UDC 637.146:613.2:641.528+637.1.04+664.68+543.3

DEVELOPMENT OF HIGH-PROTEIN *FUNCTIONAL* YOGURT TECHNOLOGY AND ITS QUALITY AND SAFETY EVALUATION

A. Trubnikova[1], PhD
O. Chabanova[2], PhD, Associate Professor,
S. Bondar[3], PhD, Associate Professor,
D. Skrypnichenko [2], PhD, Associate Professor,
E. Kotlyar[2], PhD, Associate Professor[5]
[1] SSU «Mechanical and technological professional college of Odesa National University of Technology»
St. Black Sea Cossacks 12. Odesa, Ukraine, 65003
[2] Department of technology of milk, oil and fat products and the beauty industry
[3] Department of Ecology, Water and Environmental Technologies
Odessa National Technological University
St. Kanatna, 112, Odesa, Ukraine, 65039

https://doi.org/ 10.15673/fst.v19i2.3193

Correspondence:

D. Skrypnichenko,
E-mail: skripnichenkodm@gmail.com

Cite as Vancouver style citation

Trubnikova A., Chabanova O., Bondar S., Skrypnichenko D, Kotlyar E. Development of high-protein functional yogurt technology and its quality and safety evaluation. Food science and technology.2025;19(2): 90-104. https://doi.org/ 10.15673/fst.v19i2.3193

Цитування згідно ДСТУ 8302:2015

Trubnikova A., Chabanova O., Bondar S., Skrypnichenko D, Kotlyar E. Development of high-protein functional yogurt technology and its quality and safety evaluation // Food science and technology. 2025. Vol. 19, Issue 2. P. 90-104.
https://doi.org/ 10.15673/fst.v19i2.3193

Abstract. This work presents the results of developing a technology for a high-protein, health-oriented yogurt based on buttermilk with the addition of black elderberry (*Sambucus nigra*) and pear juices. The feasibility of using buttermilk as the principal raw material was demonstrated, as it increases the nutritional and biological value of the product due to its content of complete milk proteins, trace elements, and bioactive compounds. Two technological approaches to increasing protein content in buttermilk were investigated: the addition of whey protein concentrate WPC-UF-80 and partial whey removal after buttermilk fermentation. It was established that the latter method yielded an optimal protein level of 8.20% and, in the finished product, a reduction in lactose to 3.27%, although in the yogurt base the lactose remained at 4.09%. The use of elderberry and pear juices as natural functional ingredients was substantiated; they enrich the product with vitamin C (6.31 mg/100 g), polyphenols, and anthocyanins, imparting antioxidant activity of 1408 arbitrary units and favorable sensory attributes (total score 20.0 on day 1 of storage; attributes assessed: color, taste, odor, and consistency; 5-point scale). During storage (2–6 °C, 21 days), pH decreased from 4.41 to 4.33, titratable acidity increased from 90 to 102 °Th (Thorner units), viscosity decreased from 2.20 to 2.00 Pa·s, and syneresis increased from 2.0% to 3.8%, while acceptable sensory and microbiological indicators were maintained. The developed product is characterized by mass fractions of protein 8.20%, fat 0.47%, lactose 3.27%, and minerals 0.78%, the presence of probiotic cultures (*Bifidobacterium* spp.; (0.9 ± 0.2) × 10^9 CFU·cm^{-3} on day 21), and the absence of coliform bacteria throughout the entire storage period. The combination of a buttermilk protein base with functional plant juices ensures structural stability, high consumer acceptability, and promising applicability in preventive nutrition.

Keywords: high-protein yogurt; buttermilk; elderberry juice; pear juice; antioxidants; functional products; approaches to increasing protein content; quality indicators.

Introduction. Formulation of the problem

The contemporary dietary pattern of the Ukrainian population is characterized by a deficit of complete proteins, vitamins, and mineral substances, which increases the risks of metabolic and cardiovascular diseases [1]. Dairy raw materials remain an important source of protein, and yogurt is a popular fermented dairy product with functional properties [2–3].

Using buttermilk – a secondary dairy raw material with a unique protein and lipid composition—as the basis for manufacturing high-protein yogurt is a promising direction, but it requires further study [4–6]. Enriching the product with black elderberry and pear juices can increase its biological value and broaden its sensory profile [7–8]. An analysis of the Ukrainian market for high-protein yogurts indicates an insufficient assortment and a lack of solutions that use buttermilk, which underscores the relevance of this research.

Analysis of recent research and publications

The current dietary structure of the Ukrainian population exhibits persistent imbalances: insufficient intake of complete proteins, vitamins, and minerals against a background of excess saturated fats and rapidly absorbed carbohydrates [1]. Such deviations in dietary profile are associated with elevated risks of metabolic and cardiovascular diseases, creating an urgent need for accessible foods with increased nutrient density and demonstrated functional efficacy. In this context, fermented dairy products – particularly yogurts

– are viewed as a convenient and effective carrier of protein, calcium, and bioactive fermentation metabolites, suitable for daily intake and dietary recommendations [2–6]. Clinical and observational studies report beneficial effects of yogurt consumption on glycemic control, reduced risk of type 2 diabetes and certain cancers, and a low glycemic index compared with alternative snacks [3, 7–8].

Fermentation of milk by the symbiotic culture of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* promotes the formation of a three-dimensional protein matrix composed of casein micelles and denatured whey proteins, which determines the texture, consistency, and water-holding capacity of yogurt [9–10]. Within the current trend toward higher-protein foods, formulations with protein contents of 6–10% and above are being developed to enhance satiety and enable targeted positioning for athletes, weight-control diets, and older adults [11–15]. However, increasing protein without appropriate adjustments to formulation and processing can cause excessive firmness, graininess, and syneresis, highlighting the importance of selecting an optimal enrichment technology [11–12].

Common approaches to increasing protein include adding dry dairy ingredients (skim milk powder, whey protein concentrates, caseinates), applying membrane processes (ultrafiltration, microfiltration, reverse osmosis), and post-fermentation whey removal (straining) [13–15, 17–18]. Experimental studies indicate that membrane technologies allow protein concentration without thermally degrading bioactive fractions while simultaneously reducing lactose, whereas adding powdered protein ingredients is more economical but requires precise dosing to avoid deterioration of textural properties [17–18]. Stabilizers – primarily hydrocolloids–play an important role in controlling viscosity and preventing syneresis, which is especially relevant in high-protein systems; however, their use should be aligned with “clean-label” principles [19].

There is growing interest in alternative raw-material solutions with improved emulsifying and water-binding properties. Buttermilk – a by-product of butter manufacture, rich in milk fat globule membrane (MFGM) components, phospholipids, and whey-derived protein fractions [4–6, 20–22] – is a promising ingredient for partial or complete replacement of milk in yogurt formulations. Studies [23] have shown that the phospholipid–protein complex of buttermilk stabilizes emulsion systems, improves water-holding, and reduces fat-globule size, positively affecting texture and sensory properties of fermented dairy products. Researchers [4] found that adding dry buttermilk or MFGM concentrates improves microstructural homogeneity and reduces syneresis in dairy products–effects that are particularly important for high-protein products. Subsequent work [5] concluded that using this raw material enhances the stability of omega-3 fatty acids during microencapsulation, indicating its potential as a carrier of bioactive components.

However, the open literature lacks systematic studies on the effects of completely replacing milk with buttermilk specifically in high-protein yogurts. Most publications focus on partial replacement or the use of buttermilk fractions, revealing a research gap in this area [20–21]. This necessitates further research to evaluate the effects of buttermilk on starter activity, the rate and profile of organic-acid accumulation, gel structure formation, and product rheology at different stages of protein enrichment.

Given buttermilk’s properties, two principal technological routes of use are possible: (1) using it as the main liquid raw material with subsequent protein increase via ultrafiltration prior to fermentation or partial whey removal after fermentation; and (2) using dry buttermilk or MFGM concentrates in a dairy base to improve gel structure and stability [6, 8, 20–21]. In both cases, the expected outcomes include reduced syneresis and a more homogeneous microstructure—critical for high-protein yogurts [6, 13]. At the same time, heat treatment and cooling conditions must be carefully controlled because buttermilk may contain active enzymes or lipid-oxidation products that adversely affect flavor and product stability [4, 20]. Thus, it is advisable to study how replacing milk with buttermilk influences sensory attributes, rheology, storage stability, and microbial viability, as these parameters are often overlooked when alternative dairy matrices are investigated [6, 8].

For lactose-intolerant consumers, the potential to reduce lactose in the final product is of particular interest. Combining starter cultures with enzymatic hydrolysis (lactase) or membrane processing can substantially adjust lactose content in yogurts, as confirmed by technological and experimental studies [6–8]. Post-fermentation straining—as used in “Greek” yogurt—simultaneously increases protein concentration and lowers lactose, improving the sensory and dietary properties of the product [6, 8].

