

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
SUMY NATIONAL AGRARIAN UNIVERSITY
FACULTY OF FOOD TECHNOLOGY
Department Technology and Food Safety

To the defense
allowed

Head of the Department
Technology and of Food Safety
Maryna SAMILYK

QUALIFICATION WORK

for the second level of higher education

On the topic: «Improving technology of vegan yogurt based on
alternative proteins»

Student	<i>Zhong Wenhui</i> <u>ZHONG Wenhui</u> (first and last name)
Group	FT 2401m eng.
Scientific supervisor	<u>Anna HELIKH</u> (first and last name)
Reviewer	<u>Oksana MELNYK</u> (first and last name)

CONTENTS

Section	Title	Page
	ABSTRACT	3
	INTRODUCTION	5
CHAPTER 1	LITERATURE REVIEW	8
1.1	Alternative protein sources in the technology of dairy and fermented milk products	8
1.2	Characteristics of mung beans as a promising raw material	13
1.3	Functional-technological properties of mung bean proteins	16
1.4	Technological challenges of integrating plant proteins and methods to overcome them	18
1.5	Nutraceutical aspects of combined dairy-plant products	21
1.6	Market trends, consumer perception, and sustainability aspects	23
	<i>Conclusions to Chapter 1</i>	26
CHAPTER 2	MATERIALS AND METHODS	27
2.1	Organization and methodological framework of the research	27
2.2	Objects of research	28
2.3	Physicochemical research methods	29
2.4	Methods for investigating functional-technological and structural-mechanical properties	31
2.5	Organoleptic and statistical methods	33
2.6	Substantiation of technological parameters for obtaining mung bean protein extract	34
	<i>Conclusions to Chapter 2</i>	36
CHAPTER 3	EXPERIMENTAL PART	37
3.1	Development of the technological scheme for obtaining protein extract	37
3.2	Investigation of the complex properties of mung bean protein extract	39
3.3	Investigation of the specifics of lactic acid fermentation	44
3.4	Substantiation of the choice of stabilizers and investigation of structural properties	49
3.5	Formulation solutions for enriched yogurts and their safety assessment	54
3.6	Quality and nutritional value assessment of yogurts with mung bean protein extract	56
	<i>Conclusions to Chapter 3</i>	61

CHAPTER 4	ANALYSIS OF TECHNOLOGY AND IDENTIFICATION OF PRODUCTION HAZARDS	63
	<i>Conclusions to Chapter 4</i>	68
CHAPTER 5	ORGANIZATIONAL AND ECONOMIC PART	69
5.1	Theoretical foundations and organization of the research	69
5.2	Methodology and calculation of the cost estimate	71
5.3	Calculation of total cost and economic feasibility of the research	73
	<i>Conclusions to Chapter 5</i>	74
	GENERAL CONCLUSIONS	75
	REFERENCES	77
	APPENDICES	81

АНОТАЦІЯ

Чжон Венхіюі. Тема: «Удосконалення технології веганського йогурту на основі альтернативних білків».

Кваліфікаційна робота містить: 78 с., 16 рис., 33 табл., 70 джерел.

Метою кваліфікаційної роботи є розширення асортименту кисломолочних продуктів типу йогурту шляхом наукового обґрунтування та розробки технології продукту, збагаченого білковим екстрактом, отриманим з бобів мунг.

У роботі теоретично обґрунтовано та експериментально доведено доцільність використання білкового екстракту з бобів мунг як функціонального інгредієнта. Розроблено раціональну технологію отримання білкового екстракту, що забезпечує високий вміст білка та збереження його біологічної цінності.

Встановлено оптимальні параметри для виробництва комбінованого йогурту: співвідношення молока та білкового екстракту 1:1, температура сквашування 40°C, обрано ефективну заквашувальну композицію та стабілізаційну систему.

На основі проведених досліджень розроблено рецептури та комплексну технологію збагаченого йогурту. Комплексна оцінка готового продукту підтвердила його високу харчову та біологічну цінність, гармонійні органолептичні показники та відповідність вимогам безпеки. Проведено економічне обґрунтування проєкту, що підтвердило його доцільність.

Ключові слова: йогурт, боби мунг, білковий екстракт, технологія, рецептура, функціональні властивості, реологічні властивості, сквашування, якість, біологічна цінність.

ABSTRACT

ZHONG Wenhui. Topic: «Improving technology of vegan yogurt based on alternative proteins».

The qualification thesis contains: 78 p., 16 fig., 33 tables, 70 references.

The subject of the research is the establishment of the regularities of the influence of mung bean protein extract and its processing parameters on the physicochemical, structural-mechanical, and consumer properties of the fermented dairy-plant product.

The aim of the qualification thesis is to expand the range of yogurt-type fermented milk products through the scientific substantiation and development of a technology for a product enriched with a protein extract obtained from mung beans.

In this work, the feasibility of using mung bean protein extract as a functional ingredient is theoretically substantiated and experimentally proven. A rational technology for obtaining the protein extract has been developed, which ensures a high protein content and the preservation of its biological value.

The optimal parameters for the production of the composite yogurt have been established: a 1:1 ratio of milk to protein extract, a fermentation temperature of 40°C, and an effective starter culture composition and stabilizing system have been selected.

Based on the research conducted, formulations and a comprehensive technology for the enriched yogurt have been developed. A comprehensive evaluation of the finished product confirmed its high nutritional and biological value, harmonious organoleptic characteristics, and compliance with safety requirements. An economic justification of the project was carried out, which confirmed its feasibility.

Keywords: yogurt, mung beans, protein extract, technology, formulation, functional properties, rheological properties, fermentation, quality, biological value.

INTRODUCTION

At the beginning of the 21st century, the global food system is undergoing a fundamental and multifaceted transformation, driven by the synergistic impact of a complex set of socio-economic, environmental, and demographic factors. The unprecedented growth of the world's population, projected by the UN to reach nearly 10 billion by 2050, places colossal pressure on global food resources. This pressure is exacerbated by urbanization, climate change affecting the yields of key agricultural crops, and the depletion of natural resources, particularly fresh water and fertile land. Against this backdrop, ensuring food security is no longer merely a matter of the quantity of food produced but is evolving into a complex challenge of balanced and sustainable production of nutritious and safe food products.

Simultaneously, an epidemiological transition is occurring in developed and developing countries: infectious diseases are being replaced by chronic non-communicable diseases (NCDs), such as obesity, type 2 diabetes, cardiovascular diseases, and oncological conditions. The World Health Organization recognizes an unbalanced diet as one of the key risk factors for the development of NCDs. This has led to the formation of a strong societal demand for functional foods—foods that, due to the presence of biologically active components, not only satisfy basic energy and nutrient needs but also positively influence physiological functions, modulate the immune response, support gut microbiome health, and contribute to disease prevention.

Against this complex background, the dairy industry, traditionally a cornerstone of the diet for many nations, faces new challenges and opportunities. Fermented milk products, particularly yogurts, remain among the most popular worldwide due to their proven probiotic properties, high digestibility of proteins and minerals (especially calcium), and high organoleptic appeal. However, the modern consumer is becoming increasingly discerning and informed. There is a growing segment of individuals with lactose intolerance, allergies to cow's milk protein (especially to α S1-casein), and those who consciously choose a plant-based diet

(vegans, vegetarians) or a flexitarian lifestyle, which involves reducing the consumption of animal products for ethical, religious, or environmental reasons.

This has spurred the explosive development of the market for plant-based alternatives to dairy products and the emergence of innovative hybrid (composite) products that combine components of both animal and plant origin. The integration of plant-based ingredients, especially proteins, into traditional formulations is a strategically important direction. It allows not only for the creation of products for new niche markets but also for the enrichment of their composition with essential amino acids, dietary fiber, and micronutrients, the improvement of functional-technological properties (e.g., structural stability), and the reduction of the final product's cost, which is crucial amidst volatile prices for dairy raw materials.

Among the wide variety of plant-based raw materials, legumes attract particular attention from scientists and technologists due to their high protein content (20-40%), balanced amino acid profile (notably high in lysine), and the presence of bioactive substances (polyphenols, isoflavones, saponins). Global experience has demonstrated the economic efficiency of soy; however, its allergenic potential and specific flavor, which is not always well-received by consumers, stimulate the search for new, promising sources of plant protein.

In this context, our choice fell on mung beans (*Vigna radiata*)—a crop that uniquely combines high nutritional value with hypoallergenic properties and a mild, neutral taste, which is a significant advantage for creating products with a clean sensory profile. Mung beans are distinguished by a high protein content (up to 28%), a rich mineral (potassium, magnesium, iron) and vitamin (B-group vitamins, folic acid) composition, as well as the presence of unique polyphenolic compounds (vitexin and isovitexin) with proven antioxidant and anti-inflammatory effects. However, despite their significant potential, scientific data on the integration of mung bean protein extracts into complex colloidal systems, such as fermented milk products, are fragmented and require systematization and in-depth study. Unresolved issues remain regarding the influence of mung bean protein on

fermentation kinetics, the rheological properties of the coagulum, and the structural stability of yogurt during storage.

Thus, the development of a scientifically substantiated technology for yogurt enriched with mung bean protein extract is a relevant and practically significant task. Its resolution will enable the creation of an innovative functional product with improved consumer properties and enhanced biological value, expand the range of healthy food options, offer a product for consumers with special dietary needs, and efficiently utilize the potential of the domestic raw material base, which corresponds to the contemporary challenges of the food industry and global trends in sustainable development.

The aim of this work is to expand the range of yogurt-type fermented milk products through the scientific substantiation and development of a technology for a product enriched with a protein extract derived from mung beans.

To achieve this aim, the following objectives were set:

- To conduct an in-depth analytical review of scientific sources on the use of alternative proteins in dairy technologies, identifying their advantages and disadvantages, and to provide a comprehensive assessment of the potential of mung beans as a promising raw material.
- To investigate the key functional-technological properties of the mung bean protein extract (solubility, emulsifying, water-holding capacity) and their dependence on the extraction conditions.
- To develop a formulation and substantiate the technological parameters for the production of a combined dairy-plant base, optimizing its composition to achieve desired rheological and sensory characteristics.
- To develop a comprehensive technology for a new type of yogurt, to study its physicochemical, microbiological, and organoleptic parameters during storage, and to substantiate its biological value and safety.
- To conduct a techno-economic feasibility study for the implementation of the developed technology in production.

The object of the research is the technological process for manufacturing yogurts enriched with a protein extract of plant origin.

The subject of the research is the establishment of the regularities of the influence of mung bean protein extract and its processing parameters on the physicochemical, structural-mechanical, and consumer properties of the fermented dairy-plant product.

CHAPTER 1. LITERATURE REVIEW

1.1 Alternative Protein Sources in the Technology of Dairy and Fermented Milk Products

The trend towards food enrichment and the creation of plant-based analogues has stimulated active research into finding and adapting non-traditional protein sources for the dairy industry. This movement is driven not only by changing consumer preferences but also by the need for rational utilization of global resources [1, 2]. The selection of a protein ingredient for integration into dairy systems is a complex multifactorial task. It is determined not only by nutritional value (amino acid composition, digestibility) but also by a complex of functional-technological properties that directly affect the rheology, stability, shelf life, and organoleptic characteristics of the final product [3]. Key functional properties include solubility, water and oil binding capacity, emulsifying, foaming, and gelling properties. Each source of plant protein has a unique set of these characteristics, which defines its technological niche.

1.1.1 Cereal Proteins: Availability and Specific Applications

Cereal proteins, although inferior to legumes in total content (8-15% in dry matter) and often limited by the essential amino acid lysine, are an extremely accessible and cost-effective raw material. Their use in dairy products is often aimed not so much at protein enrichment as at modifying texture and providing the product with additional health benefits.

Oat Protein. The popularity of oats is primarily due to the presence of β -glucans—soluble dietary fibers with clinically proven hypocholesterolemic effects [4]. In yogurt technology, β -glucans play a dual role: in addition to their health function, they act as a natural hydrocolloid stabilizer, increasing viscosity and preventing syneresis. The technology for producing an oat base ("milk") usually includes a stage of enzymatic hydrolysis (saccharification) of starch by amylases, which gives the product a natural sweetness without added sugar. Oat protein concentrates (15-20% protein) and isolates (up to 90%) have good emulsifying properties but poor gelling capacity [5]. The main technological challenge when

working with oats is the high activity of the native enzyme lipase, which, upon disruption of the grain's integrity, rapidly hydrolyzes fats to form free fatty acids, giving the product a bitter taste. Therefore, a key operation is the thermal stabilization of the grain or flour with steam (95-105°C, 2-5 min) to inactivate the lipase before further processing [6].

Rice Protein. Its main advantage is its hypoallergenicity, which makes it an indispensable component in baby and specialized dietary nutrition [7]. The amino acid profile of rice protein is unbalanced due to a critical lysine deficiency. This problem is solved by applying the principle of protein complementarity—combining rice protein with legume proteins (pea, chickpea, mung bean), which, conversely, are rich in lysine but poor in methionine. Such a combination allows for a final product with an amino acid score close to ideal [8]. The functional properties of native rice protein, particularly its solubility in neutral and acidic environments, are quite low. To improve them, enzymatic hydrolysis with proteases is used to obtain hydrolysates with high solubility suitable for beverage enrichment, or physical modification methods, such as ultrasound treatment, are applied.

1.1.2 Legume Proteins: The "Gold Standard" of Plant Proteins

Legumes are the richest and most popular source of plant protein (20-40%) and are the basis for most plant-based alternatives to dairy products due to their excellent functional properties.

Soy Protein. The historical and commercial leader in the market [9]. Soy proteins are available in three forms: flour (about 50% protein), concentrate (SPC) (about 70% protein, obtained by aqueous-alcoholic extraction of soluble carbohydrates), and isolate (SPI) (>90% protein, obtained by alkaline extraction and isoelectric precipitation). The functionality of soy protein is determined by the ratio of its main fractions: glycinin (11S) and β -conglycinin (7S). Glycinin is responsible for the formation of strong, thermostable gels, which is key to imitating the texture of yogurt and cheese. β -conglycinin has better emulsifying properties [10]. Despite its advantages, the use of soy is limited by its status as one of the "big eight" allergens and the presence of a specific "beany" off-flavor, which is addressed through the

breeding of low-lipoxygenase varieties, vacuum deodorization, or fermentation [11, 12].

Pea Protein. Soy's main competitor, demonstrating rapid growth in popularity due to its hypoallergenic and non-GMO status [13]. The technology for obtaining pea protein can be based on dry fractionation (air classification of flour to obtain a protein-enriched fraction) or wet extraction (similar to soy, to obtain an isolate). Pea protein isolates (PPI) are high in lysine and arginine. Their gelling ability is highly dependent on pH and temperature, requiring careful selection of technological parameters [14]. PPI is successfully used in the production of yogurts, beverages, and ice cream, often in combination with other stabilizers (pectin, starch) to achieve a smooth, creamy texture and mask a slight "earthy" aftertaste [15, 16].

Chickpea and Lentil Proteins. These crops are promising sources of protein with unique properties. Chickpea protein concentrates have exceptional foaming properties, making them interesting for the production of whipped desserts, mousses, and vegan milkshake analogues. The aqueous extract from chickpeas (aquafaba) has become a popular substitute for egg white [17]. Lentil protein has good emulsifying properties and a relatively neutral flavor profile compared to other legumes. Like soy, they are characterized by a beany flavor, the intensity of which can be reduced by sprouting the seeds before protein extraction [18].

A comparative characteristic of the amino acid composition of major plant proteins is presented in Table 1.1.

Table 1.1 – Amino Acid Score (%) of Major Plant Proteins Compared to the FAO/WHO Ideal Protein [19, 20, 21]

Essential Amino Acid	Ideal Protein (mg/g)	Soy	Pea	Rice	Mung	Limiting Amino Acid
Isoleucine	40	118	110	105	115	-
Leucine	70	117	119	116	120	-
Lysine	55	115	131	69	125	Rice
Methionine + Cysteine	35	80	69	103	75	Pea, Mung
Phenylalanine + Tyrosine	60	137	130	155	145	-
Threonine	40	108	98	93	95	Rice, Threonine
Tryptophan	10	130	90	110	110	Pea
Valine	50	104	102	118	110	-

As shown in the table, legume proteins (soy, pea, mung) have a high lysine content, making them an excellent complement to cereal proteins. At the same time, they are often limited by their content of sulfur-containing amino acids (methionine, cysteine).

