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TECHNOLOGY AND QUALITY OF A FERMENTED MILK PRODUCT WITH NATURAL SWEETENER ADDITION

Annotation: *This study presents the development of a functional yogurt technology enriched with plant-based dietary fiber - psyllium (Plantago ovata husk). The effect of psyllium addition at concentrations of 0.3-1.0% on the physicochemical, rheological, and sensory properties of the product was investigated. The results demonstrated that psyllium incorporation does not inhibit the growth of lactic acid bacteria and does not interfere with the fermentation process. The addition of plant fiber promoted the formation of a stable protein-polysaccharide matrix, increased viscosity up to 1120 mPa·s, and reduced syneresis to 1.9% compared to the control sample.*

The optimal concentration was determined to be 0.5%, providing a balanced combination of texture and sensory characteristics while preserving the traditional taste and aroma of yogurt. The use of psyllium allows for the replacement of synthetic stabilizers and aligns with the "clean label" concept.

The developed product is characterized by enhanced nutritional value due to its content of soluble dietary fiber, exhibits prebiotic properties, and can be recommended for functional, preventive, and dietary nutrition. The novelty of the technology is confirmed by a filed patent application in the Republic of Kazakhstan.

Key words: *functional yogurt, psyllium, plant dietary fiber, structure formation, rheological properties, syneresis, prebiotic properties.*

Introduction

Despite the widespread popularity of yogurt, conventional products often contain synthetic thickeners and stabilizers, which may not fully meet modern consumer expectations for natural and clean-label foods. The growing demand for functional and «clean label» products has intensified the search for natural ingredients, including plant-based dietary fibers. Psyllium, characterized by high hydrophilicity and strong gel-forming capacity, is considered a promising component for improving the rheological properties of yogurt [1, 2].

In the current context of food industry development, particular attention is being paid to the production of foods with enhanced biological value and preventive health benefits. Functional fermented dairy products are regarded not only as sources of highly digestible protein and calcium but also as carriers of probiotic and prebiotic components that positively affect gut microbiota [3]. For example, the global functional dairy market reached approximately USD 43 billion in 2022 and is projected to grow to USD 62.6 billion by 2031, with a compound annual growth rate (CAGR) of about 4.8%, driven by increasing consumption of probiotic and bioactive products.

More broadly, the global functional food market, including dairy and other categories, is valued in the hundreds of billions of dollars and is expected to grow from approximately USD 398.8 billion in 2025 to nearly USD 983.2 billion by 2034, at a CAGR of around 10.65% [4-6]. This reflects a sustained global trend toward foods that provide not only basic nutrition but also additional physiological benefits.

Furthermore, the dietary fiber market, including soluble and prebiotic fibers, is also experiencing dynamic growth. Its value was estimated at approximately USD 8.1 billion in 2024 and is projected to reach USD 19.4 billion by 2034, highlighting the increasing interest of manufacturers in incorporating fiber ingredients into various food categories, including dairy products.

Previous studies indicate that the incorporation of plant dietary fibers improves the structural and mechanical properties of yogurt and reduces syneresis during storage, which is consistent with the behavior of hydrocolloids in food systems [7-9]. The use of natural plant-based ingredients makes it possible to replace conventional stabilizers while maintaining structural stability and desirable sensory characteristics. Therefore, the development of yogurt production technology enriched with psyllium represents a relevant research direction aimed at expanding the range of functional dairy products and enhancing their competitiveness in both domestic and international markets.

Materials and methods

Raw Materials

Pasteurized cow's milk with a fat content of 1.0% was used as the main raw material, complying with the requirements of TR CU 033/2013 "On the Safety of Milk and Dairy Products." The use of low-fat milk was justified by the development of a dietetic functional product with reduced energy value [10].

A direct vat set (DVS) freeze-dried starter culture containing a symbiotic combination of Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus was used. The inoculation rate was 1.0% of the total milk weight.

Psyllium powder (Plantago ovata husk) with a total dietary fiber content of at least 80% served as the functional ingredient. The material was characterized by high hydrophilicity, with a water absorption capacity of 8-12 g of water per 1 g of dry matter.

