mucilage and pectin substances. The protein substances are represented by hydrophilic colloids. They do not melt, do not dissolve in organic solvents. But they swell in water, forming gels. These proteins are represented by glutelins (gluten is a group of storage proteins found in plant seeds, they are represented by proteins of the fraction of prolamins and glutelins) which are subject to hydrolysis in an acidic environment which are created by lactic acid bacteria enhancing the effect of hydrolysis. Therefore, the use of methods of fermentation of the flour component by the symbiosis of pure cultures of lactic acid bacteria is a reasonable technological solution from the point of view of the biosynthesis of organic acids by the fermenting microflora of the sourdough (mainly lactic and acetic ones), which contributes to the hydrolysis of proteins. In this work, it is proposed to use hydrated flax and thistle seeds. The seeds of oil crops contain carbohydrates of the first order (polysaccharides) that are well soluble in water, and polysaccharides of the second order which are high-molecular compounds, the structural elements of which are monosaccharides. They are not soluble in water and form colloidal substances. Polysaccharides include starch, the monomer of which is the remainder of glucose; fiber is a high-molecular polysaccharide that, during hydrolysis, forms a mixture of monosaccharides (galactose, mannose, arabinose, xylose). The monomers of pectin substances are methyl esters of galacturonic acid. Mucus includes the following substances: galactose, rhamnose, xylose, arabinose, glucose and galacturonic acid. When they are dissolved in water, viscous substances are formed. The seeds contain small concentrations of organic acids such as citric, succinic and acetic.

Due to the content of mucous and pectin substances, there is an adsorption interaction between lactic acid bacteria and gels of oil cultures, thanks to which their reproduction is more intense, since the polysaccharides of the studied types of seeds act as alginates, which protect the cells of the fermenting microflora.

Also, the proteins of thistle and flax seeds have catalytic properties, as they contain such biocatalysts:

- oxidoreductases – enzymes that catalyze redox reactions;
- transferases - catalyze reactions of intermolecular transfer of various chemical groups and residues;
- hydrolases – hydrolytic cleavage of intramolecular bonds;
- lyases – cleavage of groups with the formation of double bonds;
- lipases - hydrolysis of acylglycerols.

In the works [21; 22], based on research, it is recommended to add 10–12 % of hydrated flax seeds to the bread recipe (at the stage of dough kneading), which ensures high quality of the yeast bread product according to the main indicators such as porosity, moisture, as well as crumb quality. In the presented work, it is proposed to add oilseeds at the stage of obtaining the sourdough in combination with the prebiotic lactulose (4.34 % without the addition of propolis extract and 4.03 % with the addition of the extract). This biotechnological approach is proposed in order to increase the fermentation duration of hydrated seeds starting from the stage of obtaining or activating the sourdough, continuing it at the stage of dough fermentation, since this bread product is a product of lactic acid fermentation (without the addition of baker's yeast). Also, thanks to this approach, it was possible to prejudice the process stratification of sourdough during its storage in the refrigerator for 7 days.

The widespread use of propolis extract in food technology is explained by the safety of this product and increased functional characteristics. In the works it is noted that the process of biotransformation of bee products by the symbiosis of pure cultures of lactic acid bacteria of the genus *Lactobacillus* leads to the elimination of components that cause allergies in humans (phenolic compounds), therefore, the process of propolis extract fermentation by sourdough fermenting microflora is proposed at the stage of its preparation and activation, and according to the scientific statements of the authors, such approach will allow to obtain a safe product for the wider population [71; 72]. The researchers evaluated the bioconversion of propolis by various representatives of the genus *Lactobacillus* at a temperature of 30 °C and proved their influence on the phenolic profile.

Thanks to the addition of propolis ethanol extract in the amount of 1.01 %, it was possible to restrain acid accumulation in the sourdough resulting from an increase in the titer of lactic acid bacteria.

Unfortunately, in similar works on bread production [39; 40], the titrated acidity of bread was not determined taking into account the added concentrations of propolis extract, but in works on the production of cheese and milk preservation, deodorized propolis extract was added in the amount of 1–5 %, which led to a slowdown in the process of increasing acidity in the finished product and allowed to increase its shelf life. Therefore, the research results obtained in this work are correlated with the analyzed scientific works. An increase in the acidity of sourdough or dough leads to the appearance of an unpleasant sour taste for bread products made with sourdough, and also makes the crumb of bread denser and tighter. Increased acidity of bread is a sign of over-fermented bread, which has a negative effect on gastric secretion, since such bread contains an increased content of lactic and acetic acids, which can lead to exacerbation of gastritis. Bread with high acidity has worse porosity, is considered as non-standard and is not allowed for sale to the public. If, in the proposed technology, the fermentation duration of the sourdough is reduced in order to avoid excessive acid formation, then, due to the incomplete fermentation of the flour mixture, the time of the rising power according to dough ball float test increases, and as a result, the quality of the bread is inadequate according to such indicators as porosity, elasticity and volume. Considering the fact that the propolis extract was added in a small amount, and even at the stage of obtaining or activating the sourdough, the baked bread did not differ in taste, which was also confirmed in similar published works [45; 46].

