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Review Article

POTATO (SOLANUM TUBEROSUM L.) AS A RICH SOURCE OF NUTRIENTS AND BIOACTIVE COMPOUNDS: A REVIEW

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Abstract: The potato is the basis of the human diet in most countries of the world and has a significant impact on human health. Therefore, the aim of the work was to draw attention to the potato as a source of nutrients and energy as well as bioactive compounds and to use them in human and animal nutrition, in pharmacy, medicine and cosmetology. A quantitative analysis of the scientific literature indicating the beneficial effect of potato in the daily diet was carried out. The search for nutrients and bioactive compounds was based on the Scopus database. Potato tubers have a strong prebiotic effect, as they lower the pH in the intestinal environment and have an immunomodulatory effect. These properties of potato are the basis for its use in the treatment of many diseases such as diabetes, obesity, hypertension, diseases of the nervous system and cancer. In addition, potato normalizes lipid metabolism disorders by lowering elevated cholesterol levels; is helpful in the treatment of type II diabetes by reducing elevated glucose levels; facilitates slimming processes (reduces body weight) and lowers the level of uric acid. Potato also has an immunostimulant effect, improving metabolism (in disorders of lipid metabolism), while in diseases of the cardiovascular system it regulates heart rhythm disorders, and is also used in limitingthe development of some malignant types of cancer. Prevents many chronic infectious diseases; chronic fatigue states; disorders of the intestinal microflora and the immune system.

Keywords: Potato, Nutrients, Bioactive Compounds


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Dedication to Dear and Honorable Professor P.D. Gupta: "Wisdom is great and unfading:Those who love her will easily see her and those who seek it find it,for it anticipates those who desire it by first making itself known to them. Whoever gets up at dawn for her will not get tired,for he will find her sitting at his door."

INTRODUCTION

Potato is one of the main crops in the world, next to corn, wheat and rice, due to its nutritional and economic importance, ensuring food security in the world, especially in Asia and South America [1]. In terms of the amount of protein produced per hectare, potato ranks second, after soybean, among the main crops and the first in terms of energy (5600 kcal m-3) and protein production in the water reservoir (150 g m^{-3}) [2,3]. A single potato tuber provides 50% of the recommended daily intake of vitamin C, 21% potassium, 12% fibre and balanced protein [4], compared to rice and wheat [1]. In the "Feed the world" mission, which consists in engaging in the production of responsible food for the growing world population (in 2050, the number of people to be fed will increase to 9.8 billion), it is necessary to take into account not only their economic, energy and nutritional value, but primarily health-promoting values, as well as medicinal properties of potatoes. Potato tubers should therefore be treated not only as a functional, health-promoting, gluten-free, non-allergenic food, and its protein should be used for the production and enrichment of bread and other products in order to obtain their better nutritional value, but also as a medicinal plant, useful in the pharmaceutical industry for production of drugs, extracts, as well as a filler for tablets. This species is used in the treatment of many diseases, such as: anemia, arthritis, burns, allergic rash, skin irritation, dehydration of the body; gastritis and gastric ulcers. In addition, it has analgesic properties. It inhibits glycosuria, polyuria and polydipsia, and is also used in limiting the development of some malignant types of cancer [4,5]. According to Schwingshackl et al. [6] consumption of one serving of boiled or baked potato tubers a day prevents the occurrence of hypertension and stroke. Vinson et al. [7] showed that after consumption of boiled tubers with purple flesh, there was an increase in the antioxidant capacity of plasma and urine, while refined potato starch caused its decrease, which may indicate the pro-oxidative effect of the potato. In addition, it was observed that diastolic blood pressure decreases by approx. 4.3%, which means a decrease of 4 mm, and systolic blood pressure decreases by 3.5%, i.e., approx. 5 mm. Potato has a number of pharmacological activities, such as: antioxidant, anti-cancer, anti-allergic, anti-bacterial, anti-inflam-matory, anti-ulcer activity [8,9]. It is known, however, that mashed potatoes or French fries cause high glycaemic and insulin reactions. However, in most meals, potatoes are accompanied by other dishes, and adding high-fat (canola oil), high-protein (chicken breast) and/or vegetable salad to the meal reduces the glycaemic response of the body and the risk of developing diabetes [2,10]. Although diet may be the only or even the main factor in disease prevention, there is a clear role of nutrients and other bioactive compounds in the development of diseases, especially chronic ones [8,11,12]. Therefore, the aim of the work was to demonstrate the nutritional, health-promoting and medicinal properties of potato. An alternative research hypothesis assumes that the nutritional and energy value of potato as well as bioactive compounds contained in tubers affect its use in human nutrition and the prevention of many diseases as well as in the treatment of many diseases, against the null hypothesis that the nutritional and energy value and bioactive compounds of potato do not affect human nutrition and health.

MATERIALS AND METHODS

In order to demonstrate and prove that the potato is a rich source of nutrients and bioactive compounds affecting human health, a quantitative analysis of the rich scientific literature was carried out, indicating their beneficial effect in the daily diet. The search for this group of compounds was based on the Scopus database using the search title – summary – keyword (bioactive compounds, minerals, potato). All publications that mentioned these words or their derivatives in the title, abstract or keywords were then identified in the search strategy [13]. The "Analysis" and "Create citation report" functions of the "Scopus" web platform were used for key analyses. Complete records and cited references ere exported to VOSviewer [13] for administrative processing. The terms used in the titles were then analysed. papers, abstracts, publications and keywords were analysed using the VOSviewer program [13]. As a result of the search, one hundred and eighteen publications from the period from 1990 to 2023 were used.

Nutritional and energy value: The potato should be promoted around the world as a low-calorie food with a high content of nutrients necessary for a balanced diet. Contrary to the prevailing opinion, potato tubers are low in calories and easily digestible, they are not fattening. The caloric value of a potato is low (50-90 kcal) and comparable to the energy value of an apple (54 kcal) or milk (62 kcal), and 3-5 times lower than a wheat roll (278 kcal), 10 times lower than chocolate (563 kcal) [5]. The daily energy requirement of an adult should be covered in 50-65% from carbohydrates, in 25-30% from fats and in 10-15% from protein. A properly balanced diet requires vitamins, trace elements, fibre and bioactive substances. The main carbohydrate in potato is starch. Consuming complex carbohydrates makes you feel full. Potato starch is digested slowly and only a small amount is converted into fat [2,4,14,15]. Potato can be classified as a functional food, as it can contribute to reducing the risk of type 2 diabetes and help in the fight against obesity. The energy value of 100 g of potato tubers or processed potato products depends on the method of potato preparation, and so: early young potatoes – 9 kcal, late potatoes – 5 kcal, potato dumplings – 147 kcal, potato dumplings – 10 kcal, pancakes / potato pancakes – 257 kcal, fries –331 kcal, chips – 552 kcal (16). Potato tubers boiled in water, fried, baked, prepared in the form of puree, have a much lower energy value than cereal seeds, legumes and their processed products [4].