Beyond the protein matrix, enriching yogurt with plant components–primarily sources of polyphenols and natural colorants – is important for enhancing antioxidant potential and creating an attractive sensory profile. Contemporary polyphenol research focuses on their bioavailability, stability in food systems, and roles in disease prevention, defining major trends in this field [16]. Attention is devoted not only to identifying new polyphenol sources but also to improving extraction technologies and their integration into functional foods. Black elderberry (*Sambucus nigra*) is a rich source of anthocyanins–particularly cyanidin-3-sambubioside and cyanidin-3-glucoside—flavonols, and phenolic acids that exhibit pronounced antioxidant and other biological activities [5–6, 8–12, 24]. Polyphenol stability depends on cultivar, ripeness, and processing; for anthocyanins, critical factors include pH, temperature, and oxygen, which supports the use of gentle heat treatment, deaeration, and appropriate packaging in dairy products with added elderberry juice [6, 11–12]. Safety is equally important, as raw fruits contain cyanogenic glycosides and lectins that are effectively inactivated by thermal treatment, as documented in toxicological studies [27–30]. Adding elderberry juice or extract to dairy systems allows color and antioxidant properties to be retained during storage; however, excessive dosing may impart undesirable astringency, necessitating careful dose selection with the target sensory profile in mind [6, 11].

Pear (*Pyrus communis*) and its processed products—juice, purée—contain polyphenols (including arbutins and chlorogenic acid), vitamin C, minerals, and dietary fiber; combined with a mild taste and hypoallergenicity, this makes them suitable for children's and dietary nutrition [20, 24–26]. Reviews and experimental studies indicate antioxidant and antimicrobial potential, variability of the polyphenolic profile by cultivar and storage conditions, and the capacity to improve flavor and aroma of dairy products without excessive acidity [20, 24–26]. For high-protein yogurt matrices, it is especially important to control pH and soluble fiber content, since excess organic acids may intensify syneresis and coarse fiber may cause graininess; these effects can be mitigated by homogenization, appropriate stabilizers, and limiting dosage to 5–10% of product mass [11–12, 20, 26]. At present, the literature lacks systematic studies on interactions between pear polyphenols and the protein–phospholipid matrix of buttermilk in yogurt, which represents a promising direction for further experimental research.

A critical analysis of existing publications shows that the body of work on high-protein yogurts covers in detail protein-enrichment technologies, rheology, and sensory changes [4–5, 17–18], while separate studies on elderberry and pear thoroughly describe polyphenolic composition, antioxidant activity, and safety aspects [5–6, 8–12, 24, 27–28]. At the same time, comprehensive studies that combine a high-protein buttermilk matrix with plant juices in a single product remain fragmentary: individual links are addressed (structure formation involving MFGM, effects of polyphenols on the protein–lipid matrix, stability of color and antioxidant activity), but systematic assessments of rheology, sensory attributes, microbiological safety, and nutritional value are lacking [4–5, 22]. This opens a research niche for developing a high-protein yogurt technology based on buttermilk with the addition of elderberry and pear juices, with due consideration of stability and safety.

In summary, the literature indicates that high-protein yogurts are a promising tool for addressing dietary protein deficits [4, 13–16], and that buttermilk—owing to its MFGM components and phospholipids—can provide improved gel stability and creaminess without excessive reliance on hydrocolloids [17, 20–23]. Adding elderberry and pear juices can potentially enhance antioxidant capacity and sensory appeal, provided processing parameters and dosages are properly controlled [5, 9–12, 24–26]. At the same time, key questions remain open – how complete replacement of milk with buttermilk affects fermentation and gel microstructure, how polyphenols interact with MFGM and proteins, and the long-term stability of color and activity – thereby defining the research niche addressed in the present study.

Aim. To develop a technology for a high-protein yogurt based on buttermilk with the addition of black elderberry and pear juices, and to evaluate its quality and safety indicators.

Objectives. To achieve this aim, the following tasks were set and addressed:

- determine the quality indicators of the buttermilk raw material;
- investigate methods to increase non-fat milk solids (NFMS)—in particular protein—in buttermilk and select the optimal approach;
- obtain a high-protein yogurt base from buttermilk and determine its quality indicators;
- study the effect of blanching black elderberry berries on press-juice yield;
- produce black elderberry juice under laboratory conditions and determine its quality indicators;
- determine the quality indicators of pear juice;
- develop a scientifically substantiated formulation of a high-protein yogurt enriched with plant raw materials, specifically black elderberry and pear juices;
- develop a technological process flow diagram for the production of the high-protein yogurt enriched with plant raw materials;
- investigate the organoleptic, physicochemical, and microbiological quality indicators of the developed high-protein yogurt with plant additions;
- study the dynamics of quality indicators during storage of the finished high-protein yogurt containing plant components.

Research materials and methods

Study setting. The work was carried out in the laboratory of the Department of Technology of Milk, Oil-and-Fat Products and Beauty Industry, Odesa National Technological University (ONTU).

Objects of study. Formulation and technology of a high-protein yogurt; quality and safety indicators of the finished product.

Materials. Buttermilk obtained by batch churning at LLC "Gormolzavod" (Odesa, Ukraine); freeze-dried starter cultures FD DVS YF–L903 (*Streptococcus thermophilus, Lactobacillus delbrueckii* ssp. *bulgaricus*), FD DVS La–5 (*Lactobacillus acidophilus*), FD DVS Bb-12 (*Bifidobacterium animalis*) (Chr. Hansen, Denmark); stabilization system "Ultra-tex" ICE1-0023 (Tekstra-Vita, Ukraine) with the following composition: modified starch E1442, whey protein concentrate, modified starch E1450, mono- and diglycerides of fatty acids E471, guar gum E412, locust bean gum E410; wild-harvested black elderberries (*Sambucus nigra*) collected in Odesa region (Ukraine); elderberry juice obtained under laboratory conditions; commercial pear juice (TM "Nash Sik", Ukraine).

Methods. Organoleptic assessment – DSTU 2661:2010 [41]; titratable acidity, titrimetric method – DSTU 4395:2005 [42]; active acidity (pH), potentiometric method – DSTU 8550:2015 [43]; mass fraction of protein, Kjeldahl method – DSTU 8063:2015 [44]; mass fraction of lactose, enzymatic method – DIN 10344-82 [45], based on hydrolysis of lactose to glucose and galactose, subsequent oxidation of total galactose in the presence of NAD^+, and spectrophotometric determination of the NADH formed; mass fraction of sucrose; mass fraction of total sugars in fruit products– DSTU 4954:2008 [46]; mass fraction of proteins in fruit products – DSTU ISO 1871:2003 [47]; mass fraction of fat in fruit products, extraction-gravimetric method – DSTU 4941:2008 [48]; mass fraction of vitamin C by titration with alkaline 2,6-dichlorophenolindophenol – [49]; ash content – [56]; counts of lactic acid bacteria and of mesophilic aerobic and facultative-anaerobic microorganisms – DSTU 7357:2013 [50]; coliform bacteria – DSTU IDF 73 A [51]; sensory analysis of flavor/aroma – DSTU ISO 5495:2005 (Methodology. Pairwise comparison method) [52]; antioxidant activity, rapid method – [57]; total anthocyanins – [39]; yield stress determined on a rotational viscometer by stepwise increase of shear stress – [40]; water-holding capacity (WHC) – [40]; protein solubility in yogurt-base samples determined using a modified DSTU 5530:2014 method with consideration of the American Dairy Products Institute recommendations (ADPI, Analytical Method – Solubility Index) and the principles of the Protein Dispersibility Index (PDI) – [53–55].

Results of the research and their discussion

The study examined two approaches to increasing the non-fat milk solids (NFMS), in particular protein, in a buttermilk-based yogurt base and evaluated its quality indicators.

The NFMS content of buttermilk was 8.5%. For traditional yogurt, the minimum NFMS should be at least 9.5%, and for high-protein yogurt at least 12%. Therefore, NFMS—and protein—can be increased either by adding dry WPC-UF to the buttermilk or by partially removing whey from the fermented buttermilk (yogurt base).

The yogurt base, as the main formulation component of the high-protein yogurt with plant ingredients, was produced from buttermilk obtained at LLC «Gormolzavod» (Odesa). The organoleptic and physicochemical quality indicators of the buttermilk raw material are presented in Tables 1 and 2, respectively. The composition and properties of buttermilk (Tables 1 and 2) support its use for the production of high-protein yogurt.

Table 1 – Organoleptic quality indicators of the buttermilk raw material

Indicators	Characteristics
Appearance	Homogeneous liquid without visible fat granules; no sediment or flakes.
Color	Slightly yellowish, uniform throughout.
Taste and odor	Clean, milky; free of off-flavors and off-odors.