We have established that the introduction of prebiotic, functional components at the stage of obtaining the sourdough shortens the duration of kneading the dough by 2 minutes. Addition of

Journal of Chemistry and Technologies, 2024, 32(4), 1073-1097

hydrated seeds with a high content of oils increases the elasticity of the dough and improves the quality of the bread. The sliding of the structural components of the protein-carbohydrate framework is facilitated, and as a result, the process of stretching the dough is facilitated without the destruction of carbon dioxide bubbles. Thanks to the optimization of the technology for obtaining sourdough, all experimental samples of bread baked in accordance with this technology fully meet the established standard of DSTU P-4588-2006 "Bakery products for special dietary consumption" in all evaluated parameters.

By adding propolis extract to the sourdough recipe, not only is the accumulation of acidity restrained, which negatively affects the fermentative microflora and the quality of bread products when it exceeds optimal levels, but such addition also leads to an increase in the titer of lactic acid bacteria. This is confirmed by the presence of more than 300 bioactive substances, most of which are essential for bacteria growth and reproduction. According to the presented justifications, it is possible to claim that this functional product has a prebiotic effect, which is also confirmed in the works of other researchers [72–75]. The authors investigated the process of ensiling alfalfa with the symbiosis of pure cultures of lactic acid bacteria in the presence of propolis extract in amounts of 0.5 and 1 %, which led to an increase in the number of lactic acid bacteria to $5.9 \cdot 10^{10}$ CFU/g, which in turn correlates with the given research results. Also, in this work, it is noted that only if 1 % of propolis extract is added, the presence of yeast is not noted. Moreover, the authors established that the content of lactic and acetic acids in silos statistically decreases with the addition of propolis in the amount of 1.0 %.

The authors proved [75] that when propolis extract was added in the amount of 5%, the taste properties of the cheese did not deteriorate, as a result of the addition of propolis in the amount of 600 and 1000 mg/kg the growth inhibition of *S. thermophilus*, *B. bifidium* and *L. bulgaricus* occurs in all samples of Kareish cheese, which in turn correlates with the obtained research results.

Researchers determined [76] that the content of mucous substances (alginates) in flax seeds contributed to increasing the titer of various strains of lactobacilli and such substances have high antioxidant properties, which in turn confirms our statements regarding these issues.

Taking into account the obtained research results and their mathematical processing, a scientific novelty was formed.

1. For the first time, the expediency of simultaneous use of the prebiotic lactulose (4 %), hydrated flaxseed (4.4 %) or milk thistle seeds (4 %) with the addition of propolis alcohol extract (1 %) in the technology of obtaining bread sourdough for unleavened bread was proven. Experiments have shown that due to the simultaneous use of hydrated flaxseed or milk thistle seeds with lactulose, there is an intensification of acid accumulation (Table 2) and gas formation, and also, the addition of functional substrates leads to an increase in the titer of LAB, which is confirmed by the results of microbiological studies (the concentration of lacto- and bifidobacteria in different versions of starter cultures, Fig. 5).

2. Thanks to the conducted research and mathematical processing of research results, for the first time the expediency of adding propolis alcohol extract in the amount (1 %) was confirmed, which leads to the intensification of fermentation processes and a controlled increase in acid accumulation during the fermentation of the flour component in the case of the simultaneous addition of hydrated flaxseed or milk thistle seeds with lactulose (Table 4, 5). Since the increase in the content of disaccharides and polysaccharides in the sourdough due to the functional components - lactulose and flaxseed or milk thistle seeds, leads not only to an increase in the titer of LAB, but also to acidification of the sourdough and deterioration of its quality, there is a need to regulate the acidity during the fermentation of the flour component. It is known that an increase in sourdough acidity leads to a deterioration of the organoleptic properties of bread - the appearance of a sour smell and taste in finished bread products, as well as an increase in sourdough or dough acidity will lead to a decrease in gas formation at all stages of the process and a decrease in the gas-holding capacity of the dough, due to which the specific volume and porosity of bread products will decrease. In the proposed biotechnology for the production of bread sourdough, the titrated acidity is reduced by 8–10 % thanks to the addition of alcohol extract of propolis, while the porosity of the bread and the specific volume are kept at a sufficiently high level throughout the entire technological cycle.

