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PROSPECTS OF POTATO PULP DISPOSAL: A REVIEW

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Abstract

Potato pulp, which is a residual product of potato starch processing and contains large number of dietary fibre, starch and proteins in large quantities, is accumulated in potato processing plants, because its utilization leads to environmental pollution and significant economic costs. The purpose of this work was to present the main directions of using potato waste as a source of various nutrients that can be used to obtain additional resources - valuable food, feed and technical products. The article considers and analyses modern methods of potato pulp processing, outlines the main benefits of using these wastes in different industries and analyses the problems that arise with this.

More than a hundred research papers published in peer-reviewed scientific journals in the G7, Western Europe, and Southeast Asia have been studied in this area. Much attention has been paid to solving the problems of bioactive substances extraction from potato waste by enzymatic and acid hydrolysis methods. The analysed data contradict each other, as some scientists argue that such a technological operation is not economically feasible, because the costs exceed the desired effect. However, other scientists emphasize that the processing of potato pulp can reduce the cost of potato food products. In our opinion, research in this direction should be continued and physico-chemical and microbiological processing methods that provide the maximum yield of biologically active substances, should be used. Based on the literature analysis, we have identified the following components *Bacillius licheniformis, Aspergillus niger, Trichoderma asperellum* - for protein extraction, citric acid - for pectin extraction, *Acremonium cellulolyticus* - for saccharification of starch residues during ethanol production, the use of which before or during fermentation provides significant yield of biologically active substances.

We have confirmed the possibility of using pulp in the food industry, although there is very little attention paid as a raw material ingredient in the literature. However, its nutritional value and price can create all the prospects for use in the food industry.

Key words: *Potato pulp, Biotechnological processes of potato pulp processing, Food waste utilization, Biologically active components, Biogas, Ethanol, Feed additive.*

1. Introduction

In many developed countries, potatoes are among the top five crops after wheat, corn and rice [1]. Due to the growing economic potential of European countries, including Ukraine, America, China, demand for fast food products or ready-to-eat products is increasing and we can make a conclusion that the need for starch production will increase too [2]. Approximately 40% of all potato weight is unused, the amount of which is one million tons of waste each year [3]. For example, in Europe, the average annual amount of potato pulp waste is 1 x 10^6 tons [4], in northern Japan 1 x 10^5 tons [5], and in Denmark - 75 x 10^3 tons [6].

About potato pulp, which is an important source of biologically active substances, including cellulose, pectin, and protein [2]. Chemical composition of potato starch production wastes is presented in Table 1 (results used from different sources) [7 - 11].

Table 1. Chemical composition of potato pulp

Substance	Amount
Starch, % DM	37 - 50
Pectin, % DM	17
Cellulose, % DM	17
Hemicellulose, % DM	14
Soluble carbohydrates, % DM	1 - 2.5
Reducing carbohydrates, % DM	0.61
Protein, % DM	2.7 - 8
Fat, % DM	2.6
Amino acid composition, mg/kg:	
Asparagine	72.16 - 160.73
Glutamine	100.95 - 132.75
Serine	46.92 - 54.63
Threonine	62.42 - 62.73
Glycine	65.06 - 65.38
Alanine	374.13 - 377.53
Proline	800.40 - 811.81
Valine	182.13 - 195.99
Cinder, % DM	1.11 - 6.20
Mineral composition, mg/kg:	
Ca	179 - 460
Mg	236 - 254
K	5935 - 6225
Na	136
Not identified, % DM	7

Potato pulp contains a significant amount of unwashed starch, the grains of which are attached to the fiber, which is the basis of the cell walls and moreover, it is the greater part of the starch left in the pulp, and possibly explained by the process of retrogradation. High-amylose starch has the lowest rate of retrogradation, so it can be obtained a "stable starch" close in properties to the dietary fiber [12]. The pulp is a source of dietary fiber, especially pectin, cellulose and hemicellulose. Also, the protein content reaches 6%, the value of which is provided by the presence of 8 essential amino acids. Although the pulp is a waste of starch production, its valuable chemical composition causes to use it in other fields of agriculture, biotechnology, food, energy and others industries.

However, such wastes, due to the high moisture content (85 - 30%) [11], and the rate of decomposition of the compounds, lead to bacterial contamination of the environment (land and surface water) [13]. And the problem of recycling and the costs of this process lead to a decrease in the efficiency of food businesses [14]. In most cases, existing logistics systems used in the food industry are not able to cope with the obstacles that arise on the way of their disposal.

Waste Management Legislation document came into force in Europe in 1970, outlining how waste should be handled, namely how it should be processed, stored, transported and disposed of to minimize the adverse effects on human health and the environment [15].

This indicates that scientists from different countries, both last century and today, are focusing on effective ways to dispose of food waste, including potato pulp, which will increase the economic performance of agricultural processing plants.