The caloric value of cooked tubers does not exceed 90 kcal in 100 g of the product. 100 g of corn flakes have about 380 kcal, wheat bread 280 kcal,

Table 1. Chemical composition of potato tubers in 100 g of their fresh weight.

Chemical compositions	Content [in 100 g]
Calories (energy value)	77 kcal / 322 kJ
Protein	2.02 g
Total fat	0.09 g
Saturated fatty acids	0.026 g
Monounsaturated fatty acids	0.002 g
Polyunsaturated fatty acids	0.43 g
Omega-3 fatty acids	0.010 g
Omega-6 fatty acids	0.026 g
Carbohydrates	17/47 g
Dietary fibre	2.20 g
Vitamin A	2 I.U.
Vitamin D	0 I.U.
Vitamin E	0,01 mg
Vitamin K	1.9 µg
Vitamin C	19.7 mg
Vitamin B_1	0.080 mg
Vitamin B_2	0.032 mg
Vitamin B_3 (PP)	1.054 mg
Vitamin B_6	0.295 mg
Folic acid	16.0 µg
Vitamin B_{12}	0.0 µg
Pantothenic acid	0.296 mg
Calcium	12.0 mg
Iron	0.78 mg
Magnesium	23.0 mg
Phosphorus	57.0 mg
Potassium	421.0 mg
Sodium	6.0 mg
Zinc	0.29 mg
Cooper	0.12 mg
Manganese	0.15 mg
Selenium	0.3 µg
Fluorine	~
Cholesterol	0.0 mg
phytosterols	5.0 mg

(Source: own based on USDA [21])

chocolate 563 kcal. A potato with a low starch content (10-12%) has only about 50-55 kcal, while a potato with a higher starch content (>16%) – about 80 kcal per 100 g. Baked tubers have a higher energy value (93 kcal per 100 g) and cooked, skinless (86 kcal per 100 g), than raw (79 kcal per 100 g) and cooked in their jackets (78 kcal per 100 g) [2, 15, 16]. Potato tubers, compared to rice and popular groats, have much better-quality indicators [5].

Chemical composition of tubers: The quality of potato tubers is primarily related to their chemical composition. The most important feature of the chemical composition of potato tubers is the dry substance content. Its amount depends on the genetic characteristics of the varieties and environmental conditions. The dry matter content of tubers ranges from 17.0 to 25.7%, depending on the variety [17, 18]. The nutritional value of potato tubers is largely due to their chemical composition, and above all to the ingredients that are important in human nutrition (starch, total sugars and reducing sugars, protein, dietary fibre, vitamins, minerals) and the low content of harmful compounds (glyco-alkaloids, nitrates pesticide residues) [5,16,19,20] (Table 1).

Carbohydrates: The main component of potato dry matter is starch. Potato starch is starch obtained from potatoes. The tuber cells of the potato plant contain starch grains called leucoplasts. Starch is composed of two major glucose polymers: amylose, which contains α-linked (1--> 4) chains to several thousand glucose units, and amylopectin, which is highly branched (with α (1--> 6) and α (1--> 4) linkages) and can contain more than 100,000 glucose residues. Amylose is mostly unbranched, but may contain some long branches, which are more common in potato tuber starch than in cereal and potato starches. Typical starch consists of approximately 20-30% amylose and 70-80% amylopectin, although mutations in the biosynthetic pathway can affect the ratio of amylose to amylopectin. Due to the presence of small amounts of branching in amylose, precise determination of the ratio of amylose to amylopectin is difficult due to the presence of the hybrid material. Amylose and amylopectin are stored in specialized plastids called amyloplasts, in the form of well-organized granules of various sizes and shapes that depend on the starch source (Figure 1). Observation of the starch granules under a polarized light microscope reveals a characteristic Maltese cross birefringence pattern, indicating a high degree of molecular order in the starch granules. Starch grains have a semi-crystalline structure with amorphous areas, which are growth sites [18, 21, 22].

A single starch grain consists of four levels of organization: amylopectin cluster (0.1-1 nm), lamina (~10 nm), block (20-250 nm) and whole granule (>1 ìm). Amylopectin molecules are very tightly arranged, forming clusters of double helices. The crystalline lamina is formed by the fusion of amylopectin double helices interspersed with alternating amorphous regions. The block thus consists of an ordered aggregation of several crystalline amorphous lamellae forming an asymmetric structure with an axial ratio of 3:1 (referred to as "normal blocks"). Amylose and other ingredients (e.g., water, proteins, lipids) interfere with the regular formation of clots, causing "defects" ("defective blocks"). This ordered aggregation of normal and defective blocks forms concentric rings of hard (crystalline) and soft (semi-crystalline) layers in the starch granule (Figure 2) [23].

Starch under the influence of digestive enzymes (amylase) is broken down in the digestive tract to glucose, which is absorbed in the duodenum and small intestine. It is then fractionated into two types of polymers: amylose and amylopectin [18]. Normal starch contains about 20-30% amylose and 70-80% amylopectin. Starch gelatinizes during hydrothermal treatment [24]. In this form, it is practically completely and quickly digested. This causes a rapid rise in blood glucose levels. The measure of the size and speed of glucose accumulation in the blood as a result of carbohydrate digestion is the Glycaemic Index (GI), which is a numerical indicator for comparing the increase in blood glucose after consuming 50 g of carbohydrates contained in a given product, with the increase in glucose after consuming 50 g of pure glucose (taken as 100) at the same time. A GI greater than 70 is considered high, and less than 55 is considered low. Potato belongs to the group of elevated GI, similarly to rice [4,25] and has a high glycaemic index (95), which means that after consuming 50 g of potato, the glucose level can increase by as much as 95% [25,26]. However, there are various ways to reduce this indicator. An example of this may be pre-cooking and reheating or cooling down processed potatoes and reheating them [27]. Thanks to these processes, the starch in potatoes is converted into a more accessible one. The effect of eating foods with a low glycaemic index is to improve satiety, improve blood glucose control in people with diabetes, reduce blood lipids, as well as increase fermentation in the large intestine [28].