3. Thanks to the conducted experiments, it was proven for the first time that the addition of propolis extract in the amount of 1 % to the

Journal of Chemistry and Technologies, 2024, *32*(4), 1073-1097

composition of the sourdough increases the titer of LAB by 4.8 and 4 % relative to lacto- and bifidobacteria. It is known that increasing the titer of LAB in sourdough or dough has a positive effect on the dough loosening, which is ensured by the sufficient presence of LAB and their ability to ferment sugars with the formation of carbon dioxide and fermentation products.

4. Thanks to the mathematical processing of the obtained research results, it was established that the addition of propolis extract in the amount of 1 % will reduce the content of lactulose in the sourdough starter from 4.34 % to 4.03 %. The following technological parameters of the process were determined for the samples of sourdough with the addition of flaxseed, milk thistle seeds and propolis extract: when adding lactulose in the amount of 4.03 %, it is necessary to add flaxseed and milk thistle seeds in the amount of 4.11 and 4 %, respectively, while the fermentation time will be 72 hours 40 minutes and 71 hours and 43 minute, which is significantly shorter than the fermentation time without the addition of propolis alcohol extract.

5. Experiments and the method of mathematical modeling indicated that thanks to the addition of propolis alcohol extract (1 %), the fermentation time of the flour component is reduced by 17.4 % – for sourdough with the addition of lactulose and hydrated flaxseed, by 16.6 % – for sourdough with the addition of lactulose and hydrated thistle seeds, and by 12.56 % – for sourdough with the addition of lactulose (without hydrated seeds) (Table 4, 5).

The scientific significance of the presented research results lies in the establishment of the role of the alcohol extract of propolis on the course of biochemical processes in the sourdough, which directly affect the quality indicators of bread products, which are standardized by the DSTU, the optimal amount of propolis extract was calculated by mathematical modeling, taking into account the content of hydrated flax or thistle seeds, as well as lactulose that are stimulators of fermentation processes, as the duration of the fermentation process depends on their content. The obtained research results and the built mathematical model of the technological process of obtaining sourdough for bakery needs can be used in the future for further research aimed at optimizing the fermentation processes of the flour component and expanding the composition of functional components in the composition of bread sourdough based on pure cultures of the LAB in order to create an improved recipe of yeast-free bread with increased functional properties.

The practical value of the obtained research results lies in the expansion of the possibilities of using such functional components as hydrated flaxseed and milk thistle seeds, as well as alcohol extract of propolis, in the bakery industry, taking into account their stimulating effect on the growth of the titer of fermenting microflora, represented by pure cultures of the LAB. Also, there is an opportunity to expand the range of high-quality bread products that meet the requirements of DSTU, which are enriched with nutrients due to the addition of hydrated flax and thistle seeds in the optimal amount, determined by experiments with clarification due to mathematical processing of research results, provided that no simple sugars like sucrose, fructose, glucose are added, which stimulate the fermentation processes of bread, and increase its calorie content.

Conclusions

Recent studies show that microbial disturbances in the human intestine play a significant role in the development of metabolic diseases (diabetes, obesity, etc.). These disorders most often occur due to the consumption of refined foods that do not contain dietary fibers that act as prebiotics. Regular use of functional food products contributes to the maintenance of normal intestinal microflora, and considering that bakery products are products of everyday use, improving the technology of their production is a relevant and important issue today. It is the fermentation of the flour component by the sourdough microflora that increases the nutritional value of this product at the expense of:

1) modulation of the dietary fiber complex with its subsequent fermentation;

2) biosynthesis of exopolysaccharides with prebiotic properties;

3) biosynthesis of valuable metabolites of lactic acid bacteria in the fermentation process, which directly affect the intestinal microflora and the state of human health.

The results of this research contribute to the study of biotechnological approaches in the field of obtaining sourdough for bakery needs, which is enriched with functional, prebiotic components such as oilseeds, lactulose and ethanol extract of propolis. Based on the obtained results of research and mathematical processing, the possibility of complex use of prebiotics such as lactulose (4.34 %), oilseeds (flax 4.11 % and milk thistle 4.02 %) with the addition of propolis extract in the amount of 1.02 % relative to the mass of the flour mixture was established, while the calculated fermentation duration will be between 66 h. 27 minutes. up to 72 h. 43 min. for the investigated types of sourdoughs, respectively. It is important to note that the functional components added to the sourdough recipe help to increase the biomass of pure cultures of lactic acid bacteria from 4 to 9 %, which is an important factor in the technology of production of bread products without the use of baker's yeast.

