Effect of ground psyllium on the quality characteristics of dairy-plant concentrates

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Abstract

Introduction. The aim of research – to determinate of the comprehensive effect of ground psyllium on the characteristics dairy-plant concentrates obtained by enzymatic coagulation of goat milk proteins with *Plantago major* L. juice.

Materials and methods. The study utilized goat milk, *Plantago major* L. juice as a coagulant, ground psyllium powder, and calcium chloride. The granulometric composition of psyllium and its swelling capacity were determined using sieve analysis, rheological properties were measured using a Kinexus Pro+ rheometer, and water-holding capacity was assessed using a gravimetric method.

Results and discussion. The granulometric composition of psyllium was determined. The particle size of the most significant fraction of psyllium, which constitutes 46.2%, ranges from 251 to 335 µm, while for ground psyllium (51.2%), it is 126–200 µm. It was shown that under identical conditions of the enzymatic coagulation process of milk proteins with heating in the presence of the active complex of *Plantago major*, the use of ground psyllium in amounts ranging from 0.25% to 0.75% contributed to an increase in the utilization rate of goat milk dry matter by 2.15–18.71% compared to the control. The optimal amount of calcium chloride for obtaining coagulates with high organoleptic and physicochemical properties in goat milk was 0.3–0.4 g/L. With an increase in the amount of ground psyllium, the viscosity of dairy-plant concentrates decreased, indicating a reduction in the mechanical strength of model systems.

Considering organoleptic limitations and quality indicators of dairy-plant concentrates, the optimal amount of ground psyllium addition was determined as 0.5±0.1% of goat milk mass during enzymatic coagulation of proteins with the active complex of *Plantago major*. The samples had a milky taste with a slight herbal aftertaste and aroma, a firm, moderately dense coagulate with a greenish color uniformly distributed throughout the mass.

The effect of ground psyllium in enzymatic coagulation of goat milk proteins with the active complex of *Plantago major* was confirmed by the transition indicators of dry substances into the dairy-plant concentrate and whey. The loss of goat milk dry matter into whey varies within the range of 4.55–7.00%, depending on the influence of various factors. The studies revealed a similar trend in changes in the water-holding capacity of dairy-plant concentrates for all samples, indicating interactions between proteins and a decrease in hydrated water content around casein micelles when using the active complex of *Plantago major* and ground psyllium.

Conclusions. The use of psyllium during the fermentation of goat milk with *Plantago major* juice ensures the stabilization of the physicochemical properties of dairy-plant coagulates and their enrichment with soluble and insoluble dietary fibers, proteins, micro- and macroelements.

Introduction

The use of dairy and plant raw materials under traditional technological processes, including protein precipitation and concentrate formation, can impart new qualities to the system (Onopriichuk et al., 2022). A promising direction in the development of multi-component protein products is the combination of goat milk and local plant raw materials (Chechetkina et al., 2016; Shah et al., 2014). Craft enterprises actively use such dairy and plant raw materials for the production of beverages, frozen desserts with high protein content, and curd-based products (Ahmed et al., 2024; Guyomarc'h et al., 2020). Plant processing products in the form of juice, extracts, concentrates, and dry powders are introduced at different stages of the technological process. It is proposed to add plant-based raw materials to milk or dairy products in various percentage ratios depending on the technological function (enrichment, coagulation or color correction) (Grek et al., 2020; Pavlyuk et al., 2019).

Plantain is used in food technologies as an enriching agent to increase biological value in minced meat semi-finished products in the form of green mass (Luo et al., 2018; Ukrainets et al., 2017) and in fermented dairy productsin the form of husks (Arabshahi et al., 2022).

Processed products from *Plantago major* L., commonly known as great plantain, including psylliumjuice and powder, are promising as coagulants and enrichers (Dülgeroğlu et al., 2017), but comprehensive study on their combined application in the production of dairy-plant concentrates are limited. The nutritional composition of psyllium, %, is as follows: fats, 1.2±0.01; proteins, 3.9±0.05, insoluble carbohydrates, 20.23±0.4, soluble carbohydrates, 78.2±4.01; ash, 4.1±0.01; moisture, 4.9±0.01. The mineral content, mg/100 g, includes potassium, 805; calcium, 104; sodium, 62.3, and magnesium, 19.7 (Chong et al., 2019). The scientific substantiation of their effectiveness in influencing the rheological and physicochemical properties of concentrates is a relevant area of applied scientific research.

Conditions for the industrial implementation of a technology using plantain juice with a dry matter content of 6.00±0.23 % for enzymatic and thermal-acid coagulation of cow's milk proteins were formulated (Grek et al., 2018, 2019), and specific physicochemical parameters of the corresponding protein-plant concentrates were identified. There is no information on the use of goat milk as a raw material in this technology. Possible corrections to the yield of dairy-protein concentrate and the application of technological approaches, such as the inclusion of plant ingredients (dietary fibers) to strengthen the curd, have been considered. The necessity of controlling the proteolytic activity of aspartic proteases has been proven, as high activity can lead to excessive cleavage of peptide bonds and the formation of a significant amount of soluble proteins, resulting in a weak curd (Shah et al., 2014). Potential losses of dry matter beyond regulatory limits and a slowdown in the syneresis process, as well as the appearance of defects in taste and consistency, are possible.

Wild plants are already being used to obtain safe enzyme preparations, as well as dietary fiber powders for different purposes. The limitation is the seasonality and regional specificity of raw materials (Khan et al., 2024). The industrially manufactured product derived from *Plantago major* is psyllium in the form of powder and husk is used in prepatatoion of certain foods (Franco et al., 2022; Neveen and Eelbassiony; Znamiriwska-Piotrowskaet al., 2023). Psyllium contains proteins, polysaccharides, glycosides, vitamin B1, choline, and fiber, which mainly consists of hemicellulose. Psyllium is obtained by processing the outer seed coat of *Plantago*. There are different types of plantain husk that vary in particle size (Agrawal, 2021).