Psyllium Preparation

Before incorporation into the milk base, psyllium underwent preliminary technological treatment:

1. Sieving through a 250 μm mesh to remove possible agglomerates.
2. Dry sterilization at 105°C in a drying oven for 20 minutes to reduce microbial contamination.
3. Pre-hydration: psyllium was dispersed in sterile distilled water at 40 ± 2 °C in a 1:10 (w/v) ratio, followed by stirring on a magnetic stirrer (300 rpm) for 15 minutes until a homogeneous gel-like suspension was formed.

Pre-hydration prevented lump formation during incorporation into the yogurt matrix and ensured uniform fiber distribution within the system.

Yogurt Production Technology

Yogurt production was carried out under laboratory conditions.

Milk was subjected to high-temperature pasteurization at 92-95°C for 5 minutes to inactivate contaminating microflora and partially denature whey proteins. After pasteurization, the milk was cooled to 42 ± 1°C, and the starter culture was added. The mixture was incubated at 42 °C in a thermostatic chamber until the pH reached 4.6 (6-8 hours).

After gel formation, the product was cooled to 20 °C. Pre-hydrated psyllium was then incorporated into the fermented mass using mechanical stirring (1000 rpm, 3 minutes) until a homogeneous structure was achieved. Psyllium was added at concentrations of 0.3%, 0.5%, and 1.0% (on a dry matter basis).

The finished product was packaged in sterile polypropylene containers and stored at 4 ± 2°C for 14 days. Analyses were performed on days 1, 7, and 14 of storage. All experiments were conducted in triplicate.

Results and Discussion

The study demonstrated that the incorporation of psyllium did not exert any inhibitory effect on the growth of lactic acid bacteria. The pH reduction during fermentation followed a typical pattern consistent with the classical kinetics of lactic acid fermentation in all samples.

The control sample reached a pH value of 4.6 after 7.5 hours of fermentation, whereas samples containing psyllium (0.3-1.0%) achieved the same pH level within 6.5-7 hours. The slight acceleration of the fermentation process may be attributed to the formation of a more viscous dispersion medium, which facilitates better retention of bacterial cells within the product matrix and enhances their metabolic activity. In addition, psyllium may act as a prebiotic substrate, promoting the growth and activity of lactic acid microorganisms.

The titratable acidity of the final products ranged between 85 and 95 °T, which complies with regulatory standards for yogurt and confirms the proper progression of the fermentation process.

The physicochemical characteristics of the studied samples are presented in Table 1.

Table 1 – Physicochemical characteristics of yogurt samples

Parameter	Control	0.3% Psyllium	0.5% Psyllium	1.0% Psyllium
pH	4,60	4,55	4,53	4,50
Titratable acidity (°T)	88	90	92	94
Total solids (%)	11,8	12,4	12,9	13,6
Energy value (kcal/100 g)	42	44	46	49

As shown in Table 1, the incorporation of psyllium did not exert an inhibitory effect on the lactic acid fermentation process. The pH values of all samples ranged between 4.50 and 4.60, complying with regulatory standards for yogurt and confirming the proper progression of fermentation. A slight increase in titratable acidity with increasing psyllium concentration (from 88 to 94 °T) suggests enhanced metabolic activity of lactic acid bacteria. The formation of a more viscous and structured dispersion medium likely facilitates the retention of bacterial cells within the gel matrix, thereby creating favorable conditions for their growth and acid production.

It was established that the total solids content increased proportionally with psyllium dosage, rising from 11.8% in the control sample to 13.6% at a concentration of 1.0%. This effect is attributed to the high content of soluble dietary fibers characterized by pronounced hydrophilicity and swelling capacity. The increase in total solids significantly contributes to the formation of a three-dimensional protein-polysaccharide network resulting from interactions between psyllium polysaccharides and casein micelles. Such interactions lead to densification of the gel structure and improved mechanical stability.

The energy value of the product ranged from 42 to 49 kcal per 100 g, allowing the developed yogurt to be classified as a low-calorie functional fermented dairy product suitable for dietetic nutrition.