The sugar content is an important characteristic of the quality of the edible potato. The sum of sugars (total sugars), which consists of sucrose, glucose

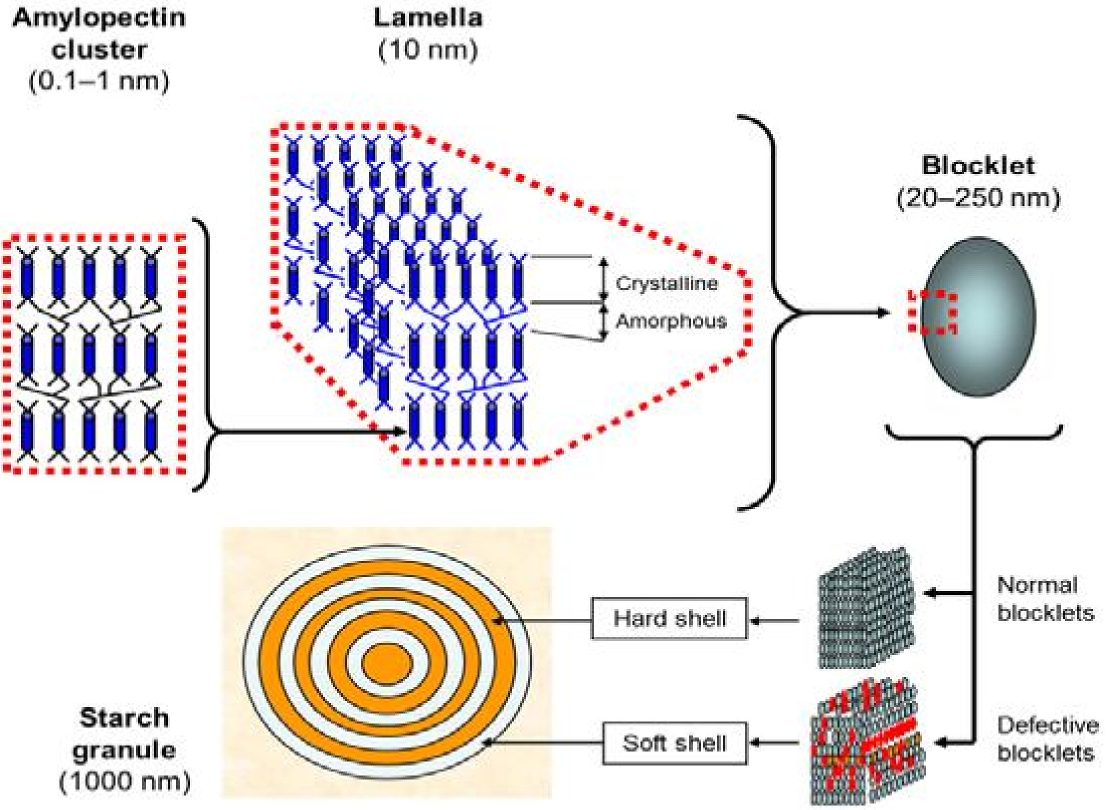

Fig. 1. A schematic illustration of levels of organization of the starch granule. Source: own adapted from Taiz et al. [2015]

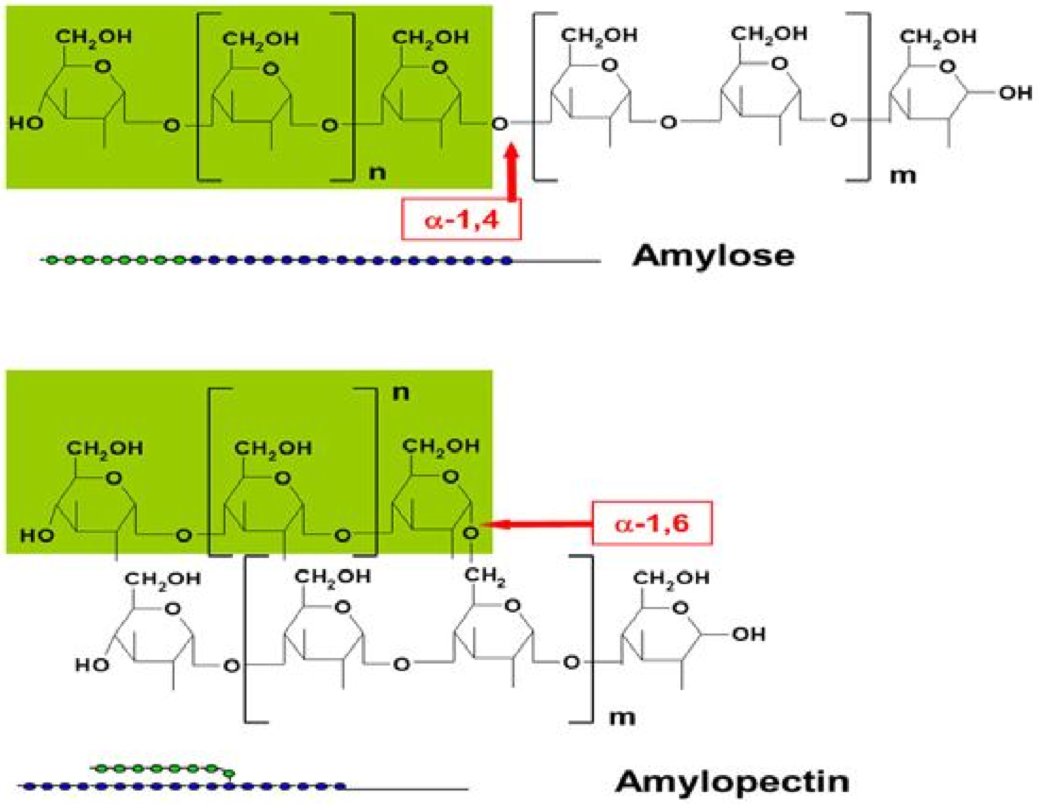

Fig. 2. The chemical composition of starch. Source: own adapted for Taiz et al. [23]

and fructose, is important. The level of sugars in a potato tuber is conditioned by genotype, environmental conditions and storage [29-31]. Reducing sugars are substrates of the Maillard reaction (carbonyl-amine reaction), which results in the formation of brown compounds in potato products subjected to thermal treatment, such as frying and drying. As a result of this reaction, dangerous acrylamides are formed [4,32]. In potato tubers there are also insoluble non-starch substances of potato, which are mainly components of cell walls (cellulose, hemicelluloses, lignin's, etc.). They form the so-called dietary fibre in the amount of up to 2.3% of the tuber weight. It is resistant to digestive enzymes, but has no energy value. However, it is essential in food, "diluting" nutrients, which makes it easier for digestive enzymes to access them. It also improves intestinal motility and adsorbs bile acids and toxic heavy metals [33,34]. The tubers also contain the so-called insoluble non-starch substances, primarily components of cell walls, such as: cellulose, hemicelluloses, lignin's, etc. they form the so-called dietary fibre.The content of dietary fibre in potato tubers is 2.0-2.3%. It is resistant to digestive enzymes and therefore has no energy value. However, in food, it is necessary to "Thinn" nutrients, thereby making them easier for digestive enzymes to access. Fiber improves intestinal peristalsis and adsorbs bile acids and toxic heavy metals. Some of its components act as a prebiotic for probiotic microorganisms in the large intestine [34]. Eating too little fibre can make it harder to control your blood sugar, as dietary fibre (DF) regulates the rate of digestion and contributes to the feeling of satiety. Fiber can move food through the intestines too quickly, which means that less minerals are absorbed than with food. It can also cause bloating and cramping, especially when fibre intake increases overnight. The recommended amount of DF depends on age and gender. For men under 50 years of age, DF intake is about 38 g of fibre per day, for women – 25 g [21]. People who have recently undergone gastrointestinal surgery or suffer from digestive disorders such as Crohn's disease, diverticulitis or ulcerative colitis can follow a low-fibre diet. In these cases, the daily intake of fibre is limited to 10-15 g, which is much less than the recommended norm for healthy adults. Low-fibre potato products, including potato pancakes, slow down the rate of digestion, reduce the amount of stool in the intestines, and allow the intestines to rest. Potato tubers boiled or baked until tender and then blended have a low fibre content and can be accepted in a low-fibre diet (without the skin) [32]. According to the USDA [21], one serving of peeled potatoes contains 3.2 g of dietary fibre, just over half the fibre you get from a large baked potato with its skin intact.