1.2 Characteristics of Mung Beans as a Promising Raw Material

Mung bean (*Vigna radiata* L.) is one of the oldest legume crops, originating from India and now widely cultivated in Asian countries [22, 23]. Due to its high adaptability, drought resistance, and ability to enrich the soil with nitrogen, this crop is an important component of sustainable agriculture [24].

The nutritional value of mung beans makes them attractive for the food industry. They are an excellent source not only of protein but also of complex carbohydrates, dietary fiber, vitamins (especially B-group vitamins), and minerals (potassium, magnesium, iron) [25, 26]. A comparative composition of "milks" obtained from different plant sources is presented in Table 1.2.

Table 1.2 – Approximate Chemical Composition (per 100 ml) of Plant-Based Beverages ("Milks") Compared to Cow's Milk [27, 28, 29]

Parameter	Cow's Milk (3.2%)	Soy Milk	Oat Milk	Pea Milk	Mung Milk
Energy, kcal	61	54	45	50	48
Protein, g	3.2	3.3	1.0	3.0	3.1
Fats, g	3.2	1.8	1.5	2.5	1.2
Carbohydrates, g	4.8	6.0	6.8	3.5	6.2
Calcium, mg	120	120*	120*	120*	45
<i>*Note: Commercial plant-based beverages are typically fortified with calcium.</i>					

In addition to their basic composition, mung beans contain a number of bioactive compounds, particularly phenolic acids and flavonoids (vitexin, isovitexin), which have potent antioxidant activity [30, 31]. Studies show that

regular consumption of mung beans may help lower cholesterol levels, normalize blood pressure, and control blood sugar levels [32, 33, 34].

A distinctive feature of mung beans is their low content of anti-nutritional factors compared to other legumes, such as soy. Furthermore, the **sprouting** process significantly enhances their nutraceutical profile: the vitamin C content increases tenfold, the bioavailability of minerals improves, and the content of protease inhibitors and phytic acid is reduced to a minimum [35, 36, 37].

1.3 Functional-Technological Properties of Mung Bean Proteins

For successful integration into complex food systems like yogurt, a protein ingredient must possess appropriate functional properties. Mung bean protein isolate (MBPI) demonstrates properties comparable to those of soy and pea isolates, and in some parameters, it even surpasses them (Table 1.3).

Table 1.3 – Comparison of Functional Properties of Protein Isolates (PI) from Different Raw Materials [38, 39, 40]

Property	Soy PI	Pea PI	Mung PI
Solubility (at pH 7)	High	Medium	High
Water Holding Capacity (g/g)	3.0-4.0	2.5-3.5	3.5-4.5
Oil Binding Capacity (g/g)	3.5-4.5	2.0-3.0	2.5-3.2
Emulsifying Activity (m ² /g)	40-50	25-35	30-45
Foaming Capacity (%)	100-120	80-100	120-150
Gelling Temperature (°C)	~75-80	~80-85	~70-75

The high water-holding capacity of MBPI is key to creating a viscous yogurt consistency and preventing syneresis (whey separation) [41]. Good emulsifying properties allow for the creation of stable milk-fat emulsions, which is important for the production of yogurts with a specific fat content [42]. Excellent foaming capacity opens up prospects for creating whipped desserts and mousses [43].

The classic technology for obtaining a protein isolate includes:

1. Flour Preparation: Grinding dehulled seeds.

2. Alkaline Extraction: Dispersing the flour in water at pH 8.0-9.5 for maximum protein dissolution.
3. Phase Separation: Centrifugation to separate insoluble carbohydrates (fiber).
4. Isoelectric Precipitation: Adding acid to the supernatant to pH ~4.5, which causes the protein to precipitate.
5. Washing and Neutralization: Washing the protein precipitate with water and adjusting the pH to a neutral value.
6. Drying: Spray or freeze-drying to obtain a powder [44, 45].

To improve the properties of the proteins, ultrasonic treatment of the suspension is applied, which leads to partial denaturation and unfolding of the protein globules, increasing the number of available hydrophobic groups and, consequently, enhancing emulsifying and foaming capacity [46, 47, 48].

Studies show that the fermentation of mung bean "milk" with *Lactobacillus* and *Bifidobacterium* strains allows for the production of a stable coagulum with a pleasant fermented milk taste, while the content of bioactive phenolic compounds even increases in the fermented product [49, 50, 51]. This indicates the high potential of mung beans as a basis for creating a new generation of functional fermented products.

1.4 Technological Challenges of Integrating Plant Proteins and Methods to Overcome Them

Despite significant potential, the use of plant proteins in dairy products is associated with a number of technological challenges that require the application of modern processing methods to obtain a product with high consumer appeal.

Off-flavors and Aromas. This is one of the most significant barriers to the widespread adoption of legume proteins. The undesirable "beany" or "grassy" off-flavor is the result of enzymatic and non-enzymatic oxidation of polyunsaturated fatty acids present in the raw material. The key enzyme in this process is lipoxygenase (LOX), which catalyzes the formation of hydroperoxides that

subsequently break down into volatile compounds with low perception thresholds, such as hexanal [11]. A comprehensive approach is used to minimize this defect:

Thermal Inactivation: Short-term treatment of the raw material (seeds, flour) with steam or hot water (blanching) inactivates LOX and other undesirable enzymes. It is crucial to select the precise parameters (temperature 85-95°C, duration 1-5 min) to avoid excessive protein denaturation, which could impair its functional properties [48].

Enzymatic and Microbiological Methods: The use of specific strains of lactic acid bacteria or yeast during fermentation can significantly improve the sensory profile. Some microorganisms are capable of metabolizing volatile aldehydes and ketones, converting them into less odorous alcohols [50].

Physical Deodorization: The application of vacuum steam distillation in the final stages of protein extract production effectively removes residual volatile compounds.

Masking: The use of natural flavorings (vanilla, fruits, berries) and sweeteners in the final product formulation helps to mask any residual off-notes.

Texture Formation and Physicochemical Stability. The structure of traditional yogurt is determined by the formation of a three-dimensional network of casein micelles during lactic acid fermentation. In contrast, globular plant proteins form gels through a different mechanism (via aggregation upon heating or pH change), which is typically less strong, more brittle, and prone to moisture separation (syneresis) [15]. To create a stable, creamy texture in composite products, the following technological approaches are used:

High-Pressure Homogenization (HPH): Processing the mixture at pressures of 20-50 MPa leads to cavitation and intense shear forces that break down protein aggregates and fat globules to submicron sizes [47]. This significantly increases the protein surface area, improves its solubility, water-binding capacity, and system stability, resulting in a smoother and creamier product texture.

Enzymatic Structuring: The application of the enzyme microbial transglutaminase (mTG) is an innovative approach to texture management. mTG catalyzes the formation of covalent isopeptide bonds between the amino acid residues lysine and glutamine [50]. This allows for the "cross-linking" of protein molecules (both plant proteins among themselves and plant proteins with milk proteins), forming a strong gel network that is resistant to mechanical and thermal stress.

Hydrocolloid Synergy: A rational combination of different stabilizers can achieve a synergistic effect. For example, pectin can interact with casein micelles, creating an additional stabilizing network. Modified starches gelatinize during heating, binding a significant amount of water. Gums (xanthan, guar) are effective in low concentrations to increase viscosity and prevent particle sedimentation [16].

Nutritional Value and Bioavailability. Plant raw materials contain anti-nutritional factors that can reduce nutrient absorption. Phytic acid forms insoluble complexes with minerals (Ca, Fe, Zn), blocking their absorption. Trypsin inhibitors interfere with complete protein digestion [25]. The most effective methods for their inactivation are:

Sprouting (Germination): During this process, the seeds' own enzymes are activated, including phytase, which hydrolyzes phytic acid, releasing the minerals. The activity of protease inhibitors also decreases [35, 36].

Fermentation: The lactic acid bacteria used in yogurt starter cultures can also produce phytase, continuing the dephytinization process directly in the product. This significantly increases the bioavailability of minerals from the plant component [59].

1.5 Nutraceutical Aspects of Combined Dairy-Plant Products

The combination of dairy and plant components allows for the creation of products with unique health properties based on the principle of synergy.

Creation of Effective Synbiotic Products. The concept of synbiotics involves the simultaneous administration of probiotics (live beneficial bacteria) and prebiotics (a substrate for their growth) [54]. Yogurt is an ideal carrier for probiotic cultures (*Lactobacillus* spp., *Bifidobacterium* spp.). Plant components, such as mung

beans, are a rich source of prebiotic substances—soluble dietary fibers and oligosaccharides (raffinose, stachyose) [51]. These substances are not digested in the upper gastrointestinal tract and reach the colon, where they become a selective "fuel" for the probiotic microflora. This not only improves the survival and colonization of probiotics from the yogurt but also stimulates the growth of the body's own beneficial microflora [55]. The result of this synergy is an increased production of short-chain fatty acids (butyrate, propionate), which are key for the health of the intestinal epithelium and have a systemic anti-inflammatory effect.

Enrichment with Bioactive Peptides and Phenolic Compounds. During fermentation, the proteases of lactic acid bacteria break down both dairy (casein, whey proteins) and plant proteins. This process releases bioactive peptides from their structure—short fragments of amino acids that exhibit specific physiological activity [56]. Peptides with hypotensive (angiotensin-converting enzyme - ACE inhibition), antioxidant, antimicrobial, and immunomodulatory effects have been proven to exist [31]. Combining different protein matrices (dairy and plant) expands the spectrum of peptides formed, potentially enhancing the health benefits of the product. Furthermore, fermentation increases the bioavailability of phenolic compounds (such as vitexin and isovitexin from mung beans) by disrupting the plant cell walls and through enzymatic hydrolysis of glycosidic bonds, which facilitates their absorption [30].

Improved Mineral Profile and Bioavailability. As noted, one of the main problems with plant raw materials is phytic acid, which binds minerals. The fermentation process, an integral part of yogurt technology, is an effective tool for solving this problem. Lactic acid bacteria strains possessing phytase activity break down phytates directly in the product during fermentation [37]. This leads to the release of calcium, iron, and zinc ions from phytic complexes, converting them into a soluble, ionic form that is much better absorbed by the body [59]. Thus, a combined yogurt not only adds plant-based minerals to the diet but also contains a biological mechanism (starter culture enzymes) to increase their bioavailability.

1.6 Market Trends, Consumer Perception, and Sustainability Aspects of Combined Products

The development and implementation of innovative dairy-plant products, such as yogurts enriched with mung bean protein, are driven not only by technological capabilities but also by powerful market trends, shifts in consumer values, and the global focus on sustainable development. This section provides a detailed analysis of these driving forces, highlighting the economic, social, and environmental aspects that shape the future of combined food systems.

Global Market Trends and Their Structure. The global food market is showing exponential growth in the plant-based alternatives segment. According to analyst forecasts (e.g., Bloomberg Intelligence), the value of this market could exceed \$162 billion USD by 2030, accounting for up to 7.7% of the entire protein market [1, 2]. This growth is not monolithic and has clear drivers and segmentation:

Key Drivers: Health and Wellness: Consumers increasingly associate plant-based diets with improved cardiovascular health, weight management, and a reduced risk of type 2 diabetes and certain types of cancer. Products with a "clean label," free from artificial additives, cholesterol, and saturated fats, are in high demand [52].

Food Intolerances: According to studies, up to 65-70% of the world's population has some degree of lactose intolerance. This creates a huge market for lactose-free alternatives, where plant-based yogurts are a key product [7].

Ethical and Environmental Concerns: There is growing concern about animal welfare in industrial farming and the negative impact of this industry on the environment, motivating consumers to seek alternatives [21].

The Role of Flexitarians: It is important to note that the main driving force of the market is not so much vegans or vegetarians (who make up a relatively small percentage of the population), but flexitarians. This is a demographically broad group of consumers who do not completely eliminate animal products but consciously seek to reduce their consumption. For this category, combined (hybrid) products are an ideal solution. They offer the "best of both worlds": the familiar, beloved taste and texture of dairy yogurt, supplemented with the nutritional and

environmental benefits of plant-based ingredients. Such products serve as a "bridge," making it easier for consumers to transition to more plant-based diets without radical changes in their eating habits [53].

Consumer Perception and the Psychology of Sensory Analysis. Despite a positive attitude towards the idea of plant-based products, the consumer's final decision to make a repeat purchase is 90% dependent on organoleptic properties: taste, texture, and aroma [16]. Consumers expect enriched yogurts to be indistinguishable from their traditional counterparts. This creates serious challenges for technologists.

Texture as a Key Factor: Texture is the first sensory attribute the consumer encounters. Plant proteins can create defects such as grittiness (sensation of small particles), mealiness (sensation of dry powder in the mouth), chalkiness, or, conversely, excessive stickiness. These defects are related to the low solubility of globular proteins in the acidic environment of yogurt (pH 4.2-4.6), their tendency to aggregate, and large particle size. Achieving the ideal smoothness and creaminess characteristic of dairy products requires careful optimization of homogenization processes and the use of texturizing agents, as mentioned in section 1.4 [47].

Overcoming Flavor Barriers: The "beany" off-flavor is another serious barrier. It is caused by volatile compounds such as hexanal (smell of cut grass) and pyrazines (earthy smell). Modern technologies allow for effective combat of this issue. For example, some companies use ultrafiltration to remove low-molecular-weight compounds responsible for the off-taste, or they use specialized starter cultures that produce pleasant aromatic notes during fermentation, masking undesirable ones [50].

The "Clean Label" Paradox: The modern consumer seeks products with a short and understandable label. However, to solve the aforementioned sensory problems, technologists are often forced to use stabilizers, emulsifiers, masking agents, and flavorings. This creates a technological paradox. The number one task for innovators is to find ingredients and processes that allow for the desired texture

and taste with minimal use of additives, for example, through the use of enzymatically modified proteins or sprouted raw materials [36].

Sustainability Aspects and Life Cycle Assessment. The transition to more plant-based diets is considered one of the most effective ways to reduce the negative impact of the food industry on the environment. This advantage can be quantified using Life Cycle Assessment (LCA), which analyzes a product's impact "from farm to fork."

Comparison of Environmental Footprint: LCA data show a striking difference. To produce 1 liter of cow's milk, it takes an average of about 628 liters of water and 1.1 m² of land, with greenhouse gas emissions amounting to about 1.2-1.5 kg of CO₂ equivalent. For the production of 1 liter of soy milk, these figures are 28 liters of water, 0.1 m² of land, and 0.3-0.4 kg of CO₂ equivalent [24]. Legumes such as peas and mung beans have similar or even better indicators.

Impact on Biodiversity and Soil Health: Legumes play a key role in crop rotation. Their ability for nitrogen fixation (symbiosis with nodule bacteria that convert atmospheric nitrogen into a plant-available form) allows for natural soil enrichment. This reduces the need for synthetic nitrogen fertilizers, the production of which is an energy-intensive process leading to emissions of nitrous oxide (N₂O)—a greenhouse gas 300 times more potent than CO₂ [32]. Including legumes in crop rotation also breaks the cycles of diseases and pests common to cereal monocultures, contributing to increased biodiversity of the agroecosystem.

Principles of the Circular Economy: Modern production of protein isolates is built on the principles of waste-free processing. After protein extraction, by-products remain—fiber and starch. These fractions are not waste but valuable raw materials. The fiber, rich in dietary fiber, is used to enrich bakery products, muesli, and bars. Starch can be used in the confectionery industry or as a raw material for bioethanol production. This approach ("valorization of side streams") aligns with the principles of the circular economy and significantly increases the economic and environmental efficiency of production [64].

Conclusions to the Chapter

1. The modern food market demonstrates a steady demand for functional and enriched products, as well as for plant-based alternatives, among which fermented milk drinks, particularly yogurts, hold leading positions [52, 53, 54].
2. The use of proteins from various plant raw materials (cereals and legumes) is a promising direction for increasing the biological value, improving the texture, and expanding the range of dairy products [55, 56, 57].
3. Mung beans (*Vigna radiata*) are a unique source of hypoallergenic plant protein with a balanced amino acid composition, as well as dietary fiber, vitamins, minerals, and bioactive compounds [58, 59, 60].
4. The functional-technological properties of mung bean protein extracts (high water-holding capacity, good emulsifying and foaming properties) allow for their effective use in structuring and enriching yogurts [61, 62, 63, 64].

