CHAPTER 10

FUNCTIONAL HEALTH PRODUCTS BASED ON POLYSACCHARIDES

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INTRODUCTION

In the conditions of the modern market, the production of high-quality, cost-effective, competitive products is simply impossible without the use of advanced technologies and innovative solutions in the field of providing people with food. Innovations in the field of food technologies are subordinated to the search for ways and means that ensure economic production and guarantee maximum safety and quality of food products, including nutritional value, organoleptic properties, as well as properties that determine health benefits, the totality of which directly depends on the ingredient composition of the food product. Priority areas of innovation in the field of food production are the development of promising methods of production, storage, transportation and processing of products; the formation of mechanisms for the rational use of raw materials; the development of new types of high-quality food products; improving methods of promoting consumer products. Intensification of scientific research and the accumulation of extensive practical material contribute to the deepening of theoretical knowledge on innovations and the improvement of modern technologies. The development of new technologies in the food industry and the creation of a wide range of qualitatively new products with a targeted change in chemical composition and properties is an important direction of modern nutriscience, contributing to the preservation of the population's health. The development of research in the field of nutrition, the development of new technologies contribute to the expansion of the range of products, stimulate the search for new sources of food raw materials. The production of food products for the prevention of common alimentary, i.e., food-related, diseases is relevant. In addition, solving the problem of preserving the health and longevity of the population correlates with the provision of adequate biologically complete nutrition for all age and social groups. An important condition for the implementation of state projects in this area is the production of special food products on modern equipment using ingredients of both dairy and non-dairy origin that satisfy the physiological needs of the human body in substances and energy and perform various functions. High-quality nutrition is one of the main factors in ensuring human health. Consumers are beginning to pay more and more attention to functional food products, that is, their ability to reduce the threat of human disease with the most common diseases of civilization – diabetes, cardiovascular, allergies, gastrointestinal. The creation of fundamentally new technologies, deep complex processing of raw materials into high-quality products that have a health-improving effect on the human body, provide prevention of nutritionally dependent conditions and diseases, contribute to the elimination of deficiencies of proteins, vitamins, micro- and macroelements, and other essential substances can be considered a priority problem. These requirements are met by products with functional ingredients, biologically active additives, and other groups. With the help of food combinatorics, it is possible to weaken the negative environmental influences by designing and constructing food products that are not only safe for humans, but also those that protect their genetic structures. One of the effective measures of diet correction and prevention is the use of modern dairy products, in particular, for mass consumption with a changed composition, but traditional taste. Such products provide additional health benefits due to their balanced and enriched composition. compliance with the norms of daily nutrient intake.

1. Main polysaccharides and their use in the food industry

Starch is the final product of carbon assimilation by plants, their reserve nutrient. It is used in cooking, for the manufacture of confectionery, certain types of sausages, concentrates, in everyday life, in the food, pharmaceutical, textile, paper, leather and other industries. Various types of modified starch, sago, molasses, glucose, glucose-fructose syrup are obtained from starch. Global production of starch and starch products has doubled over the past decade and now amounts to about 60 million tons, including 36 million tons in the USA and 9 million tons in the European Union, 45 million tons are produced from corn, 5 million tons from tapioca, 4 million tons from wheat, and about 2.5 million tons from potatoes. In plants, starch is contained in the form of microscopic grains of a crystalline structure of various sizes and structures, depending on their type. Important technological properties of starch are the ability to gelatinize and form gelatin. Potato starch forms transparent pastes of high viscosity. It is used in starch-molasses production, for the manufacture of jelly, some types of sausage and confectionery products, for thickening soups, sauces, gravy, etc. The quality and yield of starch are affected by operations such as cleaning and washing potatoes, grinding them, separating cell juice and pulp, refining starch milk, removing sand, washing starch, separating starch from milk, drying, sieving and packaging. Raw starch with a moisture content of about 50% is used to produce dry starch, molasses, and other starch products. The residual moisture content after drying should be 17–20%, which corresponds to a relative humidity of 65–75%. Underdried starch is poorly stored. Corn starch – forms pastes of low viscosity, low transparency, but stable during mixing, heat exposure and storage. Therefore, it is used in canning, for making puddings, sauces, pie fillings, as well as to weaken the action of gluten and give greater tenderness to bakery and flour confectionery products. The yield and quality of starch depend on the following operations: soaking the grain, coarse wet grinding, separation of the germ, fine wet grinding of the pulp, separation of free starch from the pulp and refining of the starch suspension, separation of starch and protein, washing on vacuum filters and drying. Coarse wet grinding makes it possible to isolate a valuable component – the germ, from which corn oil is obtained after cleaning and drying. Wheat starch. Wheat starch grains have a round or elliptical shape, mainly large (25–35 microns) and small (2–10 microns) sizes. In the center of large grains, a "eye" is barely visible. The formation of cracks in starch grains during wheat grinding is due to excessive compression, therefore it is considered advisable to use corrugated rolls. This starch forms low-viscosity pastes, more transparent compared to corn starch pastes. At high concentrations, its pastes form elastic jellies after cooling. Requirements for starch quality. Commercial starch contains various impurities of organic and mineral origin, which affect its quality, grade, price and use. Potato starch − is divided into the following grades by quality: extra, higher, 1st and 2nd; Corn − into higher and 1st; Wheat – into extra, higher and 1st. Potato starch varieties are distinguished by color: extra and superior varieties should be white with a crystalline sheen, 1st – white and 2nd – white with a grayish tint. Large starch grains reflect light better and therefore have a more pronounced shine. Corn and wheat starch of all varieties should be white, but a yellowish tint is allowed. Starch has a faint odor due to the presence of volatile substances, mainly essential oil. Potato starch smells stronger than corn. Starch should not have an off-odor that occurs due to violation of transportation or storage conditions, as well as spoilage. In appearance, starch should be in the form of homogeneous powder particles, without grains, side impurities that impair its quality. The humidity of grain types of starch is normally up to 13%, and amylopectin – up to 16%. In case of violation of transportation and storage conditions, it can increase, and this contributes to microbiological spoilage of the product. A very important indicator of starch quality is the number of specks, i.e. dark inclusions, which are visually visible on the leveled surface of the starch. It is limited and depends on the grade and type of starch, pcs. per 1 dm^3: potato grade extra – 60, higher – 280, 1st – 700; corn higher – 300;

1st – 500; wheat extra – 280, higher – 550; 1st – 750. The maximum ash content of potato starch grade extra – 0.3%, 2nd – 1, corn higher – 0.2, 1st – 0.3%. Store starch in clean, dry, well-ventilated warehouses, free from foreign odors and free from pests. The optimum storage temperature is considered to be 70% relative humidity, although it is permissible to up to 75%, and a temperature of about 100°C. Under these conditions, the standards provide for the storage of potato and corn starch for 2 years, and wheat starch for 1 year. Longer storage significantly reduces the ability of starch to gelatinize. In rooms with increased relative humidity, it becomes humid, and as a result of microbiological processes and spoilage, it acquires first a sour, musty, and then a putrid odor.