Table 2:. Comparison of nutritional value of different proteins.

Specifications	WAO/CS	WBB/BV	WBN/NPU
Potato	57-69	65-94	60-73
Wheat	30-49	66	45-51
Soybean	42-48	64-80	61-64
Casein	54	80	67-72
Beef	69	70-75	68-79
Poultry meat	59-63	77	68-77
Eggs	100	90-95	89-94

(Source: own based on [23]; WAO/CS — Chemical Score; WBP/BV – Biological Value; WBN/NPU – Net Protein Utilization)

Protein: In the fresh weight of potato tubers, protein is present in the amount of 1.7-2.3%, of which 35-68% is true protein, also referred to as "pure" protein [5,15,31]. According to USDA data [21], the protein content in 100 g of fresh raw potato tubers is 2.14 g, and after cooking, in "uniforms" – 2.86 g. It contains all essential amino acids, is rich in lysine and leucine. This protein is unique because it combines favourable texture indicators with the lack of lactose, as well as it does not have allergenic properties. The American Potato Research Association recognized potato protein as excellent, giving many possibilities of use, including for: increasing the volume and improving the texture of food products (e.g., bread), for gelling and food enrichment. The high Oser index – EAA – Essential Amino-Acid Index, characterizing potato protein in terms of amino acid composition, indicates that it is similar in quality to chicken egg protein [16]. Table 2 compares the values of biological indicators of proteins of several selected food products and potato protein [23].

The values of three indices were compared: WAO/CS (Limiting Amino Acid Index to Chemical Score) dependent on the exogenous amino acid, which is present in the smallest amount in the protein of a given product, compared to the protein standard, causes a reduction in the use of other protein amino acids, WBP/BV (Biological Value of Protein/Biological Value), expressed as a percentage of nitrogen substances assimilated by the body, and WBN/NPU (Biological Value of Nitrogenous/Net Protein Utilization), which determines the amount of retained nitrogen in the body of young rats. The high value of potato protein and its amount are necessary to maintain the human nitrogen balance. It is comparable to the amount of animal protein. In the case of whole egg protein, this amount is 0.51 g per 1 kg of body weight per day, while for potato protein this amount is 0.55, for milk protein – 0.568, for bean protein – 0.667, and for wheat protein – 0.901 [5,23]. Due to the high consumption of potato tubers per person in many European and Asian countries (over 100 kg/person/year), the protein contained in them plays an important role in human nutrition [1,32].

Proteins are used to build new cells and rebuild worn out cells and tissues (without their participation, growth and development of the body, tissue renewal, resistance to diseases, and wound healing are not possible). They are the basic component of blood, they are part of the immune system, enzymes that catalyse biochemical changes and body fluids, they are also involved in regulating blood pressure and maintaining the acid-base balance [35, 36]. Protein deficiency in the body is much less harmful than its excess. Excessive consumption of protein threatens the occurrence of many serious diseases. It can also cause weight gain, dehydration, increased risk of fractures, digestive problems, headaches and kidney damage [37-39].

Fats: The fats present in potato tubers are characterized by beneficial nutritional properties, as they contain unsaturated fatty acids. Potato tubers contain bioactive lipid compounds, such as fatty acids, glycolipids, phospholipids, sterols, tocols and carotenoids, which are highly desirable in the diet due to their health-promoting effects. Due to its high consumption, potato may be an ideal carrier of these health-promoting phytochemicals. The total lipid (TL) content of potatoes is 0.1-0.5ÿ fresh weight of tubers. Most of the lipids are found in the space between the skin and the vascular ring of the tuber, therefore, in thickly peeled potatoes, the content of this nutrient is even lower. In addition, potato tuber lipids are mainly composed of glycolic phospholipids (PL, 47%) and galactolipids GL, 22%), which are structural components of biological membranes, as well as neutral lipids (NL, 21%), such as: acylglycerols and free acids fatty. More than 94ÿ of the lipids in tubers are in the form of esterified fatty acids [40,41]. Tuber lipids consist of 21.6% of galactolipid, 6.4% of esterified stearyl glucoside, 1.3% of sulfoxide, 2.4% of cerebroside and 15.4% of triglyceride [40]. Major lipids and part of triacylglycerol TAG are bound to cell membranes. The fatty acid composition of potato tubers reflects the composition of cell membranes [41]. The composition of fatty acids isolated from potato tubers is nutritionally beneficial. The main part is formed by reactive polyunsaturated fatty acids FA PUFA with one to three double bonds, mainly linoleic acid and linolenic acid (70-75%), precursors of volatile compounds. Typically, lipids are extracted from potato starch granules [18]. PSt fatty acids occur in the following order: C16: 0 > Cl8: 2 > C18: 3 >C18: 1. The fatty acid profile of the cold extract therefore contains a high level of saturated fatty acids FA SFA (42.1%) [41].

Vitamins: An important component of tubers, from the nutritional and therapeutic point of view, is ascorbic acid, which together with dehydroascorbic acid constitutes vitamin C [31,42,43]. Plants have the ability to biosynthesise this compound, most likely due to the presence of a catalysing enzyme – galactonolactone dehydrogenase. Vitamin C is very biologically active. It takes part in many important reactions and transformations, stimulating various biochemical processes in the body [44]. Thanks to its very good solubility and active transport, it is absorbed by the body in about 70-80%. In addition, thanks to its antioxidant properties, it plays a protective role in diseases of the heart and blood vessels [45]. Factors favouring the process of vitamin C decomposition include: elevated temperature, presence of oxygen, neutral or alkaline environment, presence of oxidizing enzymes, presence of metal ions such as iron, copper and silver [46]. Its amount ranges from 14 to 30 mg·100 g^{-1} fresh weight of tubers [16]. The vitamin C content changes during processing (microwaving (<33%), baking (<51%) and frying (<67%), cooking (<88%). According to the USDA [21], the content of vitamin C in raw tubers is 5.7 mg·100 g^{-1}, and in roasted tubers – up to 12.8 g·100 g^{-1}. This content in tubers of American varieties ranges from 79 to 363 mg kg^{-1}, in Indian varieties – 104-170 mg, Canadian – 88-241 mg, Norwegian – 84-201 mg and 160-460 mg mg kg^{-1} fresh weight of tubers – in the case of Korean varieties [31,47]. Vitamin C helps in the metabolism of tyrosine, folic acid and tryptophan, as well as in the metabolism of cholesterol, increasing its elimination and thus lowering blood sugar levels. 200 g of potato covers the daily requirement of an adult human body for vitamin C – in about 50%, B6 – in 25%, and other vitamins – in 10-15% [46]. Most of the vitamins contained in potatoes are soluble in water, so potatoes should be peeled immediately before thermal processing, which should last as short as possible, and cooked in a small amount of salted water to reduce the loss of nutrients [2,33]. According to the USDA [21], its amount in raw tubers is 5.7 mg·100 g^{-1}, and in roasted tubers – 12.8 mg·100 g^{-1}. In the climatic and soil conditions of Central and Eastern Europe, the concentration of vitamin C in potato tubers ranges from 6.0 to 30.0 mg100 g^{-1} of their fresh weight [5,21,47]. Vitamin C is the strongest antioxidant, a water-soluble antioxidant, also playing an important role in neutralizing the activity of free radicals, which are mainly formed during frying, smoking and storage. Antioxidants contained in potato can be used in the treatment of cancer, inflammation and pain, as well as in the treatment of bacterial and viral diseases [2,3,47].