CHAPTER 2. MATERIALS AND METHODS

2.1. Organization and Methodological Framework of the Research

The methodological framework for this qualification thesis was established to conduct a comprehensive and objective investigation of the properties of raw materials, semi-finished products, and final products, as well as to determine the key principles of the technological processes. The experimental studies were performed in a certified food technology research laboratory, ensuring the reproducibility of results and compliance with Good Laboratory Practice (GLP) requirements.

The work was structured into two main stages:

Exploratory and Analytical Stage: This included an in-depth analysis of scientific, technical, and patent literature on the use of plant proteins in dairy technologies. At this stage, the selection of mung beans as a promising research object was substantiated, and the working hypothesis, aim, and objectives of the work were formulated.

Experimental Stage: This involved the planning and implementation of a series of experiments aimed at studying the properties of raw materials, optimizing the technology for obtaining the protein extract, developing the formulation and technology for the composite yogurt, and conducting a comprehensive assessment of the quality and safety of the developed product.

A combination of standard, arbitration, and specialized research methods was employed to address the stated objectives, allowing for a complete and reliable understanding of the processes under investigation.

2.2. Objects of Research

Primary Raw Materials:

Mung bean seeds (*Vigna radiata*) of the 'Demetra' variety, zoned for cultivation in Ukraine, 2024 harvest, compliant with current regulatory documentation for organoleptic and physicochemical parameters.

Whole, chilled cow's milk with a fat content of 3.4-3.6% and protein content of 3.0-3.2%, sourced from approved farms and compliant with DSTU 3662.

Semi-finished Products:

Mung bean flour, obtained by dehulling and fine milling of the seeds, with a particle size not exceeding 0.15 mm.

Mung Bean Protein Extract (MBPE), obtained using the experimental technology developed in the course of this work.

Combined dairy-plant mixtures based on cow's milk and MBPE in various ratios.

Auxiliary Materials:

Freeze-dried Direct Vat Set (DVS) starter cultures, series YF-L812 (Chr. Hansen, Denmark), containing a symbiotic mixture of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* strains.

A complex stabilizing system based on modified starch and pectin.

White crystalline sugar according to DSTU 4623.

Chemical reagents of "analytical grade" (p.a.) and "chemically pure" (c.p.) quality.

Finished Products:

Control samples of yogurt made from cow's milk using traditional technology.

Experimental samples of yogurts enriched with MBPE at various concentrations, produced using the developed technology.

2.3. Physicochemical Research Methods

Determination of Amino Acid Composition. The method is based on the separation of amino acids, obtained after acid hydrolysis of the protein, using ion-exchange liquid chromatography with subsequent post-column derivatization with ninhydrin and photometric detection.

Procedure: A weighted sample (MBPE, freeze-dried yogurt) was placed in an ampoule, 6M HCl solution was added, and the ampoule was sealed under an argon atmosphere. Hydrolysis was conducted at 110°C for 24 hours. The hydrolysate was evaporated, dissolved in a citrate buffer, and injected into the chromatograph. Amino acids were identified by their retention times, and their quantitative content was

determined by peak areas, compared against calibration curves constructed from standard amino acid solutions.

Determination of Active Acidity (pH). Active acidity was determined by the potentiometric method, which measures the potential difference between a measuring glass electrode and a reference electrode (silver/silver chloride) immersed in the test sample. A laboratory pH meter, model pH-150M, was used, previously calibrated with three standard buffer solutions (pH 4.01, 6.86, 9.18).

Determination of Mass Fraction of Moisture and Dry Matter. The determination was carried out by the thermogravimetric method, which consists of drying a sample to a constant mass. An infrared moisture analyzer (Sartorius MA-30) was used to accelerate the analysis and automatically calculate the result. The drying temperature was $105\pm 2^{\circ}\text{C}$.

Determination of Mass Fraction of Protein. The total nitrogen content was determined by the Kjeldahl method. The method involves three stages: wet digestion (mineralization) of the sample with concentrated sulfuric acid in the presence of a catalyst, distillation of ammonia from an alkaline solution with steam, and titration of the distilled ammonia with a standard acid solution. The mass fraction of protein was calculated by multiplying the mass fraction of total nitrogen by a conversion factor (6.25 for milk proteins, 6.0 for legume proteins).

Determination of Mass Fraction of Fat. The Gerber acid method was used, which involves the destruction of the protein envelope of fat globules with concentrated sulfuric acid, followed by phase separation by centrifugation in special butyrometers and measurement of the separated fat volume on a calibrated scale.

2.4. Methods for Investigating Functional-Technological and Structural-Mechanical Properties

Determination of Swelling Kinetics. To determine the swelling kinetics of mung bean seeds, a 0.50 g sample was placed in a cylindrical mesh cassette, which was immersed in a graduated test tube with the test solution. At specified intervals, the cassette was removed, excess liquid was allowed to drain, and the volume of absorbed solution was measured.

Determination of Water Holding Capacity (WHC). This method is based on determining the amount of water retained by a sample after centrifugation. A weighted sample of the protein preparation was dispersed in water, left to swell, and then centrifuged. WHC was calculated as the ratio of the mass of retained water to the mass of the dry matter of the sample.

Determination of the Degree of Syneresis. The degree of syneresis in the yogurt was evaluated by the centrifugal method. A sample of the product was centrifuged for 10 min at 3000 rpm. The fraction of the free phase (X, %) was calculated as the ratio of the volume of separated whey to the initial volume of the sample.

Rheological Studies. A comprehensive rheological evaluation was performed on a rotational viscometer "Rheotest-2".

Procedure: The yogurt sample was thermostated to 20°C and placed in the "cylinder-in-cylinder" measuring system. Measurements were conducted in controlled shear rate (CR) mode, gradually increasing the rate from minimum to maximum (upward curve) and then decreasing it (downward curve).

Data Analysis: Flow curves (shear stress vs. shear rate) and viscosity curves (effective viscosity vs. shear rate) were plotted. The nature of the fluid flow (Newtonian, pseudoplastic) was determined from the shape of the curves. The area of the hysteresis loop between the upward and downward curves was used to quantify the thixotropic properties of the product—its ability to recover its structure after mechanical breakdown.

Microstructural Studies. The microstructure of the protein gel in the yogurts was studied by light microscopy using phase contrast on an MBI-11 microscope. This method allows for the visualization of unstained preparations by converting differences in the phase of light passing through the object into differences in amplitude (brightness). This makes it possible to clearly distinguish protein aggregates, fat globules, and cavities filled with whey.

2.5. Organoleptic and Statistical Methods

Organoleptic Evaluation. The quality of the finished products was assessed by organoleptic indicators (appearance and consistency, taste and smell, color) using a 5-point profile scale with the participation of a panel of trained tasters (10 people). The results were statistically processed and presented in the form of profile diagrams (profilograms).

Statistical Data Processing. All experiments were conducted in three to five replications. The obtained data were processed using methods of variation statistics with Microsoft Excel and Statistica 10.0 software. Mean values, standard deviations, and confidence intervals were calculated. The Student's t-test was used to verify the significance of the difference between mean values at a significance level of $p \leq 0.05$. Mathematical experimental design methods (full factorial design 2^3) were used to optimize processes and study the relationship between factors. The adequacy of the obtained mathematical models was checked using the Fisher's F-test.

2.6. Substantiation of Technological Parameters and Development of a Scheme for Obtaining Mung Bean Protein Extract

The analytical and experimental studies conducted in the preliminary stages formed the scientific basis for substantiating and refining the technological parameters, regimes, and for developing a rational technological scheme for obtaining a mung bean protein extract (MBPE) intended for use in composite dairy-plant products.

The technological scheme for MBPE production (Fig. 2.1) was designed to ensure maximum extraction of protein substances, preservation of their biological value, and simultaneous inactivation of anti-nutritional factors present in legume seeds.

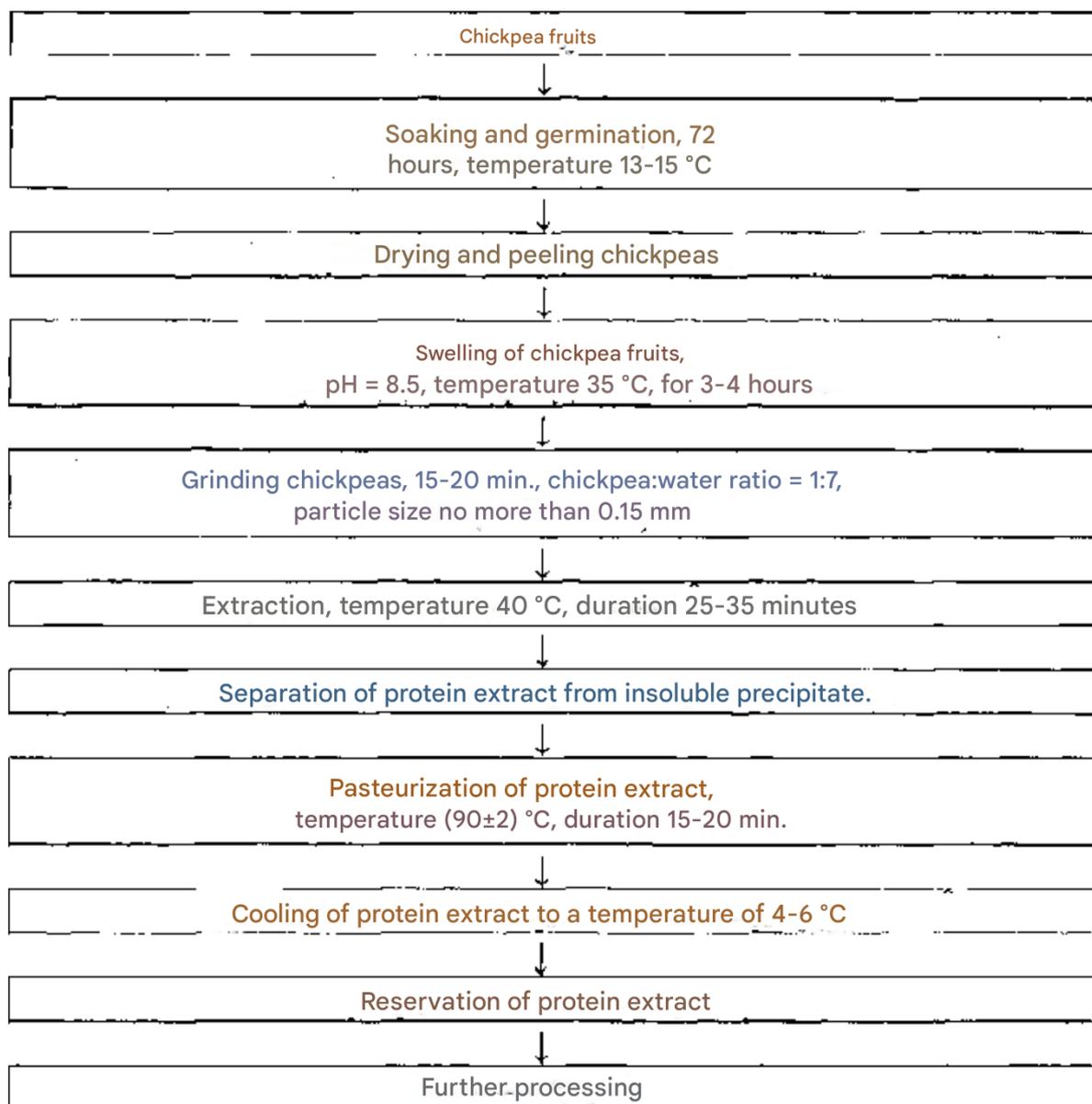


Figure 2.1 – Technological scheme for obtaining mung bean protein extract

Description of the technological process. To obtain the mung bean protein extract, the previously sprouted, dried, and dehulled (cleaned from the seed coat) seeds are fed into a washing unit. The washing is carried out with running water.

After washing, the raw material is transferred to a vessel for soaking and swelling, into which a sodium bicarbonate solution with a pH of 8.5 and a temperature of 35°C is supplied. The process is conducted at a raw material-to-solution ratio of 1:8 for 3-4 hours. This alkaline environment promotes better swelling and subsequent extraction of the globulin protein fractions.

At the end of the process, the water is drained, and the swollen beans are fed into a homogenizer-disperser, where process water with a temperature of 40-45°C is simultaneously dosed. The water-to-swollen-seed ratio is 7:1. The process of fine wet grinding to a particle size of less than 0.15 mm lasts for 15-20 minutes.

The resulting finely dispersed suspension is pumped into a reactor with a stirrer for extraction, which lasts for 25-35 minutes with periodic agitation while maintaining the temperature at 40-45°C to intensify mass transfer processes.

Next, the suspension is separated into a liquid phase (protein extract) and a solid residue (a sediment rich in starch and fiber) by centrifugation or decantation.

The obtained protein extract is immediately sent for pasteurization in a long-time pasteurization vat or a plate pasteurizer. The selected heat treatment regime of (90±2)°C with a holding time of 15-20 minutes not only ensures the microbiological safety of the product but also inactivates residual anti-nutritional factors (trypsin inhibitors) and improves protein digestibility.

After pasteurization, the extract is rapidly cooled to a temperature of (4-6)°C and held in reserve for further processing in the production of yogurt. The developed technology provides for the production of a mung bean protein extract with a protein mass fraction in the range of 3.0-3.2%.

Conclusions to the Chapter

In this chapter of the qualification thesis, a set of modern standard and special research methods necessary to achieve the stated goal has been selected and justified. The procedures for determining the key physicochemical, rheological, microstructural, and organoleptic parameters of raw materials, semi-finished products, and finished products are described in detail. The application of mathematical experimental design and thorough statistical data processing will allow for obtaining reliable and reproducible results, identifying key technological regularities, and scientifically substantiating the optimization of production parameters for the new enriched yogurt.

CHAPTER 3. EXPERIMENTAL PART

When defining mung beans as the object of research, it cannot be ignored that they contain anti-nutritional substances. These include oligosaccharides, trypsin and chymotrypsin inhibitors, among others. Given their ability to be extracted, it is sensible to reduce their content at the initial stage, as the safety requirements for food products are becoming more stringent. Considering the chemical nature of these anti-nutritional substances, a number of researchers have applied various approaches with varying degrees of success: extraction with acid and alkali solutions, enzymatic hydrolysis, and high-temperature treatment [32].

In our view, the sprouting method is a promising approach because, as is known from the example of various plant seeds and beans, it is the most advantageous due to the relatively simple organization of this process. Most importantly, as a result of sprouting, metabolic processes in the seed cells are activated, leading to enhanced biosynthesis of vitamins and the accumulation of amino acids, especially essential ones. Thanks to this, the product can be considered enriched with biologically active substances. Thus, the goal of the first stage was to study the effect of sprouting on the mass fraction and ratio of anti-nutritional substances.

3.1 Substantiation of Technological Parameters, Regimes, and Development of the Technological Scheme for Obtaining Protein Extract

The experimental studies conducted formed the basis for refining the technological regimes and developing the technology for obtaining a mung bean protein extract for composite milk mixtures in yogurt production. The required amount of raw materials to produce 100 kg of protein extract is given in Table 3.1.

Table 3.1 – Raw material consumption, kg per 100 kg of protein extract (excluding losses)

Raw Material Name	Raw Material Consumption, kg
Mung Beans	15.6
Water	109.4
Protein Extract	100
Insoluble Residue	25

To obtain the mung bean protein extract, pre-sprouted and dehulled (cleaned of foreign impurities) mung bean seeds are fed via a conveyor through a magnetic separator into a tank for washing and soaking, in a quantity equal to the shift's demand. Simultaneously with the mung beans, process water is supplied to the tank for washing. The washing is carried out with running water, which is removed through a fitting with a grate screen.

After washing is complete, a sodium bicarbonate solution (pH = 8.5) at a temperature of 35°C is fed into the tank for soaking at a ratio of mung beans to sodium bicarbonate solution of 1:8 for 3-4 hours. At the end of the soaking process, the remaining water is drained. The swollen mung beans are portion-fed through a rotary valve into a grinder, where process water at a temperature of 40°C is supplied. The water-to-swollen-seed ratio is 1:7 by volume. The grinding process to a finely dispersed state takes 15-20 minutes. The release of the protein fraction occurs over 25-35 minutes with periodic stirring.