Modified types of food starch – are mainly obtained using the following chemical treatment methods, as well as their combinations: esterification with acetic and succinic anhydrides, a mixture of acetic and adipic anhydrides, octynylic anhydride, phosphoryl chloride, trimethophosphate and sodium tripolyphosphate, as well as odono-substituted sodium orthophosphate with the formation of ester derivatives; esterification with propylene oxide, with the formation of simple esters, acid modification of hydrochloric and sulfuric acids, with the formation of hydrolyzed products; bleaching with hydrogen peroxide, peracetic acid, potassium permanganate and sodium hypochloride; oxidation with sodium hypochloride. Types of swelling starch. These include such types of modified starches that can be partially or completely dissolved in cold water (instant starch). The basis for obtaining such types of starch are physical transformations that do not cause significant destruction of starch molecules. They are obtained by drying starch suspension in a spray or roller dryer at a temperature exceeding the starch gelatinization temperature. As a result of heat treatment, the structure of starch grains is partially or completely destroyed. Extruded starch – by its properties, belongs to the group of those that swell, and by the processing method – to starch that is subject to moisture-heat treatment at a temperature above the gelatinization temperature. As a result of the loss of free and partially bound moisture, the processed product acquires a secondary structure, becomes brittle, swells in contact with water and partially dissolves in it. Extrusion is carried out on extrusion plants, in which it is premoistened to 34%, subjected to compression, heating to 200°C and intense mechanical action. As a result, starch gelatinization occurs. Types of swelling starch are used in the technology of various desserts, jelly marmalade, butter dough containing berries, and instant starch is used for quick-cooking puddings. Split types of starch are obtained by treatment with acids, sometimes in combination with oxidants and separately with enzymes. An example is hydrolyzed types of starch. They are obtained by treatment of starch suspensions, solutions of acids or hydrolytic enzymes – amylases. Depending on the conditions of hydrolysis, the corresponding properties of starch are formed. For example, starch treated with acids at elevated temperatures is capable of forming low-viscosity pastes; solutions of hydrochloric or sulfuric acids are more often used at a suspension temperature below the starch gelatinization temperature. These types of starch are used for the production of marmalade and pastille products, jellies, and chewing gums. Gelling starch – obtained by oxidizing starch grains with potassium permanganate in an acidic environment. The purified starch suspension with a dry matter concentration of 35% is oxidized for 30 min with potassium permanganate (0.15–0.20% to dry matter of starch) in the presence of hydrochloric acid. Then the mixture is washed, thickened, dehydrated, dried and packaged. Starch phosphate is a complex ester of starch and residues of phosphoric acid or its salts. It differs from ordinary starch in the increased ultimate viscosity of pastes, their greater stability to mechanical action and acidity of the medium, as well as to high and low temperatures. It is used to thicken canned meat, as a stabilizer of dietary mayonnaises with a reduced fat content, fatty creams, sauces, jelly, quick-frozen foods, to improve the quality of bread, cookies, and wafers. The color of phosphate starch of grade A is from white to white with a yellowish tint, grade B is from cream to fawn. Acetylated types of starch are obtained by heating a mixture of 25–100 parts of glacial acetic acid and 100 parts of starch and keeping it at a temperature of 100°C for 5–13 hours. The hydroxyl groups of the glucose residue form ether bonds with acetic acid residues. As a result, the content of acetyl groups in starch is 3–6%, depending on the dosage of acid and the duration of treatment. At the maximum degree of acetylation, three hydroxyl groups of each glucose residue form ether bonds with acetic acid residues. Excess acid is removed by washing the starch with cold water. Simultaneously with acetylation, starch is also cleaved. Such starch is well soluble at a temperature of 95–100°C. Molasses is a product of incomplete hydrolysis of starch by diluted acids or amylolytic enzymes, which forms a syrupy, thick, viscous, colorless or slightly yellowish, transparent liquid with a sweet taste. Due to its anti-crystallization and hygroscopic properties, it is widely used for the production of caramel, halva, jam, many types of candies, gingerbread, liqueurs, some types of bakery products, etc. Molasses dextrins increase the viscosity of sugar syrup and slow down the crystallization of sucrose, and reducing sugars, due to their hygroscopic properties, contribute to the appropriate preservation of moisture. Caramel molasses – can be low-sugar, higher and 1st grades. They are distinguished by the content of reducing substances, as well as the temperature of the caramel sample, mass fraction of ash and acidity. High-sugar glucose syrup contains 44–60% reducing sugars in terms of dry matter and is used to make jams, jellies, pastilles, and baked goods. Dextrin (maltose syrup) is a component of liquid and dry infant formulas. Maltose syrup contains at least 65% reducing sugars (in terms of maltose) and has a brown color and a sweet malt flavor. It is used to prepare sweet dishes, baby formulas, gingerbread, some types of baked goods, and in diet foods. Maltodextrins are low-sugar starch hydrolysates that contain 5 to 25% reducing substances. They are used to produce baby products, as fillers for puddings, confectionery, and artificial cream. Glucose is the final product of starch hydrolysis. Crystalline and food-grade glucose are used for the production of food products. Crystalline glucose is produced in the form of a white crystalline powder that passes through a sieve with holes with a diameter of 1.5 mm. It should have a sweet taste and be without an aftertaste. Its humidity should not exceed 9%; the content of reducing substances in terms of dry matter is 99.5%. Shelf life is 1 year. Food-grade glucose is prepared without isolating intercrystalline liquid. It is used for the production of confectionery, soft drinks, ice cream, etc. Glucose-fructose syrup is prepared from high-quality starch through saccharification and isomerization of glucose. Under conditions of chemical equilibrium, it is impossible to isomerize more than 50% of glucose in solution into fructose. Therefore, about 42% of fructose (on dry matter of SR) accumulates in the isomerized syrup. The finished syrup contains 71% dry matter and has a sweetness close to sucrose. It is used instead of sucrose in drinks, for canning fruits and vegetables, in the production of some types of confectionery and bakery products, ice cream, condensed milk, etc. [1, 2].

2. Use of polysaccharides as functional additives

Polysaccharides (polyoses) are natural polymers built from a large number of residues of monosaccharide molecules and their derivatives. According to the monosaccharide composition, polysaccharides are divided into homopolysaccharides, or homoglycans, which consist of residues of monooses of the same type, and heteropolysaccharides, or heteroglycans, the molecules of which contain residues of different monosaccharides. Polysaccharides also differ in molecular weight and molecular structure. By the nature of the polyglycoside chain, they can be linear and branched.