Table 2 — Physicochemical quality indicators of the buttermilk raw material

Indicators	Value in buttermilk
Density, kg/m³	1033
Titratable acidity, °Th	17.00
Active acidity, pH units	6.56
Mass fraction of fat, %	0.43
Mass fraction of protein, %	3.22
Mass fraction of lactose, %	4.56
Ash content, %	0.74

The high-protein yogurt base was produced using two variants: (1) addition of dry WPC-UF-80 to buttermilk; (2) partial removal of whey from the fermented yogurt base.

Variant 1. Investigation of the traditional approach to increasing non-fat milk solids (NFMS)—in particular protein – in buttermilk by adding dry WPC-UF-80 to the buttermilk.

Dry soluble whey protein (WPC-UF-80) was added according to the formulations given in Table 3. The WPC-UF-80 content was varied from 2.5% to 7.5% in 2.5% increments.

Table 3 — Yogurt formulation, kg per 100 kg of product

Component	Sample 1	Sample 2	Sample 3
Buttermilk (raw material)	97.5	95.0	92.5
Dry WPC-UF-80	2.50	5.00	7.50
Starter culture DVS YF-903, activity units	50.0	50.0	50.0
Starter culture DVS La-5 + Bb-12, activity units	25.0	25.0	25.0
Total	100.0	100.0	100.0

Preparation of samples. The buttermilk raw material was pasteurized at 85–87 °C for 5–10 min and cooled to the inoculation temperature of 36–38 °C. A portion of the buttermilk (taken from the amount specified in the formulation) was immediately cooled after pasteurization to 50–55 °C, the required amount of dry whey protein concentrate WPC-UF-80 was added, the mixture was stirred for 5–10 min, and then returned to the main pasteurized buttermilk prepared for inoculation. The mixture was stirred and a combination of starter cultures was added (FD DVS YF–L903, consisting of mixed cultures of *Streptococcus thermophilus* + *Lactobacillus delbrueckii* ssp. *bulgaricus*, in combination with FD DVS La–5 containing the monoculture *Lactobacillus acidophilus*, and FD DVS Bb–12 containing the monoculture *Bifidobacterium animalis* Bb–12). The starter combination was selected according to [21] so that the microorganisms in the cultures would produce lactase, thereby lowering the lactose concentration in the yogurt base. Immediately after inoculation, the mixture was dispensed into sterile 0.5-dm³ containers, in which fermentation was carried out at 36–38 °C. Fermentation was considered complete upon formation of a gel with active acidity (pH) 4.5–4.6. The yogurt base was then cooled to 4–6 °C.

Figure 1 presents the changes in active acidity (pH) of the yogurt-base sample during fermentation, and Figure 2 shows the changes in titratable acidity (°Th) during fermentation (36–38 °C). Experiments were performed for five sample variants—buttermilk (0% WPC-UF-80), milk (0% WPC-UF-80), and buttermilk with 2.5%, 5.0%, and 7.5% WPC-UF-80.

As a result of fermentation at 36–38 °C (Figs. 1 and 2), S-shaped pH and titratable-acidity curves were obtained for all five sample variants. In samples with higher WPC-UF-80 concentration, the phase of active pH decline began earlier and the rate of reaching the endpoint values (pH = 4.55; 90 ± 1 °Th) was higher, although at 7.5% the acceleration effect diminished due to increased buffering capacity and higher medium viscosity.

In milk, the lag phase was slightly shorter than in buttermilk, which is attributable to a more balanced protein complex (casein:whey-protein ratio ≈ 80:20) and a lower phospholipid content that may influence the membrane permeability of lactic acid bacteria. Buttermilk, by contrast, contains more milk-fat-globule membrane (MFGM) components and has a modified protein ratio, which can somewhat delay the onset of active fermentation but yields a more delicate gel.

The S-shaped profiles conform to the classical growth model of lactic acid bacteria: lag phase → exponential phase of acid accumulation → deceleration due to pH decrease and accumulation of metabolic products.

Time to reach the fermentation endpoints (pH = 4.55; 90 ± 1 °Th):

- Milk (0% WPC-UF-80): 5 h 30 min – 5 h 40 min
- Buttermilk (0% WPC-UF-80): 5 h 50 min – 6 h 00 min
- Buttermilk + 2.5% WPC-UF-80: 5 h 20 min – 5 h 25 min
- Buttermilk + 5.0% WPC-UF-80: 4 h 55 min – 5 h 00 min
- Buttermilk + 7.5% WPC-UF-80: 4 h 50 min – 4 h 55 min.

Adding WPC-UF-80 increases protein content and the buffering capacity of the medium, stimulates the growth of lactic acid bacteria, and shortens the lag phase.

Sensory analysis showed that the milk gel without WPC-UF-80 was firm with an elastic structure; the buttermilk gel without WPC-UF-80 was delicate and more creamy but prone to syneresis. The 5.0% WPC-UF-80 level provided the best balance among fermentation rate, firmness, and creaminess. At 7.5%, a "mealy" mouthfeel and a whey-protein note were observed.

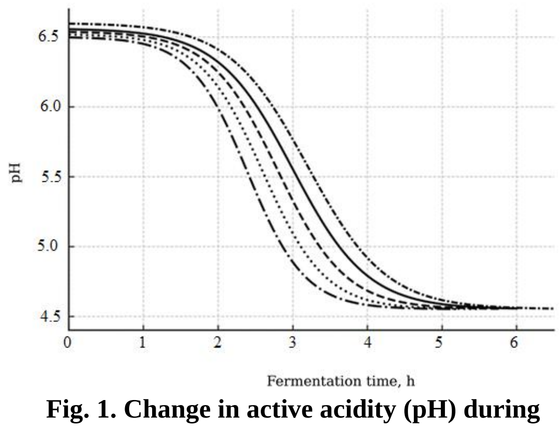

Fig. 1. Change in active acidity (pH) during fermentation (36–38 °C)

Legend: ——— Buttermilk (0% WPC-UF-80); _ _ _ 2.5% WPC-UF-80; – – – 5.0% WPC-UF-80; ••••• 7.5% WPC-UF-80; —•—•— Milk (0% WPC-UF-80).

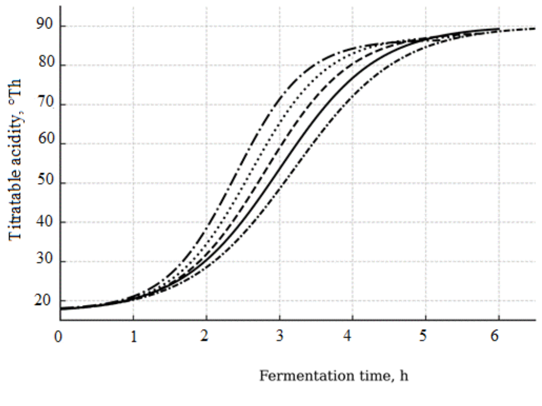

Fig. 2. Change in titratable acidity (°Th) during fermentation (36–38 °C)

Legend: ——— Buttermilk (0% WPC-UF-80); _ _ _ 2.5% WPC-UF-80; – – – 5.0% WPC-UF-80; ••••• 7.5% WPC-UF-80; —•—•— Milk (0% WPC-UF-80).

Thus, increasing WPC-UF content correlates directly with the rate of acid development, but optimal sensory and technological properties are achieved at a dosage of 5.0%.

The protein mass fractions in the yogurt-base samples and protein solubility before and after fermentation are presented in Table 4

The total protein content in the samples before and after fermentation remained practically unchanged (deviation ≤ 0.05%), which is consistent with literature data on the stability of the protein fraction during souring [Harte et al., 2002; Saint-Eve et al., 2019]. This is explained by the fact that lactic acid bacteria primarily perform proteolysis – cleaving protein macromolecules into peptides and free amino acids without reducing the overall protein mass. As a result, the solubility and bioavailability of protein components increase and bioactive peptides are formed that can positively affect antioxidant status and the immune system. Samples with higher WPC-UF-80 content potentially contain more fine-dispersed peptides, which can lead to improved sensory softness of the gel and higher water-holding capacity. The increase in solubility after fermentation (by 8–13%) can be explained by more active proteolysis and accumulation of soluble nitrogenous compounds (Table 4).

The results obtained (Table 5) indicate that increasing the proportion of WPC-UF-80 in the yogurt-base formulations slightly raises the initial lactose content (from 4.60% in Sample 1 to 4.67% in Sample 3). After fermentation with the combined starter, lactose decreased by approximately 30% in all samples, reaching 3.22–3.27%. This demonstrates the consistent ability of the cultures used to hydrolyze lactose effectively regardless of the amount of added WPC-UF-80, which is important for developing products with a reduced content of this disaccharide.

To objectively assess the structural–mechanical properties of the gels, two key indicators were considered—**water-holding capacity (WHC)** and **yield stress** (Table 6). WHC characterizes the ability of the gel structure to retain moisture under external load (centrifugation) and is expressed as a percentage; the higher the value, the less prone the product is to syneresis during storage. Centrifugation was performed at 3000 rpm for 10 min at 10 ± 1 °C. Yield stress is the minimum shear stress that must be applied to the yogurt gel for flow to begin. Up to this threshold, the gel retains its shape and behaves like an elastic system; once the yield stress is exceeded, the gel structure fails and the product transitions to a flowing state.