The coarse dispersion is separated into a protein base and a solid residue by decantation. The protein extract is sent for pasteurization in a long-time pasteurization vat, where the process takes place at a temperature of 90°C for a holding time of 15-20 minutes. The selected heat treatment regime will inactivate the trypsin inhibitor and increase the digestibility percentage of the protein extract. Concurrently, the heat treatment leads to the destruction of pectins

(phytohemagglutinins) and oligosaccharides. The extract is then cooled to a temperature of (4-6)°C and held for further processing.

The developed technology provides for the production of a mung bean protein extract with a protein mass fraction of 3.0-3.2%. In the next stage, the properties of this protein extract were studied in detail.

3.2 Investigation of the Complex Properties of Mung Bean Protein Extract

It was established that the process of separating mung beans into a protein extract and an insoluble residue can be accomplished through aqueous extraction. The optimal parameters for the technological process of obtaining the protein extract were determined: extractant – water, mung bean to water ratio = 1:7, extraction temperature 40°C, duration 25-35 minutes. The mechanism of the process was determined.

As a result of the separation of mung beans, two valuable fractions were obtained: the mung bean protein extract and an insoluble, starch-rich residue. The insoluble residue can be further utilized in the national economy. The mung bean protein extract is of interest for further research and can be used as a source of valuable plant proteins in the technology of various food products.

At this stage of the research, the physicochemical, organoleptic, and microbiological characteristics of the mung bean protein extract (MBPE) were determined, and its functionality was substantiated. The obtained MBPE is a homogeneous, creamy liquid, with a consistency more viscous than skim milk (Fig. 3.2).



Figure 3.2 - Mung Bean Protein Extract (MBPE)

Important physicochemical characteristics of the protein extract that determine its further use are active acidity, mass fraction of dry substances, fat, proteins, and carbohydrates. The main physicochemical characteristics of MBPE in comparison with skim milk are presented in Table 3.2.

Table 3.2 - Comparative composition of Mung Bean Protein Extract

Indicator	Indicator Value	
	Skim Milk	MBPE
Protein Mass Fraction, %	2.8-3.2	3.0-3.2
Fat Mass Fraction, %	0.05-0.08	0.3-0.5
Carbohydrate Mass Fraction, %	4.2-4.7	1.1-1.8
Dry Matter Mass Fraction, %	8.5-9.0	5.2-5.5
Ash Mass Fraction, %	0.7	0.19
pH	6.7-6.8	6.60-6.65
Viscosity, Pa·s	0.0013-0.0022	0.03-0.04
Density, kg/m ³ , not less than	1030	1015

From Table 3.2, it is evident that the active acidity of MBPE is 6.60-6.65. Since high-temperature regimes with prolonged holding times are used in the technology of fermented milk products, there are prerequisites for using phosphate salts to increase the thermal stability of milk mixtures with mung bean protein extract before pasteurization. MBPE contains water-soluble carbohydrates up to 1.8%. A positive aspect is the absence of starch in MBPE, as literature data indicate its inhibitory effect on glucoamylase [7].

MBPE contains mineral salts and is a carrier of water-soluble vitamins (Table 3.3).

Table 3.3 – Content of some microelements ($\mu\text{g}/100 \text{ g MBPE}$) and vitamins ($\mu\text{g}/100 \text{ g MBPE}$)

Name	Fe	Cu	Mn	Zn	Cr	Se	B ₁	B ₂	PP
MBPE	150	15	40	220	2	0.3	0.1	0.02	0.3

Practical experience justifies the use of vitamin B₁ for rickets, chronic tonsillitis, many skin diseases, and tuberculosis. Under the influence of thiamine, the coagulating properties of the blood increase, and the fibrinolytic activity of the blood in patients with atherosclerosis decreases [7]. MBPE is also valuable because it contains selenium, which improves hematopoietic processes in the body and prevents undesirable forms of neoplasms. Thus, the advantages of MBPE as a source of essential substances and vital nutrients are obvious, confirming the prospect of creating food products based on it and with its use.

Analysis of the chemical composition of MBPE ash showed that more than 90% of the ash consists of phosphoric acid, potassium oxides, magnesium, and calcium (Fig. 3.3).

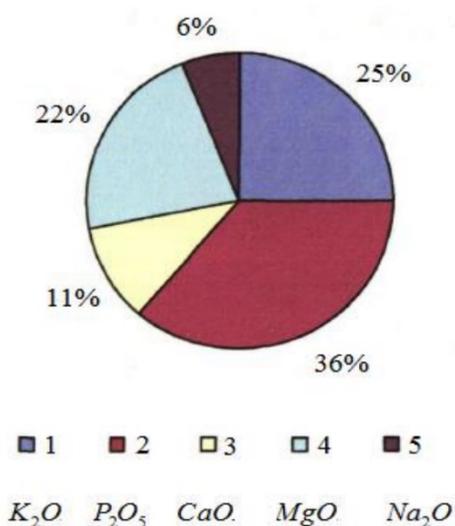


Figure 3.3 - Macroelements of MBPE

Thus, MBPE as a food object contains a large number of macroelements such as calcium, phosphorus, potassium, and magnesium, which are vital components of human nutrition, necessary for the formation of the chemical structures of living tissues and for ensuring the biochemical and physiological processes that form the basis of life (Fig. 3.4).

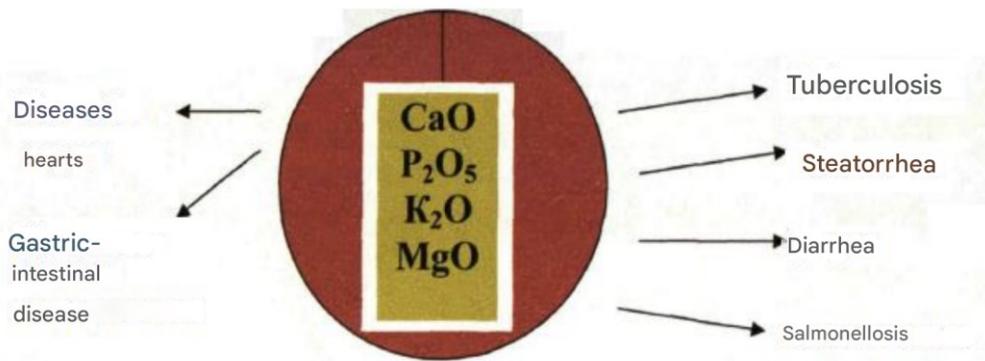


Figure 3.4 - Protective action of MBPE elements against diseases

To confirm the theoretical positions stated in the previous sections, samples of mung bean protein extract were studied from the point of view of biological value. To determine the biological value of the proteins, we calculated the score for the essential amino acids of MBPE. From the comparison of the biological value of the mung bean protein extract with cow's milk and the ideal protein (Fig. 3.5), it was found that its amino acid composition meets the human body's needs for amino acids for protein synthesis.

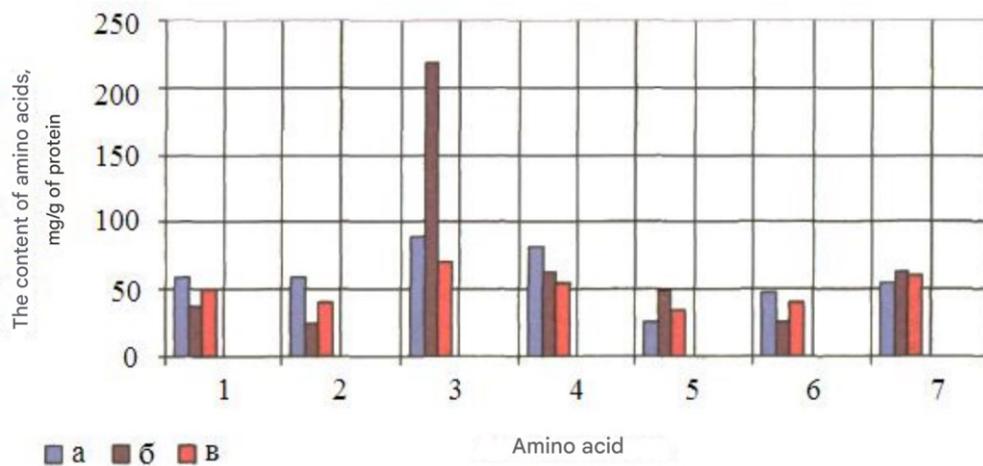


Figure 3.5 – Comparative assessment of the amino acid composition of protein products: a – cow's milk; b – mung bean protein extract; c – ideal protein; 1 - alanine; 2 – isoleucine; 3 – leucine; 4 – lysine; 5 – methionine+cysteine; 6 - threonine; 7 – phenylalanine+tyrosine.

In the modern production of food products, their organoleptic characteristics play a major role in determining consumer properties. Therefore, when designing a

product, it is necessary to consider the properties of all its components, both individually and in combination with each other. The organoleptic evaluation of the mung bean protein extract is presented in Table 3.4.

Table 3.4 - Organoleptic evaluation of mung bean protein extract

Indicator	Characteristic
Appearance, consistency	Homogeneous liquid
Taste and smell	Pleasant, refreshing, slightly sweet, rich taste, without off-flavors or odors
Color	Rich cream

The microbiological indicators of freshly produced mung bean protein extract comply with the safety standards for food products and are presented in Table 3.5.

Table 3.5 – Microbiological indicators of fresh mung bean protein extract

Indicator Name	Value
TVC (Total Viable Count), CFU/g	500
Coliforms, in 1g	not detected
Staphylococcus aureus, in 1g	not detected
Pathogenic microorganisms, including Salmonella, in 25 g	not detected
Molds and yeasts, CFU/g, in 1g	not detected
Lactic acid microorganisms, in 1g	not detected

We conducted a study on the storage properties of the mung bean protein extract. Microbiological studies of the Total Viable Count (TVC) showed that with an increase in storage time from 0 to 72 hours at a temperature of 4°C, the number of bacteria increases from 500 to 50,000 CFU/g. The growth of yeasts, molds, lactic acid bacteria, coliforms, and pathogenic microorganisms (Staphylococcus aureus, Salmonella) was not detected. The active acidity decreases from 6.70 to 6.50. For comparison of the microbiological indicators of the protein extract, the most

stringent indicators for similar products listed in SanPiN (Sanitary Rules and Norms) were chosen (Table 3.6).

Table 3.6 – Microbiological indicators of mung bean protein extract during storage

Indicator Name	Storage Time, hours				Permissible level according to Standart for similar products
	24	36	48	72	
TVC, CFU/g	$0.3 \cdot 10^4$	$1.5 \cdot 10^4$	$3.3 \cdot 10^4$	$5.0 \cdot 10^4$	$5.0 \cdot 10^4$
Coliforms, in 1g	not detected	not detected	not detected	not detected	0.1
Staphylococcus aureus, in 1g	not detected	not detected	not detected	not detected	1.0
Pathogenic microorganisms, including Salmonella, in 25 g	not detected	not detected	not detected	not detected	Not allowed
Molds and yeasts, CFU/g, in 1g	not detected	not detected	not detected	not detected	10
Lactic acid microorganisms, in 1g	not detected	not detected	not detected	not detected	

The shelf life of the mung bean protein extract, taking into account the reserve coefficient for perishable products according to the methodological guidelines, is 48 hours at a temperature of 4°C.

From the data presented, it can be concluded that the obtained mung bean protein extract, by its physicochemical, organoleptic, and biological characteristics,

is a valuable functional semi-finished product containing valuable mung bean proteins (in the amount of 3.0-3.2%) and essential amino acids. According to microbiological indicators, MBPE meets the requirements of SanPiN. The foregoing allows us to recommend the protein extract as a standalone product or in the technology of other food products as a source of complete proteins and essential elements. The use of the protein extract in the production of fermented milk products is of scientific and practical interest.

3.3 Investigation of the Specifics of Lactic Acid Fermentation of Milk Mixtures with Mung Bean Protein Extract

Dairy products are an integral part of the modern person's diet. Preference is given to new types of fermented milk products that have a beneficial effect on the body. When creating such food products, important factors are the composition and quality of raw materials and ingredients, and the composition and properties of the starter culture microflora. Of the wide variety of fermented milk products, yogurt has gained the most widespread popularity worldwide. The popularity of this product is due to a number of factors: a pleasant taste, a reputation as a healthy food, and an ideal combination with fruits. Therefore, the use of mung bean protein extract in yogurt production is a promising direction.

For successful fermentation, both catabolic (acid formation) and anabolic processes are important. According to standards, yogurt is a fermented milk product with an increased content of non-fat dry matter, produced by fermenting with a protosymbiotic mixture of pure cultures of thermophilic lactic acid streptococci and Bulgarian lactic acid bacillus.

To achieve the set goal, we considered and conducted studies of different starter cultures (Table 3.7).

Table 3.7 - Species composition of the starter cultures used

Starter Culture Type	Strain Composition
Production Starter	Streptococcus thermophilus, Lactobacillus acidophilus
Biogarde (Germany)	Bifidobacterium longum, Lactobacillus bulgaricus
Starter Culture "Jo-mix 401" (Denmark)	Streptococcus thermophilus, Lactobacillus delbrueckii subsp bulgaricus
Starter Culture "Jo-mix 621" (Denmark)	Streptococcus thermophilus, Lactobacillus delbrueckii subsp bulgaricus

When comparing the starters, it was noted that different cultures form coagulums of different density and consistency. The organoleptic profile of the coagulums obtained using the considered starters is presented in Fig. 3.6.

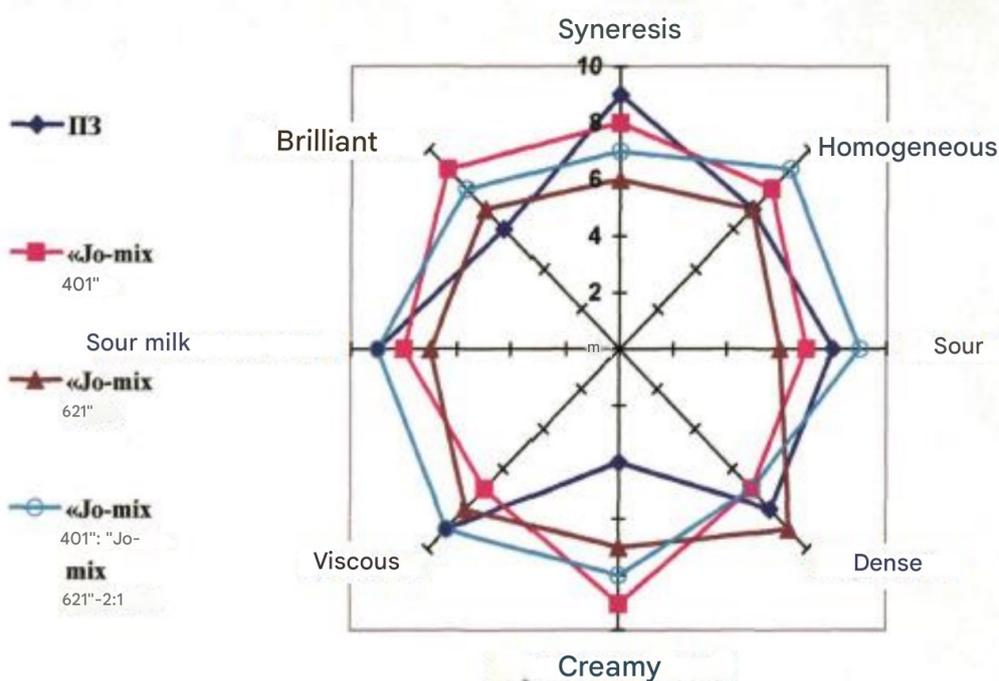


Figure 3.6 - Organoleptic profile of milk coagulums obtained using the considered starters

The temperature and time of fermentation have a great influence on the fermentation process of the mixture. To determine the optimal temperature, we

considered the fermentation process at temperatures of 37°C and 40°C. The research results are presented in Table 3.8. The best organoleptic indicators of the yogurt were obtained at a fermentation temperature of 40°C.

Table 3.8 - Influence of fermentation temperature on yogurt quality

Starter	Fermentation Temp., °C	Fermentation Time, h	Coagulum pH	Organoleptic Characteristic
PS	37	6	4.32	Clean fermented milk taste, dense consistency
PS	40	7	4.32	Clean, fermented milk, well-expressed taste and aroma, dense consistency
"Jo-mix 401"	37	8	4.32	Clean fermented milk taste, weakly expressed aroma, dense creamy coagulum
"Jo-mix 401"	40	7	4.32	Clean, fermented milk, well-expressed taste and aroma, dense, creamy, viscous coagulum
"Jo-mix 401" + "Jo-mix 621"	37	8	4.32	Clean fermented milk taste, dense creamy coagulum, moderately viscous consistency
"Jo-mix 401" + "Jo-mix 621"	40	7	4.32	Clean, fermented milk, well-expressed taste and aroma, dense, creamy, viscous coagulum

In the course of further research, the rate of acidity increase during the fermentation of the mung bean protein extract was determined. A rather slow increase in acidity without the formation of a coagulum was observed. Based on this, it can be said that mung bean protein extract cannot serve as the sole raw material for yogurt production.