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Polysaccharides, which are an integral part of many food products, can have different names depending on their purpose, economic considerations and trends: hydrocolloids, carbohydrates, dietary fibers (both natural and modified), stabilizers, emulsifiers, gelling agents and thickeners, gums, fat substitutes or imitators. At the same time, according to current regulatory documents, product labeling should reflect not only the total carbohydrate content, but also the polysaccharide content separately, since the presence of the latter increases the benefits of the product and, accordingly, affects its added value. Food polysaccharides can be considered as multifunctional food additives, the main areas of application of which are: 1) emulsification, stabilization, gelation, thickening; 2) replacement or imitation of milk fat; 3) increasing the nutritional value of the product by increasing the content of dietary fiber. Thus, each food polysaccharide can simultaneously perform several functions. For example, carboxymethylcellulose in dairy products acts simultaneously as an emulsifier, stabilizer, dietary fiber and fat substitute, since it is a surfactant and causes the dispersion of incompatible phases (fat and water), maintains the resulting emulsion structure in a stable state, is not digested in the human gastrointestinal tract, thus reducing calorie content, and gives a pleasant consistency to the product with a reduced fat content. Whatever function food polysaccharides perform in the finished product, they can be classified by chemical structure (composition of monomer units, their substituents, diversity and location of these units in the polymer chain), see Figure 1.

Polymers consisting of monomers of the same structure are referred to as homopolysaccharides, and those that have different monomers in their composition are referred to as heteropolysaccharides. Depending on the structure of the monomer units, homopolysaccharides are divided into glucans, fructans, galactans, arabinans, xylans, mannans and polyuronides. Stabilizers, emulsifiers, gelling agents and thickeners. Polysaccharide food additives, which according to the EU classification have received numbers E400–E499, are divided into four functional groups:

stabilizers, emulsifiers, gelling agents and thickeners. Emulsifiers contribute to obtaining a homogeneous dispersion of two mutually insoluble liquids, one of which is evenly distributed in the second in the form of the smallest droplets, and stabilizers maintain such a system in an equilibrium state. Gelling agents give the product a gel structure, while thickeners increase the viscosity of the food product. In practice, it is difficult to differentiate emulsifiers and stabilizers, since most food polysaccharides perform several functions simultaneously depending on pH, ionic strength,

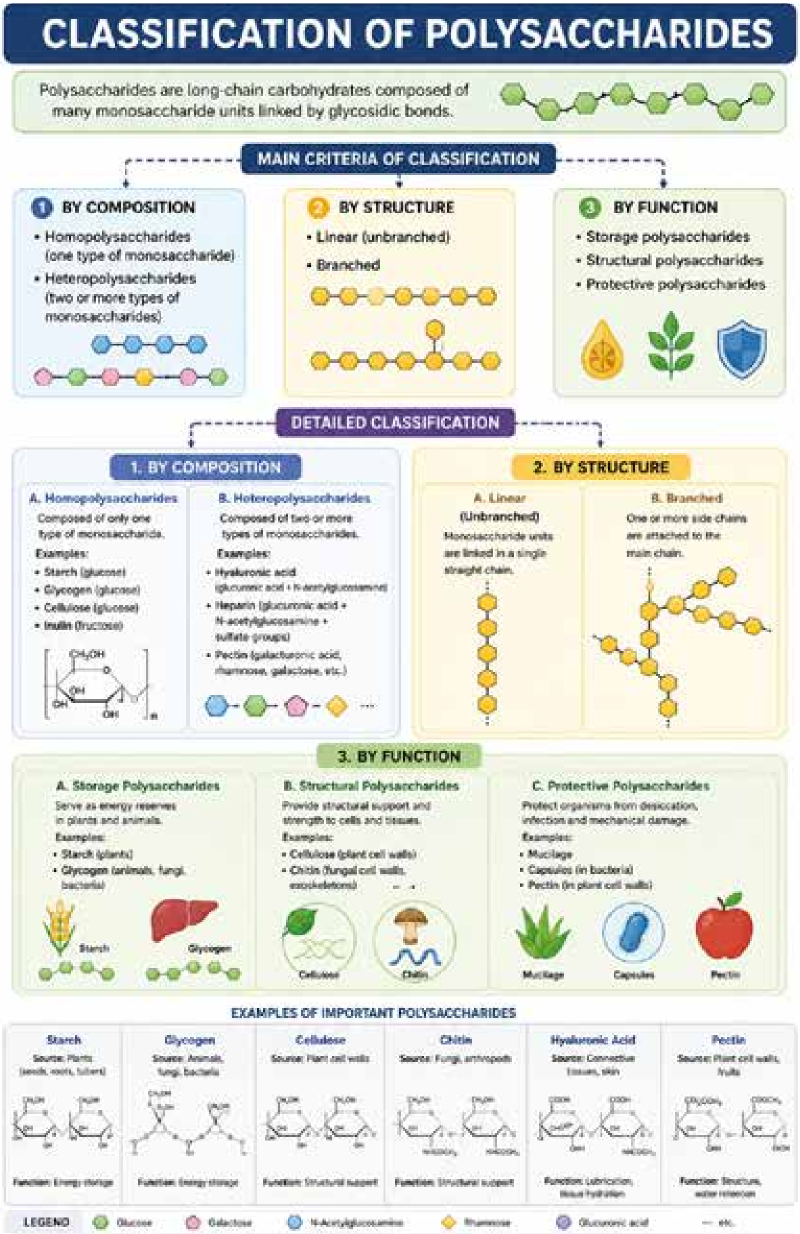

Fig. 1. Classification of polysaccharides

concentration and the presence of other compounds[3]. The nature of the interaction of the water-protein-polysaccharide components depends on factors such as the concentration of the mixture components, pH and ionic strength. Thickeners and gelling agents are, by their chemical nature, linear or branched polymer chains with hydrophilic groups that enter into physical interaction with the water present in the product. With the exception of polysaccharides of bacterial (xanthan gum E 415 and gellan gum E 418) and animal origin (gelatin), thickeners and gelling agents are carbohydrates (polysaccharides) of plant origin or plant hydrocolloids. They are obtained from terrestrial plants or algae. Alginic acid E 400 and its salts E 401...404 are obtained from brown algae. The most popular gelling agents – agar (agar-agar) E 406 and carrageenan (including furcelleran) E 407 − are obtained from red seaweed, and pectin E 440 – most often from apples and citrus fruits. Plant polysaccharides, according to the functions they perform in the plant body, are divided into protective colloids secreted by the plant when damaged (exudates, resins), and reserve polysaccharides that accumulate in seeds. The resins include: arabinogalactan E 409, tragacanth E 413, gum arabic E 414, karaya gum E 416, ghatti gum E 419. The reserve polysaccharides include locust bean gum E 410, oat gum E 411, guar gum E 412 and tara gum E 417. According to their chemical structure, hydrocolloids are divided into three groups: acidic polysaccharides with uronic acid residues, acidic polysaccharides with sulfuric acid residues and neutral polysaccharides. Acidic hydrocolloids with uronic acid residues (for example, tragacanth E 413 and gum arabic E 414) and neutral compounds (for example, locust bean gum E 410 and guar E 412) are used as thickeners. Acidic polysaccharides with sulfuric acid residues are used as gelling agents (for example, agar E 406 and carrageenan E 407).