Modern enterprises for the production of starch to facilitate the utilization of the formed pulp, firstly it is partially pressed to a mass fraction of moisture of 30.0%, and after that, they are sent to livestock feed, rarely buried. In our opinion, this technological method (dehydration) will promote the application of new ways of processing. Firstly, the potato pulp contains a valuable chemical composition, (look Table.1), while the price is low and is around € 8.5 per ton [16], and sometimes businesses give it away for free, which encourages it to be used as an ingredient for the production of biologically active substances. Secondly, the demand for wet potato pulp as a feed for cattle is reduced due to the need to control feeding regimes and feed composition [6]. All these trends give impetus to the renewal of how potatoes pulp are used.

The purpose of this review article is to determine the potential and efficiency of processing potato waste obtained during starch production.

2. Ways to use potato pulp

2.1 Manufacture of livestock feed

In addition to water and starch, potato pulp includes polysaccharides of the cell wall, which by their chemical composition contain cellulose, hemicellulose and pectin [8]. Cellulose is a polymer that consists of unbranched β-(1-4) D-glucopyranosyl units; it is one of the important components in lignocellulosic materials. That is why potato pulp is a valuable ingredient in the form of livestock feed.

Most often the residue of potato waste is dried to a mass fraction of moisture 5 - 10%, density 350 - 400 kg/m^3 [4], and in this form is used for livestock feed [17]. However, because of its high moisture-holding capacity, it is difficult to dry pulp because it requires a lot of energy, and because of its chemical composition, dried pulp is difficult to digest with the enzymes of domestic animals [18]. Lee Chang and colleagues [19] dealt with this problem. To obtain a digestible form of cellulose, they propose to remove starch from potatoes, fermenting thermostable amylase from *Bacillus licheniformis*, then hemicellulose, pectin and lignin by treatment with sodium hydroxide and sodium sulfate. According to their data, this will promote the formation of a loose structure of cellulose, which is easier to digest with enzymes of the stomach of animals. The output of cellulose obtained by this method was 24.78%, and its purity - 81.34%.

It is known that potato pulp contains protein (Table 1), and therefore it is a promising raw material ingredient in the production of animal protein feed. Protein hydrolysis and accumulation are key steps in the production of unicellular protein from potato pulp. Protein animal feed is obtained by fermentation in liquid, solid and semi-solid form [20].

Liu *et al.*, [21] studied production of unicellular protein as a result of two-stage fermentation of the pulp using *Aspergillus Niger* and *Bacallius Licheniformis*. Their results indicate the feasibility of producing high quality feed on a large industrial scale.

The team of authors in Russia has developed a technology for the production of feed, which meant to cultivate the biomass of the fungus p. *Trichoderma asperellum* 302 in a deep way. A mixture of potato pulp and potato juice with potassium phosphate and ammonium sulfate was used as the nutrient medium. The obtained mushroom biomass was separated by centrifugation. The result was a protein supplement, the yield of which was 55%, and the crude protein content - 25% [9].

Okine *et al.*, [22], claimed that the use of potato pulp as animal feed is possible through silage, which will extend its shelf life. Laboratory studies were performed using bacterial inoculants or *Lactobacillus rhamnosus*, or *Rhizopus oryzae*, or their combining. The results of studies showed that silage can be carried out with or without bacterial inoculants, as evidenced by the chemical composition of the silo, for which the content of lactic acid is not significantly increased, and sheep digestibility is the same in all samples. However, Dagaerbieke *et al.*, [23], proved that the use of other bacterial inoculants of the type *Lactococcus lactis* and *Lactococcus diolivorans* allowed significant improvement of the chemical silage composition gained from the pulp. The protein content of the silo increases from an initial concentration of 39 to 57 g/kg and 58 g/kg; and lactic acid content from 2 to 52 g/kg and up to 50 g/kg in the case of using *L. lactis*, and *L. diolivorans*, respectively. Thus, the correct choice of inoculants for silage potato pulp can improve its quality and nutrition.

In general, the practice of using potatoes pulp in the form of livestock feed is common, but it is advisable to modify these raw materials to enrich the chemical composition and digestibility. The modern ways of increasing the nutritional value of the pulp by fermentation, indicate the prospects of these measures, which simultaneously allows to solve two problems: the production of valuable chemical composition of livestock feed and environmental protection [1]. However, the cost of protein feed from potato waste remains high, due to the complex process of production, harsh fermentation conditions and high energy consumption, and therefore the issue of industrial production of high protein feed remains partially unresolved.

2.2 Biogas production

A promising way of processing potato pulp is to produce biogas, which can be an ideal replacement for energy [24].