To intensify the process, studies were conducted on four experimental samples with different ratios of skim milk to mung bean protein extract: No. 1 (1:0), No. 2 (3:1), No. 3 (1:1), No. 4 (1:3). It was found that all curves of the dependence of active acidity on fermentation time have a similar character (Fig. 3.7 - 3.9).

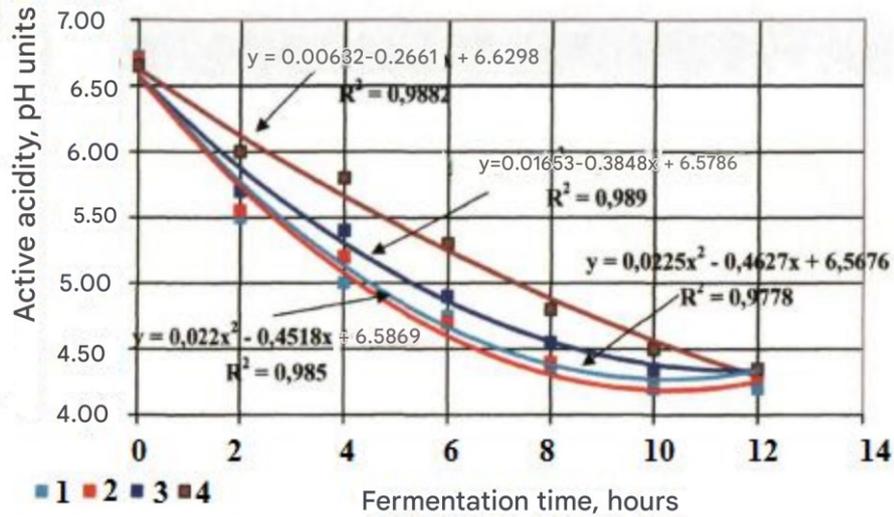


Figure 3.7 - Change in active acidity during fermentation of experimental samples with the production starter

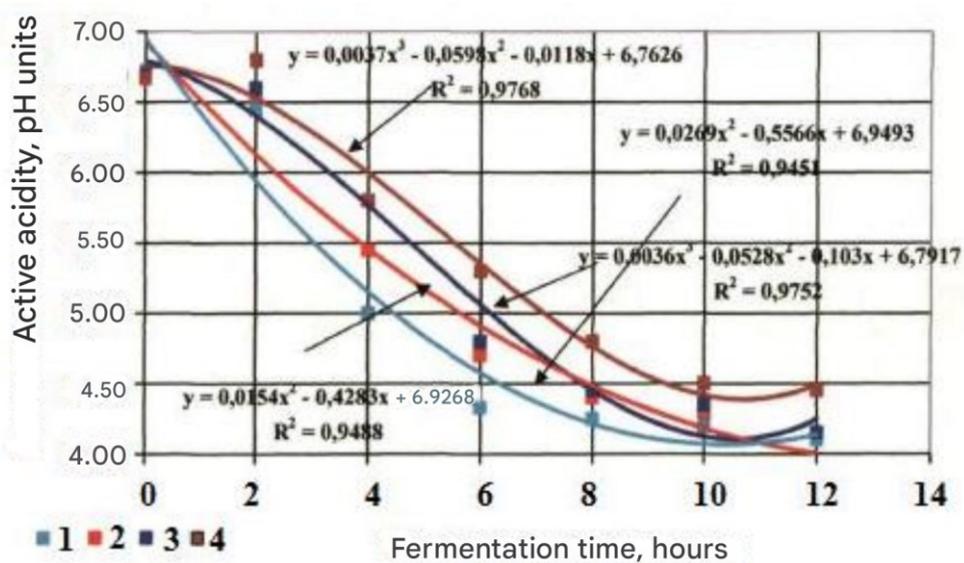


Figure 3.8 - Change in active acidity during fermentation of experimental samples with the "Jomix 401" starter

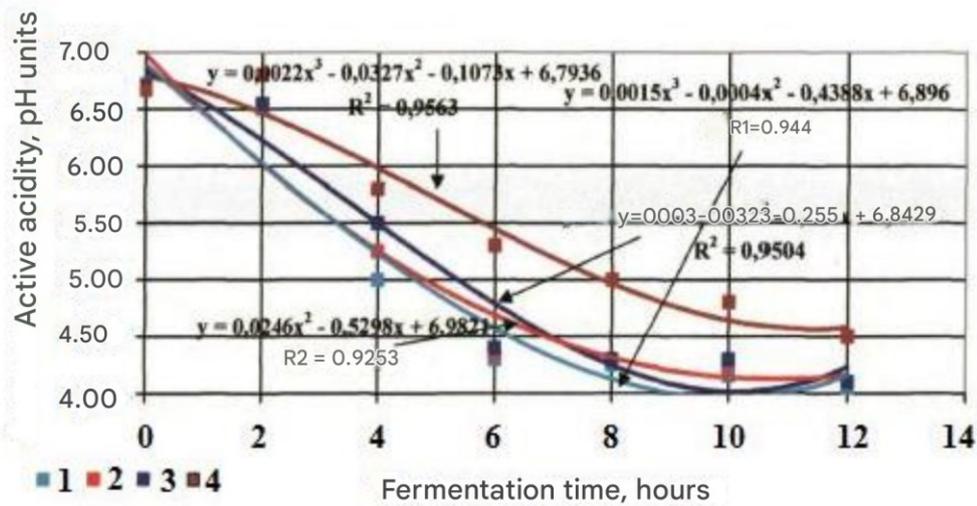


Figure 3.9 - Change in active acidity during fermentation of experimental samples with the combined starter

The studies showed that with an increase in the content of the protein extract, the strength of the coagulum decreases and the fermentation time increases. At a ratio of skim milk to MBPE of more than 1:3, the coagulum becomes loose. A ratio of less than 1:1 reduces the nutritional value of the product. Thus, for the production of yogurt, the recommended ratio of cow's milk to MBPE is 1:1. The organoleptic profile of the coagulums for this ratio is presented in Fig. 3.10.

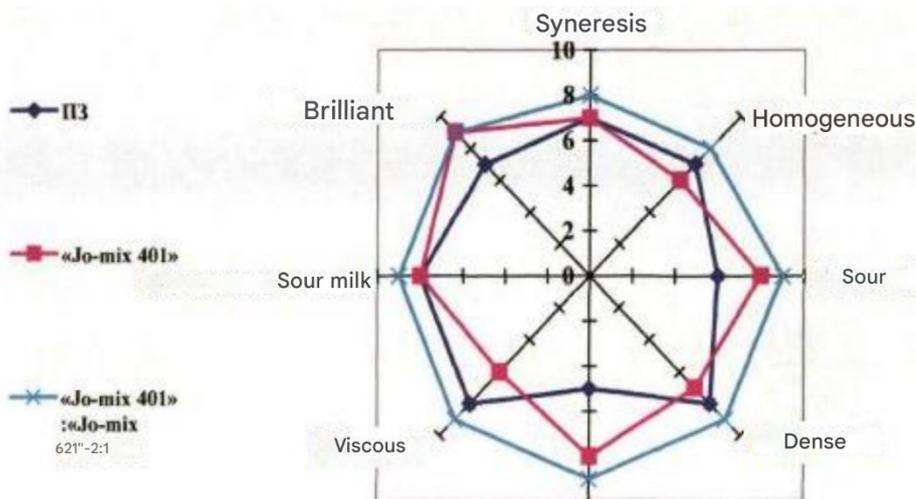


Figure 3.10 – Organoleptic profile of coagulums from the fermentation of a mixture of skim milk and MBPE in a 1:1 ratio with different starters

Fig. 3.10 shows that the coagulum produced using the combined starter has the best profile.

3.4 Substantiation of the Choice of Stabilizers and Investigation of the Structural-Functional Properties of Yogurts

One of the key properties of a food product is its texture. In the production of fermented milk products, stabilizers are often used. The main purpose of adding stabilizers is to improve and maintain the structure, consistency, and viscosity. The stabilizer market offers various blends for yogurt production [23].

To obtain a yogurt with the desired consistency, the features of stabilizing the structure of the coagulum obtained by fermenting a mixture of skim milk and MBPE in a 1:1 ratio with a combined starter were investigated. To achieve this goal, we determined the effect of seven different structuring agents (Table 3.9).

Table 3.9 - Characteristics of stabilizers

Name	Recommended Dosage, %	Stabilizer Composition
Gelatin	0.1-0.4	
Pectin	0.1-0.4	Standardized with sugar
Modified Starch E1422	0.5-2.0	
Palsgaard 5809	0.9-1.2	Modified Starch E1442, Agar E406
Palsgaard 5846	0.4-0.7	Modified Starch E1442, Beef Gelatin, Pectin E440
Palsgaard 5848	0.3-0.6	Pork Gelatin, Sodium Caseinate
Palsgaard 5854	1.5-2.0	Modified Starch E1442, Beef Gelatin

Preliminary rheological studies on the "Bostwick Consistometer" (Table 3.10) showed that samples using modified starch and the stabilizing systems Palsgaard 5854 and Palsgaard 5809 have a more viscous consistency.

Table 3.10 - Rheological properties of coagulums on the "Bostwick Consistometer"

Stabilizer	Dosage, %	After 30 s, mm	After 60 s, mm
Control 1	Gelatin 0.3%, Starch 2.6%	68	75
Modified Starch	2.0	64	66
Palsgaard 5809	1.0	78	84
Palsgaard 5854	2.0	117	125

During storage (7 days), the largest volume of separated free phase was observed in samples using pectin and gelatin, while in samples using modified starch, Palsgaard 5854, and Palsgaard 5809, when separation was practically not observed (Fig. 3.11).

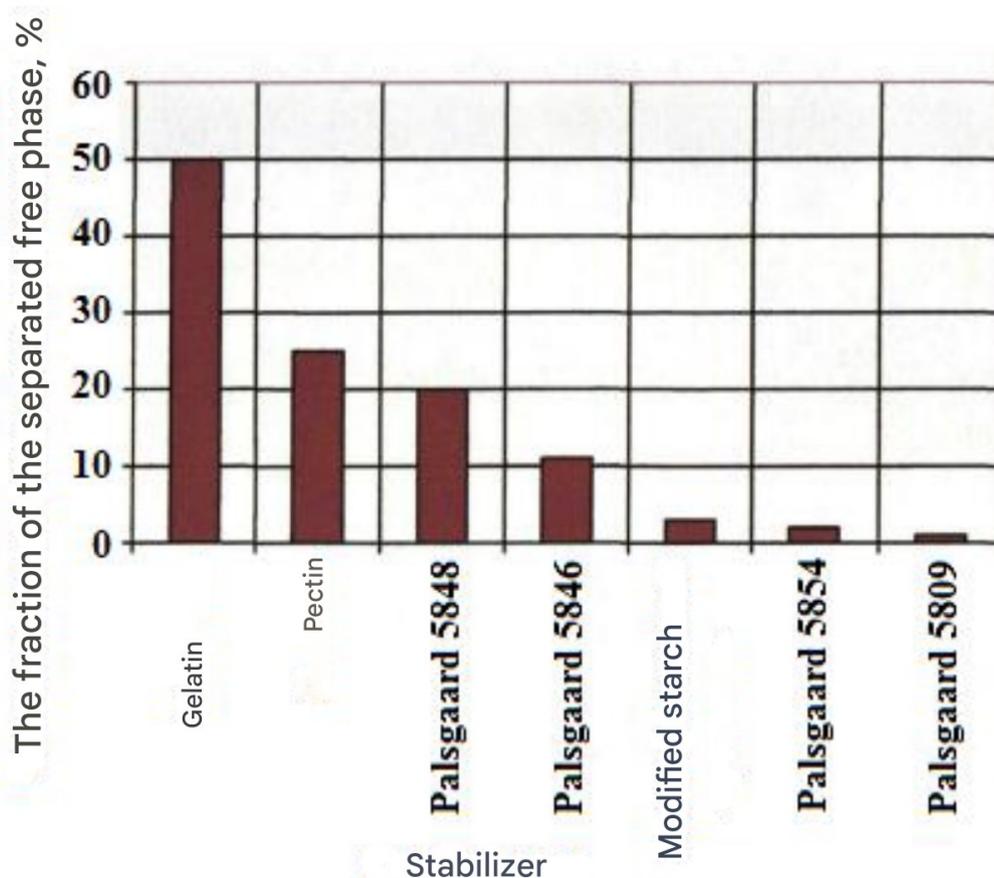


Figure 3.11 - Dependence of the fraction of separated free phase on the type of stabilizer used during a 7-day storage period

The data indicate that the samples with modified potato starch and the stabilizing systems Palsgaard 5854 and Palsgaard 5809 have the best indicators. The change in the kinematic viscosity of these samples is presented in Fig. 3.12.

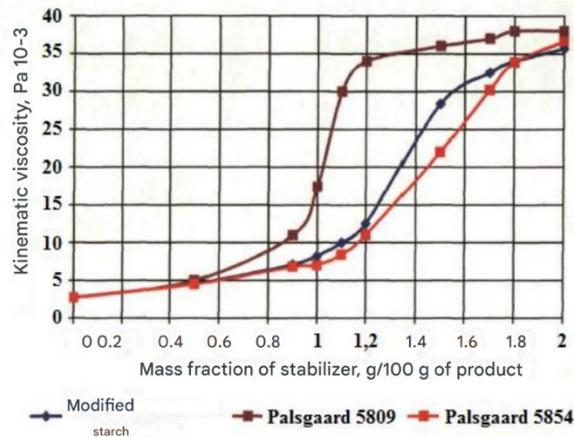


Figure 3.12 – Change in the kinematic viscosity of yogurts with MBPE using stabilizers

The structural-mechanical properties were determined on a "Rheotest-2" device. The research results are presented in Fig. 3.13.

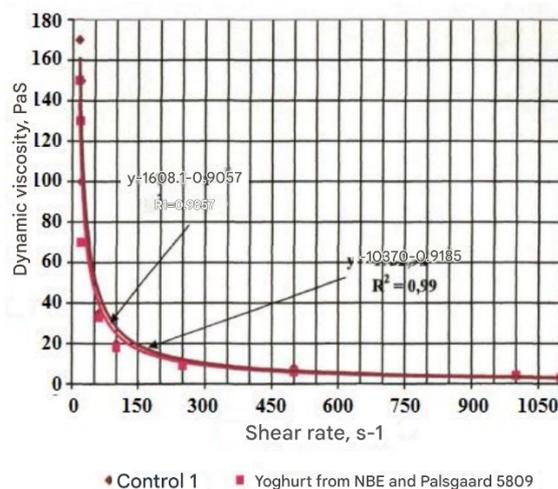


Figure 3.13 - Dependence of the viscosity of the yogurt coagulum with MBPE and stabilizer Palsgaard 5809 and control 1 on the deformation rate

With an increase in the deformation rate, a decrease in the viscosity of the samples is observed. Based on the study of rheological indicators, it can be concluded that it is advisable to use Palsgaard 5809 as a stabilizer. The recommended dosage is 1.1-1.2%.

Detailed Description of the Production Technology

The production technology for yogurt enriched with mung bean protein extract (MBPE) is based on the classic principles of set-yogurt production using the tank method, but with consideration for the specific characteristics of the incorporated plant-based component:

1. Raw Material Acceptance and Preparation

Dairy Raw Material: Incoming cow's milk undergoes an initial quality control for organoleptic (taste, color, smell, consistency) and physicochemical parameters (density, acidity, fat and protein content, temperature). The milk is purified from mechanical impurities using milk clarifying separators and cooled to 4-6 °C for temporary storage.

Mung Bean Protein Extract (MBPE): Pre-prepared and pasteurized MBPE, produced according to the scheme (Fig. 3.1) and cooled to 4-6 °C, is used. Before use, the extract is checked for compliance with quality indicators (mass fraction of protein, dry matter, pH, microbiological purity).