3. The effect of polysaccharide modification on their properties

The properties of thickeners, especially neutral polysaccharides, can be changed by physical (e.g., thermal) treatment or by chemical modification (e.g., by introducing neutral or ionic substituents into the molecule). By chemical or physical modification of starch, it is possible to achieve: a decrease or increase in the temperature of paste formation; a decrease or increase in the viscosity of the paste; an increase in solubility in cold water; the appearance of emulsifying properties; a decrease in the tendency to retrogradation; resistance to syneresis, the action of acids,

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high temperatures, and freeze-thaw cycles. In this case, various types of modified starches are obtained (E 1400–1450). Modified polysaccharides also include cellulose esters E 461–467. The effectiveness of hydrocolloids is determined not only by the structural features of their molecules (chain length, degree of branching, nature of monomer units and functional groups with their location in the molecule, presence of glycosidic bonds), but also by the composition of the food product, the method of its production and storage conditions. The dissolution and dispersion of hydrocolloids are affected by the size and shape of their particles, specific surface area, and granulometric composition. The method of preparing the solution (dispersion) is of great importance: the intensity and time of mixing, temperature, pH value, the presence of electrolytes, minerals and substances subject to hydration (for example, sugar), the possibility of forming complexes with other compounds present in the system, and the processes of decomposition caused by enzymes or microorganisms. There are thickeners that can form associates with other high-molecular components of a food product, which causes a noticeable increase in viscosity. The behavior of neutral polysaccharides, unlike polyelectrolytes, is practically independent of changes in the pH of the medium and salt concentration. Gels (jellies) are dispersed systems consisting of at least two components – a dispersed medium and a dispersed phase distributed in it. The dispersed medium is a liquid. In food systems, this is usually water, and therefore the gel is called a hydrogel. The dispersed phase is a gelling agent, the polymer chains of which form a cross-linked network and do not have the mobility that thickener molecules have in highly viscous solutions. Water in such a system is physically bound and also loses mobility. This results in a change in the consistency of the food product. The structure and strength of food gels obtained using different gelling agents can vary greatly. A gel is practically an immobilized form of a colloidal solution (sol). To transform a sol into a gel, it is necessary for forces to begin to act between molecules distributed in a liquid, causing intermolecular crosslinking. This is achieved in various ways: by reducing the amount of solvent due to evaporation; by reducing the solubility of the distributed substance due to chemical interaction; by adding substances that promote the formation of bonds and crosslinking; by changing the temperature and adjusting the pH value. The onset of gelation is accompanied by a slowdown in the Brownian motion of particles of the dispersed phase (an increase in viscosity), their hydration, and the formation of a polymer network. The ability of polymers to form a polymer network depends on the length and number of linearly oriented sections of their molecules, as well as the presence of side chains that create steric hindrance during intermolecular interaction[4, 5].

The mechanisms of gel formation can vary considerably, with three main mechanisms currently recognized; the sugar-acid model (highly esterified pectins), the "eggshell" model (e.g., low-esterified pectins), and the double-helix model (e.g., agar). Dietary fibers. Another functional domain of food polysaccharides is dietary fibers. According to the generally accepted definition, dietary fibers (dietary fibers) are edible parts of plants or similar carbohydrates that are resistant to digestion and absorption in the human small intestine and are partially or completely fermented in the large intestine. Dietary fibers enhance/regulate intestinal peristalsis, contribute to the reduction of cholesterol and/or glucose levels in the blood. The class of dietary fibers includes indigestible dietary polysaccharides, lignin and other compounds of plant origin, animal fibers, as well as modified and synthetic indigestible dietary polysaccharides[6]. Dietary fibers can be divided into traditional and functional. Traditional dietary fibers are obtained by minimal processing from plant raw materials and such dietary fibers are considered components (ingredients) of food products, while the so-called functional dietary fibers require more complex technologies (chemical, enzymatic, mechanical, thermal and others) and are considered food additives (E 400–499). The advantages of functional dietary fibers are controlled particle size and higher water-holding capacity, which brings them closer in functionality to hydrocolloid food stabilizers. Classification of dietary fibers according to the nature of their interaction with water, dietary fibers are divided into soluble (pectin, β-glucan, galactomannan, inulin and other oligosaccharides that are not digested in the human gastrointestinal tract) and insoluble (lignin, cellulose and hemicellulose)[7]. Insoluble dietary fibers are high-molecular compounds and are responsible for water adsorption and gastrointestinal regulation, while soluble dietary fibers are low-molecular and are responsible for lowering blood cholesterol levels and reducing glucose absorption in the small intestine. In addition, the amount of information on

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the therapeutic properties of low-molecular dietary fibers is increasing. In particular, it has been shown that some low-molecular agars and alginates have prebiotic activity, and low-molecular pectins have immunomodulatory activity. Dietary fibers perform such functions in the product as: binding and retaining moisture; thickening and stabilization; reducing moisture migration from the filling; ensuring the flowability of dry mixes; enrichment with ballast substances; reduction of energy value; thermal stability. Ideal dietary fibers must meet the following requirements: not contain any components harmful to health; be highly concentrated to maximize the positive effect; have no taste, unpleasant odor, color or texture; have a balanced content of soluble and insoluble fibers; contain biologically active components; do not change the properties of the product to which they are added and at the same time be characterized by a long shelf life; harmoniously fit into the production process (technological process); have the expected health effect[8]. Dietary fibers such as inulin, carboxymethylcellulose, pectin, and others have become widely used in the production of dairy products, where they are used to improve the texture and organoleptic characteristics, increase water-holding capacity, reduce syneresis, as well as increase the nutritional value of products and achieve a health effect. In light of current trends in the food industry, such as food safety control, efficient use of raw materials and waste minimization, the future of dietary fibers, and especially functional dietary fibers, looks quite promising. The rational use of secondary raw material processing products is a primary research goal of many scientific centers, because these raw materials can be successfully converted into functional food ingredients[9].