It was shown that goat's milk coagulates worse than cow's milk when enzymes are used (Nayik et al., 2022). This is due to the peculiar protein structure, a reduced content of kappa-casein, low acidity, and high dispersion of fat globules with diameters ranging from 0.5 to 15 µm. The high content of β-casein and the low content of α-caseins present a technological challenge, as they complicate protein coagulation and dense curd formation (Pokhyl et al., 2023; Ryzhkova et al., 2019). It is likely that adding psyllium during the fermentation of goat's milk with *Plantago major* juice will increase the yield of milk-plant concentrate.

However, at present there is no comprehensive approach to solving the problems outlined above. Therefore, it was advisable to determine the comprehensive effect of ground psyllium powder on the characteristics of milk-vegetable concentrates obtained by enzymatic coagulation of goat milk proteins with plantain juice.

Materials and methods

Materials

As raw materials, goat milk was used with the following composition, %: fats – 4.14, proteins – 3.6 (including casein – 3.0), carbohydrates – 4.3–4.5, mineral substances – 0.85, ash – 0.82.

Psyllium (TDS No. BF/SP/007), the husk (shell) of plantain seeds, was used in the research. The appearance of psyllium is husk powder ranging from pale yellow to light yellow, odorless, with a moisture content of 12%, and total ash content not exceeding 4%. According to the manufacturer, psyllium is a natural dietary fiber that is hygroscopic, mucilaginous, capable of retaining water, and forms a homogeneous gel (Gebremeskal et al., 2024). Mucilage consists of approximately 15% non-polysaccharide substances, such as fat and protein, while the remaining 85% is a single polysaccharide containing D-xylose (~62%), L-rhamnose (~9%), L-arabinose (~20%), and D-galacturonic acid (~9%). β-D-xylose residues in the pyranose ring form the linear framework of the polysaccharide. Another disaccharide chain is linked to the terminal α-D-galacturonic acid and O-2-α-L-rhamnose. The total protein fraction consists of approximately 23.9% globulin, 35.8% albumin, and 11.7% prolamin (Agrawal, 2021; Guo et al., 2008). The water-holding capacity of psyllium is 59.2% (Aldughpassi et al., 2021). Country of origin - India.

Juice extraction from *Plantago major*

As a coagulant, direct-pressed juice from the aerial part of *Plantago major* was used, obtained using the technology (Grek et al., 2021), which includes the following operations: washing and drying fresh plant raw materials, passing them through rollers to obtain a mush-like mixture. Under laboratory conditions, the grinding process of wild plants was carried out using a MOULINEX ME626132 device with a power of 2000 W. The juice was used for research immediately after extraction. In the juice of *Plantago major L.,* the dry matter content was 6.00±0.23%, and the active acidity index was 5.85±0.18 pH units.

Preparation of model samples of dairy-plant concentrates

Model samples of dairy-plant concentrates were prepared for research by adding psyllium in amounts ranging from 0.25% to 0.75%, followed by enzymatic coagulation. The samples were obtained in laboratory conditions as follows: goat milk was pasteurized at a temperature of 74±2 °C for 15...20 s, cooled to the coagulation temperature, calcium chloride was added as a 40% aqueous solution, psyllium powder, and direct-pressed juice from the aerial part of *Plantago major* L. in the amount of 8.0±0.1%. Coagulation conditions: temperature 50-65 °C with an incubation time of 75±5 min. For the control sample without psyllium, the curd was also cut, heated for densification, whey was removed, and the concentrate was subjected to self-pressing and cooling.

Methods

Standard and well-known methods for studying the technological-functional properties and quality indicators were used to ensure the fulfillment of the research objectives.

Functional-technological properties of psyllium

The granulometric composition of psyllium was determined as follows. From the average sample, a 100 g portion was taken and sieved using silk sieves No. 35 and No. 43. To clean the sieves, 5 rubber discs with a diameter of 1.0 cm, a thickness of 0.3 cm, and a weight of 0.5 g each were placed on each sieve. The psyllium powder sample was poured onto the upper sieve, covered with a lid, the sieve set was secured on the platform of the sieve shaker, and sieving was started. After 8 minutes, the shaker was turned off, the sieve frames were tapped, and sieving was continued for another 2 minutes. The rubber discs were removed from the sieves, and the residue on the upper sieve and the passage through the lower sieve were weighed. The result was expressed as a percentage of the psyllium sample weight.

The swelling capacity of psyllium was determined by the gravimetric method, which involves measuring the mass change of the plant ingredient after immersion in a liquid for a certain period. This indicator is quantitatively characterized by the swelling degree (K), which shows the relative increase in system mass, mg/mg. The swelling degree was calculated using the formula:

$$K = \frac{m_1 - m_0}{m_0} = \frac{m_p}{m_0}$$

where m_0, m_1 are the mass of the system before and after swelling, mg; m_p is the mass of the absorbed solvent, mg.

Effect of ground psyllium on fermentation process of goat milk

The degree of utilization of milk solids (As) was determined by the formula:

$$As = 100\frac{Cz(Cm - Cwhey)}{Cm(Cz - Cwhey)}$$

where Cz is mass fraction of dry matter in the dairy-plant concentrate, %; Cm is mass fraction of dry matter in goat milk, %; Cwhey is mass fraction of dry matter in whey, %.

