1. Introduction

Dairy products have been in continued demand from the population throughout the history of humanity. This is due both to the unique properties of milk, inherent in nature, and to the possibility of producing from it a variety of products that have a high storage capacity and attractive taste. Numerous studies confirm the role of dairy products as an important component of a healthy diet. Modern trends in the development and production of new dairy products are aimed at increasing their functionality, reducing the loss of raw materials and meeting the needs of various segments of the population. One of the promising directions in the development of new dairy products is the use of polysaccharides of various origins in them. For example, in the review [1] devoted to the analysis of modern trends in the use of food polysaccharides, mainly of plant origin, it was shown that there are promising results for their use as food additives to control the organoleptic properties of products, as well as sources of biologically active compounds for functional dairy products. This approach not only allows taking a step forward in reducing waste in the food chain, but also offers new ways to diversify dairy production, creating the opportunity to occupy a market niche based on new functional products.

Milk is the best known and most widespread natural hydrocolloid. However, there is a wide variety of other hydrocolloids, which are hydrophilic biopolymers of plants, animals, and microorganisms that can be used in the food industry. Review work [2] is devoted to the analysis of the use of known and potential natural hydrocolloids based on proteins and polysaccharides in the food industry. This review reflects the most recent concepts for the use of hydrocolloids to meet the requirements of consumers and the food industry.

Hydrogels formed from hydrocolloids are three-dimensional networks of hydrophilic biopolymers that can absorb significant amounts of water without dissolving or losing their structural integrity. The use of natural hydrogels from food biopolymers has become widespread in recent decades. In work [3], the basic principles of designing food gels are considered, aimed at changing the rheological and tribological properties of food products, modifying them while maintaining sensory perception and targeted delivery of drugs and biologically active substances into the gastrointestinal tract.

Hydrogels can be formed from hydrocolloids of protein and polysaccharide origin, as well as their composites. Protein-polysaccharide composites, as is known [4], have a wide range of applications in various areas of food production. These composites can have various physical forms, such as gels, films, fibers and individual particles, depending on their components and the particular application. Subsequent processing and use of these composites contribute to a targeted and beneficial change in their structure and properties.

Thus, the use of protein-polysaccharide compositions provides many opportunities for improving organoleptic properties, biological functions, and technological processes for the production of dairy products. The study of protein-polysaccharide interactions opens up opportunities for the development of new ingredients and biopolymer complexes with application in various areas of the food industry.

The purpose of this work is to give an idea of the elements of protein-polysaccharide compositions, how they are formed and how they are used in modern dairy production.

2. Main part

2.1. Casein is the main protein in milk

Milk proteins are the basis for the production of most dairy products. First of all, this concerns casein, which is the main protein of milk and is represented by fractions of α-, β- and κ-caseins. Casein molecules do not have a definite quaternary structure and therefore belong to the group of metamorphic proteins. The property of caseins to change their quaternary structure under the influence of external factors is decisive in the milk processing. In milk, casein is in the form of spherical micelles with a diameter of 50 to 300 nanometers (Figure 1,
The composition of a micelle can include from several hundred to tens of thousands of molecules of various caseins, and the κ-casein molecules are predominantly located on the surface of the micelle. A distinctive feature of κ-casein is the presence of a terminal hydrophilic glycomacropeptide with a diameter of 2 and a length of about 10 nanometers [6]. The aggregate of glycomacropeptides on the surface of the micelle forms a hydrophilic «hairy» layer, which determines the hydrophilicity of the micelle and the thermodynamic stability of milk as a whole. At the same time, casein micelle has a loose internal structure containing up to 70% water, i.e., each casein micelle in milk is a stable gel particle capable of subsequent deployment under certain external influences. In addition, a hydrophilic hairy layer covers the surface of a micelle by 90–95%, which, in some cases, allows micelles to carry out hydrophobic interactions [7]. This structure of micelles predetermines their interaction with the environment and determines the possibility of implementing certain technological methods in the production of dairy products.

Most of these technological methods are based on destabilization of casein micelles, which ensures the deployment of casein molecules, their activation and removal of water from micelles.