During 14 days of storage at 4 ± 2°C, no significant changes in pH were observed (4.45-4.60), indicating microbiological stability and the absence of pronounced post-acidification. These findings confirm the technological compatibility of psyllium with the starter culture and the stability of the formed structure during storage.

Overall, comprehensive analysis of the physicochemical parameters demonstrates that psyllium not only does not interfere with fermentation but also promotes structural optimization, increases total solids content, and enhances product stability. The most rational concentration was determined to be 0.5%, providing an optimal balance between acidity, textural characteristics, and energy value. Changes in sample viscosity are presented in Figure 1.

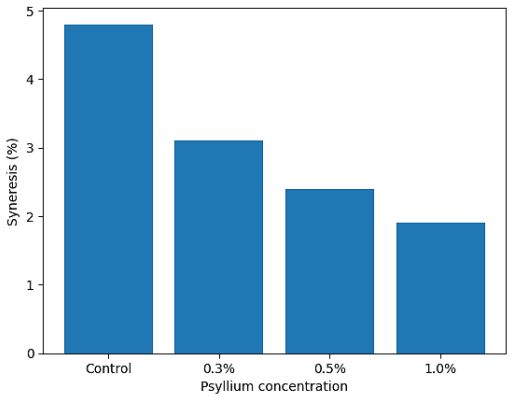

Figure 1 – Effect of psyllium concentration on the viscosity of yogurt

As shown in the histogram (Figure 1), the viscosity of the control sample was 640 mPa·s. The incorporation of 0.3% psyllium increased this parameter to 820 mPa·s, while a concentration of 0.5% resulted in 960 mPa·s, and 1.0% reached 1120 mPa·s, representing a 75% increase compared to the control sample. Thus, a clear dependence of viscosity on the concentration of plant fiber was observed.

The obtained results indicate a pronounced structure-forming effect of psyllium. The polysaccharide components of *Plantago ovata* are characterized by a high hydration capacity and

the ability to form a viscoelastic gel network. Their interaction with casein micelles leads to the formation of a denser three-dimensional structure capable of effectively retaining moisture and stabilizing the protein matrix.

The increase in viscosity directly correlates with the rise in total solids content and the enhanced water-holding capacity of the system. The formation of a protein – polysaccharide complex reduces the mobility of free water and improves overall product stability.

The reduction in syneresis is presented in Figure 2.

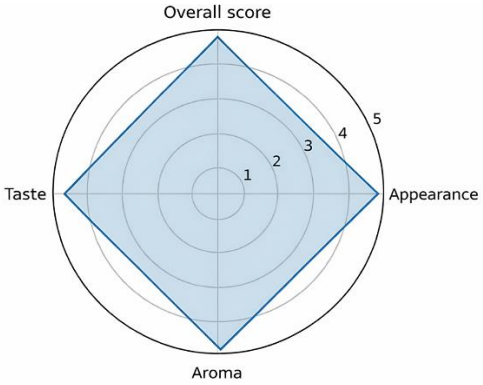

Figure 2 – Effect of psyllium concentration on yogurt syneresis

The control sample exhibited whey separation at a level of 4.8%. The incorporation of 0.3% psyllium reduced this parameter to 3.1%, while concentrations of 0.5% and 1.0% further decreased syneresis to 2.4% and 1.9%, respectively. Thus, a clear inverse relationship between psyllium concentration and the intensity of whey separation was established.

The reduction in syneresis indicates the formation of a stable protein–polysaccharide system with enhanced water-holding capacity. Due to its high hydrophilicity, psyllium effectively binds free water and forms a viscoelastic gel structure. The interaction between polysaccharide fractions and casein micelles results in the formation of a three-dimensional network capable of retaining moisture within the protein matrix. This prevents water migration and reduces structural destabilization during storage.

It should be noted that at a concentration of 1.0%, excessive gel densification was observed. Despite the minimal syneresis level, increased gel firmness may negatively affect sensory perception and overall consumer acceptance.

The sensory characteristics of the studied samples are presented in Table 2.