The calcium content in the experimental samples, %, was measured by the titrimetric method (Prylipko et al., 2020).

Complexometric titration was used to determine the calcium content in the products (dairy-plant concentrate). The method utilizes the molecule called EDTA, which forms a complex with calcium ions. Murexide dye was used as an indicator. This dye also forms a complex with calcium ions, changing color from pink/red to violet. However, the dye-metal ion complex is less stable than the metal ion-EDTA complex. As a result, when titrating the calcium-Mux complex with EDTA, Ca^{2+} ions react to form a stronger complex with EDTA. For titration, the indicator was added to the sample solution containing calcium ions, forming a pink-red calcium ion-indicator complex (Ca-Mux). This solution was then titrated with EDTA. The endpoint occurred when the solution turned violet, indicating that the Ca-Mux complex was completely replaced by the calcium ion-EDTA complex and the Mux indicator returned to its violet color.

The calcium content in the experimental samples, %, was calculated using the formula:

$$W = 0.4 \cdot (V - V_0) \cdot f / m,$$

where: W is a calcium content, %; V is a volume of potassium permanganate solution used for the test sample, ml; V_0 is a volume of potassium permanganate solution used for the control experiment, ml; m is a mass of the test sample, g; f is correction factor for the volume of precipitate obtained after precipitation with trichloroacetic acid depending on the fat content in the sample.

The degree of protein utilization (%) is determined by the formula:

$$B = 100\frac{Bdpc(B\text{м} - Bwhey)}{Bdpc(\text{Б}milk - Bwhey)}$$

where Bdpc is mass fraction of protein in the dairy-plant concentrate, %; Bmilk is mass fraction of protein in goat milk, %; Bwhey is mass fraction of protein in whey, %.

The appearance and color of dairy-plant concentrates and whey were evaluated visually, while the consistency was assessed organoleptically at a temperature of 18-20°C.

Rheological characteristics of dairy-plant concentrates

The rheological characteristics of dairy-plant concentrates were measured using a Kinexus Pro+ rheometer (Malvern Instruments Ltd, United Kingdom). A 40 mm round plate geometry (PU40 SR5040 SS:PL61 ST) was used, fixed on the vertical shaft. The sample was placed on the lower platform, and the shaft with the plate was lowered to a gap of 1 mm between them. Viscosity and flow curves were obtained by varying the shear rate in the range of 0.1-1000 s^{-1} with 10 measurement points per decade. Each step was maintained until a stable state was reached. The study was conducted at a temperature of 20±1 °C (Alvarez et al., 2015).

Physicochemical and organoleptic characteristics of dairy-plant concentrates

The organoleptic characteristics of dairy-plant concentrates were evaluated according to ISO 22935-3:2009 (2009). A panel of 10 experts assessed the quality of dairy-plant concentrate samples using a hedonic scale (1 – low quality, unacceptable taste/odor/color/appearance/consistency; 2 – below average quality, noticeable defects; 3 – average quality, generally acceptable for most consumers; 4 – high quality, pleasant taste/odor/color/appearance/consistency; 5 – exceptionally high quality, impressive taste/odor/color/appearance/consistency) (Elsamani, 2016) based on the following individual sensory attributes: appearance, consistency, taste, odor, and color. Scores for individual attributes were plotted on diagram axes to obtain sensory profiles of each dairy-plant concentrate sample.

The moisture content of dairy-plant concentrates was measured using an accelerated method on a KVARTS-21M-33 moisture analyzer by drying the sample to a constant mass, as well as a thermogravimetric method using ADS series electronic laboratory moisture analyzer scales produced by "AXIS" (Poland).

The dry matter content of dairy-plant concentrates was determined using the formula:

$$C = 100 – B,$$

where S is the dry matter content, %, and W is the moisture content, %.

The water-holding capacity (WHC) of dairy-plant concentrates was studied using the Grau-Hamm gravimetric method, based on determining the amount of water released from the product under light pressing and absorbed by filter paper (Grek et al., 2024).

The active acidity (pH) of dairy-plant concentrates and whey was determined potentiometrically using a Sartorius PB-20 universal pH meter.

The dry matter content in whey was analyzed using a refractometric method based on light refraction indices (Grek et al., 2024).

Statistical analysis

Data were expressed as means ± standard deviations for triplicate determination. Statistical analysis was performed using Microsoft Excel 2007. Differences were considered to be significant at validity of α=0.95.

Results and discussion

Functional-technological properties of psyllium

The granulometric composition of psyllium, along with its chemical composition, influences the rate of biochemical and colloidal processes. The use of psyllium in the fermentation of goat milk with *Plantago major* juice is likely to affect the qualitative characteristics of dairy-plant concentrates and the coagulation time of the curd. The granulometric composition of psyllium is a particle size characteristic that expresses the distribution function or particle density. Psyllium grinding was performed using a device with a rotation speed of approximately 3000 rpm and a power of 300 W. The duration of the process was 3–5 minutes.

The determined granulometric composition of psyllium is presented in Figure 1.

According to the diagram (Figure 1), the particle size of the most significant fraction of psyllium, accounting for 46.2±1.1%, is 251-335 µm, while for ground psyllium (51.2±1.2%), it is 126-200 µm.

Grinding psyllium increases the availability and digestibility of nutrients and enhances the potential technological effect associated with water binding in dairy-plant concentrates. The interaction of ground psyllium with different dispersion media—goat milk (raw material for dairy-plant concentrates) and water (control)—was studied to determine the impact of psyllium on the qualitative and quantitative characteristics of the samples.