At the same time, the development, implementation and use of multifunctional food additives/ingredients may be accompanied by a number of problems. First, this is the cost of obtaining modified food polysaccharides. Second, the high gelling and thickening ability of hydrocolloid stabilizers, which is an obstacle to their use as dietary fibers or milk fat substitutes, since to perform the latter functions it is necessary to use much higher concentrations of the corresponding food polysaccharides. Third, there is a lack of information on certain characteristics of food polysaccharides, in particular regarding molecular weights and distribution of carboxyl residues, which does not allow drawing correct conclusions about the relationship between their structure and changes in the product matrix. Fourth, the issue arises of developing and implementing methods for controlling the content of food polysaccharides in food products.

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The use of food additives is regulated in accordance with the Law of Ukraine "On the Safety and Quality of Food Products", however, it is worth noting that to date, an effective mechanism for comprehensive control of their production and use has not been created. In addition, for effective scientific communication and solving technological problems, the issues of terminology, classification and legislative regulation of food Pectin and pectin-containing substances have gained significant use in various sectors of the national economy, in particular[10, 11, 12]: For technical purposes – in the production of D-galacturonic acid; in geology in the production of pectin glue; in the textile industry for fabrics; in foundry production as an additive to molding mixtures; in printing for fixing printing materials; in the metalworking industry for hardening parts; In food products it is used as a gelling agent, emulsifier and stabilizer; In medicine and pharmacy for preventive and therapeutic purposes in various diseases (digestive organs, infectious, diabetes mellitus, polyarthritis, etc.), a structural unit of drugs and a radioprotector. The use of the target component depends on the nature, method of production, molecular weight and degree of esterification. In this regard, methods for deesterification of highly esterified pectins are being developed.

Functions of food in the process of human life: energy: providing the body with energy by releasing it in the process of nutrient metabolism; plastic: providing the body with plastic substances for building the body; immunoregulatory: ensuring the body's ability to resist the action of harmful factors; motivational and signaling: regulation of food motivation (appetite); adaptive and regulatory: regulation of the activity of body systems (digestion, excretion, thermoregulation); bioregulatory: regulation of metabolic processes with the participation of enzymes and hormones; rehabilitation: normalization of body functions due to the therapeutic and prophylactic action of essential nutrients. The development of modern traditional technologies for processing plant raw materials leads to a decrease in dietary fiber in it. For example, increasing the grade of flour is accompanied by a decrease in physiologically valuable ingredients, including dietary fiber. In accordance with the recommendations of FAO/WHO, a product containing dietary fiber in the amount of 3g/100g of the product is considered its source, and with its content of 6g/100g – enriched. Today, various approaches to enriching products with

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dietary fiber have been developed. One of them is the preservation of the native properties of the products, that is, the use of raw materials containing dietary fiber in full. Most often, this method involves the use of whole, crushed, extruded, whole-ground or flattened grains of various cereals (wheat, rye, triticale, barley, millet, etc.). This method is well implemented for the manufacture of bakery products, flour confectionery. Another method of enrichment is the addition of secondary products of processing plant raw materials with a high content of dietary fiber. Such sources of dietary fiber are vegetable, cereal, fruit additives, cereal bran. This method is used to enrich flour products, beverages, and meat products. Another promising way to enrich products is to introduce dietary fiber preparations. They are obtained by isolation from cereals, secondary products of plant raw materials processing, microbial synthesis, etc. Examples include cellulose preparations and their derivatives, pectins, microbial polysaccharides (xanthan, enposan). When creating a product enriched with dietary fiber, special attention is paid to the technological properties of additives, as this may require correction of the recipe and other parameters of the technological process. The choice of the stage of additive introduction is important. For example, pectins and gums used as separate preparations or as part of fruit and vegetable raw materials have the properties of structure stabilizers and thickeners. They are introduced mainly at the stages of product structure formation. This allows, in addition to obtaining a physiological effect, to significantly reduce the amount of some raw materials (sugar, eggs, butter, etc.), which, in addition, leads to a decrease in the calorie content of the product. Cereal bran and meal, which have a high water absorption capacity, are added in significant quantities during the manufacture of various products – from 5 to 25%. This, of course, affects the structural and mechanical properties of semi-finished products and the finished product and requires, in most cases, correction of the recipe amount of moisture[13], see Figure 2.

4. Waste-free, environmentally friendly technology for the production of pectin concentrate

A pressing issue today is the development and implementation of advanced technologies for the processing and use of secondary raw materials using physical and mechanical methods of processing raw materials. The use of mechanical vibrations in the ultrasonic range is of considerable interest[14, 15].

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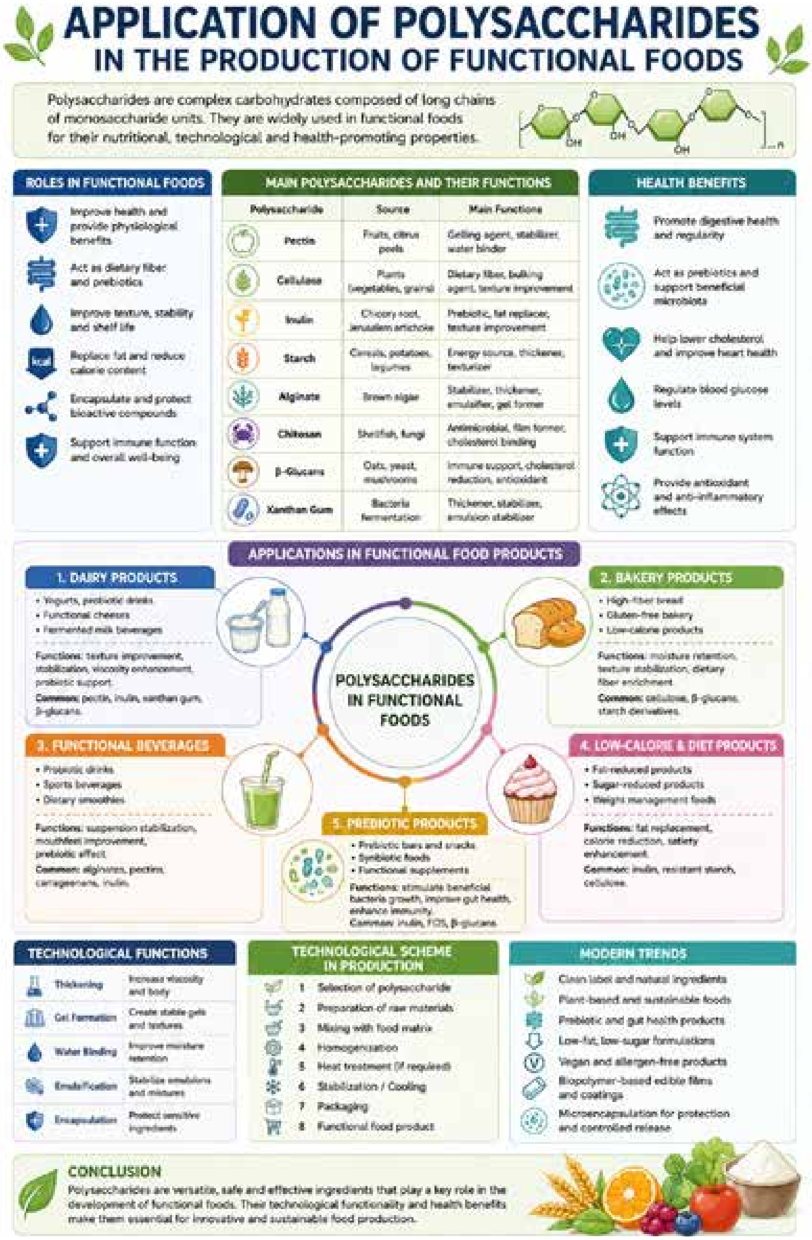