In addition to vitamin C, potato tubers also contain significant amounts of B vitamins, which include: B1 (Thiamine), B2 (Riboflavin), B6 (Niacin, Pyridoxine), B9 (folic acid), B12 (cobalamin) [48]. According to the USDA [21], the content of these vitamins in raw tubers is at the level of 0.033-1.035 mg·100 g^{-1}. Goyer and Haynes [49], analysing the thiamine content, showed its even four-fold increase between individual potato varieties, while Dong et al. [50]

Table 3: Comparison of energy and nutritional value of potato, rice and selected groats

Specification	Early potato	White rice	Buckwheat groats	Millet groats	Barley groats
Calories /energy value	69 kcal/ 289 kJ	344 kcal/ 1440 kJ	336 kcal / 1407 kJ	346 kcal/ 1449 kJ	334 kcal/ 1398 kJ
Protein	1.8 g	6.7 g	12.6 g	10.5 g	8.4 g
Total fat	0.1 g	0.7 g	3.1 g	2.9 g	2.0 g
Carbohydrates	16.3 g	78.9 g	69.3 g	71.6 g	74.9 g
Dietary fibre	1.3 g	2.4 g	5.9 g	3.2 g	5.4 g
Vitamin A	1 I.U.	0 I.U.	0 I.U.	0 I.U.	22 I.U.
Vitamin C	16 mg	0 mg	0 mg	0 mg	0 mg
Vitamin B1	0.068 mg	0.052 mg	0.541 mg	0.421 mg	0.191 mg
Vitamin B2	0.047 mg	0.027 mg	0.127 mg	0.290 mg	0.114 mg
Vitamin B3 (PP)	1.43 mg	0.82 mg	1.95 mg	4.720 mg	4.604 mg
Vitamin B6	0.26 mg	0.17 mg	0.67 mg	0.4 mg	0.260 mg
Zinc	0.33 mg	1.73 mg	3.5 mg	3.4 mg	0.92 mg
Phosphorus	52 mg	135 mg	459 mg	240 mg	181 mg
Iodine	3.0 mg	2.2 mg	0 mg	0 mg	0 mg
Magnesium	24 mg	13 mg	218 mg	100 mg	45 mg
Copper	0.09 mg	0.17 mg	0.41 mg	0.78 mg	0.18 mg
Potassium	415 mg	111 mg	443 mg	220 mg	228 mg
Calcium	4 mg	10 mg	25 mg	10 mg	20 mg
Iron	0.5 mg	0.8 mg	2.8 mg	4.8 mg	1.9 mg

(Sources: own adapted on [4, 5,21]).

proved that in potato plants its level increased six times. Thiamine deficiency generates increased oxidative stress by a decrease in the concentration of endogenous antioxidants, including reduced glutathione (GSH) [51]. The recommended dose of thiamine ranges from 0.5–2.2 mg/day, depending on age and body weight [52].

Niacin, also called vitamin B3 or vitamin PP, is a compound of nicotinic acid and its amide. It is necessary for the proper functioning of the body. Vitamin B3 can be synthesized by the human body from the exogenous amino acid – tryptophan (1 mg of niacin is produced from 60 mg of tryptophan), but often in insufficient amounts [53]. Therefore, it is recommended to take niacin with food, and if necessary, supplement it appropriately. In the human body, niacin has many important functions, primarily it is necessary for the proper functioning of the brain and peripheral nervous system. Nicotinamide is involved in the metabolism of proteins, lipids, nucleic acids and carbohydrates, as it is a precursor of coenzymes (NAD and NADP) that are part of oxidoreductases [54]. Niacin is also responsible for the synthesis of sex hormones, thyroxine and cortisol. It regulates the level of cholesterol (reduces the concentration of bad LDL and triglycerides in the serum) and sugar (takes part in the synthesis of insulin) [55]. Niacin also improves the condition of the skin and hair, dilates blood vessels, improves blood circulation, participates in the formation of red blood cells and has a positive effect on the human mental state [53]. The increased content of niacin, according to Sansano et al. [56] is of interest in the potato processing industry because it reduces acrylamide formation in processed potato products and preparations. Vitamin B9 (folic acid) deficiency is a global nutritional problem even in developed countries. The coefficient of variation of this vitamin in potato tubers is about 60% [57,58]. Vitamin B9 plays an important role in the metabolism of amino acids and nucleic acids, it is an important component in the hematopoietic and nervous systems [59]. It participates in the prevention of cardiovascular diseases (participation in lowering homocysteine levels) [58]. The main sources of vitamin B12 in the diet are products of animal origin, but also fermented vegetables (e.g., produced by fermentation of soybeans) and some algae [60]. Cobalamin is an organic chemical compound well known primarily in combating anaemia and optimizing the work of the brain and the entire nervous system [61].

Vitamin B12 is involved in the construction of DNA nucleic acids, and probably also in the bone marrow. It is one of the most important B vitamins, so its level should be periodically controlled. Its effect on the nervous system is known, which ensures less fatigue and greater vitality [62]. Potato contains minimal amounts of both vitamin B9 and B12. It is important to balance your diet and consume a variety of foods to get the full spectrum of vitamins and nutrients [5].

Minerals: The nutritional value of potatoes, apart from proteins, carbohydrates and vitamins, is also determined by the content of minerals, which, after being digested and absorbed into the blood, are used by the body as a source of energy and a building material or a factor regulating life processes. Potato tubers contain from 0.5 to 2.0% of minerals, such as: potassium, phosphorus, magnesium, calcium, sodium, chlorine, manganese, copper, zinc, iron, iodine and others (Table 3).