Methods for the production of biogas from food waste from aerobic fermentation are described in detail in works of Mayer, [4], Van Ginkel, [24], Zhang *et al.*, [25], Saratale *et al.*, [26], and Heguang Zhu [27], based on hydrothermal liquefaction - in work of Gollakota *et al.*, [28], hydrothermal carbonation - Tradler *et al.*, [29]. Also, an overview of various technologies related to the bio-conversion of food waste into energy is presented in the works of such scientists as Mckendry, [30], Murugan *et al.*, [31], and Pham *et al.*, [32].

With regard to the current state and future directions of the development of potato pulp processing into biogas, Stephen and Periasamy, [33], have dealt with this issue in detail. To obtain an alternative source of energy, they propose to use an anaerobic fermentation process.

Fermentation biogas production is a relatively sophisticated technology that involves the processes of hydrolysis, acidification, enzymatic cleavage and methanogenesis in dynamic equilibrium. From the studies of Ahring *et al.*, [34], it was found that when using only potato pulp, low biogas content with high organic acid content is obtained, and the addition of other inoculants (rice straw, cassava waste and weeds) improves biogas output.

Another method of producing biogas from potato waste was proposed by Benemann *et al.*, [35, 36], later confirmed by Zhu *et al.*, [27]. They claim that using a two-step anaerobic digestion process makes it possible to produce hydrogen and methane together. According to their technology, at the first stage, acidogenic bacteria convert substrates such as carbohydrates into hydrogen, carbon dioxide and fatty acids. The gaseous products exit the reactor, and the volatile fatty acids enter the second stage, where they are further converted by methanogens into methane and carbon dioxide. According to them, the output of hydrogen and methane from potato waste is 30 L/kg

TS (max 68 l/kg) and 183 L/kg TS (max 225 l/kg). The total energy output is 2.14 kW hour/kg TS, max 2.74 kW hour/kg TS [35, 36].

The use of enzymatic methods for the production of biogas is gaining in popularity compared to thermal methods. First of all, this tendency is explained by the ability to process waste with a high content of mass fraction of moisture, which contributes to the reduction of greenhouse gas emissions into the atmosphere [37 - 38] and maximum heat output [39]. In addition, the advantages of this method include its low cost of operation and reduction of volume and mass of waste [40].

Thus, the use of potato mash in biogas production technology is one of the main options for the commercial production of renewable energy from organic waste, in addition, this technology can be used directly in food and processing plants to produce both heat and electricity [32].

2.3. Production of bioadsorbents

Adsorbents include substances that are highly porous in their structure, such as activated carbon. Due to its high adsorption properties and speed of removal, it is used to purify water from dyes, metal ions and other low molecular weight organic compounds [41].

The problem of water pollution is increasing every year, and so the demand for adsorbents for its purification is increasing. Commercial adsorbents have a relatively high price, which prevents its widespread use in wastewater treatment technology [42]. Therefore, the search for non-expensive adsorbents is an important task for chemists.

Currently, rice husks are used as a raw material ingredient for the production of bioadorbents [43], rice straw [44], tea brewing [45], olive waste [46], coffee husk [47], barley husk [48], shell of oil palm tree [49] etc., as such material has a high carbon content and low cost [50]. An availability, chemical composition and price of potato pulp promote the production of low-cost adsorbent.

Zhe Zhang *et al.*, [4] worked on the creation of potato biosorbent production from potato pulp capable of removing organic dyes from water.

In this study, the adsorbent was obtained by salting the pulp soaked in $ZnCl_2$ under conditions of limited oxygen content, or under conditions of N_2-atmosphere. As a result, scientists received activated carbon with a surface area BET 1357 m^2/g, total pore volume 1.065 sm^3/g and volume of mesopores 0.982 sm^3/g.

Li Cheng *et al.*, [19], also proposed to use potato pulp as a bioadsorbent. We discussed the technology of sorbent production in the section “Production of feed for cattle”. As a result, researchers have obtained cellulose, which has an adsorption capacity of 5.7 mg of protein/g glucan.

In order to produce the adsorbent for T-2 mycotoxin, Yagofarov *et al.*, [9], used potato marrow and its juice as a nutrient substrate for the cultivation of the fungus biomass of *Trichoderma asperellum* 302 in a deep way. The obtained biomass of the fungus was separated by centrifugation, and the cell wall and protein by fermentation using Protex 6L. This treatment made it possible to impart high cell wall adsorption properties to T-2 mycotaxin, which was up to 77%.

Although the potato pulp uses and processing are described to have several advantages due to the high adsorption capacity of the adsorbent and the cheap raw material base, different parameters of the enzyme synthesis process and operating conditions affect the binding process and, as a consequence, the efficiency of the adsorbing properties [51].

Therefore, the use of potato waste for the production of bioadorbents with well-optimized parameters of the cultivation and purification process of the adsorbent, will contribute to the treatment of wastewater in a cost-effective way, in addition will solve the problem of disposal of such waste.