Fig. 2. Polysaccharides in functional products

Pectin production is an important integral component of the food, pharmaceutical and chemical industries. At the same time, the technique and technology of its production, which should be oriented towards environmental friendliness and versatility, are not sufficiently developed[16, 17]. In this regard, the task of developing highly efficient, energy-saving and environmentally friendly processes and equipment that allow realizing the advantages of using ultrasound to obtain pectin from plant raw materials, in particular apple pomace[18], becomes relevant. Based on research and improvement of ultrasonic cavitation processing processes of apple raw materials, schemes for waste-free, environmentally friendly and energy-saving production are proposed. The optimal modes of the proposed technologies were established and their hardware design was improved[19]. The extraction of pectin from pectin-containing raw materials includes the stages of grinding, washing, swelling and pressing of pectin-containing raw materials, dispersion-extraction, separation of solid and liquid phases and concentration. Dry apple pomace 1–2 mm in size, 8% humidity is washed in water at a temperature of 25–45 ^{o}C and a hydromodulus of 1:15 for 30 days, after which the water is separated from the washed raw materials and pressed to a dry matter content of 12–14%. The prepared raw material is mixed with water in a ratio of pomace and water 1:5–1:15, heated to a mixture temperature of 40–50 ^{o}C and fed into an ultrasonic cavitation apparatus for the stage of continuous extraction of pectin from it. Dispersion of protopectin and extraction of water-soluble pectin are performed in an ultrasonic field with the following process parameters: intensity 5–10 W/cm^2, duration 45–60 food fibers. Next, the mixture is sent for separation, i.e. separation of the extract from the spent pomace. The separated extract is evaporated and packaged. The advantages of the proposed technology are: improving the method of obtaining pectin and simplifying the process by using ultrasonic cavitation treatment of raw materials, avoiding the use of acids or bases at the stage of extracting the key component from the raw materials, environmental friendliness and safety while maintaining a high yield and quality of the target component, and the

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16 Берник І. М., Кутняк М. М., Коц І. В. Віброекстрактори з гідроімпульсним приводом для застосування в робочих процесах систем «тверде тіло – рідина». *Продовольчі ресурси.* 2019. 12. С. 16–24.

17 Дейниченко Г. В., Мирончук В. Г., Гузенко В. В., Мазняк З. О. Застосування мембранних процесів у технології одержання пектинових концентратів : монографія. Харків : Факт, 2016. 176 с.

18 Целень Б., Гоженко Л., Радченко Н., Іваницький Г. Використання кавітаційних ефектів в процесах екстрагування. *Scientific Works.* 2020. 84 (1). С. 92–97.

19 Луговський О. Ф., Шульга А. В., Берник. І. М., Гришко І. А., Мовчанюк А. В., Зілінський А. І. Ультразвукові технологічні процеси. Розпилення та екстрагування : монографія. Вінниця : Видавець ФОП Кушнір Ю.В. 2022. 288 с.

possibility of further using spent pomace for the production of products with a high content of dietary fiber[20].

One of the most important properties of pectin is the ability to form gels, which is due to their chemical structure, the peculiarity of which is the trans-position of hydroxyl groups at the second and third carbon atoms of anhydrogalacturonic acid, which creates the possibility of forming intermolecular bridges, limited flexibility of molecules due to the existence of 1,4-trans-diaxal bonds between monomers, as well as the presence of dry dissolved substances, pH and calcium. Since the pectin presented in the material samples is highly esterified, the determination was carried out in the pectin-sugar acid system. According to the data, the gelation index is within 47–53 kPa. It should be noted that it depends on the intensity of sound, which is also confirmed by the indicators of the degree of esterification. The highest indicator is possessed by pectin obtained by ultrasonic treatment of apple pomace with an intensity of 5 W/cm^2. According to the distribution of highly methoxylated pectins by modifications, the mentioned samples obtained at an intensity of 5 W/cm^2 corresponded to the values of a fast-setting additive (SM 70–80%), and 7–10 W/cm^2 – to an average one. The obtained data indicate the possibility of using the extracted pectin as a gel-forming agent in the production of jelly confectionery products. Pectic substances have the ability to complex, which is based on free carboxyl groups, as well as a specific cooperative interaction of pectin molecules with ions of heavy and radioactive metals. The ability of apple pectin extract obtained during processing in an ultrasonic field at an intensity of 5, 7 and 10 W/cm^2 to complex with lead salts was studied. Effect of ultrasound intensity on the complexing ability of pectin extracts (pectin content 5 g per 100 g of extract) Analysis of experimental data on the determination of complexation of apple pectin extract with a pectin content of 5 g per 100 g of extract shows that the indicator increases with increasing ultrasound intensity, reaching the highest value of 14 mg Pb^{2+}/g at an intensity of 10 W/cm^2. Studies of the interaction of pectin with metals were carried out in a weakly acidic medium (extract pH 5.5–6.5), which corresponds to the most intensive process and is consistent with literature data. The value of the complexing ability of pectin extracts (pectin content 35%) varies within the range of 87–107 mg Pb^{2+}/g. The comparative ability of pectin extracts to sorb lead ions shows that the selectivity increases with the concentration of pectin.