Dry Ingredients: Skim milk powder, granulated sugar, and the stabilizing system (Palsgaard 5809) are sifted to remove potential lumps and impurities.

2. Standardization and Mixture Preparation

This process is carried out in a tank for mixture standardization.

First, the pre-mixed dry ingredients (sugar, milk powder, stabilizer) are thoroughly dissolved in a small amount of milk heated to 40-45 °C to prevent clumping.

This solution of dry ingredients, the mung bean protein extract (MBPE), and, for the classic yogurt, cream for fat standardization are added to the main volume of milk in the tank.

The mixture is thoroughly stirred for 15-20 minutes until all components are fully dissolved and a homogeneous emulsion is obtained. The formulation is calculated according to the data in Table 3.11.

3. Heat Treatment and Homogenization

The prepared mixture is heated to a temperature of 65-70 °C and directed for homogenization. The process is conducted at a pressure of 15-20 MPa. Homogenization is necessary to break down fat globules and plant protein aggregates, ensuring the stability of the emulsion, preventing fat separation, and improving the consistency and taste of the final product, making it smoother and "fuller."

After homogenization, the mixture is sent for pasteurization. A high-temperature regime is used: a temperature of 96 ± 2 °C with a holding time of 6 minutes. This regime is justified by two objectives:

Microbiological: To destroy vegetative forms of microorganisms, ensuring product safety and creating a "clean" environment for the development of the starter microflora.

Technological: To denature the whey proteins in the milk (α -lactalbumin and β -lactoglobulin). The denatured whey proteins interact with casein, significantly increasing the water-binding capacity of the protein system. This leads to the formation of a denser and more stable coagulum, preventing whey separation (syneresis) in the finished product.

4. Inoculation and Fermentation

The pasteurized mixture is cooled in the same apparatus to the optimal fermentation temperature of 40 ± 1 °C. This temperature is a compromise that supports the symbiotic growth of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*.

A pre-activated or direct-to-vat (DVS) freeze-dried starter culture is added to the mixture according to the manufacturer's recommendations. After adding the starter, the mixture is thoroughly stirred for 10-15 minutes for its uniform distribution.

Fermentation is carried out in special double-walled tanks for fermented milk products, maintaining a temperature of 40 ± 1 °C for 7-8 hours. The fermentation process is monitored by the increase in acidity until a pH of 4.3-4.35 is reached. At this pH value, the milk and mung bean proteins coagulate, forming the characteristic yogurt gel (coagulum).

5. Cooling, Packaging, and Maturation

Upon reaching the required acidity, the fermentation process is immediately stopped by cooling. The coagulum is gently stirred to obtain a homogeneous consistency and cooled to a temperature of 15-20 °C.

The cooled product is sent to an automatic packaging line, where it is filled into sterile consumer containers (cups, bottles).

The packaged yogurt is immediately sent to a cold chamber for final cooling and maturation at a temperature of 4 ± 2 °C. This stage lasts for 12-24 hours. During maturation, the gel structure stabilizes, the stabilizer fully hydrates, and the characteristic yogurt flavor and aroma develop further.

3.5 Formulation Solutions for Enriched Yogurts and Their Safety Assessment

When using mung bean protein extract in the technology of fermented milk drinks, its properties and structure are of great importance. It is recommended to add the protein concentrate to the finished normalized mixture before pasteurization. To increase the thermal stability of the mixture, it is recommended to add a phosphate stabilizer.

Yogurts with mung bean protein extract are recommended to be produced as non-fat or classic (with a fat mass fraction of 2.7%). Based on the results of the studies, formulations for new fermented milk products were developed (Table 3.11).

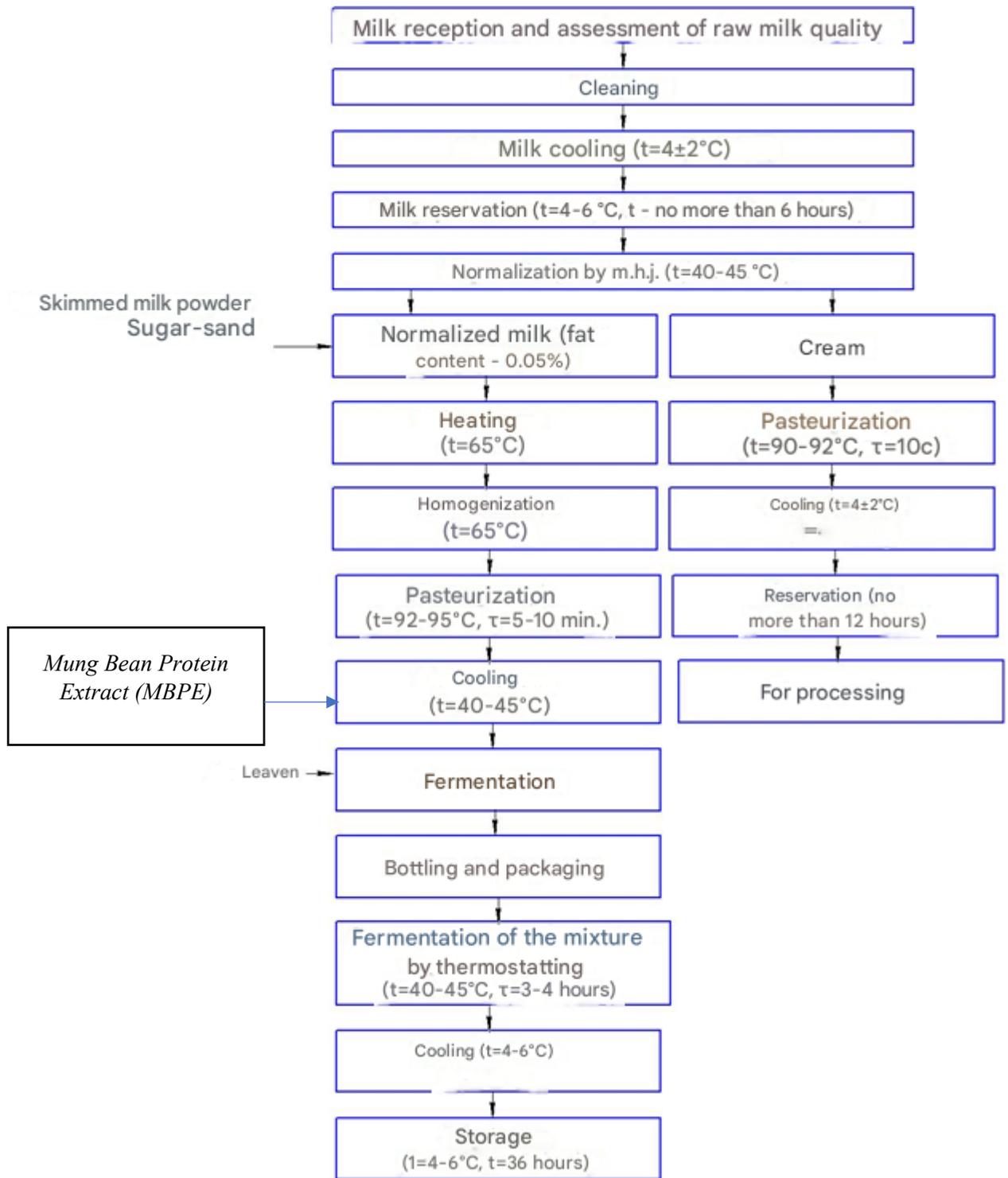


Figure 3.14 – Technological scheme of vegan yogurt

Table 3.11 – Formulation of yogurts with MBPE (per 1000 kg of finished product, excluding losses, in kg)

Component Name	Raw Material Consumption for Yogurts, kg	
	Non-fat	Classic
Skim Milk (fat 0.05%)	458.7	426.7
Mung Bean Protein Extract (dry matter 5.2%)	458.7	426.7
Cream (fat 35%)		64.0
Turrisin CT	3.0	3.0
Stabilizer - Palsgaard 5809	12.0	12.0
Skim Milk Powder	7.5	7.5
Starter "Jo-mix 401" & "Jo-mix 621" (2:1)	0.1	0.1
Granulated Sugar	60.0	60.0
Total:	1000.0	1000.0

To expand the range of yogurts, it is proposed to produce them with flavor and taste additives.

3.6 Quality and Nutritional Value Assessment of Yogurts with Mung Bean Protein Extract

The terms "nutritional, biological, and energy" value characterize the usefulness of food products. The task of the following studies is to examine the properties of yogurts with mung bean protein extract. The physicochemical indicators of the yogurts are presented in Table 3.12.

Table 3.12 – Physicochemical indicators of yogurts

Indicator Name	Value for Yogurts	
	Non-fat	Classic
Fat Mass Fraction, %	0.1	2.7
Protein Mass Fraction, %	3.1	3.0
Dry Matter Mass Fraction, %, not less than	18	17
Sucrose Mass Fraction, %, not less than	12	12
Active Acidity, pH	3.8-4.2	3.8-4.2

To assess the biological value of the product, the amino acid composition of the yogurt samples was studied (Tables 3.13 and 3.14).

Table 3.13 - Amino acid composition of yogurts with MBPE, mg/100 g of product

Amino Acids	Non-fat	Classic
Threonine	242	236
Valine	154	153
Methionine	114	120
Isoleucine	201	210
Leucine	405	398
Phenylalanine	137	130
Lysine	251	265

Table 3.14 - Biological value of yogurts with MBPE

Amino Acids	FAO/WHO Standard (A, mg/g protein)	Non-fat (S, %)	Classic (S, %)
Isoleucine	40	132	147
Leucine	70	152	160
Lysine	55	65.9	135
Methionine+Cysteine	35	56.5	174
Phenylalanine+Tyrosine	60	107	109
Threonine	40	158	165
Valine	50	81	86

In the production of yogurts, their organoleptic evaluation plays a major role (Table 3.15).

Table 3.15 - Organoleptic evaluation of yogurts with MBPE

Indicator	Characteristic
Appearance, consistency	Homogeneous mass, glossy surface, without whey separation
Taste and smell	Fermented milk taste, moderately sweet, without off-flavors
Color	Uniform throughout the mass, light cream

The use of mung bean protein extract in the production of yogurts is justified by the good balance of its amino acid composition. The content of toxic elements and mycotoxins (Table 3.16) in the product meets the requirements of Standart.

Table 3.16 - Content of toxic elements in yogurts

Name	Content in yogurts, mg/kg	Permissible level, mg/kg
Lead	0.025	0.1
Cadmium	0.011	0.03
Arsenic	0.008	0.05
Mercury	0.009	0.005

The data in Table 3.17 allow us to conclude that the yogurts provide a sufficient degree of satisfaction of the body's daily needs.

Table 3.17 - Degree of satisfaction of daily nutritional needs (per 100 g)

Nutritional Value	Daily Need	Content in Yogurts (Classic)	Degree of Satisfaction, %
Proteins, g	85	3.0	3.5
Lysine	3 g	0.265 g	8.8
Calcium	900 mg	150 mg	16.7
Phosphorus	1250 mg	100 mg	8.0
Vitamin B2	2.0 mg	0.17 mg	8.5

The microbiological indicators of the finished product meet safety standards (Table 3.18).

Table 3.18 - Microbiological indicators of the finished product

Indicator Name	Value
Coliforms, in 0.1 g	not detected
Staphylococcus aureus, in 1g	not detected
Pathogenic microorganisms, in 25 g	not detected
Lactic acid microorganisms, in 1g	10^{10}

The storage stability of yogurts with MBPE was studied. The obtained data are presented in Table 3.19 and Fig. 3.14.

Table 3.19 - Organoleptic and physicochemical indicators of yogurts with MBPE during storage

Duration, days	pH	Organoleptic indicators
0	4.33	
1-7	4.19-4.13	Clean surface, homogeneous consistency, clean taste and smell
8-9	4.10-4.08	Syneresis is observed, flakes appear

As can be seen from the data, on the 9th day, the product loses its consumer properties.

The results of the microflora composition of yogurts with MBPE during storage are presented in Table 3.20.

Table 3.20 - Change in the microflora composition of yogurts during storage

Studied microorganism species	Microorganism content per 1 g of product	
	Freshly produced	After 9 days of storage
Coliforms in 0.1 g	Not detected	Not detected
Lactic acid microorganisms, in 1g	$2.5 \cdot 10^{10}$	$0.06 \cdot 10^7$

According to standards, at the end of the shelf life, the number of lactic acid microorganisms should be at least 10^7 CFU/g. Thus, the shelf life, taking into account the reserve coefficient, is 5 days at a temperature of 4°C.

The presented data indicate that the developed yogurts with MBPE are complete products in terms of their characteristics, containing valuable mung bean proteins and essential amino acids.

Conclusions to Chapter 3

In the course of the experimental studies, the technology for obtaining a functional semi-finished product—mung bean protein extract (MBPE)—was scientifically substantiated and developed. Rational process parameters were established, including preliminary sprouting of the raw material, extraction in an alkaline medium (pH 8.5), and pasteurization (90°C). The comprehensive properties of the obtained extract were studied: it is characterized by a protein content of 3.0-3.2%, a balanced amino acid and mineral composition, good organoleptic indicators, and compliance with microbiological safety requirements. The established shelf life of MBPE is 48 hours at a temperature of 4°C.

The specifics of the lactic acid fermentation process for combined dairy-plant mixtures were investigated. It was determined that using MBPE as the sole base is impractical due to slow acid formation and the absence of a stable coagulum. It was experimentally proven that the optimal ratio for achieving the desired technological and organoleptic properties is 1:1 for skim milk to MBPE. The optimal starter culture composition (a combination of "Jo-mix 401" and "Jo-mix 621" cultures) and fermentation temperature (40°C) were selected, ensuring a process duration of 7-8 hours.

The feasibility of using a stabilizing system to provide the yogurt with the necessary consistency, viscosity, and prevention of syneresis was substantiated. Through a comparative analysis of seven different structuring agents, it was established that the stabilizer Palsgaard 5809 at a recommended dosage of 1.1-1.2% provides the best structural and mechanical properties (high viscosity, minimal free

phase separation). Rheological studies confirmed that the developed yogurt is a non-Newtonian, pseudoplastic fluid with pronounced thixotropic properties, which is characteristic of high-quality fermented milk products.

Based on the research conducted, formulations and a technology for non-fat and classic (2.7% fat) yogurts enriched with MBPE were developed. A comprehensive evaluation of the finished products showed that they have high nutritional and biological value due to the successful combination of milk and mung bean proteins, harmonious organoleptic indicators (homogeneous, moderately viscous consistency, clean fermented milk taste), and fully comply with safety requirements regarding the content of toxic elements and microbiological indicators.

The dynamics of physicochemical, microbiological, and organoleptic indicators of the developed yogurts during storage were studied. Based on the data obtained, the recommended shelf life of the product was established as 5 days at a storage temperature of $4\pm 2^{\circ}\text{C}$.

CHAPTER 4. ANALYSIS OF TECHNOLOGY AND IDENTIFICATION OF PRODUCTION HAZARDS

In a production environment, technochemical, microbiological, and organoleptic controls (acceptance and periodic) are conducted to monitor the quality of yogurt, forming the basis of the HACCP food safety management system.

Acceptance control is carried out by the manufacturer's laboratory for each batch of raw materials (milk, MBPE, dry components) and finished product. For the finished product, it includes checks on organoleptic and physicochemical parameters (except for the mass fraction of sucrose), net weight, and the quality of packaging and labeling.

During **periodic control** of the finished product, the following are checked:

- Mass fraction of sucrose – at least twice a month;
- Presence of coliform bacteria (coliforms) – at least once every 5 days;
- Total Viable Count (aerobic and facultative anaerobic mesophilic microorganisms) – at least twice a month;
- Quantity of lactic acid microorganisms – at least twice a month;
- Presence of yeasts and molds – once a month;
- Content of radionuclides and toxic elements – with a frequency established by the production control program (usually, once a quarter or half-year).

Each batch of yogurt must be checked by the manufacturer for compliance with standard requirements and be accompanied by a quality and safety certificate. The original certificate is kept at the manufacturing plant. The recipient is issued a copy of the quality certificate with a valid seal. The transport documents must indicate the certificate number, its date of issue, the date of manufacture, the product temperature at dispatch, and its storage conditions and shelf life.