This work presents the new results of research on the use and combination of oilseeds, lactulose and propolis extract, in the technology of obtaining sourdough, which led to the regulation of acidity (10–11 ^{0}T), maintaining the optimal value of the rising power according to dough ball float test (no more than 25 min.) relative to the minimum technological duration of fermentation of the flour component while maintaining the maximum titer of lactic acid bacteria (lacto- and bifido-). The use of such a technological method will allow to continue the fermentation of the added components at the stage of fermentation of the dough, which will lead to a more complete hydrolysis of the components and improve the quality of bread products that meet the standard DSTU P – 4588-2006 "Bakery products for special dietary consumption" in all parameters.

Undoubtedly, in the future, it is necessary to carry out further research on the clarification of the content of mucus and pectin substances, as well as phenolic and polyphenolic components, which have antioxidant properties and are contained in sufficient quantities in the seeds of oil crops and propolis, also, it is necessary to consider the influence of these components not only within the generic area, but also for each type of lactic acid bacteria that are present in sourdough for baking bread.

Acknowledgments

This research work has been supported projects "Scientific developments of the technology of production of functional bakery products" (state registration number 0121U111446), as well as "The influence of biologically active substances on the course of fermentation processes in the technology of production of functional bread" (state registration number 0123U102191) of a scientific direction "Technical Sciences" National Aviation University funded by the Ministry of Education and Science and of Ukraine.

References

[1] Neposhyvaylenko, N., Kornienko, I. (2020). Current problems of individual health of adolescents and the use of modern food biotechnology to solve them. *Actual problems of natural sciences: modern scientific discussions*, 391–409. https://doi.org/10.30525/978-9934-26-289-0-18.

[2] Snigdha, M., Debapriya M., Swati M. (2019). Applications of Probiotics as a Functional Ingredient in Food and Gut Health. *Journal of Food and Nutrition Research*, *7*(3), 213–223. https://doi.org/10.12691/jfnr-7-3-6.

[3] Korniienko, I., Lutsenko, O., Isaienko, V., Baranovskyi, M., Anatskyi, A., Laricheva, L. (2021). Optimization of technological parameters of nutrition mixture fermentation process with the use of spline interpolation. *Chemistry and Technologies*, *29*(1), 118–136. https://doi.org/10.15421/082115.

[4] Guidebook "Indicators of population health. State of health of children aged 0-17 inclusive (pediatrics)" 2014-2018. State institution "Center of Medical Statistics of the Ministry of Health of Ukraine". (Electronic resource). Access mode: http://medstat.gov.ua/ukr/MMXIV.html. (in Ukrainian).

[5] Omelych, I., Neposhyvailenko, N., Zberovskyi, O., Kornienko, I. (2021). Improvement of the methodology for the assessment of soil biogenig pollution through the use of geological approaches and the use of information technologies. *Eastern European Journal of Entepise Technologies*, *3*(111), 42–56. https://doi.org/10.15587/1729-4061/2021.235845.

[6] Cherniak, L., Mikhyeyev, O., Madzhd, S., Lapan, O., Dmytrukha, T., Korniienko. I. (2021). The Usage of Plant Test Systems for the Determination of Phytotoxicity of Contaminated with Petroleum products soil. *Journal of Ecological Engineering*, *22*(6), 66–71. https://doi.org/10.12911/22998993-/137363.

[7] Kyung, S.L., Geum, S.P. (2015). Quality Characteristics of Bread Containing Sourdough Using Various Grain Flours. *Korean Journal of Food and Cookery Science*, *31*(3), 264–279. https://doi.org/ 10.9724/kfcs.2015.31.3.264.

[8] Alday, E., Navarro-Navarro, M., Garibay-Escobar, A., Robles-Zepeda, R., Hernandez, J., Velazquez, C. (2016). Advances in Pharmacological Activities and Chemical Composition of Propolis Produced in Americas. In: *Beekeeping and Bee Conservation -Advances in Research,* 99–151. https://doi.org/10.5772/63145.

[9] Jin Hee Park, Chon-Sik Kang, Kyeong-Min Kim, Kyeong-Hoon Kim. (2020). Characteristics of Sourdough Breads Baked Using Korean Bread Wheats. *Korean Journal of Breeding Science*, *52*(4), 408–418. https://doi.org/10.9787/KJBS.2020.52.4.408.

[10] Pasqualone, A., De Angelis, D., Squeo, G., Difonzo, G., Caponio, F., Summo, C. (2019). The Effect of the Addition of *Apulian black* Chickpea Flour on the Nutritional and Qualitative Properties of Durum Wheat-Based Bakery Products. *Foods*, 8(10), 504. https://doi.org/ 10.3390/foods8100504.

[11] Mohammed, I., Ahmed, A., Senge, B. (2014). Effects of chickpea flour on wheat pasting properties and bread making quality. *J Food Sci Technol*., *51*(9), 1902–1910. https://doi.org/10.1007/s13197-012-0733-9.