The complexing ability increases in proportion to the content of pectin substances and reaches the highest values from pectin extract to pectin

[20] Берник І. М., Луговський О. Ф., Лобань Ю. М. Модель управління технологічним процесом ультразвукового кавітаційного вилучення пектину з рослинної сировини. *Вібрації в техніці та технологіях*. 2011. 1 (61). С. 133–137.

preparations. Apple pectin extract obtained using ultrasound has high sorption and detoxification properties[21, 22]. It can be widely used for the prevention of chronic occupational poisoning, in the nutrition of workers with unhealthy working conditions, in places of radioactive environmental aggression, as well as in preventive nutrition in the treatment of foodborne diseases with varying degrees of pronounced autointoxication in workers exposed to heavy metal salts in production. Thus, a technological scheme for the production of pectin concentrate using ultrasonic cavitation technologies at the stage of dispersion-extraction of protopectin has been proposed, which, compared to typical ones, has a number of advantages: simplification of the process, use of softened water as an extractant, use of spent pomace as dietary fiber, environmental cleanliness and safety of production. At the same time, the indicators of gelling and complexing ability of the obtained pectin extracts confirm their high quality and the possibility of using them in various sectors of the national economy. By changing the processing parameters, in particular the intensity of the ultrasonic field, it is possible to influence the value of these indicators.

Pectins are a group of high-molecular polysaccharides that are part of the cell walls and intercellular structures of plants along with cellulose, hemicellulose, and lignin. The largest amount of pectic substances is found in fruits and root crops. Pectins are obtained from apple pomace, beet, sunflower baskets, and citrus fruits. There are insoluble pectins (protopectin), which are part of the primary cell wall and intercellular substance, and soluble pectins, such as those contained in the cell sap. During ripening and storage of fruits, insoluble forms of pectin are converted into soluble forms, which is associated with the softening of fruits during ripening and storage. The conversion of insoluble forms of pectin into soluble forms occurs during heat treatment of plant products[23, 24].

Pectic substances are able to form gels in the presence of acid and sugar, which is why they are used as gelling agents for the production of marmalade, pastilles, jellies and jams, as well as in baking and cheese making. Non-starch polysaccharides are not digested by enzymes found in the gastrointestinal tract.

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22 Луговський О. Ф., Берник І. М. Виробництво пектинового концентрату з використанням ультразвукових кавітаційних технологій. *Збірник наукових праць Вінницького національного аграрного університету. Серія «Технічні науки»*. 2011. 9. С. 159–163.

23 Пересічний, М. І. Технологія продуктів харчування функціонального призначення : монографія. Київ : Київський національний торговельно-економічний університет. 2008. 718 с.

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However, they are not considered as ballast and useless food substances, but as those that are important for the normal function of the gastrointestinal tract and the prevention of many human diseases. Pectic substances are found in food products, e.g. fruits, vegetables. The name comes from the Greek "pectos" − gelatinous, solidified. Due to the property of forming jelly-like products, it is used in the production of confectionery, fruit jellies, marmalades, jams. Pectin is a group of dietary fibers, has detoxifying properties – a very interesting physiological feature – swells, binds ions of heavy metals, radionuclides and removes them from the body. These properties of pectin make it possible to use them as a valuable additive in the production of food products for therapeutic and prophylactic purposes. For modern conditions of environmental and food pollution − this is a wonderful wealth of vegetables! The preventive norm of pectin for an average resident of Ukraine should be 2–4 g per day, and in severe conditions of pollution − up to 10 g.

HEALTH BENEFITS OF POLYSACCHARIDES

– Digestive Health improved intestinal motility; prevention of constipation;
– Cholesterol Reduction β-glucans help lower LDL cholesterol;
– Blood Sugar Regulation Certain fibers reduce glucose absorption;
– Immune Support Fungal and oat β-glucans stimulate immunity;
– Antioxidant Activity Some polysaccharides demonstrate antioxidant properties.

5. Modern biotechnological applications

Modern food biotechnology uses polysaccharides for: microencapsulation; probiotic protection; edible films and coatings; controlled release systems; biodegradable packaging. MODERN TRENDS: clean label products, plant-based foods, prebiotic nutrition, low-fat products, vegan functional foods, sustainable biopolymers. Polysaccharides are essential functional ingredients widely used in modern food technology. Their nutritional, technological, and physiological properties make them valuable components in the development of functional foods aimed at improving human health and food quality.

Preservation and consolidation of people's health is an important task of every civilized state. Nowadays, it has been scientifically established that the health of a nation depends on the health care system by only 8–12%, while socio-economic conditions, including diet, determine the state of health by 52–55%. The results of regular studies of the actual nutrition of the population, conducted by the Institute of Cardiology, as well as the Institute of Gerontology of the National Academy of Medical Sciences of Ukraine in different regions of Ukraine, indicate significant violations in the diet: excessive consumption of animal fats and easily digestible carbohydrates, which leads to an increase in the number of people with various forms of obesity and excess body weight; lack of omega-3 polyunsaturated fatty acids and complete (animal) proteins; lack of vitamins (groups B, A and C, D) and minerals, especially calcium, iron, magnesium, zinc, iodine and selenium. Among the reasons for insufficient consumption of macro- and micronutrients, such factors as: monotony of the diet, which means that a person consumes a standard set of several main groups of products and ready-made dishes; increased consumption of refined, high-calorie, but low in vitamins and minerals, such as premium flour, bread, pasta, confectionery, sugar, etc.; increased proportion of products in the diet that have been canned, long-term stored, and intensively processed; these include canned and reconstituted juices, jams, and preserves, in which a greater proportion of vitamins is lost; the use of intensive methods of growing plants and animals, which leads to a change in their chemical composition, including a decrease in the content of biologically active substances.

The following also contribute to an unbalanced diet: low purchasing power of the population; low level of food culture, including the lack of knowledge among the majority of the population about the benefits of individual food components; bad eating habits (excessive consumption of fatty foods, smoked foods).

It is not possible to solve these problems by increasing the calorie content of the diet, as this leads to an increase in the number of calories consumed, which is unacceptable with insufficient physical activity and physical inactivity. Therefore, it is necessary to develop and master new technologies and food recipes.

The technical process in the food industry became possible thanks to new technological opportunities that arose as a result of the development of science, engineering and technology. All this contributed to the development of the science of nutrition with a gradual transition from the theory of rational nutrition (1930) to the theory of balanced nutrition (1964), then to the theory of adequate (1987) and ideal nutrition (1991) and further to the theory of functional or healthy nutrition (1998). 6 Currently, products with functional ingredients make up no more than 3% of all known food products. According to forecasts for the next decade, their share will reach 30–50% of the entire food market. More and more products are being produced, enriched with vitamins, trace elements and other substances necessary for human health. Already now, 90% of all consumers believe that nutrition plays a key role in the prevention of diseases, and 60% of them already consume fortified foods. On the Ukrainian market, products with functional ingredients are dominated by mass-market products, the main characteristics of which are natural and balanced composition.