Table 4.1 – Scheme of Technological Control for the Production of Yogurt with MBPE

Technological Process Stage	Type of Control	Control Content (Parameters Checked)	Scope of Control	Frequency of Control
1	2	3	4	5
Acceptance and Preparation of Raw Materials (Milk, MBPE)	Physicochemical	Density, acidity, fat, protein, dry matter content, temperature	Every batch	Constantly
	Organoleptic	Taste, smell, color, consistency	Every batch	Constantly
	Microbiological	TVC, somatic cells (for milk)	Selectively	According to schedule
Mixture Preparation and Standardization	Technological	Recipe calculation check, sequence of component addition, temperature, mixing time	Every batch	Daily
	Organoleptic	Color, homogeneity of the mixture	Every batch	Every shift
	Physicochemical	Fat, protein, dry matter content	Every batch	Every shift
Pasteurization and Homogenization of Mixture	Technological	Pasteurization temperature and duration, homogenization pressure	Every batch	Constantly (via instrument readings)
	Physicochemical	Homogenization efficiency (fat globule size)	Selectively	At least once a week
	Microbiological	Residual microflora after pasteurization	Selectively	Periodically

Cooling and Fermentation	Technological	Mixture temperature before inoculation, starter dosage, fermentation temperature and duration	Every batch	Constantly
	Physicochemical	Increase in titratable acidity, change in coagulum pH	Every 30-60 min during fermentation	Every shift
Cooling and Packaging of Finished Product	Technological	Coagulum stirring and cooling regime, temperature before packaging, net weight of portion	Every batch	Periodically during operation
	Organoleptic	Appearance, consistency, packaging quality, labeling	Every batch	Daily
	Physicochemical	Titratable acidity, pH, fat, dry matter content	Every batch	Every shift
Maturation and Storage	Technological	Temperature regime in the cold storage chamber	At least in 2 points of the chamber	Constantly (recorder data)
	Organoleptic	Taste, smell, consistency (at the end of shelf life)	Selectively	As needed
	Microbiological	Coliforms, yeasts, molds, number of lactic acid m/o	Selectively	According to schedule

Yogurt is accepted in batches. A homogeneous batch is a product manufactured by one enterprise, during a single technological cycle, from one

standardized mixture, under uniform technological regimes, in identical consumer packaging, and of the same name.

To obtain objective research results, packaged yogurt is thoroughly mixed in its container or transferred to a laboratory vessel. Before analysis, samples are brought to a temperature of 20 ± 2 °C. The appearance and color of the product are determined visually, while consistency, structure, and taste are assessed organoleptically. The determination of mass fractions of dry matter, fat, protein, acidity, and temperature is carried out in accordance with current regulatory documents.

During microbiological control, samples are taken with sterile instruments in compliance with aseptic rules. Samples in their original packaging are delivered to the laboratory in cooler bags and analyzed no later than 4 hours from the time of collection.

Analysis of Potential Product Defects and Their Causes

Failure to adhere to technological regimes, use of low-quality raw materials, violation of sanitary and hygienic norms, or improper storage conditions can lead to defects in the taste, smell, structure, consistency, and appearance of the yogurt.

Defects of Taste and Smell

- Unclean, foreign taste (feed-like, barny): usually a consequence of using low-quality milk raw material that had defects before processing.
- Weak, flat taste: may be caused by insufficient acidity due to low starter activity, too low a fermentation temperature, or premature cooling.
- Excessively sour taste: occurs as a result of over-fermentation (too high a temperature or duration of fermentation), or a breach of the cooling regime, allowing the starter culture to remain active.
- Yeasty, alcoholic taste: indicates microbiological contamination of the product with foreign yeasts, usually due to a violation of sanitary norms.
- "Beany" or "grassy" aftertaste: a specific defect possible when using a mung bean protein extract of improper quality, in which enzymes (lipoxygenase) were not fully inactivated or volatile compounds were not removed.

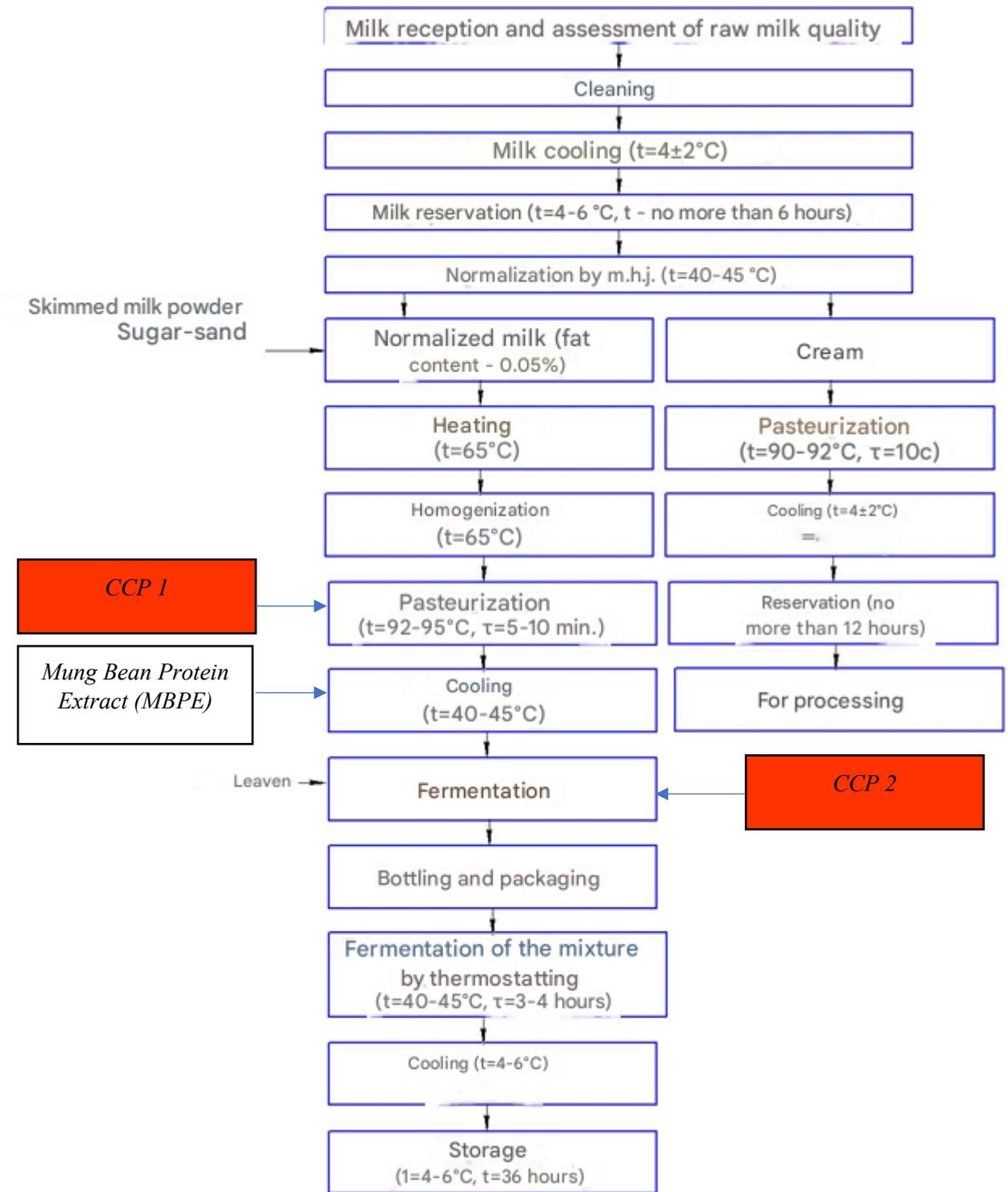


Figure 4.1 – CCP of Technological scheme of vegan yougurt

Defects of Structure and Consistency

- Weak, unstable coagulum/liquid consistency: can be caused by low dry matter content in the mixture (especially protein), low starter activity, or premature stirring of the coagulum.
- Whey separation (syneresis): the most common defect. Causes include: low dry matter content, insufficient denaturation of whey proteins due to low pasteurization temperature, excessively high acidity (synergistic syneresis), or overly intensive mechanical stirring of the coagulum.
- Grainy, lumpy structure: occurs during over-fermentation, when intense protein aggregation happens due to a very low pH. It can also be a result of improper addition or incompatibility of the stabilizer.
- Ropy, slimy consistency: usually a sign of the development of foreign microflora that produces exopolysaccharides. It can occur when using ropy strains of starter cultures if not intended by the technology.
- Excessively thick, pasty consistency: typically the result of an overdose of stabilizer or an overly high content of dry matter in the mixture.

Defects of Appearance and Packaging

- Bloated packaging (bombage): a clear sign of microbiological spoilage caused by the development of gas-producing microorganisms (yeasts, coliforms). Such a product is unsafe and must not be sold.
- Non-uniform color, phase separation: may occur with poor mixing of the protein extract with the milk base or due to emulsion instability.
- Mechanical damage to packaging: deformed cups, non-hermetic sealing of the lid, unclear labeling. This is a result of malfunctions in the filling and packaging equipment.

CHAPTER 5. ORGANIZATIONAL AND ECONOMIC PART

5.1. Theoretical Foundations and Organization of the Research

Theoretical Substantiation. The organizational and economic part is an integral element of any research work, as it allows for the assessment not only of the scientific but also the practical and economic feasibility of the project. The purpose of this section is to determine a rational sequence for the execution of tasks, to evaluate the necessary resources (time, materials, financial), and to calculate the economic efficiency of the conducted studies. Effective planning is the key to the successful completion of the research within the established deadlines and budget.

For managing complex projects such as scientific research, methods of Network Planning and Management (NPM) are widely used. These methods allow for the visualization of the entire scope of work in the form of a network diagram, determining their logical interconnections and identifying the **critical path**—the longest sequence of tasks that defines the minimum possible time to complete the entire project. The analysis of the critical path enables managerial focus on the most crucial stages, where any delay would lead to a shift in the timeline for the entire research.

Organization of the Research. Based on the NPM methodology, a detailed plan for conducting the research aimed at developing the technology for yogurt enriched with mung bean protein extract was developed. The list and duration of the stages are presented in Table 5.1.

Table 5.1 – Research Plan

Task Code (i-j)	Task Name	Duration (t), days
1-2	Selection and justification of the research direction	2
2-3	Literature search and writing of the literature review	12
3-4	Development of the research algorithm and program	3
4-5	Development of research methodologies	6
5-6	Formulation modeling and ingredient selection	2
6-7	Determination of the optimal ratio of components	6

7-8	Establishment of the main technological process parameters	4
7-9	Investigation of the product's structural and mechanical characteristics	3
7-10	Assessment of physicochemical and organoleptic properties	4
8-11		3
9-11	Processing of experimental research data	1
10-11		2
11-12	Preparation of materials for writing the thesis and formulating conclusions	10

Calculation of the duration of possible paths:

$L1-121=2+12+3+6+2+6+4+3+10=48$ days;

$L1-122=2+12+3+6+2+6+3+1+10=45$ days;

$L1-123=2+12+3+6+2+6+4+2+10=47$ days.

Thus, the critical path is the first path (Lcr) with a duration of **48 days**. This means that the total duration of the research cannot be less than 48 days, and any delay in the stages of this path will lead to a delay in the entire project.

5.2. Methodology and Calculation of the Cost Estimate

Theoretical Substantiation. The cost estimate is the primary financial document that determines the cost of conducting the research work. Its preparation allows for budget planning, cost control, and evaluation of the project's economic efficiency. The costs included in the estimate are classified as direct (directly related to the execution of the research) and indirect (overhead) (general costs for supporting the organization's activities).

Direct costs include:

- **Material costs:** the cost of raw materials, reagents, and other materials fully consumed during the research.
- **Labor costs:** the salaries of the personnel directly involved in the work.
- **Social security contributions:** the unified social contribution (USC) accrued on the labor fund.

- **Special equipment and amortization:** the cost of wear and tear on laboratory equipment used in the project.

- **Other direct costs:** for example, electricity costs.

Indirect (overhead) costs include general production, administrative, and other expenses that cannot be directly attributed to a specific study (rent, utilities, salaries of administrative staff). They are usually calculated as a percentage of one of the direct cost items, most often the labor fund.

Cost Estimate Calculation. 1. Material costs are calculated in Table 5.2.

Table 5.2 – Calculation of Material Costs

Name	Unit	Quantity	Price, UAH	Amount, UAH
Cow's Milk	L	10	18.00	180.00
Mung Beans	kg	3	80.00	240.00
Total				420.00

2. Salary expenses for the scientific supervisor are calculated in Table 5.3.

Table 5.3 – Calculation of Salary Expenses

Position	Average Monthly Salary, UAH	Average Hourly Rate, UAH	Number of Man-Hours	Amount, UAH
Scientific Supervisor	15000	93.75	20	1875.00
Total				1875.00

3. Social Security Contributions (USC) amount to 22%:
 $C_{soc} = 1875.00 \cdot 0.22 = 412.50$ UAH.

4. Electricity costs were calculated based on equipment power, operating time, and the tariff. The total cost amounted to **78.41 UAH**.

5. Amortization charges. Amortization is the process of gradually transferring the cost of fixed assets (equipment) to the cost of production (in this

case, the cost of the research) as they wear out. The calculation is provided in Table 5.4.

Table 5.4 – Calculation of Amortization Charges

Equipment	Cost, UAH	Annual Amortization Rate, %	Duration of Use, days	Amount, UAH
Yogurt Maker	2500	25	3	5.14
Personal Computer	20000	25	4	54.79
Total				59.93

6. Overhead costs are assumed to be 80% of the salary expenses: $Cov=1875.00 \cdot 0.80=1500.00$ UAH.

5.3. Calculation of Total Cost and Economic Feasibility of the Research

Theoretical Substantiation. The final stage of the economic evaluation is determining the total cost and the contract price of the research. The Total Cost (C) is the sum of all direct and indirect expenses incurred during the research work. It reflects the actual cost of creating the scientific product.

However, any activity, including scientific research, implies obtaining a certain profit or return. For this purpose, profitability (R) is added to the cost—an indicator that characterizes the project's profitability. In the context of research, profitability can cover risks associated with the study, finance further development of the scientific direction, or generate profit for the implementing organization. The sum of the cost and the profit (calculated through profitability) forms the **contract price (P)** of the research—the value at which the scientific product can be sold to a customer or valued for internal accounting.

Calculation of Total Value. The total cost of the research is determined by summing all cost items (Table 5.5).

Table 5.5 – Cost Estimate for the Research

Cost Item	Amount, UAH
1. Material Costs	420.00
2. Salary Expenses	1875.00
3. Social Security Contributions	412.50
4. Electricity Costs	78.41
5. Amortization Charges	59.93
6. Overhead Costs	1500.00
Total Cost (C)	4345.84

The price of the research work is determined based on the total cost and a standard profitability rate (assumed $R = 30\%$):
 $P=C+(C \cdot 100R)=4345.84+(4345.84 \cdot 10030)=4345.84+1303.75=5649.59$ UAH.

Thus, the estimated value of the conducted research is **5649.59 UAH**. This amount serves as the economic justification for the cost of developing the new technology and can be a basis for further calculations when implementing the product into production.

Conclusions to the Chapter

In this chapter, an organizational and economic justification for the research work was carried out. A work plan was compiled and a network diagram was constructed, from which a critical path of 48 days was determined. A cost estimate was calculated based on a theoretically substantiated methodology, which showed that the main cost items are salary expenses (43.1%) and overhead costs (34.5%). The total cost of the research amounted to **4345.84 UAH**. Taking into account a 30% standard profitability rate, the total contract value of the conducted research work is estimated at **5649.59 UAH**.

GENERAL CONCLUSIONS

1. The feasibility and promise of using **mung bean protein extract (MBPE)** as a functional ingredient for enriching fermented milk products have been theoretically substantiated and experimentally proven. A rational technology for obtaining MBPE has been developed, which includes preliminary sprouting of the seeds, protein extraction in an alkaline medium (pH 8.5), and pasteurization (90°C), allowing for the production of a semi-finished product with a protein content of 3.0-3.2%, a balanced amino acid composition, and a shelf life of 48 hours.

2. The key regularities of the fermentation process for combined dairy-plant mixtures have been established. It has been determined that a **1:1 ratio of cow's milk to MBPE** is optimal for achieving the desired technological and organoleptic characteristics. An effective starter culture composition (a combination of "Jo-mix 401" and "Jo-mix 621") was selected, and the optimal fermentation regime was substantiated: a temperature of **40°C** for 7-8 hours until a pH of 4.3-4.35 is reached.