For better distribution of ground psyllium, (a powder composed of soluble and insoluble fiber) within the structure of dairy-plant concentrates, pre-dissolution is advisable. The relative increase in system mass due to solvent absorption is characterized by the swelling degree (K) and depends on the type of dispersion medium. Swelling of ground psyllium was conducted in water and goat milk at temperatures of 20±2 °C, 60±2 °C, and 90±2 °C for 10±1 minutes. The swelling ability of ground psyllium at different temperatures in water and goat milk is presented in Figure 2.

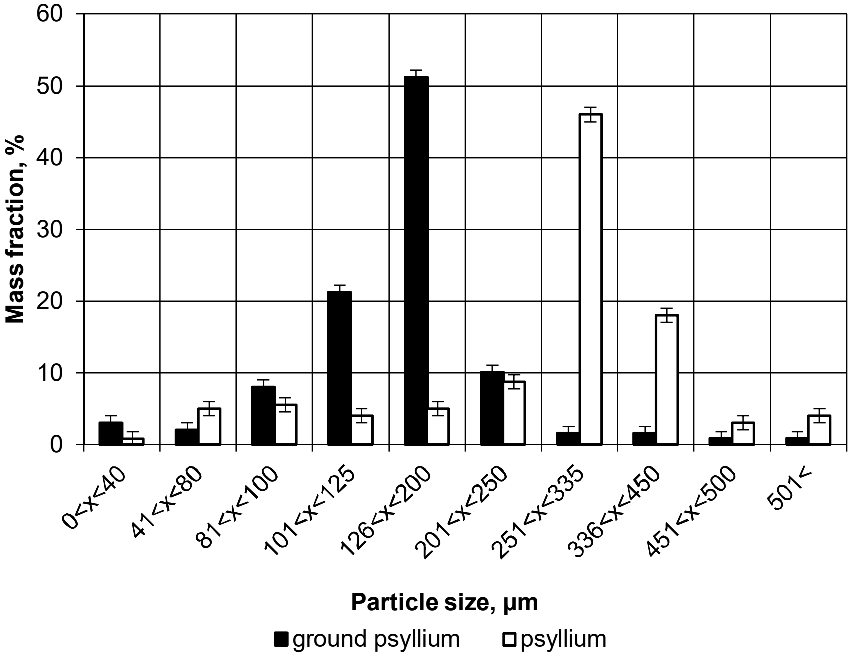

Figure 1. Granulometric composition of psyllium

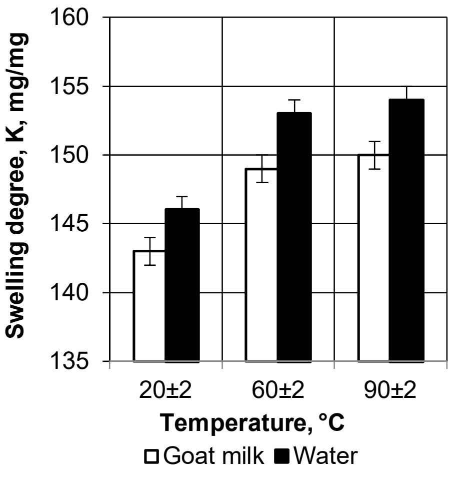

Figure 2. Swelling ability of ground psyllium at different temperatures in water and goat milk

It was found that the swelling degree of ground psyllium in goat milk was 2.1–2.7% lower than in water within the specified temperature range. When the process temperature increased to 90±2°C, the swelling ability increased slightly (by 0.7% in goat milk and by

0.8% in water) compared to 60±2°C. Pre-mixing ground psyllium with water before adding it to goat milk reduces the nutritional value of the product. Given the relatively minor deviations in swelling degree indicators in milk and water, the process should be conducted directly in goat milk. The optimal swelling temperature was determined to be 60±2°C, as it is the closest to the pasteurization regime required to ensure the necessary microbiological parameters.The obtained data correlate with the water-holding capacity of psyllium, which is 59.2±0.1% (Aldughpassi et al., 2021).

Psyllium consists of 35% soluble fractions and 65% insoluble polysaccharides such as cellulose, hemicellulose, and lignin. Psyllium is a hydrophilic mucilloid with a highly branched arabinoxylan polysaccharide structure, possessing a high water-holding capacity and gel-forming ability. The gel-forming fraction of polysaccharides consists of xylose, arabinose, and small amounts of other sugars (Agrawal, 2021; Chong et al., 2019).

Effect of ground psyllium on fermentation process of goat milk

The degree of dry matter utilization in goat milk during enzymatic coagulation with heating in the presence of an active *Plantago major* complex and different amounts of ground psyllium is presented in Figure 3.

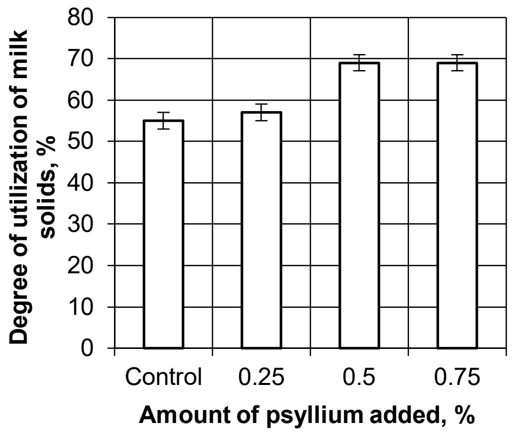

Figure 3. The degree of utilization of goat milk solids during enzymatic coagulation with heating in the presence of the active complex of *Plantago major* and different amounts of psyllium