CONCLUSIONS

The functional food market is a dynamic and promising industry that continues to develop actively. In Ukraine, there is a gradual increase in interest in healthy eating, but for further development, comprehensive measures are needed from the state, business, and the scientific community. The main areas of further development include: improving production technologies to ensure high quality products; expanding the range of functional products in accordance with modern consumer needs; introducing environmental standards and the concept of waste-free production; active use of international certification systems to increase the competitiveness of Ukrainian products. Thus, functional food plays a key role in the formation of a healthy nation, contributing to the improvement of the quality of life of the population and the sustainable development of the food industry.

Functional products must meet the following requirements: be natural; have the appearance of ordinary food, i.e. not be produced in such dosage forms as tablets, capsules, powders; be taken orally, i.e. as ordinary food; be beneficial for health, while the beneficial qualities must be scientifically substantiated, and the daily doses must be approved by specialists; be safe from the point of view of a balanced diet; do not reduce the nutritional value of food products; have established values of physicochemical indicators and accurate methods for their determination.

Functional products are intended: to compensate for the deficiency of biologically active components in the body; maintain normal functional activity of organs and systems; reduce the risk factors of any disease, for example, return to normal cholesterol levels; maintaining beneficial microflora in the human body, maintaining normal functioning of the gastrointestinal tract.

The modern concept of healthy eating is based on the following main principles: to minimize the amount of pollutants (toxic elements, radionuclides) entering the body with food; control over the sorption and accumulation of pollutants in the body; adherence to the principle of balanced nutrition; introduction into the daily diet of concentrated products that promote health, with the functional ingredient of dietary fiber (which has detoxifying properties). The best way to produce functional products for special nutrition is to use processed raw materials of natural origin, which have no side effects on the human body, but have a fairly pronounced effect of binding various pollutants. A typical example is dietary fiber.

The presence of carboxyl groups in hemicellulose and pectin substances of dietary fibers, carboxyl and amino groups in proteins and phenolic hydroxyl groups in lignin determine their ability to bind cations, affect mineral metabolism in the digestive tract, bind toxic elements and radionuclides into insoluble complexes that are not absorbed and are excreted from the body. Dietary fiber is a natural food component that is resistant to the action of enzymes, is not digested by endogenous secretions of the human gastrointestinal tract and is not absorbed in the small intestine, affecting the processes of digestion and absorption of nutrients. It is characteristic that it is resistant to the action of glycolytic enzymes. In the large intestine, dietary fiber is partially hydrolyzed by the existing microflora. Dietary fiber can be used as technological additives that change the structure and chemical properties of food products, as well as functional ingredients that have a positive effect on both individual systems of the human body and the entire body as a whole. Products enriched with dietary fiber include primarily bakery, pasta, culinary and confectionery products, drinks, desserts and snacks. The recommended dietary fiber intake is 20 g/day. In case of colon dysfunction, the amount of fiber in the diet should be increased.

SUMMARY

One of the most important and most difficult tasks is to provide the population of the globe with food. Being one of the most important environmental factors, nutrition from the moment of birth to the very last day of a person's life affects his body. The ingredients of food substances, entering the human body with food and transforming during metabolism as a result of complex biochemical transformations into structural elements of cells, provide our body with plastic material and energy, create the necessary physiological and mental performance, determine the health, activity and lifespan of a person, his ability to reproduce. Therefore, the state of nutrition is one of the most important factors determining the health of the nation.

Food products should not only satisfy human needs for basic nutrients and energy, but also perform preventive and therapeutic functions. According to the Institute of Nutrition, the majority of the population of Ukraine has nutritional disorders caused by both insufficient consumption of nutrients and a violation of the nutritional status of the population of Ukraine, primarily a lack of vitamins, macro- and microelements, complete proteins, and their irrational ratio. The most important violations of the nutritional status of the population of Ukraine are excessive consumption of animal fats deficiency: of polyunsaturated fatty acids; of complete (animal) proteins; of vitamins (ascorbic acid, riboflavin (B2), thiamine, folic acid, retinol (A) and (β-carotene, tocopherol and others); of minerals (calcium, iron); of microelements (selenium, zinc, iodine, fluorine); of dietary fiber.

Poor nutrition can lead to obesity, diabetes, pancreatitis and cause "hidden hunger". The trend towards a decrease in carbohydrate consumption has contributed to the development of the use of resistant starch (RS) in food production. Resistant starches are a source of functional fiber, play an important role in the physiology of digestion and are considered prebiotics. Products made with resistant starch have a low glycemic index. In addition, resident starches have a positive effect on the function of the gastrointestinal tract, microflora and blood cholesterol levels, reduce the risk of colon cancer and diabetic diseases. Adding resistant starch to the human diet increases the number of lactobacilli and bifidobacteria. Thus, resistant starch is a promising functional food ingredient. Most starches are completely digested and broken down to glucose in the small intestine, which is then absorbed into the bloodstream. Resistant starch cannot be fermented in the small intestine, so it enters the large intestine, where it becomes a highly valuable food for anaerobic (oxygen-free) microflora, where it undergoes microbial fermentation to produce short-chain fatty acids, carbon dioxide, hydrogen, and methane. Resistant starch is a starch that can resist enzymatic hydrolysis in the human gastrointestinal tract due to its amylose to amylopectin ratio, crystallinity type, granule size, starch-protein interactions, formation of amylose-lipid complexes, and reverse-gradient starch content. According to the European Commission, the energy value of: resistant starch is 2 kcal/g, wheat starch is 3.44 kcal/g, potato starch is 3.57 kcal/g, corn starch is 3.81 kcal/g. Starch is fermented by the colonic microflora, producing short-chain fatty acids, increasing the number of beneficial bacteria and stimulating butyrate-producing bacteria, thereby benefiting human health. This leads to the formation of carboxylic acids, such as acetic, propionic and butyric acids. Butyric acid is a source of energy for the cells of the colonic mucosa. The carboxylic acids are absorbed by bacteria living in the lower intestine and are beneficial for prebiotics, i.e. the natural microflora of the human intestine. The physiological functionality of resistant starch is similar to that of dietary fiber. Resistant starch improves colon health and increases bowel movements. Compared to dietary fiber, resistant starch promotes the formation of butyrate and improves colon and rectal function. In addition, resistant starch affects metabolism by lowering blood glucose levels and promotes weight loss. As a result, resistant starch is classified as a prebiotic and acts as a substrate for the microflora of the gastrointestinal tract. The most important physiological action of resistant starches in the colon is enzymatic metabolism. Fermentation of polysaccharides provides energy that promotes the growth of bacterial microflora and the formation of inert gases (CO_2, methane and hydrogen) and short-chain fatty acids (which reduce the risk of cancer cell growth). Some types of resident starches are excreted from the body mainly unchanged.

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