They are particularly rich in potassium, which affects the ionic and water balance of the body [63]. 200 g of potato covers up to 30% of the daily requirement for this element. Potato consumption in the amount of 200 g partially covers the body’s need for molybdenum (up to 100%), iodine (20%). chromium (50%), selenium (20%), fluorine (15%), magnesium (15%), iron (15%), copper (12%) and phosphorus (12%). During the cooking of the tubers, there is some loss of these elements, which end up in the decoction (15,16). 200 g of potato covers up to 30% of the daily requirement for this element [18, 24]. When potato tubers are boiled in water, potassium losses reach 33% of its content [14,15]. These losses do not occur in the case of potato baking. Potato consumption in the amount of 200 g partially covers the body’s need for molybdenum (up to 100%), iodine (20%), chromium (50%), selenium (20%), fluorine (15%), magnesium (15%), iron (15%), copper (12%) and phosphorus (12%). During the cooking of potatoes, there are some losses of these elements, which end up in the broth [2, 31-32].

Nitrogen is one of the macroelements that are present in relatively large amounts in all living organisms, it is a component of not only proteins, but also other biologically important compounds, including: nucleic acids and nucleotides, porphyrins, plant hormones, secondary metabolites, as well as energy carriers e.g., ATP. Nitrogen deficiency in the human body causes a disturbance of the nitrogen balance and, as a result, weight loss and enema. In addition, long-term nitrogen deficiency can cause necrosis and cirrhosis [64]. An important mineral component of potato is phosphorus, which plays an important role in the ion and water management of the body. Consumption of 200 g of potato covers up to 30% of the daily requirement for this element [16]. According to USDA research [21], the content of phosphorus in tubers is 5.5 $g \cdot kg^{-1}$ and is reduced during their cooking or baking. According to Zarzecka and G¹siorowska [65], the concentration of phosphorus in potato tubers is at the level of 1.9-2.0 g kg^{-1}, according to Sienkiewicz et al. [66] " 2.9-3.0 g kg^{-1}. In experiences. with several dozen cultivars, Walworth and Muniz [67] found from 2.1 to 5.0 g P kg^{-1}, and according to Tekaligna and Hames [68] it was at the level of 4.0-4.7 g P kg^{-1}. Phosphorus is essential for plant growth and is found in every living cell of the plant. He deals with photosynthesis. storage and transfer of respiratory energy, cell division and enlargement. Supports early root formation and growth. It improves the quality of fruits and roots [69].

It is known that P is an essential component of photosynthesis processes that systematically contribute to the formation of sugars, oils and starches, and also help convert solar energy into chemical energy, ensure proper plant maturation and prevent stress [70]. This element is closely related to homeostasis and to the formation of bones and teeth, and to most metabolic activities in the body, including kidney function and cell growth [5,71,72]. Deficiency of this element causes bone pain, irregular breathing. Fatigue, anxiety, numbness, skin sensitivity and changes in body weight [73].

According to USDA data [21], the amount of potassium in raw tubers is approx. 41.7 g kg^{-1} and changes during cooking. The concentration of this element in boiled, skinless tubers was about 32.8 $g \cdot kg^{-1}$, in roasted tubers – 39.1 $g \cdot kg^{-1}$, and in "uniform" tubers – 40.7 $g \cdot kg^{-1}$. In the research of Zarzecka et al. [74], the potassium content was at the level of 15.0-16.6 g kg^{-1}, and according to Bolig³owa and Dzienia [75], this concentration was slightly higher (27.5 g kg^{-1} in dry matter, while in leaves – 27.5 g kg^{-1}). This element plays an important role in photosynthesis and food production. It controls the enzymatic activity of the human body. It acts as a catalyst in about 60 plant enzyme systems. It regulates water transport and reduces the negative effects of salt in plants. It is helpful in the transport of prepared food from the leaves to the rest of the plant [63,76].

Magnesium deficiency in potato plants reduces photosynthesis by reducing the formation of chlorophyll, reducing the accumulation of carbohydrates, mainly starch, reducing the formation (formation) of tubers and reducing their yield [68]. Deficiency of this element is associated with aging and age-related disorders, mainly as a result of insufficient dietary intake [76]. Recent findings have shown that increasing intake of this mineral helps protect people from chronic diseases such as diabetes, metabolic syndrome, hypertension and several cardiovascular diseases where a low Mg diet can contribute to insulin resistance, especially when the deficiency is combined with a high-fructose diet [77].

Calcium, in turn, plays an important role in plant growth and human health. Plants use Ca^{2+} to strengthen cell walls, neutralize vascular anions and protect against stress [78]. If membrane-bound calcium levels are reduced, membranes may leak, leading to loss of cell salts and organic compounds [79]. The content of calcium in potato tubers is conditioned by cultivar properties, soil, weather conditions during the growth period and agricultural practices, including mineral fertilization [74]. Transpiration is the main driving force for calcium transport in plants. Hence, calcium moves with the water in the xylem. Organs with low calcium carrying capacity, such as tubers, suffer from calcium deficiency. Poorly conductive tubers store much less calcium than leaves and stems. Calcium deficiency in tuber tissue is even greater in the case of potatoes grown in sandy soil due to the very low level of water-soluble Ca in these soils [80]. In addition, with irrigation and rain, the water-soluble Ca is often washed away. Calcium is also an essential component important for human health, participating in the biological functions of several tissues (musculoskeletal, nervous and cardiac systems, bones and teeth, thyroid). In addition, Ca may participate in the reaction of enzymes (oxidation of fatty acids, mitochondrial ATP carrier) [81].

Iron (Fe) is the fourth most abundant element in the earth's crust, but about 30% of the world's arable soils are classified as Fe-poor [82]. The main cause of Fe deficiency is that Fe exists mainly in the form of water-insoluble hydroxides and oxides that are not bioavailable for uptake by plant roots [83]. Other factors affecting iron deficiency are: soil salinity, low temperature, high pH, presence of carbonates, high humidity, high concentration of nitrates, interactions of Fe with other soil minerals [5,83- 85]. Reduced availability of Fe2+ causes chlorosis, stunted growth, reduced quality and yield, and a decrease in the nutritional value of many plants (86,87). Iron participates in the processes of cellular respiration, protein synthesis and DNA biosynthesis. Iron is also an important component of haemoglobin, myoglobin and hemi enzymes. Iron deficiency causes anaemia as well as metabolic, circulatory and nervous disorders (88).

Manganese (Mn) is an essential mineral that plays a key role in several physiological processes, in particular photosynthesis. Deficiency of this element is a common problem, occurring most often on sandy, organic soils with a pH above 6.0 and heavily weathered. It is also aggravated by cold and humid conditions [89]. This element is a nutrient found in plant tissue in amounts from 10 to 500 mg kg^{-1} and more. In most plants, the deficiency of this component occurs at the level of 10 mg kg^{-1}, and when the concentration exceeds 300 mg kg^{-1}, it is considered toxic [90]. Manganese is an element necessary for the proper functioning of the human body, where it is an activator of many enzymes involved in cholesterol metabolism and energy production, which control the metabolism of glucose and other sugars [91].