2.4 Production of enzymes

Enzymes are of great importance in the processing of plant and animal raw materials on an industrial scale due to their high specificity and environmental friendliness. For example, cytolytic enzymes are used to extract juice from fruits, vegetables and berries, pectolytic and proteolytic enzymes are used to clarify the juice, and protease is used to enhance the fermentation process in beer technology, while oxidized reductase enzymes are used during fermentation of tea and coffee etc. Enzymes are used not only in the food industry, but also in the production of biofuels (cellulase), the textile industry (cellulase, protease), the pulp and paper industry (xylase, manase, cellulase), in the production of detergents (protease, lipase, amylase, cellulase, amylase, cellulase pectinases) [52].

The high volume of enzyme utilization and their multifaceted use drives researchers to develop technologies for their production from cheaper substrates such as food and agro-waste.

Solid-phase fermentation is the use of by-products of agriculture, the use of which must be accompanied by a number of advantages, namely: not expensive, easily accessible, high enzyme yield [53]. Due to rapid industrialization, there is a tendency to use new technologies in biological processes for the reuse and recycling of food waste [54]. Therefore, knowledge of the ways in which potato pulp is used in enzyme production technology is relevant and timely.

As a nutrient medium for the development of microorganisms of the strains of *Aspergillus oryzae* Murthy *et al.*, [55], it is used potato pulp, spray dried, to which only nitrogen was added. The fermentation process took place in a central composite rotatable design under the following conditions: mass fraction of moisture 50%, temperature - 30 ^{0}C, duration of the process 120 h. On the enriched medium was identified *Aspergillus oryzae* RIB 40 (ATCC 42149), receiving 20.5 units/mL of acidic protease.

In order to obtain the producers of the enzymes *Trichoderma reesei* Rut C30 and *Trichodenna reesei* MGC 77 Klingspohn *et al.*, [56] the potato pulp was precipitated into fractions: pectin and starch; hemicellulose and cellulose. For this purpose, the pressed starch production was treated with dilute sulfuric acid at pH - 3.3 and a temperature of 121 ^{0}C for one hour and then centrifuged. The result is a "pulp residue" that can be used for ethanol production, or as a substrate for enzyme production, both periodically and continuously. The result was enzymes for which have highest specific enzyme activities (6.1 U mg^{-1} avicelase, 23.4 U mg^{-1} CMC-ase and 668 U mg^{-1} xylanasej and productivities (8 - 9 U litre^{-1} h^{-1} avicelase, 34.3 U 1itre^{-1} h^{-1} CMC-ase and 978 U litre^{-1} h^{-1} xylanase).

During the continuous cultivation of the same enzymes, the team of authors Klingspohn *et al.*, [57], proved that the use of potato pulp, from which the starch and pectin were previously removed, but which additionally contains complexes of salts, allows for high yield of the enzyme. Thus, by using cross-flow microfiltration and the recovery process by cross-flow ultrafiltration, the following average performance is obtained under dilution rate D = 0.008 h^{-1} and PR and PPL: 6.5 U 1^{-1} h^{-1} avicelase, 30 U 1^{-1} h^{-1} CMCase, and 75 U 1^{-1} h^{-1} xylanase. At a higher dilution rate of 0.019 h^{-1}, the productivities improved (35 U 1^{-1} h $^{-1}$ CMCase and 90 U 1^{-1} h^{-1} xylanase) up. Finally, almost 90% of the potato pulp can be processed.

The extensive chemical composition of potato pulp, the difficulty of production enzymes and their purification, can interfere with the processing of pulp on an industrial scale. Therefore, research in this area is continue, aimed at minimizing the cost and increasing the efficiency of enzyme recovery processes.

2.5 Ethanol production

The interest of scientists from different countries is focused not only on the production of biogas from food waste as an alternative source of energy, but also on the production of bio-alcohol. The most widespread bio-alcohol produced by microbial fermentation of agricultural products rich in sugars - ethanol [39]. Currently, ethanol is referred to as an alternative liquid fuel having similar characteristics to oil. Ethanol is also a major component in the production of polyethylene and other plastics.

According to the classical technology for the production of ethanol use carbohydrate raw materials, namely crops (rice, wheat) and sugar-containing raw materials (sugar beet, sugar cane, sorghum, etc.), about the fact that such raw materials have limitations in use because of its food security. It is known that a cheap source of lignin and cellulose, which serve as an intermediate substrate for biotechnological ethanol production processes - is food and agricultural waste, which reduces the risk of environmental pollution [58]. It is no exception that the potato pulp obtained from starch production.

Use of food waste such as banana peel [59], oilcake of apple, sugar beet and grape [60], pineapple and citrus wastes [61], waste coffee grounds [62] as a raw material ingredient in ethanol production, has been studied and analyzed in detail. According to classical technology, the first stage in the production of ethanol from lignocellulosic substrates is the saccharification, which mean hydrolysis of starch and other carbohydrates to sugars such as glucose, under the action of industrial enzymes (α-amylase, β-amylase, glucoamylase, etc.). Then the fermentation of the formed sugars with the help of yeast *S. cerevisiae*. Yeast-producing enzymes, namely invertase and zymase, ferment reducing sugars to ethanol and CO_2. Mushrooms and bacteria are also used to ferment sugars [63].