2.2. Whey proteins

Whey proteins are a group of different globular proteins that differ from each other in structure and properties, and, despite their small amount, are the physiologically most valuable components of milk. Whey proteins, primarily, include β-lactoglobulin (55–60% of all whey proteins) and α-lactalbumin (20–25%); their molecules usually form dimers, tetramers and octamers in milk. The rest of the serum proteins are serum albumin, immunoglobulins, lactoferrin and other minor proteins [8]. β-lactoglobulin and α-lactalbumin are of the greatest importance in the technological processes of the production of dairy products. For example, high temperatures denature whey proteins, which releases the hydrophobic regions of the molecules and triggers hydrophobic interactions with other proteins and, in some cases, the formation of protein gel. These proteins largely affect the organoleptic properties of the finished product by binding to caseins and other components or forming their own macrostructures (Figure 2).

Various types of whey proteins, as well as products from them, such as whey protein isolate and whey protein concentrate, are widely used in various areas of food technology, including stabilization of foam and fat emulsions, gel formation, etc. Each specific application of whey proteins may require modification of their functional properties. For example, using enzymatic hydrolysis, thermally induced polymerization, high-pressure treatment or chemical functionalization [9].

2.3. Vegetable proteins

Vegetable proteins are increasingly used in the production of dairy products. Since the range of vegetable proteins is very wide and their properties are very diverse, they are used to achieve different goals. There are several types of classification of vegetable proteins by their properties and fields of application (by origin, by solubility, by amino acid composition by structure, etc.) [10]. In nature, vegetable proteins mainly exist in a bound form, and therefore, for use in dairy products, it is necessary to first extract them from vegetable raw materials, purify and grind them. Depending on the results obtained of extraction, vegetable proteins can be added to dairy products to achieve various goals — structuring, enrichment, prevention, etc., attractive to potential consumers [11]. At the same time, vegetable proteins cannot completely replace milk proteins, neither in terms of amino acid composition, nor in terms of processing, nor in terms of organoleptic properties.

There are many attempts to create a milk-like food product. These milk drinks are obtained using vegetable proteins and various technological operations so that their components have dimensions close to those of natural milk components. However, this is difficult to achieve and, as a rule, electron microscopy can reveal the differences. As an example, Figure 3 shows an electron microscopic photograph of the dispersed phase of soy «milk». Comparing this photograph with Figure 1 makes it easy to notice significant differences in the structure of dispersed phases and to recognize such a structure in any way corresponding to the structure of natural milk is hardly possible. However, this and similar dairy drinks generally do not carry potential health risks and can be sought after by the consumer. However, there is a potential risk of the possibility of adulteration of a natural product.
2.4. Polysaccharides

Among natural biopolymers, polysaccharides are ideal candidates for widespread use in the food industry. They are nontoxic, biocompatible, biodegradable, hydrophilic, and have high biomimetic and physicochemical properties. Polysaccharides quantitatively represent the most important group of nutrients in food. For these reasons, in recent years, more and more attention has been paid to the non-traditional use of polysaccharides in the production of dairy products.

Polysaccharides are macromolecules of monosaccharides linked by glycosidic bonds. There are a huge number of polysaccharides with different composition and structure, with different physicochemical properties and specific functional use. All polysaccharides can be classified into groups depending on their origin: natural, semi-synthetic, synthetic [12].

Natural polysaccharides are biopolymers (Figure 4) of plant, animal, and microbial origin, for example, starch, chitin, pectin, xanthan, cellulose, etc.

Semi-synthetic polysaccharides are synthesized by modifying natural polysaccharides [13]. Starch and cellulose derivatives such as carboxymethyl cellulose and phosphorylated starch are examples of semi-synthetic polysaccharides. Semi-synthetic polysaccharides have enhanced specific properties, for example, emulsifying, non-toxic and less susceptible to microbiological deterioration.