Copper (Cu) is a heavy metal, but at the same time a microelement necessary for the proper metabolism of all living organisms. Copper ions are part of about 30 enzymatic and non-enzymatic proteins, including such important proteins as: cytochrome C oxidase (one of the main proteins of cellular respiration), ceruloplasmin, Hephaestion (iron oxidase), â-dopamine hydroxylase (production of neurotransmitters), superoxide dismutase (strong antioxidant), tyrosinase (melanogenesis), and lysis oxidase (production of collagen and elastin) [90]. The daily human diet should contain 2–3 mg of Cu, and the consumption of 200 g of potatoes covers up to 30% of the daily demand for this element. Cu uptake by plant roots is an active process influenced mainly by the form of copper. Copper is most readily available at a pH of 6.0 or lower. Most sources report Cu availability in soils with a pH above 7.0. An increase in soil pH then results in a stronger binding of Cu to the soil [92]. Copper deficiency can lead to premature aging or a reduction in chlorophyll levels, and in the final stage also a reduction in yield [90]. Copper deficiency in the human body reduces the level of copper-dependent enzymes, which leads to anaemia, various neurological disorders, muscle weakness and blood pressure disorders [93,94].

Zinc is closely related to the nitrogen metabolism pathway, causing an increase in protein synthesis with zinc fertilization. Thus, zinc is an essential micronutrient for plant growth and plays an important role in the catalytic part of several enzymes [90]. Zinc deficiency affects root growth, resulting in reduced water and nutrient uptake from the soil, leading to reduced plant growth, nutrient composition, and yield [95]. Potato is sensitive to zinc deficiency. Zinc also affects the immune system in humans and is critical for the function of over 300 biological enzymes [96]. Symptoms of Zn deficiency cause stunted growth, diarrhoea and pneumonia in children, and Zn deficiency contributes significantly to recurrent infections and infant mortality [97].

Boron is a microelement necessary for the proper growth of plants, because it performs important metabolic functions and therefore a deficiency of this element causes root growth disorders, which hinders the absorption of water and nutrients. It also impairs photosynthesis. Boron deficiency can lead to reduced production of chlorophyll, which affects the plant's ability to carry out photosynthesis and can lead to poor plant growth and reduced production of assimilates. The lack or deficiency of boron also causes disorders in reproduction and fruiting. Deficiency of this element can cause abnormal flower morphology, e.g., shorter pistils, which affects the process of pollination and fruiting. This may lead to a smaller number and deterioration of the quality of potato fruits [90]. This can lead to uneven development of potato tubers, with smaller tubers compared to healthy plants [98]. Boron is an important trace element for the metabolism of minerals necessary for building healthy bones. Boron deficiency can lead to malabsorption and utilization of these minerals, which can contribute to bone weakness and increase the risk of osteoporosis. Boron is also involved in hormonal regulation, including the metabolism of oestrogen and vitamin D. Boron may have a positive effect on brain function, including memory, concentration and motor coordination. It has anti-inflammatory properties and can affect the regulation of the body's immune response. Boron deficiency can contribute to increased inflammation in the body, which can have negative health consequences, such as an increased risk of chronic diseases [99].

More research is needed to better understand the impact of macro- and micronutrient deficiencies on plant and human health. However, to ensure an adequate supply of these elements, it is recommended to consume a variety of food sources, such as fruits, vegetables, nuts and whole grains, which can provide these macro- and micronutrients [90, 95, 97, 99].

Bioactive compounds: with purple flesh is characterized by significantly In the human diet, vegetables and fruits play an important role due to the presence of nutrients such as: dietary fibre, minerals, vitamins and non-nutritive phytochemicals: phenolic compounds, flavonoids, bioactive peptides, etc. Eating foods containing large amounts of calories, animal protein, sugar, fatty acids deprived of vegetables and fruits increases the risk of diseases such as diabetes, obesity, hypertension, diseases of the nervous system, cancer [100]. The most important bioactive components in the human diet are: polyphenols, carotenoids, lycopene, tocopherols and phytosterols [101]. Most of the world's cultivated potato varieties are varieties with white, cream or yellow flesh. Currently, there is a growing interest in varieties with red, blue or purple flesh, which are the source of anthocyanins, polyphenolic compounds with confirmed pro-health and antioxidant activity. Health-promoting compounds in potatoes with traditionally coloured flesh include phenolic acids, ascorbic acid, carotenoids, tocopherol and selenium, and in potatoes with coloured flesh also anthocyanins, kynurenic acid (KYNA), phenolic acids, coloured compounds with high antioxidant potential [8, 102]. Kita et al. [31] proved that the 'Provita' cultivar higher levels of kynurenic acid (KYNA), phenolic acids and amino acids than the 'Ismena' cultivar with yellow flesh. In addition, the variety with purple flesh is characterized by 40-66% lower content of total glycoalkaloids (TGA). Such varieties are a potential raw material for the production of food with an increased content of bioactive compounds. Phenolic acids present in potato tubers, such as: chlorogenic, ferulic, syringic, gallic, protocatechuic, coumaric and vanillic acids; flavonoids (quercetin, catechin, kaempferol, and myricetin) and anthocyanins (cyanidin, delphinidin, malvidin, pelargonidin, peonidin, and petunidin) help reduce cardiovascular disease and cancer [31,103,104]. The beneficial effects of anthocyanins in cardiovascular diseases, as reported by Dong et al. [104] consists in inhibiting inflammatory processes, endothelial dysfunction and nitric oxide production. Anthocyanins can also keep blood pressure stable by regulating vasoconstriction in the body, thereby reducing the incidence of cardiovascular disease [105]. The content of phenolic acids and anthocyanins depends on the potato variety. Brown et al. [106] showed that potato varieties with coloured flesh, compared to varieties with white flesh, contained 186% more antioxidants and 3-4 times more phenolic acids. Yellow-fleshed varieties, on the other hand, are rich in lutein and zeaxanthin, and according to Brown et al. [106] provide up to 10 times more carotenoids than their white-fleshed counterparts. The content of phytochemicals was also assessed by Oertel et al. [107]. These authors found significant correlations between some metabolites, including a negative correlation between the main anthocyanins of red and blue potato varieties, which was associated with better regulation of the expression and activity of hydroxylases and methyltransferases. In addition to the phenolic compounds found in tubers, saponins are also present, which play a key role as anticancer agents [108]. There are many groups of saponins. such as: cyclooctanes, Amaras, oleates, lupines and steroids, showing a strong anticancer effect on various types of cancer. For example, cycloartenol saponins have anticancer properties in human colon cancer cells [109], and lupines in liver cancer cells [110].methods of potato processing allow to effectively reduce the content of these unfavourable substances [15,111].

Others compounds: Potato plants also contain unfavourable components, such as: nitrates, glycoalkaloids, heavy metals, aflatoxins, pesticide residues [16,31,111]. However, appropriate methods of potato processing allow to effectively reduce the content of these unfavourable substances [15,111].