For the control sample, the degree of utilization of dry matter from goat's milk was 50.93±0.05 %. The highest value of the aforementioned indicator, 69.64±0.01 %, was observed in the dairy-plant concentrate obtained with the addition of 0.5% ground psyllium. When 0.75% psyllium was added, the aforementioned indicator did not change. It is likely that the coagulation process of goat milk proteins with *Plantago major* juice and the thickening of the curd with the addition of ground psyllium occur due to the cleavage of an unstable peptide bond in χ-casein – Phe 105 – Met 106. This can be explained by the hydrophobic nature of serine, leucine, and isoleucine, which participate in the initial stage of the process. As a result, the χ-casein chain is split into two unequal segments: 1-105, which forms para-χ-casein, and 106-169, which forms caseinomacropeptide. Further, para-χ-casein binds with α- and β-caseins and remains part of the micelle, exhibiting pronounced alkaline and hydrophobic properties. Caseinomacropeptide, having an acidic and hydrophilic nature, is released into the whey. Consequently, para-χ-casein molecules transition into an unstable state. The next phase of coagulation, associated with thickening, occurs under the technological influence of dietary fibers from psyllium. This technological approach neutralizes the specificity of the fractional composition of goat milk proteins (dominance of β-casein and α-lactoglobulin) and their low ability to form dairy curds (Ryzhkova et al., 2019).

At the next stage of the study, a technological method of adding $CaCl_2$ was used to influence the coagulation rate and curd density. Calcium ions play an important role in the aggregation of casein micelles. The addition of $CaCl_2$ to milk, especially thermally treated milk, is the simplest way to reduce sedimentation time and increase curd stability during production. It is likely that adding $CaCl_2$ during enzymatic coagulation with plant proteases in the presence of ground psyllium is appropriate.

The effect of different $CaCl_2$ concentrations on the degree of protein utilization from goat's milk, curd characteristics, and calcium content was studied. For this purpose, a $CaCl_2$ solution was added to goat's milk at concentrations ranging from 0.1 g to 0.6 g of dry salt per liter of milk. The milk was mixed until curd formation and whey separation. The protein curd was drained into lavsan bags and left for self-pressing. The study results are presented in Figure 4 and Table 1.

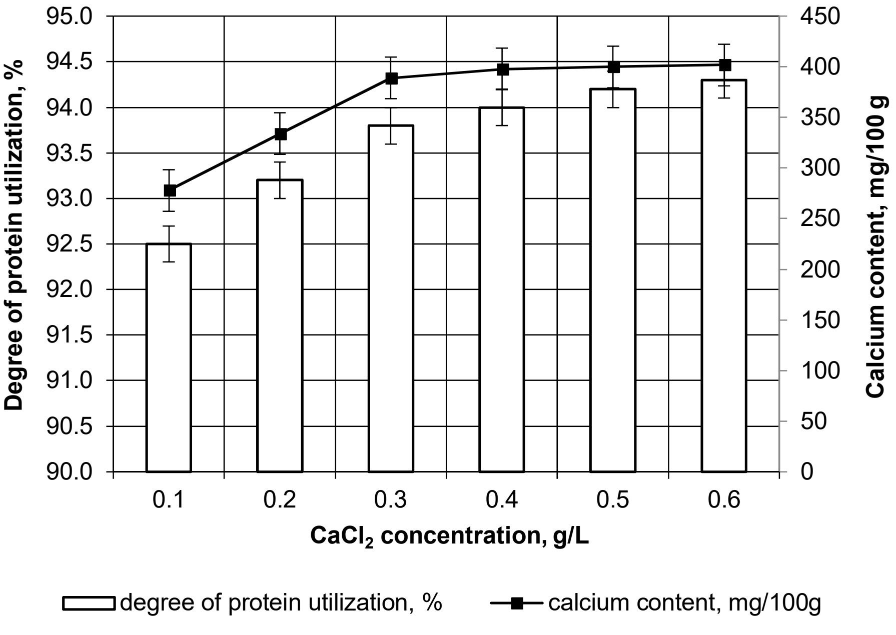

Figure 4. Degree of protein utilization in goat milk and calcium content in curds obtained by enzymatic coagulation with heating in the presence of the active complex of *Plantago major* and 0.5% ground psyllium with the addition of $CaCl_2$.

Table1

Effect of $CaCl_2$ concentration on the characteristics of goat milk curds obtained through enzymatic coagulation with heating in the presence of an active *Plantago major* complex and 0.5% ground psyllium

$CaCl_2$ concentration, g/L	Characteristic	
	Dairy-plant concentrates	Whey
0.1 – 0.2	Flaky soft	Yellow-green, turbid
0.1 – 0.4	Soft curd	Yellow-green, clear
0.5 – 0.6	Soft curd	Yellow-green, clear

According to the results (Figure 4 and Table 1), as the concentration of $CaCl_2$ increased, the degree of protein utilization from goat's milk also increased. When $CaCl_2$ was added at 0.1–0.2 g/L, loose curds and yellow-green turbid whey were formed. Curds with the appropriate organoleptic characteristics were obtained when $CaCl_2$was added at 0.3–0.4 g/L to goat's milk. With an increase in calcium chloride concentration, calcium binding by protein curds also increased. It was established that in goat milk protein curds, the calcium content was 400 mg/100 g when 0.50 g/L of $CaCl_2$was added. Thus, the optimal amount of calcium chloride to be added to goat's milk is 0.35±0.05 g/L. Further additions are unnecessary, as they do not yield superior curd quality in terms of organoleptic and physicochemical properties. The obtained results correlate with the findings of Kethireddipalli and Hill (2015), which indicate that 0.4-0.6 g/L $CaCl_2$ is needed for milk subjected to more intense heat treatment. Similar information is presented in the works of Brutti et al. (2012), Lo Piero et al. (2002), and Mazorra-Manzano et al. (2013). The disruption of enzymatic coagulation (extended coagulation time) in thermally treated milk is primarily explained by the interaction between denatured whey proteins and casein micelles, which hinders the aggregation of the latter.