Synthetic polysaccharides are completely produced by the chemical industry, starting from the basic components obtained during the processing of natural hydrocarbons — oil, gas. The result of the synthesis of these polysaccharides is a product with structure and properties corresponding to natural polysaccharides. Synthetic polymerization has made it possible to create analogues of natural polysaccharides such as cellulose, xylan, chitin, hyaluronan, and chondroitin, as well as unnatural polysaccharides such as a cellulose-chitin hybrid, a hyaluronan-chondroitin hybrid, and others [14]. Synthetic polysaccharides have very high rates of specific properties, do not support the development of microorganisms and can be very effective for the food industry, but their possible toxicity has not yet been fully studied, and the cost remains exorbitant.

In modern conditions, the use of natural polysaccharides in the food industry, in comparison with synthetic and semi-synthetic, is preferable due to the following advantages: economy; availability; biodegradability; biocompatibility; the ability to physical and chemical modifications; non-toxicity; environmental friendliness; public acceptance. On the other hand, the growing demand for processed foods and the increasing public awareness of the importance of fiber in food has increased the consumption of foods high in polysaccharides. However, natural polysaccharides also have a number of disadvantages associated with low efficiency (compared to semi-synthetic or synthetic) and sensitivity to microorganisms. With all these advantages and disadvantages, natural polysaccharides are gradually being replaced, and further will be replaced by semi-synthetic and synthetic ones.

According to the classification based on their chemical structure, the following main structural groups of food polysaccharides are distinguished [15]: galactomannans (guar gum, tara gum), glucans (starch, curdlan), fructans (inulin, levan), xylan, rhamnan, glucomannans (alginate, konjac), arabinoxylan (flaxseed gum), galactans (agar, carrageenan), arabinogalactan (gum arabic), galacturonans (pectin), glycano-rhamnogalacturonan, glycano-glycosaminoglycans, glucosamine polymers (chitin, chitosan).

The demand and supply for environmentally friendly food ingredients with natural technological (structuring, texturizing, stabilizing) and functional potentials is constantly growing. Plant seed mucilage, which is a polysaccharide hydrocolloid with a certain physicochemical and structural conformational diversity, provides a wide range of technological and functional aspects. The review [16] examines recent advances in the extraction of mucilage from plant seeds, their characteristics, and their use as alternative hydrocolloids for use in the food industry. It has been shown that food intake with mucilage from plant seeds through the oro-gastrointestinal pathway provides modulation of postprandial glycemic and insulinc responses, counteraction of hyperlipidemia, increased satiety, and regulation of the intestinal microbiota function. In addition to their important physiological role, plant seed mucilage has interesting technological, dietary, and functional properties comparable to common commercial polysaccharide hydrocolloids. Their physicochemical and structural diversification correlates with their technofunctionality, for example, gel formation, texturing, interfacial adsorption capacity, etc.

Microbial polysaccharides are released into the environment by numerous types of microorganisms in the course of their vital activity, and therefore they are collectively called exopolysac-
charides. Due to their unique structure and physical properties, exopolysaccharides are widely used as emulsifiers, stabilizers, thickeners, texturizers, film formers and gelling agents. The most commonly used exopolysaccharides are xanthan gum, gel- lan gum, dextran, and pullulan [17].

Exopolysaccharides produced by lactic acid bacteria are used as natural stabilizers in fermented milk products. Figure 5 shows a photograph illustrating the interaction of thermophilic strepto- tococci with casein micelles in yogurt and their release of exopolysaccharide (light clouds around bacteria). The ability of exopolysaccharides to regulate viscosity largely depends not only on their concentration, but also on their structure and ability to interact with other dairy components. The aim of the study [18] was to compare the effect of exopolysaccharides secreted by different strains of *Streptococcus thermophilus* on the formation of milk gel and rheological / physical properties (density, apparent viscosity, elastic modulus, syneresis) of the finished product. This work showed that gel formation and rheological / physical properties of fermented milk products are determined by the structural characteristics of exopolysaccharides, especially the magnitude of its negative charge, structural flexibility, degree of branching and molecular weight.