For fermented dairy products, including yogurts, a high yield stress indicates a strong and stable gel structure that better retains moisture and prevents whey separation. This parameter correlates closely with viscosity and WHC and substantially influences sensory perception—thickness, creaminess, and the stability of consistency during storage.

In our study, yield stress was determined rheometrically under a protocol of stepwise increase in shear stress, recording the point at which the gel transitioned from a solid-like to a liquid state. Values were expressed in pascals (Pa) and compared across samples to establish relationships with their protein composition and total solids content.

The rheological and water-holding values obtained for the yogurt-base samples (Table 6) reflect the specificity of using buttermilk as the principal liquid fraction. Unlike whole milk, buttermilk contains less casein and more whey proteins and milk-fat-globule-membrane (MFGM) components, which promotes formation of a softer, more elastic gel structure capable of retaining moisture more effectively and distributing fat more uniformly. The high content of phospholipids and the fine fat emulsion in buttermilk contributes to higher WHC because polar lipids interact with proteins, retaining water within the gel. Even at the minimal WPC-UF level (2.5%), WHC exceeded 68%, whereas increasing the concentrate to 7.5% yielded 80–86%.

Table 4 – **Protein mass fractions in yogurt base samples and their solubility**

Sample	Protein mass fraction, %	Protein solubility before fermentation, %	Protein solubility after fermentation, %
Sample 1 (2.5% WPC-UF-80)	5.14	45	55
Sample 2 (5.0% WPC-UF-80)	7.06	50	62
Sample 3 (7.5% WPC-UF-80)	8.98	55	68

Note. The solubility values reflect the extractability of protein fractions in a simplified test (water, 3000 rpm) rather than true solubility; therefore, they should not be compared with the DSTU/ADPI solubility index for dry milk.

Table 5 – **Lactose mass fraction (%) in yogurt base samples**

Sample	Lactose mass fraction before fermentation, %	Lactose mass fraction after fermentation, %
Yogurt base (Sample 1)	4.60	3.22
Yogurt base (Sample 2)	4.63	3.24
Yogurt base (Sample 3)	4.67	3.27

Table 6 – Rheological and water-holding indicators of Samples 1–3 (Variant 1)

Indicator	Sample 1 (2.5% WPC-UF-80)	Sample 2 (5.0% WPC-UF-80)	Sample 3 (7.5% WPC-UF-80)
Viscosity, Pa·s (50 s^{-1})	1.1–1.4	1.6–2.0	2.2–2.8
Yield stress, Pa	35–45	55–70	80–100
Water-holding capacity (WHC), %	68–72	76–82	80–86
Syneresis, day 1, %	2.0–3.0	1.0–1.8	0.8–1.5
Syneresis, day 14, %	3.5–4.0	2.0–3.0	1.5–2.5
Syneresis, day 21, %	4.5–5.5	2.5–3.5	2.0–3.0
Sensory evaluation	Gel with low firmness	Optimal consistency	Firm gel; "mealy" texture; note of dry whey protein

Notes.

1. Rheology measurement parameters: 24 h after cooling; sample temperature 10 ± 1 °C (10 °C was chosen as a model storage temperature and may yield higher values than at 20 °C); rotational rheometry, "apparent" viscosity at 50 s^{-1}; yield stress—protocol with stepwise increase in shear stress (Herschel–Bulkley model).
2. Water-holding capacity (WHC): rapid method in a graduated centrifuge tube; centrifugation 3000 rpm, 10 min, 10 ± 1 °C; result expressed as % of the initial sample volume.
3. Syneresis: percentage of whey separated on the surface during storage at 4 ± 1 °C (assessed on days 1, 14, and 21).
4. The yogurt-base samples contain WPC-UF-80 at 2.5% / 5.0% / 7.5%, as per Table 3.

Regarding syneresis, the buttermilk-based yogurt gel shows gradual increase during storage, but in samples with higher WPC-UF levels this effect is minimized due to a denser protein network; by day 14, syneresis in Sample 3 does not exceed 2.5%.

Sensory evaluation supports the rheological data: Sample 2 (5.0% WPC-UF-80) exhibits optimal consistency—balancing firmness and creaminess. Sample 1 has a less firm gel, whereas Sample 3 is overly firm with a risk of a "mealy" mouthfeel and a slight whey-protein note due to the high level of concentrate.

Therefore, combining buttermilk with WPC-UF-80 at around 5.0% provides an optimal balance of structural, rheological, and sensory characteristics in the yogurt base.

The physicochemical indicators of the yogurt base are presented in Table 7.

Table 7 – **Physicochemical indicators of the yogurt base (Sample 2) (Variant 1)**

Indicators	Component content
Total solids, %, incl.	11.82
Mass fraction of fat, %	0.65
Mass fraction of protein, %	7.06
Mass fraction of lactose, %	3.24
Ash content, %	0.85

The yogurt base with 5.0% WPC-UF-80 (Table 7), under Variant 1, is characterized by an increased total solids (11.82%) due to the addition of WPC-UF-80. The protein mass fraction (7.06%) is more than twice that of traditional yogurts, favoring the formation of a dense and stable protein network in the gel. After fermentation, lactose is reduced to 3.24%; the low fat content (0.65%) and moderate ash (0.85%) provide an optimal balance of nutritional and energy value. Taken together, these physicochemical indicators demonstrate the high potential of this buttermilk-based yogurt base for manufacturing a high-protein functional yogurt with stable consistency.

Variant 2 – ***Study of increasing NFMS by partial dewatering of the yogurt base***

The buttermilk raw material was pasteurized at 85–87 °C for 5–10 min, cooled to the inoculation temperature (36–38 °C), and inoculated with a combination of starter cultures FD DVS YF–L903, FD DVS La–5, and FD DVS Bb–12. Fermentation was conducted in sterile containers (0.5 dm^3) to an active acidity of pH 4.55. The resulting gel was gently heated to 55–60 °C to arrest fermentation and facilitate whey removal, cooled to 5–7 °C, and strained through gauze bags to the target total solids (24 h at 5–7 °C; overall whey removal ≈ 69–70%). The base was then filled, further cooled to 4–6 °C, and stored at this temperature.

The dynamics of pH and titratable acidity during fermentation were identical to Variant 1 (Figs. 1 and 2), as the raw material and starters were the same. The time to reach the endpoint parameters was 5 h 50 min – 6 h 00 min.

The organoleptic and physicochemical quality indicators of the partially dewatered yogurt base are presented in Tables 8 and 9, respectively. The yogurt base obtained by Variant 2 had better organoleptic properties and a protein content higher by 3.1% compared with the yogurt base obtained by Variant 1 (Sample 2).

After partial dewatering, total solids increased to 15.64%, protein to 10.11% (by 3.05 percentage points more than in Variant 1 at 5.0% WPC-UF), and lactose was 4.09%. Fat and ash remained within ranges typical of buttermilk-based products (0.52% and 0.89%, respectively).

Table 8 – Organoleptic indicators of the partially dewatered yogurt base (Variant 2)

Indicators	Characteristics
Appearance and consistency	Delicate, creamy, spreadable consistency; homogeneous throughout.
Taste and odor	Clean fermented-milk taste; free of off-flavors and off-odors.
Color	White with a creamy tint.

Table 9 – Physicochemical indicators of the partially dewatered yogurt base (Variant 2) (laboratory partial dewatering in gauze bags for 24 h at 5–7 °C)

Indicators	Component content
Total solids, %, incl.	15.64
Mass fraction of fat, %	0.52
Mass fraction of protein, %	10.11
Mass fraction of lactose, %	4.09
Ash content, %	0.89

Table 10 – Rheological and water-holding indicators of the partially dewatered yogurt base (Variant 2)

Indicator	Value
Viscosity, Pa·s (50 s^{-1})	2.5–3.0
Yield stress, Pa	75–85
Water-holding capacity (WHC), %	85–88
Syneresis, day 1, %	0.5–1.0
Syneresis, day 14, %	≤ 1.5
Syneresis, day 21, %	≤ 2.0
Sensory evaluation	Delicate, creamy, spreadable consistency without a “mealy” mouthfeel; homogeneous texture; clean fermented-milk taste with balanced acidity

Partial dewatering of the buttermilk-based yogurt base provides the maximum protein content without adding dry ingredients, enhances the structural stability of the gel, and improves sensory characteristics. On day 21 of storage, syneresis did not exceed 2.0%, indicating high stability of the protein network and the effectiveness of the selected dewatering method.

By the sum of organoleptic scores, Variant 2 outperformed all samples of Variant 1, especially in spreadability and the absence of whey separation on the surface.

The obtained data support selecting this approach for developing the final formulation of a high-protein yogurt with the addition of elderberry and pear juices.