Rheological characteristics of dairy-plant concentrates

The study of rheological characteristics and the patterns of their changes with the addition of technological ingredients is important for developing new types of dairy-plant concentrates and adapting existing equipment for mechanical processing and transportation.

Due to the chemical structure and ability to swell and gel in the presence of liquid, ground psyllium influences the structural formation of dairy-plant concentrates. The study of the dependence of effective viscosity on shear rate in dairy-plant concentrate samples obtained by fermenting goat's milk with *Plantago major* L.juice and adding different amounts of ground psyllium (Figure 5) showed that the latter affects the shape of the curves.

It was found that the initial shear viscosity of dairy-plant concentrates was higher in the control sample than in dairy-plant concentrates with 0.25% to 0.75% ground psyllium. The shear viscosity value in the concentrate with 0.25% psyllium was the closest to the control sample. Changes in the viscosity of dairy-plant concentrates with increasing shear rate can be explained by the deformed arrangement of polysaccharides, friction between expanded granules, and hemicellulose content (Sasaki et al., 2002).

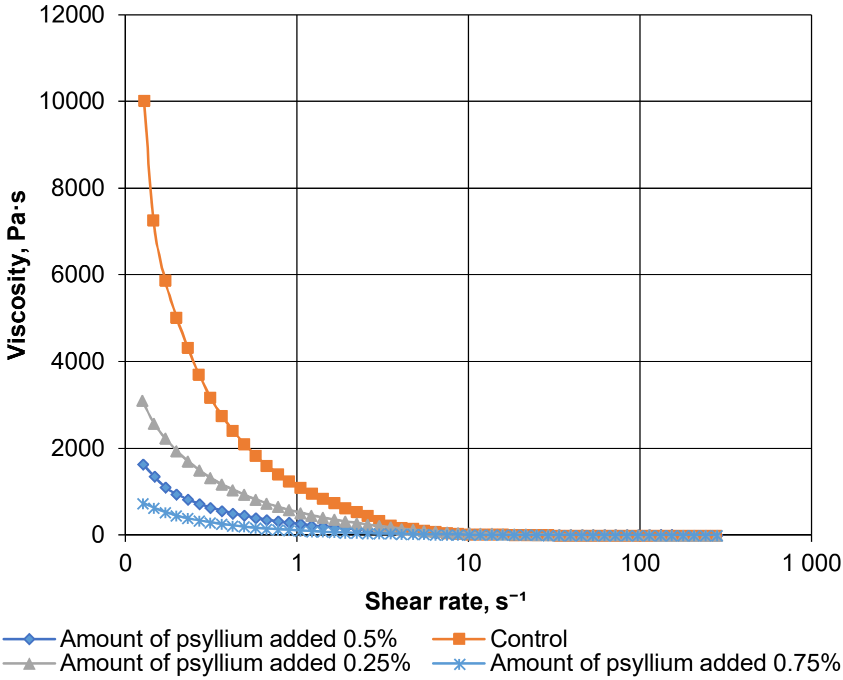

Figure 5. Dependence of effective viscosity changes on shear rate in dairy-plant concentrate samples with different amounts of ground psyllium during fermentation

In samples of dairy-plant concentrates with ground psyllium, the shear viscosity decreased compared to the control, regardless of psyllium concentration. This is due to the effect of liquid on soluble and insoluble dietary fibers and milk proteins, which slows down swelling (Lan et al., 2008). This effect indicates a reduction in the mechanical strength of the model systems. In psyllium, dietary fibers and mucilage are predominantly represented by soluble, highly branched, gel-forming polysaccharides – arabinoxylans (85%), which have a xylose backbone with arabino- and xylose-containing side chains (Craeyveld et al., 2009).

Additionally, dairy-plant concentrate samples with 0.25% ground psyllium reached stable viscosity significantly earlier – at a shear rate of 3 s^{-1}, while samples with 0.5% reached stability at 5 s^{-1}, and those with 0.75% at 7 s^{-1}. The viscosity of dairy-plant concentrates with 0.25% psyllium was slightly higher – about 105 Pas compared to 43 Pas for the 0.75% psyllium sample. This effect is likely related to greater fragmentation of psyllium chains at 0.75% concentration (Zambelli et al., 2018). The concentrates likely exhibited a coagulation structure formed by protein particle adhesion through thin layers of free or adsorbed whey.

The identified rheological characteristics correlate with the organoleptic perception of dairy-plant concentrates obtained by enzymatic coagulation of goat milk proteins with an active *Plantago major* complex and different amounts of ground psyllium. The observed changes in system properties are explained by psyllium's highly hydrophilic nature, forming a molecular solution in the dispersion medium and exerting a significant dehydrating effect on protein molecules by reducing the hydration shell. As a result, moisture is better separated from the curds, and the effective viscosity of dairy-plant concentrates decreases.

Organoleptic properties, water-holding capacity, and moisture content of dairy-plant concentrates

The obtained dairy-plant concentrates represent a polydisperse colloidal system, where the dispersion medium is whey, and the dispersed phase consists of milk proteins, dry substances of *Plantago major*, and psyllium. The formation of the dairy-plant coagulum structure occurs due to the swelling of psyllium dietary fibers at the stage of goat milk protein coagulation during fermentation. The specific structure of the coagulum determines its organoleptic characteristics. The obtained dairy-plant concentrates exhibit a thixotropic coagulation-type structure with liquid interlayers between the particles, which results in lower structural strength but provides plasticity and elasticity (Grek et al., 2019).