![Figure 5. Exopolysaccharide *Streptococcus thermophilus* during milk gel formation](image)

According to the main purpose of use, polysaccharides can be conditionally classified [19, 20, 21] into the following groups:

- Stabilizers that maintain a uniform dispersion of two or more immiscible components in a product;
- Thickeners that increase the texture of the product;
- Emulsifiers that ensure the stability of dispersed systems with different phases such as oil/water or water/oil;
- Gelling agents that cross-link the components of the original dispersed food systems into a single structure with high water retention;
- Texturators that provide solid food products with a given texture;
- Sensitizers that improve the organoleptic properties of products;
- Functional polysaccharides, which serve as biologically active food additives to improve the condition of the human body;
- Technological polysaccharides serving to improve the efficiency of food production.

However, some polysaccharides can simultaneously perform different functions or perform different functions under different conditions of use.

2.5. *Protein-polysaccharide interactions*

 Proteins and polysaccharides are found in many complex multiphase food systems. Considering the fact that in the production of dairy products together with milk proteins, vegetable proteins can be used, the number of varieties of which is quite large, as well as various polysaccharides, the number of which is even greater, the number of paired, triple and more combinations of them is simply immeasurable. Despite the obvious difficulty of describing protein-polysaccharide interactions in such food systems, leading scientists in many countries are actively involved in this problem. Thus, work [22] provides an overview of the types and nature of interactions that can occur between milk proteins and polysaccharide molecules. The extensive research carried out over the past decades describing various protein-polysaccharide interactions and their effect on the structure and functionality of products is discussed.

The review [23] reports on some of the latest advances in this field, demonstrates interesting physicochemical properties of protein-polysaccharide conjugates as stabilizers and emulsi- fiers, as well as texture modifiers in food products. It also provides an overview of possible interactions between protein and polysaccharide, from the Maillard reaction to enzymatic cross-linking passing through coacervates.

Interactions of casein with various polysaccharides are considered in detail in the review work [24]. It is noted that, in general, these interactions can be associative or segregating. There are two main types of interaction between polysaccharides and proteins: strong association — irreversible binding of proteins with polysaccharides or strong electrostatic complexes; weak as- sociation — potentially reversible binding involving non-ionic and weak electrostatic complexes. Electrostatic interactions of proteins with charged sites of polysaccharides play a dominant role. Strongly interacting electrostatic complexes usually form between positively charged proteins and anionic polysaccharides. Weak reversible complexes can form between anionic polysaccha- rides and proteins that carry almost zero total charge or total negative charge. The distribution and type of charges on the surface of casein micelles create a repulsive barrier that contributes to the stability of the micelles in suspension. This means that if the repulsive and steric stabilizer layer is damaged or destroyed, van der Waals interactions appear and primary aggregation of casein micelles occurs. The polysaccharide macromolecules adsorbed in this process stabilize the dispersed system through steric and electrostatic interactions. The photograph in Figure 6 illustrates the nanostructure of casein-polysaccharide gel.

![Figure 6. Nanostructure of casein-polysaccharide gel of a dairy product](image)
The aim of the study [25] was to determine the effect of bacterial exopolysaccharide on the milk gel formation. It was determined that the result of the interaction between casein micelles and exopolysaccharide appears in the form of an integral polysaccharide-protein network structure, in which casein micelles were interconnected by exopolysaccharide. The results obtained showed that exopolysaccharides could be used to increase the density of milk gel.

In a study [26], based on the analysis of interfaceal adsorption and the microstructure of complexes observed at the air-water interface, it was demonstrated that the intramolecular electrostatic protein-polysaccharide complex, with appropriate stoichiometry, can potentially act as an effective foaming agent in the food industry.

The review [27] outlines the current understanding of the nature of the interaction of casein and pectin at the molecular level in various contexts, that is, acidified milk drinks, oil-in-water emulsions, solid particles, and other colloidal systems. Influencing factors are considered, including pH, ionic strength, concentrations of two biopolymers, processing factors, and others. In addition, current and potential nutritional and pharmaceutical applications of some selected colloidal systems are discussed with illustrative examples. Understanding the mechanisms of casein-pectin interaction makes it possible to develop individual food systems that are of great use for increasing the stability of dairy drinks, encapsulation and protection, as well as for the controlled release of biologically active compounds.