[12] Korniienko, I.M., Huljajev, V.M., Anatskyj, A.S., Černenko, Ja.M., Filimonenko, O.Ju., Mončenko, O.A.,

Sobol', O.O. (2021). [The influence of functional components on the titer of lactic acid bacteria of "VIVO"]. *Collection of scholarly papers of Dniprovsk State Technical University (Technical Sciences)*, 2(38), 118–130. (in Ukrainian). https://doi.org/10.31319/2519-2884.39.2021.12.

[13] Korniienko, I.M., Huljajev, V.M., Anatskyj, A.S., Černenko, Ja.M., Nepošyvajlenko, N.O., Hordijenko, B.V., Hudkova, I.H. (2022). [The method of production of yeast-free bakery products]. Kyiv: Ukrainian Institute of Intellectual Property publishing house. (in Ukrainian).

[14] Korniienko, I., Anatskyi, A., Baranovskyi, M. (2022). Providing Wasteless Manufacturing of Aviation Biofuels by Using Camelina Seed Residues for Producing Functional Bread. In: *Chemmotological Aspects of Sustainable Development of Transport. Sustainable Aviation*, *Springer*, *Cham*., 127-153. https://doi.org/10.1007/978-3-031-06577-47.

[15] Korniienko, I. M., Kuznietsova, O. O., Garkava, K. H. (2023). Formation of individual human health: modern biotechnological trends in the use of probiotic microorganisms in functional sourdough bakery products. In: *Scientific and Educational Dominicans of natural sciences*, «Baltija publishing», Riga, Latvia. https://doi.org/10.30525/978-9934-26-289-0-18.

[16] Drobot, V. I. (2019). [Guidebook on the technology of bakery production.] Kyiv: National University of Food Technologies publishing house. (in Ukrainian).

[17] Drobot, V.I., Iževs'ka, O. P., Bondarenko, Ju. V. (2016). [Flax seed meal in the technology of bakery products. Technology and food safety]. *Food Science and Technologies*, *10*(3), 76–81. (in Ukrainian). https://dx.doi.org/10.15673/fst.v10i3.183.

[18] Drobot, V. Y. (1988). [The use of non-traditional raw materials in the baking industry]. Kiev: "Urožaj" publishing house. (in Russian).

[19] Drobot, V.I., Stepanenko, T.O. (2006). [*Industry technology (bakery production)*]. Kyiv: National University of Food Technologies publishing house. (in Ukrainian).

[20] Drobot, V. I. (2002). [*Bakery production technology*]. Kyiv: "Logos" publishing house. (in Ukrainian).

[21] Bondarenko, Ju.V., Andronovyč, H.M., Hryščenko, A.M., Anyč, A.M. (2020). [Application of the operation of hydration of flax seeds in the production of wheat bread]. *Scientific works of NUFT*, 26 (2), 232-243. (in Ukrainian). https://doi.org/10.24263/2225-2924-2020-26-2-24.

[22] Bondarenko, Ju. V., Juščenko, H.P., Iževs'ka, O.P. (2015). [Use of flax seed meal to enrich wheat bread]. International scientific and practical conference: Development of food production of restaurant and restaurant-hotel industry and trade: problems, prospects, efficiency, 58–59. (in Ukrainian).

[23] Korniienko, I.M. (2020). [Assessment of biosafety of flour and leaven for bakery needs by microbiological indicators]. *Collection of scholarly papers of Dniprovsk State Technical University (Technical Sciences)*, 2(37), 128–131. (in Ukrainian). https://doi.org/10.31319/2519-2884.37.2020.23.

[24] Jaroševyč, T.S. (2011). [Modern methods of diagnosing bread potato diseases and means of preventing their spread]. *Bulletin of Khmelnytskyi National University (Technical Sciences)*, 2, 121–123. (in Ukrainian).

[25] Correa, FT., de Souza, AC., de Souza Júnior, EA, Isidoro, SR, Piccoli, RH, Dias, DR, de Abreu, LR. (2019). Effect of Brazilian green propolis on microorganism contaminants of surface of Gorgonzola-type cheese. *J Food Sci Technol*, *56*(4), 1978–1987. https://doi.org/10.1007/s13197-019-03664-2.

[26] Alday, E., Navarro-Navarro, M., Garibay-Escobar, A., Robles-Zepeda, R., Hernandez, J., Velazquez, C. (2016). Advances in Pharmacological Activities and Chemical Composition of Propolis Produced in Americas. In: *Beekeeping and Bee Conservation - Advances in Research*, 99–151. https://doi.org/10.5772/63145.

[27] Arung, E. T., Ramadhan, R., Khairunnisa, B., Amen, Y., Matsumoto, M., Nagata, M., Kusuma, I. W., Paramita, S., Sukemi, Y., Tandirogang, N., Takemoto, N. (2021). Cytotoxicity effect of honey, bee pollen, and propolis from seven stingless bees in some cancer cell lines. *Saudi Journal of Biological Sciences*,*28*(12), 7182–7189. https://doi.org/10.1061/j.sjbs.2021.08.017.