Table 2 – Sensory evaluation of yogurt samples (5-point scale)

Parameter	Control	0,3 %	0,5 %	1,0 %
Appearance	4,5	4,8	4,9	4,6
Consistency	4,3	4,7	4,8	4,4
Taste	4,6	4,7	4,8	4,6
Aroma	4,6	4,7	4,8	4,6
Overall score	4,5	4,7	4,8	4,5

As shown in Table 2, psyllium incorporation positively influenced the sensory characteristics of the product. The most pronounced improvement was observed in the «consistency» parameter, which is consistent with the rheological findings and confirms the impact of structural modification on sensory perception.

The highest scores were obtained for the sample containing 0.5% psyllium. This sample was characterized by a dense, homogeneous, and creamy texture without visible syneresis, a uniform gel structure, and a balanced fermented milk flavor. The increase in scores for «appearance» and «consistency» is associated with the formation of a stable protein-polysaccharide matrix, ensuring structural stability and improved consumer appeal.

The sensory profile of the sample containing the optimal psyllium concentration (0.5%) is presented in Figure 3.

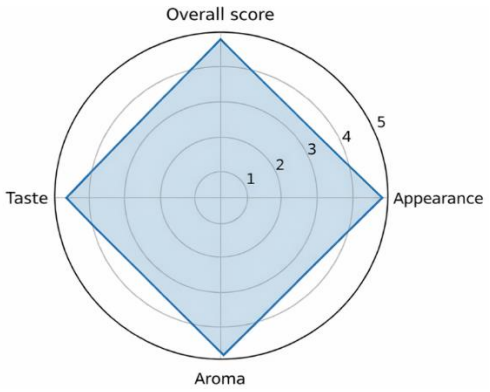

Figure 3 – Sensory profile of yogurt containing 0.5% psyllium based on individual sensory attributes (appearance, consistency, taste, and aroma).
The overall sensory score is presented separately in Table 2

As shown in Figure 3, the product is characterized by a well-balanced combination of sensory attributes. The highest scores were obtained for “appearance” and “consistency,” confirming the pronounced structure-forming effect of psyllium. The parameters “taste” and “aroma” remained at a high level, indicating that the incorporation of plant fiber did not negatively affect the organoleptic properties of the product.

The sample containing 0.3% psyllium also demonstrated improved sensory characteristics compared to the control; however, the texture-enhancing effect was less pronounced.

At a dosage of 1.0%, excessive thickness and increased structural density were observed. This was subjectively perceived by the sensory panel as overly high viscosity, resulting in a decrease in the overall score to 4.5 points.

The control sample was characterized by a less stable consistency and partial whey separation during storage, which negatively influenced the «appearance» and «consistency» scores.

Thus, the analysis of the data presented in Table 2 and Figure 3 confirms that 0.5% psyllium represents the optimal concentration, providing the best combination of textural and flavor characteristics while maintaining high consumer acceptability.

Conclusion

As a result of the conducted research, a technology for producing functional yogurt enriched with plant-based dietary fiber – psyllium (*Plantago ovata* husk) – was developed. It was established that the incorporation of psyllium at concentrations of 0.3-1.0% does not exert an inhibitory effect on lactic acid microflora and contributes to the improvement of the structural and mechanical properties of the product.

The use of psyllium increased viscosity up to 1120 mPa·s and reduced syneresis to 1.9%, while maintaining regulatory acidity parameters (pH 4.50-4.60; 88-94°T). The concentration of 0.5% was identified as optimal, providing a balanced combination of rheological and sensory characteristics.

A patent application has been filed in the Republic of Kazakhstan for the developed technology entitled «Method for Producing Yogurt with Added Plant-Based Dietary Fiber» (Application № 394201, Reg. № 2025/0799.1 dated August 21, 2025; currently under substantive examination).

The developed technology may be recommended for industrial implementation in the production of functional and dietetic fermented dairy products.