The aim of the study [28] was to assess the ability of biopolymer complexes consisting of whey protein isolate and pectin to form and stabilize nanoemulsions with an interfacial structure. It has been shown that protein-polysaccharide complexes can be formed as a result of electrostatic interactions and can be useful for increasing the stability of nanoemulsions containing short-chain alkanes, which are subject to destabilization upon Ostwald maturation.

In [29], the influence of the acidity of the medium on the formation of stable complexes has been reviewed. It was shown that covalent and non-covalent (mainly electrostatic and hydrophobic) interactions contributed to the formation of stable complexes between caseins and polysaccharides, preventing precipitation near the isoelectric point of pH 4.5.

Biopolymer complexes formed by proteins and polysaccharides may have some specific or innovative functionality. However, little is known about the structural characteristics and mechanisms of molecular interaction of protein-polysaccharide biopolymer complexes. Understanding these interactions is of great interest for the development of new biopolymer complexes. In [30], the structural characteristics and mechanisms of the molecular interaction of lactoferrin and β-glucan were studied. It has been shown that the binding between lactoferrin and β-glucan at 25 °C is a spontaneous process, and electrostatic interactions, hydrogen bonds, and van der Waals interactions promote self-assembly. Self-assembly of lactoferrin-β-glucan provided the formation of physically cross-linked networks at a low concentration of β-glucan, while spherical complexes were formed at its high concentration.

The results of studies [31] have shown that the physical state of whey protein molecules (i.e., native or hydrolyzed) has a significant effect on the rate and degree of protein-polysaccharide conjugation. Low levels of hydrolysis of whey protein molecules resulted in an increase in the rate and extent of their conjugation to polysaccharides with limited associated and improved Maillard reaction products. Native and hydrolyzed solutions of the whey protein-polysaccharide conjugate had increased protein solubility and thermal stability of the solution. It is noted that the conjugation of proteins with polysaccharides represents a potential method for increasing the functionality of hydrolyzed whey proteins in food products.

The review [32] describes in detail the current trends in the creation of functional milk drinks with the addition of plant-based polysaccharides. These include drinks based on whole milk and cream, dairy by-products (whey, butter milk), and fermented milk drinks with probiotic cultures (kefir, yogurt, etc.). Functional drinks include health-promoting ingredients including polysaccharides of various origins in excess of the normal nutritional value of the product. The use of such polysaccharide additives as gellan gum, carboxymethyl cellulose, various types of carrageenan and pectin, as well as a number of others in dairy products, has significantly expanded the range of milk-based drinks [33, 34].

The project [35] investigated the effect of methoxylpectin, carboxymethylcellulose, and their mixtures on the stability of acidified beverages from skim and whole milk. The stability and physical properties of acid-induced skim and whole milk have been shown to be markedly transformed in the presence of these polysaccharides. The stability of the drinks improved with increasing amounts of methoxylpectin in the polysaccharide ratio, which underscores the importance of the molecular properties of this polysaccharide. The combination of these polysaccharides has been found to be better suited for stabilizing high-fat milk drinks.

Several studies [36] show that antioxidant effects are the result of a complexation reaction between phenolic compounds and milk proteins after ingestion. The main goal of the study in [37] was to determine the antioxidant and antigenotoxic effect of dairy products, milk and yoghurt after adding 2% of Korean red ginseng extract to them. This study shows that supplementing with red ginseng extract can provide enhanced antioxidant and antigenotoxic effects in dairy products and provide a new functional value-added dairy product to the market.

The work [38] provides an overview of modern knowledge about various polysaccharides of seaweed, their structural compositions, biological activity, and possible nutraceutical applications in food. It has been shown that biologically active components of seaweed polysaccharides have various useful properties, including anticoagulant, anti-inflammatory, antioxidant, anticarcinogenic and antiviral activity and can be successfully used in the development of new food products.