[28] Grosso, G., Tangarife, M. (2021). Effect of bee propolis as a hypoglycemic agent and diabetes control. *International Journal of Family & Community Medicine*, *5*(6), 223–227. https://doi.org/10.15406/ijfcm.2021.05.00249.

[29] Berretta, A. A., Silveira, M. A. D., Cóndor Capcha, J. M., De Jong, D. (2020). Propolis and its potential against SARS-CoV-2 infection mechanisms and COVID-19 disease. *Biomedicine and Pharmacotherapy*, 131. https://doi.org/10.1016/j.biopha.2020.110622.

[30] Guler, HI., Tatar, G., Yildiz, O., Belduz, AO., Kolayli, S. (2021). Investigation of potential inhibitor properties of ethanolic propolis extracts against ACE-II receptors for COVID-19 treatment by molecular docking study. *Archives of Microbiology*, *203*(6), 3557–3564. https://doi.org/10.1007/s00203-021-02351-1.

[31] Arung, E.T., Ramadhan, R., Khairunnisa, B., Amen, Y., (2021). Cytotoxicity effect of honey, bee pollen, and propolis from seven stingless bees in some cancer cell lines. *Saudi J Biol Sci*., *28*(12), 7182–7189. https://doi.org/10.1016/j.sjbs.2021.08.017.

[32] Özkök, A., Keskin, M., Tanuğur Samancı, AE., Önder, YE, Takma, Ç. (2021). Determination of antioxidant activity and phenolic compounds for basic standardization of Turkish propolis. *Appl Biol Chem*., *64*(1), 37. https://doi.org/10.1186/s13765-021-00608-3.

[33] Mădălina, MN., Josceanu, AM., Isopescu, RD., Isopencu, GO., Geana, EI., Ciucure, CT., Lavric, V. (2021). Polyphenolics profile effects upon the antioxidant and antimicrobial activity of propolis extracts. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-97130-9.

[34] Anjum, SI., Ullah, A., Khan, KA. (2019). Composition and functional properties of propolis (bee glue): A review. *Saudi Journal of Biological Sciences*, 26(7), 1695–1703. https://doi.org/10.1016/j.sjbs.2018.08.013.

[35] Oak, SJ., Jha, R. (2019). The effects of probiotics in lactose intolerance: a systematic review. *Crit. Rev. Food Sci. Nutr*., *59*(11), 1675–1683. https://doi.org/10.1080/10408398. 2018.1425977.

[36] Lorini, A., Wobeto, C., Bonaldo, SM. (2018). Chemical composition and antifungal activity of propolis on *Aspergillus flavus*. *Bioscience Journal*, *34*(5), 1298–1307. https://doi.org/10.14393/BJ-v34n5a2018-36601.

[37] Duman, M., Özpolat, E. (2015). Effects of water extract of propolis on fresh shibuta (*Barbus grypus*) fillets during chilled storage. *Food Chemistry*, *189*(15), 80–85. https://doi.org/10.1016/j.foodchem.2014.08.091.

[38] Korkmaz, BI., Bilici, C., Korkmaz, S. (2020). Sensory, pH, synaeresis, water-holding capacity, and microbiological changes in homemade yogurt prepared with maca