In work Oberoi *et al.*, [59], is noted that the benefits of using such waste in bio-ethanol production are: lowering the cost of waste disposal and ethanol production, reducing carbon emissions and energy efficiency. But Klingspohn *et al.*, [56], argued that the production of ethanol from potato pulp is not economically feasible, because the cost of splitting the cereals into separate fractions of carbohydrates and cellulose, followed by fermentation of the latter to glucose and xylose, far exceeds the desired yield of monosugars.

Therefore, the attention of scientists is focused on the study of effective ways of extracting reducing sugars from potato pulp, which are a source for yeast fermentation. Thus, Gao *et al.*, [64], based on analytical studies, has been shown that potato pulp saccharification with *Acremonium cellulolyticus* is highly effective because it exhibits amylase and cellulase activity. In addition, hydrothermal treatment of the pulp at 121 ^{0}C increases the rate of saccharification by 3 times, which allows to accelerate the process of bio-ethanol production.

Hydrolysis of potato pulp by a complex of three enzymes (Termamyl, Viscozyme, Celluclast) followed by fermentation of the formed sugars by *S. cerevisae*, allows to ensure the yield of ethanol in the amount of 76 g/L [11].

The use of cellulase and pectinase as a hydrolyzing agent removes up to 168.13 g/L of glucose from potato pulp. Subsequent fermentation of *S. cerevisae* glucose provided 79 g/L ethanol yield. Thus, from each kilogram of dried potatoes got 225.71 g of ethanol [12].

Increasing the yield of ethanol from potato pulp can be ensured not only by expensive enzyme preparations, but by enriching the environment with different classes of compounds. It is proved that the inclusion in the potato pulp a mixture of yeast, malt extracts and $MgSO_4$ x $7H_2O$ promotes the yield of ethanol in the amount of 24.6 g/L at a fermentation temperature of 30 ^{0}C, the rotational speed of the stirring body 150 rpm for 48 h [6, 65]. Addition of ammonium sulfate, as a source of nitrogen, to the pulp under fermentation conditions - temperature 25 ^{0}C, pH 3.5 for 3 days, ferment the substrate to an ethanol concentration of 9%.However, such technologies yield 3 times less ethanol compared to the use of enzyme preparations.

Thus, research results show that potato pulp, as a starch production product, has high potential in ethanol production, such technologies are environmentally friendly, high-performance, cost-effective, and easy to manage [12].

2.6 Extraction of bioactive components

Integrated use of food waste in the production of new natural products, including, for example, health-promoting food ingredients, can also help offset the expected rising costs and environmental problems of waste disposal, which is a progressive way of ensuring resource conservation [6].

Innovative technologies for the continuous extraction of biologically active substances must ensure production efficiency, reliability, low cost and environmental friendliness [66].

Among the wide variety of extraction methods used to extract biologically active substances from food waste, solvent extraction refers to the conventional method of using a solvent (methanol, ethanol, acetone, etc.) as an extractant [67]. For maximum extraction of the required compounds from the raw material, it is necessary to select the solvent (extractant) and technological parameters such as temperature, time, pH, hydromodule, particle size of the raw material, mixing frequency, etc. However, this method requires a long extraction time, the use of expensive, sometimes even toxic, organic solvents, which must be removed in the future [39].

It is known that the use of enzymes (cellulase, α-amylase, and pectinase) before the solvent extraction process, helps to destroy the cell walls of the raw material and hydrolyze structural polysaccharides, which makes them more accessible to the extractants; and this promotes the release of biologically active substances [68]. The advantages of this method include - reduction of extraction time, minimization of the use of organic solvents, improved quality and quantity of biologically active components [69]. However, when large amounts of food waste are used, it should be borne in mind that the activity of enzymes varies depending on the reaction of the environment, temperature and catalytic capacity [39].

Modern technologies used for the extraction of biologically active substances from food waste include the use of supercritical liquids, such as CO_2, in the form of an extractant. CO_2 - the extractant has moderate operating parameters under which we can have the maximum transition of the compounds from the raw material to the extractant occurs, namely: temperature - 31 ^{0}C, pressure - 73.8 MPa. It is non-toxic, has high chemical resistance, in addition to CO_2 - the extractant has a high diffusion coefficient due to its low viscosity and low surface tension, so the wetting and penetration stage of the raw material matrix is faster, which helps to reduce the extraction time compared to using classic extractants [70]. Since the use of an organic solvent is minimal for carrying out critical extraction, this technology is referred to as environmentally friendly. CO_2 is a cheap, safe and easy-to-use raw material. However, the high capital cost of the factor of production limits its use on an industrial scale [39].