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ӨСІМДІК ТЕКТІ ТАҒАМДЫҚ ТАЛШЫҚ ҚОСЫЛҒАН ФУНКЦИОНАЛДЫ ЙОГУРТТЫ ӘЗІРЛЕУ ЖӘНЕ БАҒАЛАУ

Мақалада өсімдік текті тағамдық талшық – псиллиум (Plantago ovata husk) қосылған функционалдық йогурт өндіру технологиясы ұсынылған. Псиллиумды 0,3-1,0 % мөлшерде енгізудің өнімнің физика-химиялық, реологиялық және органолептикалық көрсеткіштеріне әсері жан-жақты зерттелді. Зерттеу нәтижелері псиллиумның сүтқышқылды микрофлораның дамуына кері әсер етпейтінін және ашыту процесінің қалыпты жүруіне кедергі келтірмейтінін көрсетті. Өсімдік талшығын қосу тұрақты ақуыз-полисахаридті құрылымның түзілуіне ықпал етіп, тұтқырлықты 1120 мПа·с-қа дейін арттырып, бақылау үлгісімен салыстырғанда сарысудың бөлінуін 1,9 %-ға дейін төмендететіні анықталды.

Ең тиімді концентрация ретінде 0,5 % мөлшер белгіленді, себебі бұл көрсеткіш йогурттың дәстүрлі дәмі мен хош иісін сақтай отырып, құрылымдық және сенсорлық қасиеттердің оңтайлы үйлесімін қамтамасыз етеді. Псиллиумды қолдану синтетикалық тұрақтандырғыштарды пайдаланудан бас тартуға мүмкіндік береді және «clean label» тұжырымдамасына толық сәйкес келеді.

Әзірленген өнім еритін тағамдық талшықтардың болуына байланысты жоғары тағамдық құндылыққа ие, пребиотикалық қасиеттерімен ерекшеленеді және функционалдық, профилактикалық әрі диеталық тамақтану үшін ұсынылады. Технологияның жаңалығы Қазақстан Республикасында өнертабысқа патент алуға өтінім берумен расталған.

Түйін сөздер: *функционалдық йогурт, псиллиум, өсімдік текті тағамдық талшық, құрылым түзілу, реологиялық қасиеттер, сарысу бөлінуі, пребиотикалық қасиеттер.*

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РАЗРАБОТКА И ОЦЕНКА ФУНКЦИОНАЛЬНОГО ЙОГУРТА С ДОБАВЛЕНИЕМ РАСТИТЕЛЬНОГО ПИЩЕВОГО ВОЛОКНА

В статье представлена разработка технологии функционального йогурта с добавлением растительного пищевого волокна - псиллиума (Plantago ovata husk). Исследовано влияние дозировки псиллиума (0,3-1,0 %) на физико-химические, реологические и органолептические показатели продукта. Установлено, что внесение псиллиума не оказывает ингибирующего воздействия на молочнокислую микрофлору и не нарушает процесс ферментации. Добавление растительного волокна способствует формированию устойчивой белково-полисахаридной матрицы, увеличению вязкости до 1120 мПа·с и снижению синерезиса до 1,9 % по сравнению с контрольным образцом.

Оптимальной признана концентрация 0,5 %, обеспечивающая сбалансированное сочетание текстурных и сенсорных характеристик при сохранении традиционного вкуса и аромата йогурта. Показано, что использование псиллиума позволяет отказаться от синтетических стабилизаторов и соответствует концепции «clean label».

Разработанный продукт характеризуется повышенной пищевой ценностью за счёт содержания растворимых пищевых волокон, обладает пребиотическими свойствами и может быть рекомендован для функционального, профилактического и диетического питания. Новизна технологии подтверждена подачей заявки на патент на изобретение Республики Казахстан.

Ключевые слова: *функциональный йогурт, псиллиум, растительное пищевое волокно, структурообразование, реологические свойства, синерезис, пребиотические свойства.*

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PLANT MODIFIERS OF COAGULATION AND PROTEIN RETENTION IN MIXTURES OF COW AND CAMEL MILK

Abstract: *The aim of this review is to analyse the mechanisms of plant extract action on milk coagulation and to evaluate their applicability in mixtures of cow and camel milk. The review includes publications devoted to the milk-clotting activity of plant proteases, the influence of polyphenolic compounds on casein micelle aggregation, and the role of technological parameters in the coagulation process.*

The analysis shows that plant extracts can act through two main mechanisms. The first mechanism is associated with proteolytic hydrolysis of κ-casein and the initiation of micelle aggregation. The second