(*Lepidium meyenii*) powder and propolis extract. *International Journal of Gastronomy and Food Science*, 23 (5). https://doi.org/10.1016/ijgfs.2020.100291.
[39] Betancourt, N., García-Contreras, L., Sánchez, T. (2015). Propolis in Dogs: Clinical Experiences and Perspectives (A Brief Review). *Open Journal of Veterinary Medicine*, 05(01), 11–17. https://doi.org/10.4236/ojvm.2015.51002.
[40] Elkassas, W.M., Yassin, S.A., Taksira, D.M. (2023). Effect of adding propolis on quality standards of raw milk and yoghurt. *Current Research in Nutrition and Food Science Journal*, *11*(1), 231–245. https://doi.org/10.12944/CRNFSJ.11.1.17.
[41] Bankova, V., Popova, M., Trusheva, B. (2016). New emerging fields of application of propolis. *Macedonian Journal of Chemistry and Chemical Engineering*, *35*(1), 1–11. https://doi.org/10.20450/mjcce.2016.864.
[42] Mahdavi-Roshan, M., Gheibi, S., Pourfarzad, A. (2021). Effect of propolis extract as a natural preservative on quality and shelf life of marinated chicken breast (chicken Kebab). *LWT*, 155. https://doi.org/10.1016/j.lwt.2021.112942.
[43] Azime Özkan Karabacak, AO., Senanur Durgut, O.O., Bağatırlar, S.R., Kaçar, O., Korukluoğlu, M. (2021). Development of purple basil (Ocimum basilicum L.) sherbet fortified with propolis extract using response surface methodology. *Journal of Food Measurement and Characterization*, *15*(6), 4972–4991. https://doi.org/10.1007/s11694-021-01064-9.
[44] Ucak, I., Khalily, R., Carillo, C., Tomasevic, F., Barba, J. (2020). Potential of propolis extract as a natural antioxidant and antimicrobial in gelatin films applied to rainbow trout (Oncorhynchus mykiss) fillets. *Foods*, *9*(11). https://doi.org/10.3390/foods9111584.
[45] Khabbazi, H., Mansouripor, S., Saremneshad, S. (2023). The effect of propolis extract as a valuable natural additive on the quality characteristics of toast bread. *Food Science & Nutrition*, *11*(9), 5438–5445. https://doi.org/10.1002/fsn3.3500.
[46] Chong-Tai, K., Soo-Jeong, L., Jae-Kwan, H., Chul, K., Byung-Hak, A. (1997). Effect of Propolis Addition on the Shelf-Life and Staling of White Bread. *Korean Journal of Food Science and Technology*, *29*(5), 982–986.
[47] Aliyazicioglu, R., Yildiz, O., Sahin, H., Eyupoglu, O.E., Ozkan, M.T., Karaoglu, S.A., Kolayli, S. (2015). Phenolic Components and Antioxidant Activity of Prunus spinosa from Gumushane, Turkey. *Chemistry of Natural Compounds*, *51*(2), 346–349. https://doi.org/10.1007/s10600-015-1278-8.
[48] Pobiega, K., Kraśniewska, K., Gniewosz, M. (2019). Application of propolis in antimicrobial and antioxidative protection of food quality-A review. *Trends Food Sci. Technol*, *83*, 53–62. https://doi.org/10.1016/j.tifs.2018.11.007.
[49] Cottica, S., Sabik, H., Bélanger, D., Giroux, H. J., Visentainer, J. V., Britten, M. (2015). Use of propolis extracts as antioxidant in dairy beverages enriched with conjugated linoleic acid. *European Food Research and Technology*, 241, 543–551. https://doi.org/10.1007/s00217-015-2483-1.
[50] Oršolić N. (2022). Allergic Inflammation: Effect of Propolis and Its Flavonoids. *Molecules*, *27*(19), 6694-6698. https://doi.org/10.3390/molecules27196694.
[51] Rao, H., Chen, C., Tian, Y., Yuanyuan, L., Gao, Y. (2018). Germination results in reduced allergenicity of peanut by degradation of allergens and resveratrol enrichment. *Innovative Food Science & Emerging Technologies*, 4(8), 188–195. https://doi.org/10.1016/j.ifset.2018.10.015.
[52] Moneret-Vautrin, F., Franck, A., Morisset, P. (2010). Prospective study of sensitization and food allergy to flaxseed in 1,317 subjects. *European annals of allergy and clinical immunology*, 42, 103–11.
[53] Bianco, MV., Calvano, G., Losito, C., Tommaso, I. (2023). Food allergen detection by mass spectrometry: From common to novel protein ingredients. *PROTEOMICS*. https://doi.org/10.1002/pmic.202200427.
[54] Jenerowicz, D., Silny, W., Dańczak-Pazdrowska, A., Polańska, A. (2012). Environmental factors and allergic diseases. *Ann Agric Environ Med.*, 19(3), 475–481.
[55] Benedé, S., Blázquez, AB., Chiang, D., Tordesillas, L., Berin, MC. (2016). The rise of food allergy: Environmental factors and emerging treatments. *EBioMedicine*, 7, 27–34. doi: 10.1016/j.ebiom.2016.04.012.
[56] Rossi, CM., Lenti, MV., Merli, S., Santacroce, G. (2022). Allergic manifestations in autoimmune gastrointestinal disorders, *Autoimmunity Reviews*, *21*(1). https://doi.org/10.1016/j.autrev.2021.102958.
[57] Han, P., Gu, J., Li, L., Wang, X. (2021). The Association Between Intestinal Bacteria and Allergic Diseases-Cause or Consequence? *Front. Cell. Infect. Microbiol.*, 11. https://doi.org/10.3389/fcimb.2021.650893.
[58] Münstedt, K., Hellner, M., Hackethal, A., Winter, D. (2007). Contact allergy to propolis in beekeepers. *Allergologia et Immunopathologia*, *35*(3), 95–100.
[59] Walgrave, SE., Warshaw, EM., Glesne, LA. (2005). Allergic contact dermatitis from propolis. *Dermatitis*, 16, 209–215. https://doi/10.2310/derm.1.2005.2119.
[60] Cho, E., Lee, JD., Cho, SH. (2011). Systemic contact dermatitis from propolis ingestion. *Ann Dermatol*, *23*(1), 85–88. https://doi.org/10.5021/ad.2011.23.1.85.
[61] Hausen, B.M., Evers, P., Stüwe. T., König, W.A, Wollenweber, E. (1992). Propolis allergy (IV). Studies with further sensitizers from propolis and constituents common to propolis, poplar buds and balsam of Peru. *Contact Dermatitis*, 26, 34–44.
[62] Trevisan, G., Kokeli, F. (1987). Contact dermatitis from propolis: role of gastrointestinal absorption. *Contact Dermatitis*, 16, 48.
[63] Zullkiflee, N., Taha, H., Usman, A. (2022). Propolis: Its Role and Efficacy in Human Health and Diseases. *Molecules,* 27 (18). https://doi.org/10.3390/molecules27186120.
[64] Etebarian, A., Alhouei, B., Mohammadi-Nasrabadi, F., Esfarjani, F. (2024). Propolis as a functional food and promising agent for oral health and microbiota balance: A review study. *Food Sci. Nutr.*, *12*(8), 5329–5340. https://doi.org/ 10.1002/fsn3.4216 .
[65] Oršolić, N. (2022). Allergic Inflammation: Effect of Propolis and Its Flavonoids. *Molecules*, *27*(19), 66–94. https://doi.org/10.3390/molecules27196694.
[66] Basista-Sołtys, K. (2013). Allergy to Propolis in Beekeepers, *Occup. Med. Health Aff*, *1*(1), 12-13. http://dx.doi.org/10.4172/2329-6879.1000105.
[67] Nyman, G., Wagner, O., Prystupa-Chalkidis, K., Ryberg, K., Hagvall, L. (2020). Contact Allergy in Western Sweden to Propolis of Four Different Origins. *Acta Derm Venereol*, *100*(16). https://doi.org/10.2340/00015555-3615.
[68] Batsta, A., Nolasso, R., Moura, P., Franca, L. (2024). Green Propolis: A Review of Pharmaceutical Patents with Potential Therapeutic Applications. *Comb Chem High*