Dietary fiber, pectin, are protein are included in biologically active substances contained in potato pulp (Table 1). Therefore, their extraction and concentration in order to produce nutritional supplements from cheap and readily available raw materials is relevant today.

2.6.1 Dietary fiber

It is a class of organic compounds consisting of a mixture of oligosaccharides and polysaccharides, for example, cellulose, hemicellulose, pectin, resistant starch, lignin and other non-carbohydrate components [71]. The benefit of these compounds to humans is the reduced risk of heart disease, diabetes, obesity, and some forms of cancer [72]. Depending on their ability to dissolve in water, dietary fiber is classified as soluble (pectin, resin, mucus and soluble hemicellulose) and insoluble (cellulose, lignin, insoluble hemicellulose).

Soluble dietary fiber is characterized by the ability to lower glycemic index and blood cholesterol levels. Insoluble dietary fiber refers to porous compounds that are inert to the body's metabolism, but are characterized by the ability to increase fecal volume and decrease intestinal transit [73]. Usually soluble dietary fiber gives a better structure and taste to foods, as opposed to insoluble, so they are easier to use in the food industry [74].

Potato pulp is a source of pectin, cellulose and hemicellulose, which is why it is a potential source of cheap raw materials for the extraction of dietary fiber with a content of up to 50%.

Usually extraction or solubilization of dietary fiber from raw materials begins with the removal of starch and protein. The removal of starch is usually carried out by treatment with α-amylase, which in the future may adversely affect the extraction process. The effect of α-amylase on starch is significantly reduced due to the presence of cellulose, hemicellulose and pectin, namely, it inhibits the swelling and gelatinizing ability of starch grains. This in turn leads to poor hydrolysis efficiency and, as a consequence, poor separation of dietary fibers [74].

The solution to this problem was achieved by the use of fermentation. Cheng *et al.*, [74], proposed to use cellulase, oxylonase or a combination of them before solubilization to weaken the cellulose and hemicellulose bonds with potato starch grains from potato pulp, which in turn increases the yield of dietary fiber by up to 31.9% (w/w), 25.7% (w/w), and 39.7% (w/w).

2.6.2 Pectin

It is a complex macromolecular polysaccharide found in the primary cell walls and in the middle of the plates. It is made of homogalacturonan (HG), ramogalacturonan I (RG-I) and ramogalacturonan II (RG-II). HG is a linear polymer consisting of α- (1, 4) - bound galacturonic acids and is the main domain of pectin [10]. Remains of galactic acid in the main chain homogalacturonan can be methylated in C-6 and acetylated in O-2 and/or O-3 bonds. According to the degree of methylation, pectin is classified as a pectin with a high content of methoxylated groups (DM > 50%) and a pectin with a low content of methoxylated groups (DM < 50%) [8].

The RG-I portion consists of 100 repeating disaccharide units ([→ 4) - α-D-GalpA- (1 → 2) - α-L-Rhap- (1 →]), but 20 - 80% of the rhamnose residues in the main chain may be substituted by neutral carbohydrate side chains (galactan, arabinan and arabinogalactan) in the O-4 position; in addition galacturonic acids can also be acetylated in the C - 2 and/or C - 3 position [75].

Part RG-II contains at least seven galacturonic acids linked by α- (1,4) linkages in the main chain, and the lateral ones are composed mainly of carbohydrates such as apiosis, rhamnose, xylose, galactose and fructose [76].

The ratios of HG, RG-I and RG-II affect the technological properties of pectin. For example, the proportion of HG, RG-I in industrial citrus and apple pectins is 65% and 20 - 35%, respectively, while potato pectin has a significant portion of RG-II (75%), and only 20% HG. In addition, in the potato pectin RG-I is in the β- (1, 4) position. The degree of acetylation of potato pectin is about 14%, which is 7 times higher than that of industrial citrus pectin (2%) and 3.5 times that of apple pectin (4%) [77]. Citrus and apple pectin in the food industry, most commonly used as gel-forming ingredients due to their high methylation, high molecular weight and high HG content. In comparison, potato pectin has more acetylated groups and side chains of neutral carbohydrates, but the proportion of HG is shorter than that of citrus and apple pectins, and therefore, potato pectin has no gelling ability [10].

However, studies of Leroux *et al.*, [78], and Funami *et al.*, [79], have shown that acetylated groups and side chains of neutral carbohydrates have a positive effect on the emulsifying properties of pectin. Thus, the unique structure of potato pectin allows you to use it as an emulsifier. However, little attention is paid to the properties of potato pectin, which limits its use in the food industry [10].

Alkaline, acid and enzymatic methods are used to extract pectin from potatoes, apples, sugar beets, cocoa husks. However, for the production of pectin from potatoes it is necessary to use such a method that would be fast, had the maximum yield of pectin with high molecular weight and degree of esterification, which will allow to make it on an industrial scale with high technological properties.