Study of the effect of blanching black elderberries on press-juice yield

Elderberry fruits were sorted, washed, destemmed, blanched with sharp steam for 30–40 s, cooled to 18–20 °C, crushed, pressed, and the juice was filtered.

Blanching was used to increase juice yield during pressing (juice yield with blanching: 73%; without blanching: 64%), to eliminate pathogenic microorganisms, and to inactivate enzymes—particularly polyphenol oxidase and peroxidase—that reduce the biological activity of polyphenols in elderberries.

The results shown in Figure 3 indicate that the total anthocyanin content increased by 42.6% during blanching of elderberry fruits and by 65.4% during pressing, which is attributable to cell-wall degradation and the consequent release of anthocyanins in these processes.

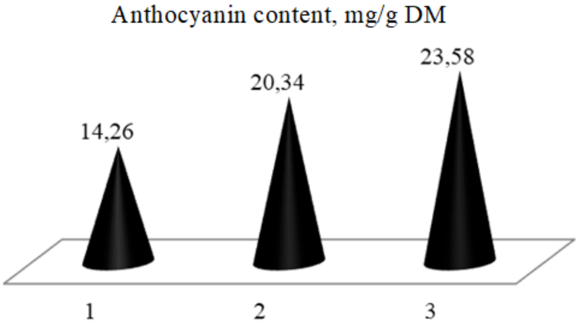

Fig. 3. Changes in anthocyanin content (mg/g DM) in fresh elderberry fruits (1), after blanching (2), and in the pressed juice (3)

Technology for producing black elderberry juice. The process comprised the following steps: inspection of elderberry fruits, washing, destemming, blanching with sharp steam for 30–40 s, cooling to 18–20 °C, crushing, pressing, juice filtration, deaeration at 60–70 °C and p = 95 kPa, pasteurization for 50–60 s at 75–78 °C, and cooling to 6–8 °C.

Determination of quality indicators of elderberry juice.

The organoleptic indicators of elderberry juice are presented in Table 11.

Table 11 – Organoleptic indicators of elderberry juice

Indicator	Characteristics
Appearance	Homogeneous liquid.
Taste and odor	Sweet-and-sour taste with a slightly astringent aftertaste; fruity-floral, sweet aroma.
Color	Violet color.

The physicochemical indicators of elderberry juice are given in Table 12. For analysis, laboratory-produced elderberry juice from fruits and commercial pear juice (TM “Nash Sik”, Ukraine) were used.

The vitamin C content of elderberry juice was 42.8 mg/100 g, and that of pear juice was 3.6 mg/100 g. The pH of elderberry juice was 4.21, and the pH of pear juice was 4.64.

As evidenced by the results (Tables 11, 12; Fig. 3), the selected fruit juices, when added to yogurt, not only improve sensory attributes but may also positively affect consumer health and the product’s functional characteristics. Elderberry and pear juices can be used as functional additives in probiotic yogurts, serving as natural colorants and antioxidants.

Development of a scientifically substantiated formulation of high-protein yogurt with plant additions.

The principal component of the formulation is the yogurt base obtained by Variant 2, whose quality indicators are presented in Tables 8 and 9. The additional components are black elderberry and pear juices.

The study focused on determining the rational proportions between the main and additional components. The ratios were optimized based on sensory indicators, protein mass fraction, and antioxidant activity of the yogurt samples.

The elderberry-juice concentration was varied from 10 to 20%, and pear-juice concentration from 5 to 10% (based on analysis of analogous product formulations). The high-protein yogurt concentration was varied from 70 to 85%.

Seven product samples with different component ratios (yogurt base : elderberry juice : pear juice) were produced: Sample 1 – 85:10:5; Sample 2 — 80:10:10; Sample 3 – 80:15:5; Sample 4 – 75:20:5; Sample 5 – 75:15:10; Sample 6 – 70:20:10; Sample 7 – 70:25:5.

Sensory indicators were determined for the samples. To optimize the component ratios, the pairwise comparison method with selection of the preferred sample was used [51]. The expert evaluation results are presented in Table 13

Calculation of preference frequency (Fi) according to:

F_i = (Sum of preferences for the sample) / (Number of experts). (1)

Calculation of the score (G_i) according to:

$G_i = F_i / C$. (2)

where C is the total number of assessments per expert in pairwise comparisons:

$C = m \cdot (m - 1) / 2$. (3)

Here, m is the number of samples evaluated.

After calculations using formulas (1)–(3), Sample 5 (component ratio yogurt base : elderberry juice : pear juice = 75:15:10; see Table 13) obtained the highest score (G_i = 0.22), i.e., this ratio proved optimal by sensory criteria.

Table 12 –Physicochemical indicators of elderberry and pear juices

Juice type Elderberry juice	Mass fraction, (%) — total solids				
	Mass fraction, (%) — total solids	protein	sugars	fat	ash
Elderberry juice	12.38	0.19	10.32	0.12	0.73
Pear juice	12.34	0.21	9.71	0.10	0.30

Table 13 – Sensory characterization of samples with different component ratios (yogurt base : elderberry juice : pear juice)

Sample No.	Expert preferences (points)					Sum of preferences	Preference frequency (F_i)	Score (G_i)
	1	2	3	4	5			
1	3	4	4	3	4	18	3,6	0,17
2	4	4	4	4	4	20	4	0,19
3	4	5	5	3	5	22	4,4	0,21
4	4	3	3	5	3	18	3,6	0,17
5	5	5	4	4	5	23	4,6	0,22
6	5	4	4	4	4	21	4,2	0,20
7	3	3	3	3	4	16	3,2	0,15

For the samples with the highest sensory scores (Samples 3 and 5 in Table 13), antioxidant activity was determined. The results are shown in Figure 4.

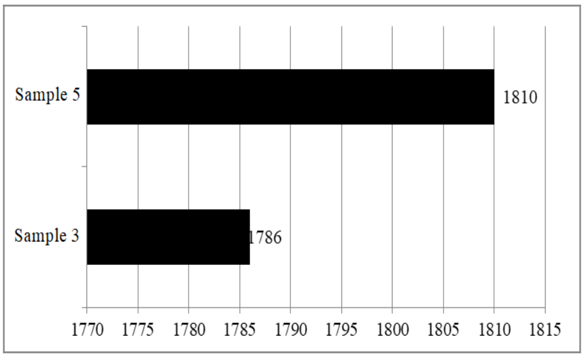

Fig. 4 – Antioxidant activity (arb. units) of samples with different formulation ratios.

The results presented in Figure 4 show that the antioxidant activity of Samples 3 and 5 differs only slightly. The protein mass fraction in Sample 3 was 8.12%, and in Sample 5 it was 7.61%.

Therefore, based on the sensory evaluation results, protein mass fraction, and antioxidant activity, the recommended ratio of formulation components (Sample 3) is: yogurt base : elderberry juice : pear juice = 80:15:5.

During storage, whey separation may occur; to prevent this, the universal stabilization system “Ultra-tex” ICE1-0023 (Tekstra-Vita, Ukraine) is proposed for addition. Its composition is: modified starch E1442, whey protein concentrate, modified starch E1450, mono- and diglycerides of fatty acids E471, guar gum E412, locust bean gum E410. The concentration of the stabilization system was chosen as 0.2% (in accordance with an analogous product formulation).

Table 14 — Formulation of the high-protein yogurt with plant components

Component	Mass, kg
High-protein yogurt (P = 10.11%)	798.0
Black elderberry juice	150.0
Pear juice	50.0
Universal stabilization system “Ultra-tex”	2.0
TOTAL	1000.0

Development of the process-flow diagram and description of the production process for high-protein yogurt with plant additions

Based on the research results, a process-flow diagram for manufacturing a high-protein yogurt with plant additions was developed. The process-flow diagram is shown in Figure 5.

Buttermilk obtained during butter manufacture by batch churning is filtered, cooled, and collected in an intermediate tank. From the intermediate tank, the buttermilk is directed to a plate pasteurizing–cooling unit, pasteurized at 85–87 °C with a holding time of 5–10 min, and cooled to the inoculation temperature of 36–38 °C. A combination of starter cultures is then added to the pasteurized and cooled buttermilk (FD DVS YF–L903, comprising mixed cultures of *Streptococcus thermophilus* + *Lactobacillus delbrueckii ssp. bulgaricus*, in combination with FD DVS La–5 containing the monoculture *Lactobacillus acidophilus*, and FD DVS Bb–12 containing the monoculture *Bifidobacterium animalis*). This combination of cultures was chosen to reduce lactose in the yogurt base, since these microorganisms produce the enzyme lactase. The buttermilk is mixed and fermented for 6 h at 36–38 °C. During this period, the sample reaches the isoelectric state of the proteins under the influence of lactic acid alone or of a mixture of lactic and acetic acids formed by the starter microflora during lactose fermentation. Lactic acid is produced by *Streptococcus thermophilus*, *Lactobacillus delbrueckii ssp. bulgaricus*, and *Lactobacillus acidophilus*, while *Bifidobacterium animalis* produces a mixture of lactic and acetic acids.