The optimal psyllium dosage was determined based on maintaining standard organoleptic characteristics typical of dairy-plant concentrates, which could serve as a basis for producing various types of curd-based products. Figure 6 presents the results of the organoleptic evaluation of dairy-plant concentrates with psyllium.

Organoleptic characteristics are a limiting factor for using dairy-plant concentrate as a base for dairy-protein products due to variations in coagulum color, ranging from light pistachio to intensely pistachio-colored.

The profilogram of the organoleptic evaluation of dairy-plant concentrates obtained by coagulating goat milk proteins with *Plantago major* juice and different amounts of psyllium is presented in Figure 6.

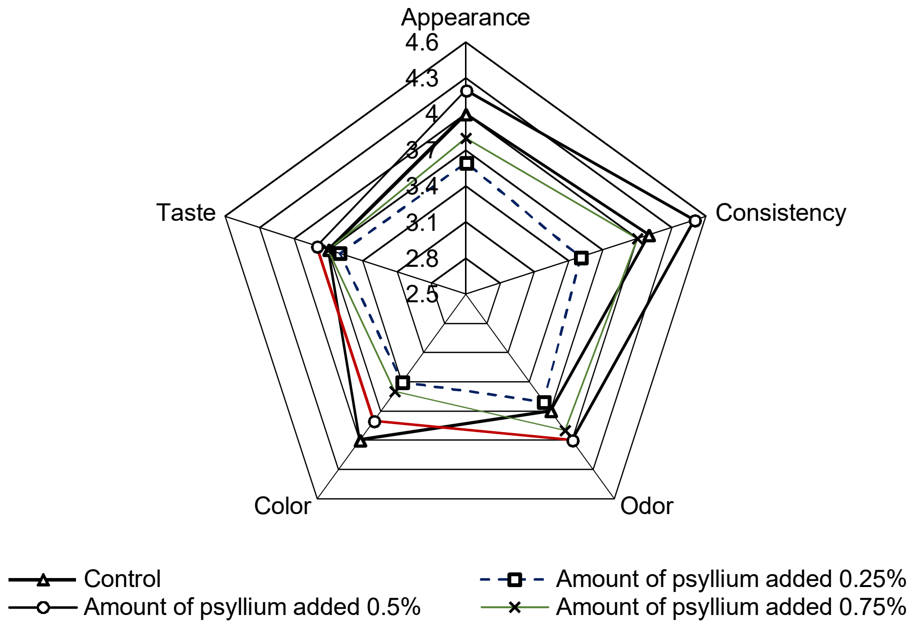

Figure 6. Profilogram of the organoleptic evaluation of dairy-plant concentrates obtained by coagulating goat milk proteins with *Plantago major* juice and different amounts of psyllium

The organoleptic evaluation of the dairy-plant concentrate obtained by coagulating milk proteins with *Plantago major* L. juice and finely ground psyllium at a concentration of 0.5±0.1 % is presented in Table 2.

Table 2

Organoleptic evaluation of the dairy-plant concentrate obtained by coagulating milk proteins with *Plantago major* juice and psyllium at a concentration of 0.5±0.1 %

Parameter	Characteristic
Color	Greenish, uniform throughout the mass with green inclusions
Taste and aroma	Milky with a slight herbal aftertaste and aroma
Consistency	Firm curd, moderately dense

The best taste and consistency of the dairy-plant concentrate were achieved with the addition of 0.5±0.1 % psyllium. The samples exhibited a milky taste with a mild herbal aftertaste and aroma, a firm and moderately dense coagulum, and a greenish color evenly distributed throughout the mass with visible inclusions. The addition of psyllium in amounts greater than 0.75% led to undesirable organoleptic changes in the dairy-plant concentrate, resulting in a jelly-like soft consistency. Adding less than 0.25% psyllium had no significant positive effect on organoleptic properties and minimized the enrichment of the coagulum with biologically active nutrients. Inconsistencies in texture, which complicate the self-pressing process, must be considered.

The color of the dairy-plant concentrate is determined by the presence of chlorophyll in *Plantago major* .juice, which is present in two forms: chlorophyll a (75%) and chlorophyll b (25%). The inclusion of this component in the diet has a positive physiological effect on the human body.

A dairy-plant concentrate containing 0.5±0.1 % finely ground psyllium with appropriate organoleptic characteristics can be used as a base for dairy-protein products with a plastic structure (e.g., creams, desserts, sauces).

The main physicochemical characteristics of dairy-plant concentrates were investigated. The corresponding changes in the mass fraction of dry matter in dairy-plant concentrates and whey, depending on the amount of psyllium added, are presented in Figure 7.

The changes in moisture content and water-holding capacity of dairy-plant concentrates depending on the amount of psyllium added are presented in Figure 8.

The efficiency of the above-mentioned technological solutions can be confirmed by quantitative indicators of dry matter transfer into the dairy-plant concentrate and whey. In the control sample of the dairy-plant concentrate, up to 7.11±0.11% of dry matter transfers into the whey, while 57.36±1.2% remains in the coagulum. The active acidity of the samples decreases with an increasing amount of psyllium, ranging from 6.47±0.12 to 6.25±0.11 pH units, while for the control sample, this value is 6.16±0.11 pH units.The losses of goat milk dry matter into the whey for all model samples varied between 4.53±0.12 % and 7.11±0.11 %, depending on various factors. The water-holding capacity of dairy-plant concentrates decreases as the amount of finely ground psyllium increases. The changes in moisture content and water-holding capacity of dairy-plant concentrates obtained using the active complex of *Plantago major* and finely ground psyllium can be explained by continuous protein interactions, leading to a reduction in hydrated water content around casein micelles.