A group of scientists Yang *et al.*, [10], investigated how organic and inorganic acids affect the release of pectin from the pulp. They investigated the effects of HCl, H_2SO_4, HNO_3, citric and acetic acids. Previously, to remove starch and protein residues, the pulp was treated with thermostable α-amylase and 85% ethyl alcohol, and then dried and ground. The prepared pulp was diluted with water, brought to pH = 2.04 ± 0.02 using the appropriate acid and heated, and then treated with ethyl alcohol of various concentrations. The resulting pectin was dried with a sublimator. As a result of studies, scientists have determined that the maximum yield of pectin (14.34%) was obtained using citric acid, less - HNO3 (9.83%), HCl (9.72%), H_2SO_4 (8.38%), and the least - from acetic acid (4.08%).The highest rates of methylation (37.45%) and acetylation (15.38%) of pectin were obtained using acetic acid, for which (galactose + arabinose)/rhamnose is 33.34, indicating the presence of a highly branched RG-I fraction.

Enzymatic solubilization studies of potato marrow pectin fractions, type galactan RG-I, have been carried out. The release of high-molecular-weight pectin polysaccharides from potato pulp was performed using a multicomponent pectinase preparation of *Aspergillus aculeatus*. They noted that enzymatic treatment of the pulp for one hour at pH 3.5 and 62.5 ^{0}C really increases the yield of dietary fiber, namely galactose and uronic acid [6].

As already mentioned, potato pulp contains protein from 1 to 4 g/L, in addition pure protein is 50% [80], which has high nutritional properties due to the presence of lysine [81, 82]. Potato proteins are usually divided into three major fractions, namely, patatin, protease inhibitors, and high molecular weight proteins [83, 84]. Together, all three of these fractions have beneficial properties: low allergenicity [85], high antioxidant activity [86], and ability to model lipid metabolism [87].

Patanin, known as glycoprotein, is a homogeneous group of isoforms with a molecular weight in the range of 39 to 45 kDa [88]. The use of patanin as a food ingredient is of high biological value due to its similarity to egg white [89]. Patanin has a foaming agent [16], emulsifying [89] and the ability to gel [90]. Therefore, this raw material is not only the object of production of feed, but the raw material for the manufacture of protein additives.

Protease inhibitors belong to the heterogeneous group, they are classified depending on the molecular weight, which ranges from 5 to 25 kDa, amino acid composition and their inhibitory activity [91]. Six major groups of protease inhibitors have been identified: potato inhibitor I, potato inhibitor II, potato aspartate protease inhibitors, potato cysteine protease inhibitor, potato Kunitz-type protease inhibitor, and potato carboxypeptidase inhibitor. It has been shown that each group has several useful properties. Thus, protease inhibitors I and II, potato cysteine protease inhibitor and Kunitz type have antimicrobial activity [63], whereas protease inhibitors form unstable foams and emulsions compared to patine [82].

In industry use the traditional technique of protein extraction from potatoes, which is a combination of intense thermal (100 °C) and acid (pH 4.5 - 5) processing [92]. Such conditions lead to protein denaturation as the patatin begins to coagulate at 45 °C and protease inhibitors denature within 55 - 70 ^{0}C [89].

In researches of Andersson *et al.*, [93], Bártova *et al.*, [83], Kamnerdpetch *et al.*, [94], and Løkra *et al.*, [95], different extraction methods were studied for the extraction of potato proteins, which combined a combination of heat and acid treatment. For example, Bártova and Bárta, [83], claim that during the deposition of proteins, ammonium sulfate ($(NH_4)_2SO_4$) increases their yield, moreover, by increasing the concentration of the precipitant, the protein yield increases, while Waglay *et al.*, [84], emphasize the opposite of concentration, reaching a maximum yield of 98%. Therefore, improving the methods of protein extraction from potatoes is an important task for scientists and industry.

From the studies Partsia *et al.*, [80], that have been confirmed Waglay *et al.*, [96], proved that the complexing compound carboxymethylcellulose requires a pH adjustment to 2.5, which is between the pKa value of the polysaccharide and the isoelectric point of the protein, which facilitates their interaction.

A method for the extraction of undenatured proteins from potato pulp was proposed by Waglay *et al.*, [96]. According to their research, before protein extraction, it is necessary to destroy polymers that encompass the protein. First, the starch is removed using α-amylase from *Bacillius licheniformis*, and then fermentation of the cell wall of the pulp using polygalacturonase and endo-β-1,4-galactanase. Thus receive undenatured proteins with the target composition [96, 97]. Other studies Waglay and Karboune, [84], have suggested the use of a mixture of enzymes having multiple glycosylhydrolase activities. They determined that the use of Depol 670L and Ceremix 2XL provides patatin yield up to 60% and protease inhibitors up to 72%, respectively. In addition, the advantage of this method is the reduction of trypsin inhibitory activity compared with the traditional, industrial method.