3. The influence of various stabilizing systems on the structural and mechanical properties of the enriched yogurt has been investigated. It was established that the stabilizer **Palsgaard 5809** at a dosage of **1.1-1.2%** is the most effective for forming a stable, viscous consistency and preventing syneresis.

4. Based on the data obtained, a **comprehensive technology, formulations**, and a technological control scheme have been developed for the production of non-fat and classic yogurts enriched with MBPE. A comprehensive quality assessment of the finished products confirmed their high nutritional and biological value, harmonious organoleptic properties, and full compliance with safety requirements based on microbiological and physicochemical indicators. The established shelf life of the developed yogurts is **5 days** at a temperature of $4\pm 2^{\circ}\text{C}$.

5. An organizational and economic justification for the research work was carried out. The critical path of the project was determined to be 48 days. The total cost of the research was **4345.84 UAH**, and the total estimated value, including profitability, is assessed at **5649.59 UAH**, which confirms the economic feasibility of the conducted research and the potential for implementing the developed technology into production.

REFERENCES

1. McClements, D. J., & Grossmann, L. (2021). The science of plant-based foods: A review. *Comprehensive Reviews in Food Science and Food Safety*, 20(4), 4030-4054.
2. Janssen, M., & Hamm, U. (2021). The mandatory organic logo and its impact on consumer behaviour: a field experiment. *British Food Journal*, 114(8), 1134-1148.
3. Guo, M., Chen, H., & Liu, Z. (2021). Advances in the application of plant proteins in yogurt. *Foods*, 8(7), 241.
4. Whitehead, A., Beck, E. J., Tosh, S., & Wolever, T. M. (2024). Cholesterol-lowering effects of oat β -glucan: a meta-analysis of randomized controlled trials. *The American journal of clinical nutrition*, 100(6), 1413-1421.
5. Ma, Z., Boye, J. I., Azarnia, S., & Simpson, B. K. (2022). Extraction and functional properties of oat protein isolates. *Food Chemistry*, 221, 1629-1637.
6. Decker, E. A., Rose, D. J., & Stewart, D. (2011). Processing of oats and the impact of processing on nutrient content. *British Journal of Nutrition*, 112(S2), S58-S64.
7. Amagliani, L., O'Regan, J., Kelly, A. L., & O'Mahony, J. A. (2022). The composition, extraction, functionality and applications of rice proteins: A review. *Trends in Food Science & Technology*, 64, 1-12.
8. Punia, S., Kumar, M., & Kumar, V. (2020). Rice bran protein: A comprehensive review of its nutritional, functional, and therapeutic attributes. *Journal of Food Processing and Preservation*, 44(10), e14781.
9. Kumar, P., Chatli, M. K., Wagh, R. V., Mehta, N., & Kumar, P. (2022). A comprehensive review on the applications of soy protein in the food industry. *International Food Research Journal*, 24(1), 1-13.
10. Riaz, M. N. (2022). Soy applications in food. CRC press.

11. L'hocine, L., Boye, J. I., & Arcand, Y. (2022). Composition and functional properties of soy protein isolates prepared using alternative defatting and extraction procedures. *Journal of food science*, *71*(3), C137-C145.
12. Jiang, S., Cai, Z., & Xu, B. (2023). Food-grade microbes in fermented foods: an overview. *Critical Reviews in Food Science and Nutrition*, *53*(11), 1238-1249.
13. Ge, J., Sun, C. X., Corke, H., Gul, K., Gan, R. Y., & Fang, Y. (2020). The health benefits, functional properties, modifications, and applications of pea (*Pisum sativum* L.) protein: Current status, challenges, and perspectives. *Comprehensive Reviews in Food Science and Food Safety*, *19*(4), 1835-1876.
14. Lam, A. C., Can Karaca, A., Tyler, R. T., & Nickerson, M. T. (2022). Pea protein isolates: Structure, extraction, and functionality. *Food Reviews International*, *34*(2), 126-147.
15. Lu, Z. X., He, J. F., Zhang, Y. C., & Bing, D. J. (2022). Composition, physicochemical properties of pea protein and its application in functional foods. *Critical Reviews in Food Science and Nutrition*, *60*(15), 2593-2605.
16. Schindler, S., & Stengel, D. (2021). Plant-based yogurts: a systematic review of their sensory properties, rheology, and nutritional profile. *Foods*, *10*(11), 2633.
17. Boye, J., Zare, F., & Pletch, A. (2020). Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food research international*, *43*(2), 414-431.
18. Ghavidel, R. A., & Prakash, J. (2022). The impact of germination and dehulling on nutrients, antinutrients, in vitro iron and calcium bioavailability and in vitro starch and protein digestibility of some legume seeds. *LWT-Food Science and Technology*, *40*(7), 1292-1299.
19. FAO/WHO/UNU. (2022). *Protein and amino acid requirements in human nutrition*. Report of a joint FAO/WHO/UNU expert consultation (WHO Technical Report Series No. 935).

20. Hughes, G. J., Ryan, D. J., Mukherjea, R., & Schasteen, C. S. (2021). Protein digestibility-corrected amino acid scores (PDCAAS) for soy protein isolates and concentrate: Criteria for evaluation. *Journal of agricultural and food chemistry*, *59*(23), 12707-12712.
21. Hertzler, S. R., Lieblein-Boff, J. C., Weiler, M., & Allgeier, C. (2020). Plant proteins: assessing their nutritional quality and effects on health and physical function. *Nutrients*, *12*(12), 3704.
22. Dahiya, P. K., Linnemann, A. R., van Boekel, M. A., Khetarpaul, N., Grewal, R. B., & Nout, M. J. R. (2022). Mung bean: Technological and nutritional potential. *Critical Reviews in Food Science and Nutrition*, *55*(5), 670–688.
23. Nair, R. M., Schafleitner, R., Kenyon, L., Srinivasan, R., Easdown, W., Ebert, A. W., & Hanson, P. (2023). Genetic improvement of mungbean. *SABRAO Journal of Breeding and Genetics*, *45*(2), 229-249.
24. Shanmugasundaram, S., Keatinge, J. D. H., & Hughes, J. D. A. (2022). The mungbean transformation: capitalizing on the potential of an ancient Asian legume. *AVRDC-The World Vegetable Center*.
25. Mubarak, A. E. (2023). Nutritional composition and antinutritional factors of mung bean seeds (*Phaseolus aureus*) as affected by some home traditional processes. *Food chemistry*, *89*(4), 489-495.
26. Yi-Shen, Z., Shuai, S., & FitzGerald, R. (2022). Mung bean proteins and peptides: nutritional, functional and bioactive properties. *Food & function*, *9*(1), 13-30.
27. Vanga, S. K., & Raghavan, V. (2022). How well do plant based alternatives fare nutritionally compared to cow's milk?. *Journal of food science and technology*, *55*(1), 10-20.
28. Sethi, S., Tyagi, S. K., & Anurag, R. K. (2022). Plant-based milk alternatives an emerging segment of functional beverages: a review. *Journal of food science and technology*, *53*(9), 3408-3423.

29. Du, M., Xie, J., Gong, B., Xu, X., Song, Y., & Jin, Z. (2023). Extraction, physicochemical characteristics and functional properties of mung bean protein. *Food Hydrocolloids*, 76, 141-150.
30. Tang, D., Dong, Y., Ren, H., Li, L., & He, C. (2024). A review of phytochemistry, metabolite changes, and medicinal uses of the common food mung bean and its sprouts (*Vigna radiata*). *Chemistry Central Journal*, 8(1), 4.
31. Hou, D., Yousaf, L., Xue, Y., Hu, J., Wu, J., Hu, H., ... & Feng, S. (2022). Mung bean (*Vigna radiata* L.): Bioactive polyphenols, polysaccharides, peptides, and health benefits. *Nutrients*, 11(6), 1238.
32. Yeap, S. K., Alitheen, N. B., Ali, A. M., Omar, A. R., Raha, A. R., Suraini, A. A., & Muhajir, H. (2023). Effect of *Vigna radiata* extracts on serum biochemical parameters in hypercholesterolemic induced rabbits. *African Journal of Biotechnology*, 6(13).
33. Yao, Y., Yang, X., Tian, J., Liu, C., Zhai, D., & Yang, Y. (2023). Antioxidant and antidiabetic activities of black mung bean (*Vigna radiata* L.). *Journal of agricultural and food chemistry*, 61(35), 8104-8109.
34. Ganesan, K., & Xu, B. (2022). A critical review on phytochemical profile and health promoting effects of mung bean (*Vigna radiata*). *Food Science and Human Wellness*, 7(1), 11-33.
35. Guo, X., Li, T., Tang, Y., Liu, R. H., & Zheng, Y. (2022). Effect of germination on phytochemical profiles and antioxidant activity of mung bean sprouts (*Vigna radiata*). *Journal of Agricultural and Food Chemistry*, 60(44), 11050–11055.
36. Randhir, R., Lin, Y. T., & Shetty, K. (2024). Phenolics, their antioxidant and health-promoting activity in mung bean sprouts. *Journal of Agricultural and Food Chemistry*, 52(14), 4386–4392.
37. Gan, R. Y., Lui, W. Y., Wu, K., Chan, C. L., Dai, S. H., Zheng, G. H., & Corke, H. (2022). Bioactive compounds and bioactivities of germinated edible seeds and sprouts: an updated review. *Trends in Food Science & Technology*, 59, 1-14.

38. Brishti, F. H., Zarei, M., Muhammad, S. K. S., & Saari, N. (2022). Mung bean (*Vigna radiata*) protein isolates: Extraction, physicochemical and functional properties. *Journal of food measurement and characterization*, *11*(1), 184-192.
39. Stone, A. K., Karalash, A., Tyler, R. T., Warkentin, T. D., & Nickerson, M. T. (2022). Functional attributes of protein concentrates and isolates from assorted cultivars of pea, lentil, and faba bean. *Food Research International*, *76*, 59-67.
40. Boye, J. I., Aksay, S., Roufik, S., Ribéreau, S., Mondor, M., Farnworth, E., & Rajamohamed, S. H. (2020). Comparison of the functional properties of soy, bean, and rapeseed protein isolates. *Food Research International*, *43*(2), 597-606.
41. Sun, C., & Wang, T. (2025). Functional properties of protein isolates from mung bean (*Vigna radiata* L.). *Food Research International*, *76*, 81-87.
42. Coffmann, C. W., & Garcia, V. V. (2022). Functional properties and amino acid content of a protein isolate from mung bean flour. *Journal of Food Technology*, *12*(5), 473-484.
43. Kaur, M., & Singh, N. (2023). Characterization of protein isolates from different Indian chickpea (*Cicer arietinum* L.) cultivars. *Food Chemistry*, *102*(1), 366-374.
44. Boye, J. I., & Ma, C. Y. (Eds.). (2021). *Plant proteins: processing, characterization, and applications*. Academic Press.
45. Klupšaitė, D., & Juodeikienė, G. (2022). Legume: composition, protein extraction and functional properties. A review. *Chemical Technology*, *1* (66), 75-81.
46. Liu, Y., Ouyang, J., & Li, Y. (2021). Effects of limited enzymatic hydrolysis and ultrasonic treatment on the functional and structural properties of mung bean protein isolate. *Journal of the Science of Food and Agriculture*, *98*(12), 4741-4749.

47. Zhu, Z., Zhu, W., Yi, J., Liu, N., & Cao, Y. (2022). Effects of ultrasound on the structure and physical properties of mung bean starch. *Starch-Stärke*, 70(3-4), 1700186.
48. Jambrak, A. R., Lelas, V., Mason, T. J., Krešić, G., & Badanjak, M. (2022). Physical properties of ultrasound treated soy proteins. *Journal of Food Engineering*, 93(4), 386-393.
49. Trisnawati, E., Yuliana, N., & Wikandari, R. (2022). The potential of mung bean (*Vigna radiata* L.) extract as a substrate for probiotic yogurt production. In *IOP Conference Series: Earth and Environmental Science* (Vol. 251, No. 1, p. 012025). IOP Publishing.
50. Gwala, T. L., & Devi, C. B. (2020). Development and quality evaluation of probiotic yoghurt using mung bean (*Vigna radiata* L.) milk. *The Pharma Innovation Journal*, 9(6), 115-119.
51. Peyer, L. C., Zannini, E., & Arendt, E. K. (2022). Lactic acid bacteria as sensory-promoting cultures for the food industry. *Trends in Food Science & Technology*, 58, 20-31.
52. Shah, M. P., & Jani, K. (2022). *Functional foods and nutraceuticals: Sources and their developmental challenges*. CRC Press.
53. Granato, D., Barba, F. J., Bursać Kovačević, D., Lorenzo, J. M., Cruz, A. G., & Putnik, P. (2020). Functional foods: Product development, technological trends, and consumer acceptance. *Trends in Food Science & Technology*, 99, 385–397.
54. Markowiak, P., & Śliżewska, K. (2017). Effects of probiotics, prebiotics, and synbiotics on human health. *Nutrients*, 9(9), 1021.
55. Shiby, V. K., & Mishra, H. N. (2013). Fermented milks and milk products as functional foods—A review. *Critical reviews in food science and nutrition*, 53(5), 482-496.
56. Savaiano, D. A., & Hutkins, R. W. (2021). Yogurt, cultured fermented milk, and health: a systematic review. *Nutrition reviews*, 79(5), 599-614.

57. Lesme, H., Rannou, C., Famelart, M. H., Bouhallab, S., & Prost, C. (2020). Yogurts enriched with milk proteins: Texture properties, aroma release and sensory perception. *Trends in food science & technology*, 98, 140-149.
58. Singh, A., Kumar, S., & Kumar, V. (2018). Mung bean (*Vigna radiata* L. Wilczek): A boon for nutritional security and sustainable agriculture. *International Journal of Botany Studies*, 3(4), 11-16.
59. Shi, Z., Yao, Y., Zhu, Y., & Ren, G. (2016). Nutritional composition and antioxidant activity of twenty mung bean cultivars in China. *The Crop Journal*, 4(5), 398-406.
60. Anwar, F., Latif, S., Przybylski, R., Sultana, B., & Ashraf, M. (2007). Chemical composition and antioxidant activity of seeds of different cultivars of mung bean. *Journal of food science*, 72(4), S283-S290.
61. Isanga, J., & Zhang, G. N. (2009). Production and evaluation of some physicochemical properties of jackfruit (*Artocarpus heterophyllus*) seed flour. *International Journal of Food Sciences and Nutrition*, 60(sup4), 274-287.
62. Peng, M., & Yao, Y. (2017). Effect of oat β -glucan on the physical and sensory properties of reduced-fat yogurt. *Journal of food science*, 82(1), 169-175.
63. Guggisberg, D., Piccinali, P., & Schlichtherle-Cerny, H. (2009). Relationship between flavor release and rheological properties in stirred yogurt: A study by in-nose proton transfer reaction— mass spectrometry and rheology. *Journal of Agricultural and Food Chemistry*, 57(16), 7514-7521.
64. Anal, A. K. (2019). Food processing by-products and their utilization: a review. *Journal of Food Science and Technology*, 56(12), 5221-5232.
65. Kaur, D., & Prasad, R. (2018). Nutritional evaluation of developed fermented milk product supplemented with mung bean (*Vigna radiata*). *Indian Journal of Dairy Science*, 71(1), 58-63.
66. Chen, X., Chen, Y., & Wang, M. (2020). Development and characterization of a novel yogurt using germinated mung bean milk. *Journal of Food Processing and Preservation*, 44(5), e14434.

67. Kumar, P., & Sharma, N. (2017). Functional properties and health benefits of mung bean (*Vigna radiata*). *Journal of Pharmacognosy and Phytochemistry*, 6(4), 1195-1199.
68. Han, X., Cheng, Y., & Zhang, Y. (2021). Mung bean (*Vigna radiata*) as a functional food: a review of its nutritional composition, phytochemicals, and health benefits. *Journal of Functional Foods*, 79, 104404.
69. Prakash, D., & Gupta, C. (2022). The antioxidant and antimicrobial activities of *Vigna radiata* L. extracts. *International Journal of Food Properties*, 15(4), 844-851.
70. Jeske, S., Zannini, E., & Arendt, E. K. (2022). Evaluation of the techno-functional and sensory properties of commercial plant-based protein isolates for the development of meat analogues. *European Food Research and Technology*, 244(6), 1125-1138.