The resulting gel is fed through a double-mesh filter into a separator for whey removal. In the separator bowl, the gel is split into a high-protein yogurt base and whey. The high-protein yogurt base is discharged from the bowl through nozzles into a receiver and then to a hopper. Level sensors monitor the hopper fill level. A variable-speed positive-displacement pump moves the high-protein yogurt base from the hopper through a cooler into an intermediate storage tank. Whey is discharged under pressure without foaming by a built-in centrifugal pump into a storage tank. Into the intermediate tank with the high-protein yogurt base, the stabilization system is added at a concentration of 0.2%; the mixture is stirred and held for 20–30 min, after which the pre-prepared juices obtained from black elderberry and pears are added (according to the formulation). The mixture is stirred for 10–15 min.

Technology for producing black elderberry juice.

The process consisted of the following operations: inspection of elderberry fruits, washing, destemming, blanching of fruits with sharp steam for 30–40 s, cooling to 18–20 °C, comminution, pressing of the pomace, juice filtration, deaeration at 60–70 °C and p = 95 kPa, pasteurization for 50–60 s at 75–78 °C, and cooling to 6–8 °C.

The finished high-protein yogurt enriched with juices from black elderberry and pear is pumped from the holding tank to a filling machine and filled into 200-g plastic cups. Storage is at 2–6 °C for no more than 21 days.

Determination of organoleptic, physicochemical, and microbiological quality indicators of the developed high-protein yogurt with plant additions

In the finished product, organoleptic, physicochemical, and microbiological indicators were determined; the results are presented in Tables 15–17.

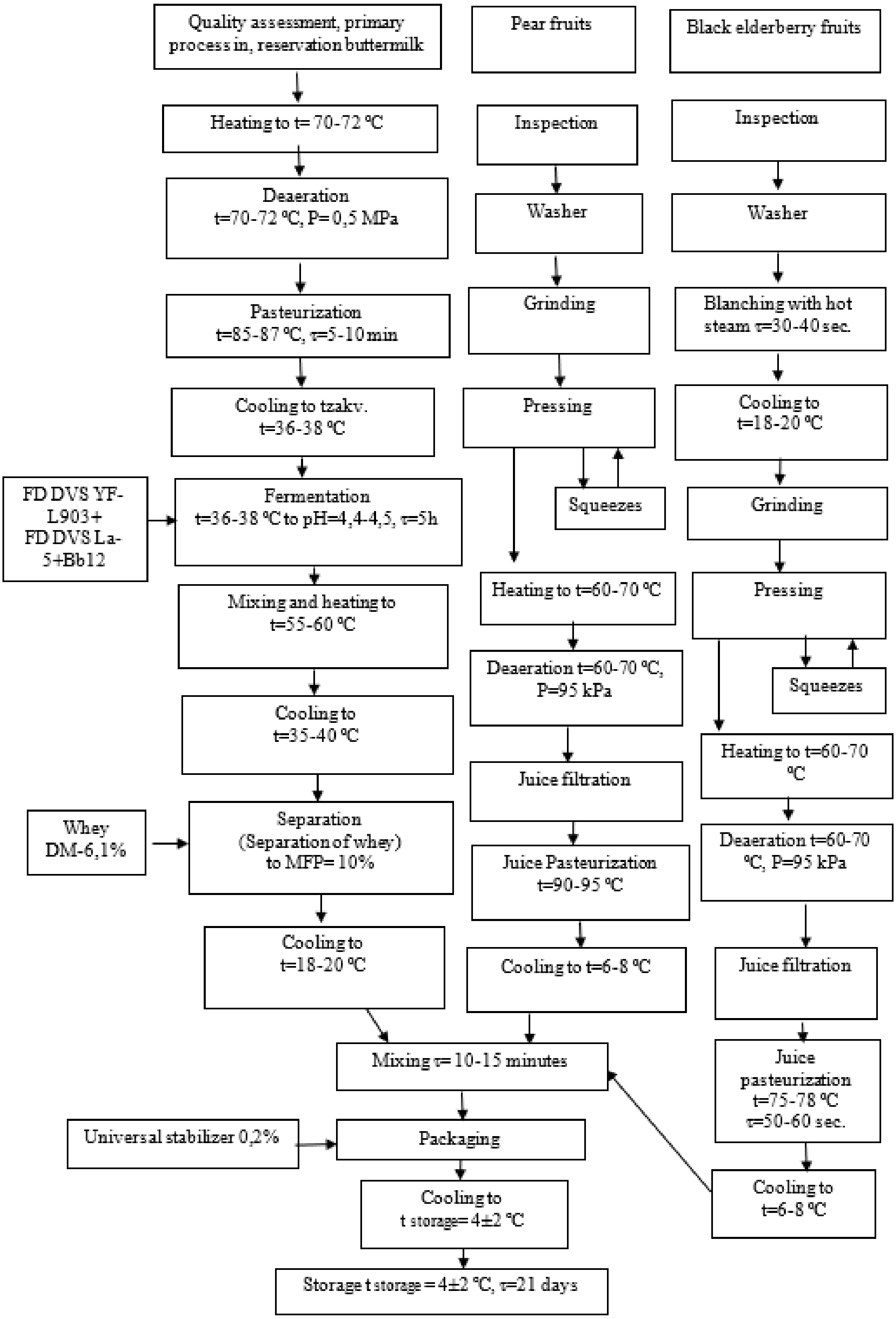

Fig. 5. Process-flow diagram for the production of high-protein yogurt enriched with plant ingredients

Table 15 — Organoleptic indicators of the developed high-protein yogurt

Indicator	Characteristics
Taste and odor	Clean fermented-milk taste without off-flavors or off-odors; slightly sour-sweet, with a pronounced floral aroma and a pear note.
Consistency	Homogeneous, delicate, creamy; no whey separation.
Color	Deep red.

Table 16 — Physicochemical indicators of the developed high-protein yogurt enriched with elderberry and pear juices

Indicator	Value
Mass fraction of fat, %	0.47
Mass fraction of lactose, %	3.27
Mass fraction of sugars, %	5.13
Mass fraction of proteins, %	8.20
Mass fraction of mineral substances, %	0.78
Active acidity, pH units	4.41
Antioxidant activity, arb. units	1408
Vitamin C content, mg/100 g	6.31

Table 17 — Microbiological indicators of the developed high-protein yogurt

Indicator	Value
Most probable number of lactic acid microorganisms, $\text{CFU}\cdot\text{cm}^{-3}$	$(2.0 \pm 0.9) \times 10^8$
Bifidobacteria count, $\text{CFU}\cdot\text{cm}^{-3}$	$(1.5 \pm 0.2) \times 10^9$
Coliform bacteria in 0.1 cm^3	Absent

Determination of coliform bacteria (in 0.1 cm^3 of the developed high-protein yogurt) showed their absence in the tested volume, which supports the correctness of the pasteurization regimes selected for the high-protein yogurt base and the elderberry and pear juices. The counts of lactobacilli and bifidobacteria indicate a high probiotic effect.

The dynamics of quality indicators during storage of the finished high-protein yogurt with plant components (as per the formulation in Table 14) are summarized in Tables 18–20.

The physicochemical indicators (Table 18) show that storage at 2–6 °C leads to a gradual decrease in pH from 4.41 to 4.33 and an increase in titratable acidity from 90 to 102 °Th, due to continued mild fermentation even under refrigeration.

Table 18 — Physicochemical indicators of the developed high-protein yogurt during storage (2–6 °C)

Indicator	Day 1	Day 7	Day 14	Day 21
Active acidity, pH units	4.41	4.38	4.36	4.33
Titratable acidity, °Th	90	94	98	102
Syneresis, %	2.00	2.70	3.20	3.80
Viscosity, $\text{Pa}\cdot\text{s}$ ($50\ \text{s}^{-1}$)	2.20	2.12	2.05	2.00
Antioxidant activity, arb. units	1408	1380	1340	1315

Table 19 — Sensory evaluation high-protein yogurt during storage (per DSTU 2661:2010; 5-point scale)

Indicator	Day 1	Day 7	Day 14	Day 21
Color	5.0	4.9	4.8	4.7
Taste	5.0	4.9	4.8	4.7
Odor	5.0	4.9	4.9	4.8
Consistency	5.0	4.9	4.8	4.7
Total score	20.0	19.6	19.3	19.0

Table 20 — Microbiological high-protein yogurt indicators during storage

Indicator	Day 1	Day 7	Day 14	Day 21
Most probable number of lactic acid microorganisms, $\text{CFU}\cdot\text{cm}^{-3}$	$(2.0 \pm 0.9)\times10^8$	$(1.7 \pm 0.8)\times10^8$	$(1.3 \pm 0.6)\times10^8$	$(1.0 \pm 0.5)\times10^8$
Bifidobacteria count, $\text{CFU}\cdot\text{cm}^{-3}$	$(1.5 \pm 0.2)\times10^9$	$(1.3 \pm 0.2)\times10^9$	$(1.1 \pm 0.2)\times10^9$	$(0.9 \pm 0.2)\times10^9$
Coliform bacteria in 0.1 cm^3	Absent	Absent	Absent	Absent

Viscosity decreases from 2.20 to 2.00 Pa·s, which is associated with partial destabilization of the protein–polysaccharide matrix in the presence of fruit juices. Syneresis increases from 2.0% to 3.8%, but the values remain within limits acceptable for fermented dairy desserts, with the product maintaining a homogeneous consistency. Antioxidant activity declines by 6.6% from the initial level, which is attributable to oxidation of phenolic compounds in the fruit components.