All in all, using modern methods of extraction of biologically active substances from the potato pulp allows obtaining a high yield of protein, dietary fiber and pectin. Also, using pulp as a recyclable material helps reduce the cost of producing food additives and eliminates the problem of recycling it.

2.7 Other ways of using potato pulp

Other scientists have been working on the issue of potato mousse, turning their attention in another direction. Thus, in work Obidziński, [98], states the prospect of using potato pulp as an environmentally friendly solid fuel (pallets). The pallets were formed in three steps using the SS-3 installation. The scientist suggested firstly the potato pulp was dried to a moisture content of 35% by mass and crushed. Then moisten the dried pulp to a moisture content of 40 - 45% by weight and heat.

In the third stage, prepared in this way pulp was pressed. The result is a solid environmental fuel for which in the dry state the heat of combustion is 16.33 MJ/kg, and the thermal conductivity - 15.41 MJ/kg. Thus, Obidziński, [98], proved that the pulp is a material with high energy performance.

Currently developed methods of using potato pulp in the technology of production of low-fat sausages, chips, pasta, and bakery products.

Thus, homogenized and heat-treated pulp at a temperature of 85 ^{0}C, as a source of dietary fiber, added to the meat, which helps to strengthen the structure of ready-made fat-free sausages. Bengtsson *et al.*, [99], proved that this is due to the high content of insoluble fiber, which creates a fibrous mesh without interfering with the framework of meat proteins. Also, the addition of cereals to low-fat sausages allows for high yield of products due to low technological losses, namely water.

The use of potato waste in pasta technology makes it possible to create products for celiac patients. Bastos *et al.*, [100], suggested using either dried or extruded pulp instead of wheat flour. The result is spaghetti with a positive structure and high organoleptic characteristics.

Cao *et al.*, [101], proved that the replacement of wheat flour with potato pulp in the production of breads contributes to the development of energy-efficient and cost-effective technologies for the production of bakery products with improved nutritional value. Thus, made bread, enriched with 30% and 50% enriched pulp, has a significantly lower specific volume and elasticity, while its hardness, on the contrary, increases compared to bread made without the addition of pulp. However, an important effect of this technology is that as a result of the replacement of wheat flour with potato pulp, the amount of fast-digested starch and glycemic index of the finished product is reduced.

Partial substitution of wheat flour for potato pulp in deep-fried snack technology contributes to a 24% reduction in finished lipid content. In addition, such snacks received a positive organoleptic evaluation from consumers [102].

Thus, the use of new technologies for the production of potato-based foods creates positive conditions for the development of the agro-industrial complex by reducing the environmental impact and promoting the production of special or functional and/or healthy food. But in our opinion, too little attention is paid to the issue of waste-free production of potato starch and the development of such technologies. This may be due to the high humidity of the potato pulp, which promotes rapid microbial deterioration and therefore requires special storage conditions.

3. Conclusions

- Thus, the production of potato starch contributes to the fact that the waste of its production, in the form of potato pulp, is accumulated in large quantities, and therefore their disposal is an important issue for humanity. A review of the latest developments has shown that it's use in the production of biogas, adsorbents, biologically active substances, ethanol, and more, not only solves the issue of environmental protection, but also allows the use of cheap and valuable, in its chemical composition, raw materials.
- Although there are contradictions in the literature on this issue, namely concerning the cost-effectiveness of potato pulp processing. Some scientists claim that its processing significantly exceeds the cost of the obtained yield of various nutrients that can be used to obtain additional resources - valuable food, feed and technical products that are then used in various fields. While others emphasize the opposite. In our opinion, an important issue in this problem is the correct and rational way to extract the desired biologically active components from the pulp, and especially - the selection of the necessary microorganisms or acids for the complete extraction of biologically active components before or during fermentation. Many authors have achieved significant results in this regard.
- Some of the technologies have already been put into practice and are showing positive results. Thus, the pulp is used in the production of microbial biomass, animal feed, and biogas. However, there is little information on the use of potato pulp as an ingredient on an industrial scale in food production technologies. Scientists are suggested to use this raw material in technologies of production of low-fat sausages, chips, pasta, and bakery products. However, in our opinion, pulp is a promising raw material (fresh, dried, extruded

aggregate) for the production of other foodstuffs and can either completely or partially replace potatoes in the production of snacks, flour - in the production of long cookies, soybeans - in the production of meat products and etc. However, such technologies require additional research and analysis.

- In addition, a promising area of application of potato pulp is the use of methods of its mixed utilization, i.e. a combination of fermentation and physico-chemical processes. Wang *et al.*, [103], and Klingspohn *et al.*, [56], basked this question, but in general there is little in the literature. In our opinion, this area is one of the most promising, since it will allow the maximum use of potato waste.

4. References

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