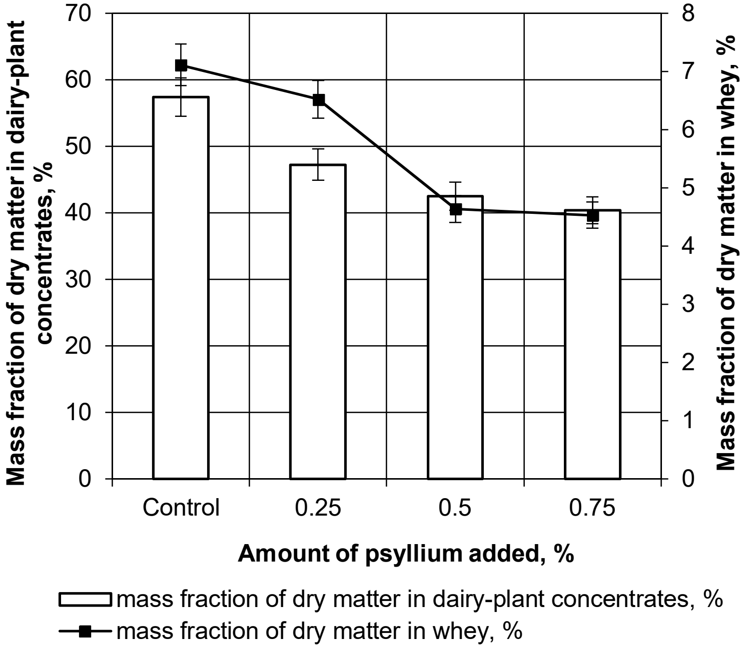

Figure 7. Changes in the mass fraction of dry matter in dairy-plant concentrates and whey depending on the amount of psyllium added

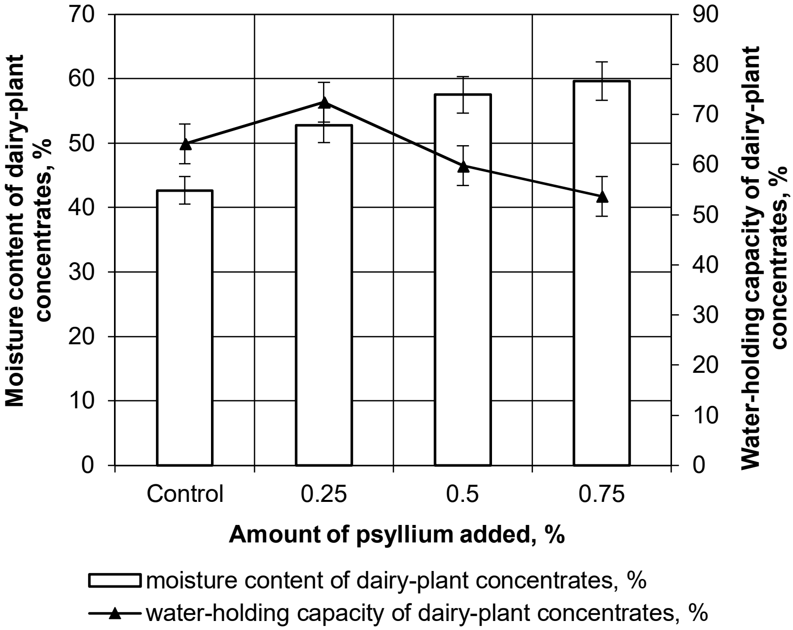

Figure 8. Changes in moisture content and water-holding capacity of dairy-plant concentrates depending on the amount of psyllium added

Conclusions

1. The feasibility of using ground psyllium during the fermentation of goat milk with *Plantago major* L. juice to stabilize the physicochemical parameters of milk-plant coagulates and enrich them with soluble and insoluble dietary fibers, proteins, micro- and macroelements has been substantiated.
2. The granulometric composition of psyllium has been determined, with the main particle size fractions ranging from 126 to 200 μm (51.2±1.2 %) and 251 to 335 μm (46.2±1.1%). The swelling temperature of ground psyllium when added to goat milk has been specified at 60±2°C.
3. Technological solutions have been proposed to increase the yield of milk-plant concentrate from goat milk: the addition of $CaCl_2$ in an amount of 0.35±0.05 g/L and ground psyllium with moisture-retaining properties in an amount of 0.5±0.1 %. Milk-plant concentrates are characterized by a dense spatial structure and syneresis properties, which are regulated by the husk content under thermomechanical influence.
4. The presence of whey layers between protein particles and highly branched gel-forming psyllium polysaccharides results in lower structural strength while ensuring plasticity and elasticity. This has been confirmed by the effective viscosity ranging from 735.7±1.2 Pa·s to 3101.0±2.1 Pa·s in milk-plant concentrates with the addition of ground psyllium.
5. The physicochemical and organoleptic characteristics of milk-plant concentrates and whey have been studied depending on the amount of added ground psyllium. The milk-plant concentrate obtained by fermenting goat milk with *Plantago major* juice with the addition of 0.5±0.1 % ground psyllium had an appropriate consistency and taste properties—a milky flavor with a light herbal aftertaste and aroma, a firm and moderately dense coagulate with a greenish color, uniform throughout the mass with inclusions. It has been established that when the husk addition increased from 0.25 % to 0.75%, the loss of dry substances from goat milk into whey varied in the range of 7.11±0.11 % to 4.53±0.12 %.

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