Sensory indicators (Table 19) remain high throughout storage: the total score decreases from 20.0 to 19.0 (5-point scale, DSTU 2661:2010), driven by a slight reduction in the intensity of taste, aroma, and body due to gradual structural changes in the gel. Color and odor remain stable, characteristic of the plant ingredients used, with no signs of spoilage.

Microbiological indicators (Table 20) show a decrease in lactic acid bacteria counts: lactobacilli from $(2.0 \pm 0.9)\times10^8$ to $(1.0 \pm 0.5)\times10^8$ $CFU\cdot cm^{-3}$, and bifidobacteria from $(1.5 \pm 0.2)\times10^9$ to $(0.9 \pm 0.2)\times10^9$ $CFU\cdot cm^{-3}$. This is due to depletion of nutrients, accumulation of organic acids and metabolic products, and the antagonistic effects of polyphenols from plant components. At the same time, coliform bacteria were not detected in 0.1 cm^3 at any stage of storage, confirming the microbiological safety of the product.

Overall, after 21 days of storage at 2–6 °C, the high-protein buttermilk-based yogurt with plant additions retains high sensory and microbiological quality, remains safe for consumption, and meets regulatory requirements, despite gradual decreases in viscosity and in the counts of viable probiotic cultures.

Conclusion

1. The organoleptic and physicochemical indicators of the buttermilk raw material obtained by batch churning at LLC «GMZ» (Odesa) were determined.
2. Two approaches to increasing the protein content of buttermilk were investigated: the addition of dry whey protein concentrate WPC-UF-80 and partial whey removal after fermentation. A comparative analysis of organoleptic, physicochemical, and microbiological indicators showed that the latter method is the most effective, providing an increase of approximately 3 percentage points in the protein mass fraction and a reduction in lactose compared with the former method.
3. The quality indicators of the obtained high-protein yogurt base were established: mass fractions (%): protein – 10.11; fat – 0.52; lactose – 4.09; ash – 0.89.
4. The effect of blanching elderberry fruits on press-juice yield was studied. Blanching with live steam for 30–40 s increases juice yield by 9%. It was demonstrated that blanching of black elderberry fruits and subsequent pressing do not lead to losses of anthocyanins in the juice.
5. Elderberry juice was produced under laboratory conditions and its organoleptic and physicochemical indicators were determined. It was established that elderberry juice can be used as a functional additive in probiotic yogurts, acting as a natural colorant and antioxidant.
6. The organoleptic and physicochemical indicators of pear juice were determined. It was established that it has a pleasant sweet taste, light-yellow color, and optimal acidity and total solids, which allows recommending it as a hypoallergenic and technologically compatible plant additive for enriching probiotic yogurts.
7. A scientifically substantiated formulation of a high-protein yogurt enriched with plant material (black elderberry and pear juices) was developed at the following ratio: yogurt base – 80%, elderberry juice – 15%, pear juice – 5%.
8. A process-flow diagram for the production of the high-protein yogurt enriched with plant material was developed, and the technological process was described.
9. The organoleptic, physicochemical, and microbiological quality indicators of the developed high-protein yogurt with plant additions were investigated. Mass fractions (%): protein – 8.20; fat – 0.47; lactose – 3.27; ash – 0.78. Vitamin C content – 6.31 mg/100 g; antioxidant activity – 1408 arb. units. The absence of coliform bacteria throughout storage confirms the correctness of the selected pasteurization regime. The counts of lactobacilli and bifidobacteria indicate a pronounced probiotic effect.
10. During storage at 2–6 °C for 21 days, a decrease in pH from 4.41 to 4.33, an increase in titratable acidity from 90 to 102 °Th, a reduction in viscosity from 2.20 to 2.00 Pa·s, and an increase in syneresis from 2.0% to 3.8% were observed. Nevertheless, the product retained stable color and structure as well as desirable sensory properties.
11. The developed high-protein yogurt from buttermilk with the addition of black elderberry and pear juices complies with DSTU 4343:2004 “Yogurts. General technical specifications,” as well as the microbiological safety criteria approved by Order No. 548 of the Ministry of Health of Ukraine (19 July 2012). The product shows high consumer appeal and is recommended for use in health-promoting and preventive nutrition.

Note. Some of the results presented in this article were obtained within the framework of the master’s thesis by Ilenchuk Ye.Yu. (2022, ONTU).

References

1. Food and Agriculture Organization of the United Nations (FAO). Dairy market review: emerging trends and outlook. Rome: FAO; 2020. [Internet]. [cited 2025 Aug 12]. Available from: http://www.fao.org/3/cb2322en/CB2322EN.pdf
2. Chandan CR, Gandhi A, Shah PN. Yogurt: historical background, health benefits, and global trade. In: Shah NP, editor. Yogurt in health and disease prevention. London: Academic Press; 2017. p. 3–29. https://doi.org/10.1016/B978-0-12-805134-4.00001-8