Protein-polysaccharide interactions were in the center of attention of scientists during research, the results of which are presented in [39]. This study aims to improve the antioxidant and hepatoprotective effects of milk proteins and whey protein hydrolyzate through non-covalent interactions with Psyllium husk plant mucilage (ispaghula) and Naqab mucilage. The chemical composition, phenolic content and antioxidant activity of milk-protein complexes were studied. The effect of the obtained complexes on liver function, hyperlipidemia and liver histopathology was also investigated. The results showed that the obtained protein-polysaccharide complexes had a significant effect on the normalization of the tested parameters.

The main purpose of the study [40] was to evaluate the physicochemical, rheological and organoleptic properties of ultrafiltered low-fat cheese, when adding various polysaccharides to it. It has been shown that the introduction of galactomannan and novagel into the composition of low-fat (8%) cheese in a concentration (0.1–0.5%) allows obtaining cheese with a texture and organoleptic properties very close to fatty cheeses.

2.6. Probiotics and prebiotics

Research work [41] reports on the prebiotic and antibiofilm potential of proteins and polysaccharides extracted in water from legumes, in particular from red beans (Phaseolus

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2.7. Nanotechnology in manufacturing

Despite the seeming simplicity of creating protein-poly saccharide compositions in food, in reality, all changes in food systems initially occur at the molecular and supramolecular levels. In this case, new nanoparticles, nanofibers, nanostructures, nanocapsules, etc. with specific properties can be formed. Micro- and macrostructures are subsequently formed from these nano-objects, which are subsequently perceived organoleptically. Thus, the properties of food are laid down at the nanoscale, and they are manifested at the macrolevel. Therefore, the research of interactions of components in food systems at the nanoscale is currently receiving much attention [46,47].

Among potential nanoparticle systems for the food industry, core-shell nanoparticles based on biopolymers are of particular interest. This interest is mainly due to their unique physical properties, including self-assembly, interfacial properties, binding capacity, as well as their high biocompatibility. In [48], various types of core-shell nanoparticles, modern methods of production, and their use as delivery systems for small molecules, proteins, and nucleic acids were considered. The main problems of their use in the food industry were also identified.

The electron microscope photograph in Figure 7 illustrates the nanostructure of the emulsion shell of a fat globule in the production of a dairy product.

The research results presented in [49] showed that nanoparticles of the ternary complex of soluble curcumin, casein, and soy polysaccharide obtained in the aqueous phase had polysaccharide surfaces, which ensured their hydrophilicity and good solubility. FTIR spectra have shown that hydrogen bonds, hydrophobic and electrostatic interactions provide the formation of ternary complex nanoparticles.

In addition, nanoparticles of the ternary complex were developed and investigated in [50]. Here, a chitosan-caseinate-dextran complex has been obtained through a Schiff base reaction, which has promising properties as a delivery vehicle for oral use of lipophilic bioactive substances. In particular, it is reported that the activity of encapsulated astaxanthin, which is a potential therapeutic agent for the treatment of liver fibrosis, has been significantly improved.

2.8. Dietary fiber

The greatest positive effect on human health can be achieved when using symbiotic substances (prebiotics) in food products, which stimulate the growth and activity of microorganisms (probiotics) and improve their adhesion to the walls of the gastrointestinal tract. These properties are common to non-hydrolyzable plant oligo- and polysaccharides such as pectin, inulin, fructooligosaccharides, xylo-oligosaccharides, and starch [51,52]. Dietary fibers of various origins have different physiological effects depending on the chemical composition and microstructure. This leads to the search for new sources of raw materials and a well-defined process for their use to preserve the target functional properties of the final product. Dietary fiber lowers postprandial serum glucose levels in at least three ways. Firstly, dietary fiber increases the viscosity of the juice of the small intestine and prevents the diffusion of glucose; secondly, they bind glucose and reduce the concentration of available glucose in the small intestine; and thirdly, they slow down the action of α-amylase by encapsulating the starch and the enzyme, and can directly inhibit the enzyme.

The photograph in Figure 8 illustrates the nanostructure of dietary fiber in an innovative dairy product.