According to Rytel [112], the content of nitrates in potato tubers ranges from 100 to 740 mg $NaNO_3$.kg^{-1}, on average 150-300 mg $NaNO_3$.kg^{-1}, with an acceptable level of 200 mg.kg^{-1} of fresh weight. The content of nitrates and nitrites depends on the genetic characteristics of the variety, the date of harvest, fertilization and meteorological conditions in the years of research. Toxic nitrites (III) in potato tubers occur in trace amounts, in the order of 0.0-0.5 mg $NaNO_2$ 100 g^{-1}, and the permissible dose is 0.2 mg.kg^{-1} of human body weight and the lethal dose – 2- 9 g for an adult [112, 113]. Nitrates themselves are not toxic. However, there is a possibility of reducing them by the intestinal microflora to nitrites, with the participation of which carcinogenic nitrosamines can be formed. On the other hand, nitrates and nitrites in the digestive tract inhibit the growth of pathogens. Although the potato belongs to the group of plants with a low tendency to accumulate nitrates, some varieties have a particularly strong genetic predisposition to accumulate this form of nitrogen in tubers. On average, potato tubers contain 0-300 mg of NO_3^-. kg^{-1} of fresh mass, however, high doses of nitrogen and unfavourable conditions during the growing season may increase their concentration even to 1200 mg kg^{-1} of fresh mass. Most nitrates accumulate under the skin or in the skin itself, so as a result of domestic or industrial potato processing methods, the nitrate content can be reduced by up to 80% [16,31,112].

Thioglycosides are a group of chemical compounds present in potatoes that are responsible for their characteristic taste and smell. They belong to the class of sulphate compounds, the most famous being sodium thiocyanate (NaSCN) or potassium thiocyanate (KSCN). The main thioglycoside compound in potatoes is S-methyl thiocyanate (SMTC), which is formed as a result of an enzymatic reaction between ethylene glycoside and sulphate [114]. Thioglycosides are safe to consume in adequate amounts, but may affect the taste and quality of potatoes. When potato tissues are damaged, enzymes called thiosulfates release thioglycosides, which when in contact with other ingredients can produce a characteristic sulphur smell, often described as “potato” or “sulphurous”. Some people may be sensitive to this smell and taste, and in rare cases it may cause allergic reactions. In the process of cooking or baking potatoes, thioglycosides are partially degraded, which can reduce the intensity of the sulphur smell. There are also differences between different potato varieties in terms of thioglycoside content, which affects the taste and aroma of cooked potato tubers [114, 115].

Heavy metals such as lead, cadmium, mercury, copper and zinc may be present in potatoes in small amounts. Most of these metals come from the soil in which potato plants grow, and their presence may be caused by environmental pollution or the use of fertilizers and pesticides containing these metals [111, 116]. The heavy metal content of potatoes can be monitored and regulated by relevant authorities and regulations to ensure food safety [116].

SUMMARY

The direct proof of the high nutritional value of the potato is the content and biological quality of the substances contained in the tubers. Potatoes are easy to digest and the compounds they contain are easily absorbed. They contain almost no fat (approx. 0.1%) and provide low calories (on average 77 kcal in 100 g). In addition, they have alkaline properties, thanks to which they balance the acid-forming effect on the body of the meat with which we usually serve them. They also provide almost all vitamins - most of them contain vitamin C. Potato tubers contain a small amount of vitamins A, B1, B2, B3, B6 and PP. Although there are not many of them, but - since we eat potatoes often and in large quantities – they are an important source of them. In addition, potato tubers contain fibre, which facilitates digestion, helps in the fight against overweight and lowers cholesterol. They have little protein (2%), but when supplemented with wholesome animal protein, it will be put to good use. In developed countries, already about 60% of potatoes are consumed in processed form. This is due to a change in the lifestyle of consumers who prefer greater convenience and security [48,57,111,117]. Potato processing plants require the supply of raw materials with specific biochemical and morphological characteristics (e.g., for the production of crisps and fries, tubers must have a high specific density, low content of simple and reducing sugars) [4, 16, 30]. Anti-nutritional substances are present in potatoes in very small amounts. They are mostly located in the skin and directly under it, thanks to which most of these substances are removed during cooking. The potato does not accumulate harmful compounds from the polluted environment. Potato tubers, which are part of a varied and well-balanced diet, can alleviate symptoms or improve health parameters in some diseases (heart, kidney diseases). They can also improve digestive health and fight the signs of aging. Potatoes are also filling, which means they can help you lose weight. Valuable health-promoting properties of potato, including a low glycaemic index, which means that it causes a lower increase in blood sugar levels compared to other sources of carbohydrates [4,34,118]. In addition, it contains many nutrients such as fibre, vitamins and minerals that may have health benefits. Therefore, the potato may be of great use in the future in the pharmaceutical industry for the production of drugs and dietary supplements. There are studies on the potential applications of the potato in the pharmaceutical industry, such as: the production of natural active ingredients, as well as anti-inflammatory, anti-hypertensive, anti-obesity, anti-hyperlipidaemia and anti-cancer drugs [118]. In addition, potato starch is often used as a filler in the production of pharmaceutical tablets and dietary supplements, as it is easily absorbed by the human body and does not cause allergic reactions. The nutritional value of a potato may vary depending on the variety, method of preparation (cooking, baking, frying) and additives, such as butter or cream. To maximize the health benefits of potatoes, it is best to eat them cooked or baked, without added fat or excess salt [4, 118].

CONCLUSION

Potato is a rich source of carbohydrates, fibre, vitamin C, minerals and bioactive compounds. There is an increased demand for organic potatoes and the growing use of potato tubers in processing for the production of chips, French fries, potato haberdashery, starch syrup or potato flour. In the "Feed the World" mission, aimed at producing responsible food for the growing world population, potatoes are very important due to their nutritional value, health-promoting properties and potential use in the pharmaceutical industry for the production of medicines and dietary supplements. Potato is also important in the treatment of many diseases, because it has analgesic, anti-inflammatory, antihypertensive, antihyperlipidemic and anticancer properties. It also exhibits anti-obesity properties and is used as a satiety stimulant, as well as in reducing the development of certain types of cancer. Various phytonutrients in potato tubers play a vital role in improving the health of the digestive system, including the intestines. Recently, colourful potato varieties with blue, red and purple flesh have become popular, not only because of their originality, but above all because of their high nutritional and health-promoting values. Cell culture, animal and human studies have shown that potato tubers are a healthy food.

The challenge for the future is to develop improved potato varieties that will provide food for the entire world and reduce the use of environmentally harmful chemicals. Research on the health-promoting properties of dietary fibre is also important. Some of these properties are already explored, while others require further research. The effects of using different fibre fractions may vary, but they are also reproducible. The fibre supply itself is important because of its specific health benefits. Potato starch varieties are of great importance not only for the industry, but also for the human diet. Therefore, it is extremely important to constantly educate the public and remind them of the importance of food products in a well-balanced diet.

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