3. Astrup A. Yogurt and dairy product consumption to prevent cardiometabolic diseases: epidemiologic and experimental studies. Am J Clin Nutr. 2014; 99(5):1235S–1242S. https://doi.org/10.3945/ajcn.113.073015
4. Barukčić I, Jakopović KL, Božanić R. Valorisation of whey and buttermilk for production of functional bioactive compounds. Front Nutr. 2019; 6:91.
5. Cais Sokolińska D, Bielska P, Baranowska HM, Tomaszewska-Gras J. Determining the behavior of water in buttermilk cheese with polymerized whey protein using DSC and NMR. Appl Sci. 2022; 12(22):11528.
6. Augustin MA, Sanguansri P, Netzel M, Le TT, et al. Use of whole buttermilk for microencapsulation of omega-3 oils. Food Res Int. 2015; 67:377–388.
7. Barengolts E, Smith ED, Reutrakul S, Tonucci L, Anothaisintawee T. Effect of probiotic yogurt on glycemic control in type 2 diabetes or obesity: meta-analysis of nine RCTs. Nutrients. 2019; 11(3):671. https://doi.org/10.3390/nu11030671
8. Śliżewska K, Markowiak-Kopeć P. The role of probiotics in cancer prevention. Sci Rep. 2024; 14:1247.
9. Shelestun A, Yeliseieva TH. Pear juice—natural elixir of health and beauty. J Healthy Nutrition and Dietetics. 2022. [Internet]. [cited 2025 Aug 12]. Available from: https://journal.edaplus.info/index.php/journal/article/download/199/583
10. da Silva RFR, Barreira JCM, Heleno SA, Barros L, Calhelha RC, Ferreira ICFR. Anthocyanin profile of elderberry juice: a natural-based bioactive colouring ingredient with potential food application. Molecules. 2019;24(13):2359. https://doi.org/10.3390/molecules24132359
11. Pliszka B. Polyphenolic content, antiradical activity, stability and microbiological quality of elderberry (Sambucus nigra L.) extracts. Acta Sci Pol Technol Aliment. 2017; 16(4):393–401. http://dx.doi.org/10.17306/J.AFS.2017.0523
12. Sidor A, Gramza-Michałowska A. Advanced research on the antioxidant and health benefit of elderberry (Sambucus nigra) in food—review. J Funct Foods. 2015; 18:941–958. http://dx.doi.org/10.1016/j.jff.2014.07.012
13. European Medicines Agency. Assessment report on Sambucus nigra L., fructus. London: EMA; 2013. Report No.: EMA/HMPC/44208/2012. [Internet]. [cited 2025 Aug 12]. Available from: https://www.ema.europa.eu/en/documents/herbal-report/final-assessment-report-sambucus-nigra-l-fructus_en.pdf
14. Viapiana A, Wesołowski M. The phenolic contents and antioxidant activities of infusions of Sambucus nigra L. Plant Foods Hum Nutr. 2017; 72(1):82–87. https://doi.org/10.1007/s11130-016-0594-x
15. Senica M, Stampar F, Veberic R, Mikulic-Petkovsek M. Differences in phenolics and cyanogenic glycosides in Sambucus nigra leaves, flowers and berries from different altitudes. J Sci Food Agric. 2017; 97(8):2623–2632. https://doi.org/10.1002/jsfa.8085
16. Terzić M, Majkić T, Zengin G, et al. Elderberry fruits processed by modern and conventional drying/extraction as a source of health-promoting compounds? Food Chem. 2023; 405:134766.
17. Kay CD, Pereira-Caro G, Ludwig IA, Clifford MN, Crozier A. Anthocyanins and flavanones are more bioavailable than previously perceived: review. Annu Rev Food Sci Technol. 2017; 8:155–180. https://doi.org/10.1146/annurev-food-030216-025636
18. Gullón B, Lú-Chau TA, Moreira MT, Lema JM, Eibes G. Trends in polyphenol research in food science. Trends Food Sci Technol. 2017; 67:220–235.
19. Vujanović M, Majkić T, Zengin G, et al. Elderberry (Sambucus nigra L.) juice as a functional product rich in health-promoting compounds. RSC Adv. 2020; 10(73):44805–44814. https://doi.org/10.1039/d0ra09129d
20. Hong SY. A review of pears (Pyrus spp.), ancient functional food for the modern world. Front Nutr. 2021; 8:734614. https://doi.org/10.3389/fnut.2021.734614
21. Trubnikova AA, Sharakhmatova TE, Mamintova KO, Tsupra OS. Biotechnological aspects of yogurt base production for low-lactose ice cream. Visnyk NTU “KhPI”. Ser.: New Solutions in Modern Technologies. 2018;9(1285):243–255. https://doi.org/10.20998/2413-4295.2018.09.35 (in Ukrainian).
22. Bojanic J, et al. Recent advances in dairy processing and milk proteins utilization: a review. Foods. 2023;12(6):1112.
23. Rafiq L, Zahoor T, Sagheer A, Khalid N, Rahman UU, Liaqat A. Augmenting yogurt quality attributes through hydrocolloidal gums. Asian-Australas J Anim Sci. 2020; 33(2):323–331. https://doi.org/10.5713/ajas.18.0218
24. Kim ED, Lee H-S, Kim K-T, Paik H-D. Antioxidant and ACE-inhibitory activities of yogurt supplemented with Lactiplantibacillus plantarum NK181 and Lactobacillus delbrueckii KU200171 and sensory evaluation. Foods. 2021; 10(10):2324. https://doi.org/10.3390/foods10102324
25. Pascariu OE, Simulescu V, Popescu MC, Ficai A, et al. Bioactive compounds from elderberry (Sambucus nigra L.): extraction, health benefits and potential use in food industry. Processes. 2022; 10(11):2288.
26. Iglesias R, Ferreras JM, Girbés T, et al. Structure and biological properties of ribosome-inactivating proteins and lectins from Sambucus nigra L. Toxins. 2022; 14(9):634.
27. Jiménez P, Cabrero P, Córdoba-Díaz D, Girbés T. Lectin digestibility and stability of elderberry antioxidants to heat treatment in vitro. Molecules. 2017; 22(10):1767.
28. Wang Y, et al. Nutritional composition and health benefits of pear (Pyrus spp.). Trends Food Sci Technol. 2022; 123:160–174.
29. Kobus-Cisowska J, et al. Chemical composition and in vitro antibacterial and antifungal activities of different pear cultivars (Pyrus communis L.). Molecules. 2019; 24(4):682.
30. Wu X, Sun C, Yang L, Zeng G, Liu Z, Li Y. Identification of arbutin in peel and pulp of pear cultivars (Pyrus spp.) and its potential as a skin-whitening agent. J Funct Foods. 2022; 98:105313.
31. Yoo KM, Lee CY. Pear (Pyrus spp.) phytochemicals and health benefits. Food Rev Int. 2020; 36(6):542–560.
32. Korekar G, Stobdan T, Bhatt BP. Phenolic profile and antioxidant potential of fruit juice of wild pear (Pyrus pashia) during storage. Heliyon. 2021; 7(2):e06341.
33. Sokol OV. Photocolorimetric determination of anthocyanins and other phenolic compounds in plant raw materials. Pharmacognosy, Pharmaceutical Chemistry and Pharmacy. 2017; (2):60–64. (in Ukrainian).
34. Harte F, Clark S, Barbosa-Cánovas GV, Swanson BG. Yield stress and microstructure of set yogurt made from high-hydrostatic-pressure-treated milk. J Food Sci. 2002; 67(1):84–88. https://doi.org/10.1111/j.1365-2621.2002.tb11363.x
35. Ben-Harb S, Saint-Eve A, Panouillé M, Souchon I, Bonnarme P, Dugat-Bony E, et al. Design of microbial consortia for the fermentation of pea-protein-enriched emulsions. *Int J Food Microbiol.* 2019; 293:124–136. doi:10.1016/j.ijfoodmicro.2019.01.012.
36. Yukalo VG. Laboratory practicum in chemistry and physics of milk and dairy products. Ternopil: Ternopil Ivan Puluj National Technical University; 2018. (in Ukrainian).
37. Khomych HP, Vikul SI, Kaprelyants LV, Osypova LA, Lozovska TS. Method for determining the biological activity of objects of natural origin. Ukrainian Patent UA 107506 C2. 2015 Jan 12. Application No. U 201302626; filed 2013 Mar 04. Assignee: Odesa National Academy of Food Technologies. (in Ukrainian).

РОЗРОБЛЕННЯ ТЕХНОЛОГІЇ ВИСОКОБІЛКОВОГО ФУНКЦІОНАЛЬНОГО ЙОГУРТУ ТА ОЦІНЮВАННЯ ЙОГО ЯКОСТІ І БЕЗПЕЧНОСТІ

А.А. Трубнікова[1], кандидат технічних наук, *E-mail*: sc228004@ukr.net
О.Б.Чабанова[2], кандидат технічних наук, доцент, *E-mail*: oksana_chabanova17@ukr.net
С.М. Бондар[3], кандидат технічних наук, доцент, *E-mail:* snbondar2011@gmail.com
Д.М.. Скрипніченко[2], кандидат технічних наук, доцент, *E-mail*: skripnichenkodm@gmail.com
Є.О. Котляр[2], кандидат технічних наук, доцент, *E-mail:* yevhenii11@ukr.net
[1] ВСП «Механіко-технологічний фаховий коледж Одеського національного технологічного університету»
вул. Чорноморського козацтва 12. м. Одеса, 65003
[2] Кафедра технології молока, олійно-жирових продуктів та індустрії краси
[3] Кафедра екології, води та природоохоронних технологій
Одеський національний технологічний університет
вул. Канатна, 112, м. Одеса, Україна, 65039

Анотація. У роботі представлено результати розроблення технології високобілкового йогурту оздоровчого призначення на основі маслянки з додаванням соків плодів бузини чорної та груші. Доведено доцільність використання маслянки як основної сировини, що дозволяє підвищити харчову та біологічну цінність продукту завдяки вмісту повноцінних молочних білків, мікроелементів і біологічно активних речовин. Вивчено два технологічні підходи до підвищення вмісту білка у маслянці: внесення сироваткового білкового концентрату КСБ-УФ-80 та часткове видалення сироватки після сквашування маслянки; встановлено, що останній метод забезпечує оптимальний білковий рівень 8,20 % та забезпечення оптимального рівня білка у готовому продукті (8,20 %) та зниження лактози до 3,27 % на етапі готового продукту, хоча у йогуртній основі лактоза залишалася на рівні 4,09 %. Обґрунтовано доцільність використання соків бузини та груші як природних функціональних інгредієнтів, що збагачують продукт вітаміном С (6,31 мг/100 г), поліфенолами та антоціанами, надаючи йому антиоксидантну активність на рівні 1408 ум. од. і привабливі органолептичні властивості (сумарний бал 20,0 на 1 добу зберігання (оцінювались колір, смак, запах, консистенція; сума балів за п'ятибальною шкалою)). Встановлено, що під час зберігання (2–6 °С, 21 добу зберігання) pH зменшувався від 4,41 до 4,33, титрована кислотність зростала від 90 до 102 °Т, в'язкість знижувалася з 2,20 до 2,00 Па·с, а синерезис зростав з 2,0 % до 3,8 %, при збереженні прийнятних сенсорних і мікробіологічних показників. Розроблений продукт характеризується масовою часткою білка 8,20 %, жиру 0,47 %, лактози 3,27 %, мінеральних речовин 0,78 %, наявністю пробіотичних культур (біфідобактерії — $(0{,}9\pm0{,}2)\times10^9$ КУО/см^3 на 21 добу) та відсутністю бактерій групи кишкових паличок протягом усього терміну зберігання. Поєднання білкової основи з маслянки з функціональними рослинними соками забезпечує стабільну структуру, високу споживчу прийнятність та перспективність застосування у системі профілактичного харчування.

Ключові слова: високобілковий йогурт, маслянка, сік бузини, сік груші, антиоксиданти, функціональні продукти, способи підвищення рівня білка, показники якості.