Work [53] examines current knowledge about the health effects of dietary fiber, prebiotics and dairy products. The beneficial effects of certain dietary fiber on human health — on defecation, lowering postprandial glycemic response, and maintaining normal blood cholesterol levels — are generally accepted, but other probable health benefits of dietary fiber are still debated. Although the concept of prebiotics has evolved significantly over the past two decades, the line between prebiotics and non-probiotic dietary fiber remains unclear.

Studies of the influence of processing technology of dietary fibers on their properties, the results of which are given in [54], showed that the structural modification of fibers that occurs dur-
2.9. Technological applications

The results of studies of the interaction of casein micelles with κ-carrageenan and λ-carrageenan, carried out using scanning electron microscopy [58], showed that the ability of κ-carrageenan to form gel, in contrast to λ-carrageenan, is explained by the ability of κ-carrageenan to form larger aggregates at a similar concentration of carrageenan. This is achieved by the formation of κ-carrageenan strands, to which casein micelles are attached, which is not observed for λ-carrageenan. It is also suggested that part of the product structure arises from the unfolding of casein micelles upon dehydration.

The effect of κ-carrageenan on acid-induced gelation of whey proteins was studied in [59], where the effect of adding κ-carrageenan on the relationship between the total charge density of proteins and pH was determined and it was shown that an increase in the gelation temperature leads to an increase in its elastic modulus.

Four polysaccharides of plant origin — okra polysaccharide, apple pectin, sodium alginate and konjac glucomannan — were studied in yoghurt to study their effect on gelation characteristics [60]. The results showed that okra polysaccharide, konjac glucomannan and apple pectin increased the water holding capacity, density and elasticity of yoghurt, while sodium alginate showed opposite effects. Research has also shown that the addition of okra polysaccharide and apple pectin reduces the porous structure of the gel and promotes the formation of larger protein clusters, ultimately resulting in a more compact protein network.

The work [61] was devoted to the assessment of the microstructural, rheological, and textural state of aqueous mixtures of sodium caseinate and gum container and their acid gels. Acid gels with different microstructure and texture were obtained, depending on the concentration ratio of both biopolymers, either a continuous network of a protein gel or a water-in-water emulsion was observed.

Rheological and microscopic studies of the stabilizing effect of pullulan on the structure of yoghurt were carried out in [62]. Molecules of salecan, a linear, negatively charged polysaccharide representing (1 → 3)-β-D-glucan, formed an additional string structure in yogurt that anchors casein micelles. The new structure provided yoghurt with increased stability, improved rheological properties. The effect of pullulan on the physicochemical properties of yoghurt was investigated in [63]. It was determined that yoghurt with 1% of pullulan has a weakened milk gel structure, with a reduced initial viscosity and increased syneresis compared to the control. The addition of 2% of pullulan significantly improves product stability by increasing gel strength, higher viscosity, and reduced syneresis. This study demonstrated that the physicochemical properties of yoghurt are largely determined by the concentration of pullulan in yoghurt.

In an experimental study [64], a soluble fraction of polysaccharides was isolated from the fungal fruit of Pleurotus ostreatus mushrooms (oyster mushroom), which was used to stabilize a casein-glucanate matrix of kefir with a low lactose content. Research has shown that the soluble fraction of polysaccharides added to milk before fermentation affects the texture of the finished kefir, organoleptically improving its texture.

The aim of the study in [65] was to evaluate the properties of yoghurt powder obtained by drying in a drying cabinet; carrageenan was added to the yoghurt at the initial stage as a stabilizer. It was shown that the optimal concentration of carrageenan was 2%, while the resulting yoghurt powder had the highest bulk density and the best granulometric texture. The water activity in the resulting product was rather low, which ensured a long shelf life. Better recovery of the yoghurt was achieved using warm water, resulting in a stable product with no visible phase separation.