Throughput Screen, *10*(1), 131-141. https://doi: 10.2174/0113862073298470240522093733

[69] Fedorova, D. V. (2018). [Research of technological properties of dry fish and vegetable semi-finished products and their use in food technologies]. *Technical Sciences and Technologies*, 4(10), 217–227. (in Ukrainian). https://doi.org/10.25140/2411-5363-2017-4(10)-217-227.

[70] Lu, E., Yeung, M., Yeung, C.K. Comparative analysis of lactulose and fructooligosaccharide on growth kinetics, fermentation, and antioxidant activity of common probiotics. *Food and Nutrition Sciences*, *9*(3), 161–178. https://doi.org/10.4236/fns.2018.93013.

[71] Gardana, C., Barbieri, A., Simonetti, P., Guglielmetti, S. (2012). Biotransformation strategy to reduce allergens in propolis. *Appl. Environ. Microbiol.*, 78, 4654–4658. https://doi.org/10.1128/AEM.00811-12.

[72] Kalkan Yıldırım, H., Canbay, E., Öztürk, Ş., Aldemir, O., Sözmen, E. (2018). Biotransformation of propolis phenols by *L. plantarum* as a strategy for reduction of allergens. *Food Sci Biotechnol.*, *27*(6), 1727–1733. https://doi.org/10.1007/s10068-018-0413-2.

[73] Güney, F., ERTÜRK, Ö. (2020). Determination of the effects of propolis ethanolic extract on some properties of fruit yoghurt during storage. *Mustafa Kemal University Journal of Agricultural Sciences*, *25*(2), 145–152. https://doi.org/10.37908/mkutbd.694712.

[74] Yerlikaya, O. (2014). Effect of bee pollen supplement on antimicrobial, chemical, rheological, sensorial properties and probiotic viability of fermented milk beverages. *Mljekarstvo*, *64*(4), 268–279. https://doi.org/10.15567/mljekarstvo.2014.0406.

[75] Eldeeb, A., Omar, SA. (2017). Effect of Propolis Extract as a Natural Preservative on the Microbial Content of Kareish Cheese. *Journal of Food and Dairy Sciences*, *8*(7), 295–302. https://doi.org/10.21608/jfds.2017.38715.

[76] Vesela, K., Němečková, I., Kyselka, J. (2018). Influence of flaxseed components on fermented dairy product properties. *Czech Journal of Food Sciences*, *36*(1), 1–6. https://doi.org/ 10.17221/411/2017-CJFS.