2.10. Whey protein binding

The study of the mechanism of interaction between whey proteins and polysaccharides is the subject of work [66]. The structure-function relationship was determined for mixtures of basil gum and whey protein isolate at the beginning of the formation of a soluble complex, the formation of the most soluble complex and the prevailing thermodynamic incompatibility. Regardless of the ratio of the components in the mixture, all dispersions showed the maximum interaction at pH = 5.0, the beginning of the formation of a soluble complex near pH = 6.0, and the behavior of the interaction of thermodynamic incompatibility at pH = 7.0. Cole-Cole
2.11. Packaging

Proteins and polysaccharides, as well as their compositions, can be used to not only create new dairy products or improve their properties, but also to increase the efficiency of technological processes for their production and storage. For example, the review [73] considers the creation of packaging materials for food products, their mechanical and thermal stability, biodegradability, non-toxicity, and antibacterial activity when using biocomposites of various proteins and polysaccharides. It is noted that along with the positive properties of polysaccharides, such as chitosan, carboxymethylcellulose, starch and cellophane, in relation to packaging materials, polysaccharides have some deficiencies, for example, poor mechanical properties and low water resistance. It has been shown that these deficiencies can be eliminated in the development of biocomposites based on polysaccharides. An article [74] is also devoted to a review of current advances in research and development of protein-based biocomposites for use in food packaging. The interest in protein-based biocomposites is due to their stability, renewability, biodegradability, and low carbon footprint. The inherent deficiencies of protein-based materials for food packaging are their low mechanical strength, poor thermal, barrier, and low physicochemical properties. Biocomposites based on the combined basis of proteins and polysaccharides provide an opportunity to overcome these problems and can displace non-biodegradable plastic for food packaging made from petroleum resources.

In [75], it is noted that replacing existing plastics with modern packaging materials obtained from non-renewable sources requires the creation of new environmentally friendly biopolymers. Natural products such as protein-containing waste from dairy plants have significant potential for bioplastics. Rich in casein and whey proteins, material collected from dairy wastewater using a flotation method is self-associating and has the potential to form bioplastics, but produces brittle films. The use of additional biopolymers such as polysaccharides to form composites with these proteins has the potential to improve the physical properties of such films.

2.12. Manufacturing applications

Industrial wastewater from dairy plants contains a variety of valuable residual materials, including lactose, milk fat, phospholipids, and milk proteins. It is clear that there are economic, environmental and social benefits to the efficient recovery of these materials from dairy wastewater. Since the volume of this wastewater discharge is enormous and the concentration of materials is low, isoelectric precipitation, salting out and ion exchange adsorption are not cost effective. Work [76] demonstrates the promise of using the flotation method for the extraction of casein from wastewater generated during milk processing. It has been shown that the best results are obtained by using xanthan gum as a foam stabilizer based on the association between a protein and a polysaccharide. Electrostatic interactions between protein and polysaccharide, which is significantly dependent on pH, provide a close relationship between them and have a noticeable effect on surface tension, foaming, foam stability, zeta potential and average particle size of the dispersion. The level of extraction of casein from dairy wastewater using the flotation process reached 86 percent in the experiment.

3. Conclusion

The interaction of milk proteins with polysaccharides of various origins and possessing a wide variety of properties, as well as the use of non-dairy proteins in the production of dairy products, has recently attracted the attention of researchers in many countries of the world. The nature of protein-polysaccharide interactions, depending on the proteins and polysaccharides used in various combinations and the conditions of their interactions can be completely different. Therefore, despite the different
goals pursued by researchers, ultimately all research is aimed at finding basic patterns in these interactions.

Knowledge of the basic patterns of protein-polysaccharide interactions makes it possible to simplify the achievement of the following main goals in food production:
- obtaining balanced food products for functional purposes;
- involvement in the production of new raw food materials;
- improving the quality of products;
- increasing the shelf life of products;
- increasing the efficiency of production processes;
- reduction of production waste;
- creation of biodegradable non-toxic packaging materials.

Modern studies of protein-polysaccharide interactions are based on the use of high-tech analytical equipment, such as electron and confocal microscopy, spectrometry of various types, etc. As these studies have shown, the physicochemical and, accordingly, organoleptic properties of food products are laid down at the nanoscale, and are already manifested at the macro level at the consumer.

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