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Review

Jerusalem artichoke (*Helianthus tuberosus* L.) as a medicinal plant and its natural products

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Abstract: Identifying the nutritional and health properties of *Helianthus tuberosus*, and learning more about this valuable species. It is believed that increased consumption of Jerusalem artichoke (JA) products is related to low blood pressure. One of many questions to answer is whether supplementation of inulin and inulin derivatives obtained from *Helianthus tuberosus* tubers and aerial parts can be used as antidiabetic, anti-carcinogenic, anti-fungistatic, anti-constipation, body mass-reducing, metabolism-improving agents. We ran a search in Medline, Web of Science, Scopus, Agricola, EBSCO - Food Science Source, Europe PMC, PBL, Cochrane Central Register of Controlled Trials until March 2020. We also browsed reference lists of articles and previous reviews. No language limitations were applied. Jerusalem artichoke (JA) has multiple applications thanks to its rich chemical composition, resistance to biotic and abiotic factors, as: functional food, bioactive ingredient, raw material for the production of ethanol and butanol, succinic, citric and lactic acid. It can be used in medicine and the pharmaceutical industry, because it contains anti-fungistatic, anti-carcinogenic and antioxidant components, and the production of the raw material is easy and inexpensive. It also lowers high cholesterol, triglycerides and high glucose levels; facilitates weight loss; detoxes the organism (e.g. alcohol, heavy metals, radionuclides); lowers uric acid levels; has immunostimulating properties; protects the gastric mucosa, prevents constipation; prevents acne; improves metabolism in lipid disorders; reduces body mass; has cytotoxic properties in breast cancer. It also helps in cardiovascular diseases, chronic infectious diseases; chronic fatigue syndrome; gut flora disorders; immune system disorders. A number of Jerusalem artichoke-derived products were discussed.

Key words: Jerusalem artichoke; Bioactive ingredients; Medicinal use; Pharmaceutical use; Probiotics; Prebiotics; Functional food.

Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) from the *Asteraceae* family is characterised by good freezing and draught tolerance, high resistance to pests and plant diseases. For years, it has been cultivated as a valuable edible plant with strong medicinal properties. In folk medicine, the leaves are used to treat bone fractures and pain. *Helianthus tuberosus* tubers are rich in inulin, protein and other bioactive ingredients and are used to produce functional food ingredients (1-5). A lot of bioactive compounds were also isolated from the aerial parts, which have antifungal, antioxidant and anti-cancer properties. So far, JA has been used to produce food or fodder (6-7). For the last two decades, it has found alternative applications in the production of functional food ingredients, such as: inulin, oligofructose, fructose (1, 4, 5, 9-11). In recent years, there have also been numerous animal experiments in order to assess the health properties of *Helianthus tuberosus*. Therefore, the species has a wide application in pharmacy and medicine, e.g. by lowering glucose level in plasma, lowering total cholesterol and triglycerides. It is also a valuable alternative source of prebiotic compounds (8, 12). Some bioactive ingredients can be extracted from leaves and stems, offering additional applications in the pharmaceutical industry (6, 7, 13-15). Those various applications and low cultivation costs make Jerusalem artichoke (JA) a promising alternative species with a rich chemical composition, sensory qualities, medicinal properties and others, which increase its popularity as a raw material that can partly or completely replace scarce raw materials and broaden the offer of products, including functional food and drugs (7, 12, 16-17). Therefore, the aim of this paper was to determine the nutritional and health properties of *Helianthus tuberosus*, identify its medicinal products and learn more about this valuable species.

Systematics and biology

H. tuberosus L. belongs to the *Helianthus* genus, *Asteraceae* family, *Asteroideae* subfamily of the *Heli-*

antheae tribe (18). The *H. tuberosus* plant produces annual thick, hairy stems filled with spongy mass, divided into nodes and internodes. Leaves are located alternately on the stem. The inflorescence is an anthodium made up of small numerous disc florets and yellow ligulate florets. The underground part of JA is highly developed and includes roots, stolons and tubers. At the ends of the underground stolons, stem tubers are formed. One plant can produce up to tens of tubers of various sizes, shapes and colours (roundish, pear-shaped, clavate or elongated, from white to red and even purple) (Figure 1) (7).

Tubers overwintered underground withstand temperatures down to -30°C (11), and even -50°C (19). In temperate climate conditions, tuber development starts in August, in the period of the fastest growth of the aerial part. They grow until November, but in case of mild winter, they can grow until spring. In a temperate climate, *H. tuberosus* L. tubers remain dormant from late autumn until spring. Dormancy reduces the *H. tuberosus* population in such climate to a single growth cycle per year (13-14, 20). Arakawa et al. (21) were characterised the responses of FSP120, also known as FSP-3, to freezing treatment by immunoblotting. Levels of FSP120 in the plasma membranes of tubers decreased after sublethal freezing, whereas no degraded products were detected in the microsomes or the soluble fraction. The amount of FSP120 in the crude extract of frozen tubers remained at a comparable level to that of the unfrozen tubers. These results suggest that FSP120 might be released from plasma membranes during freezing treatment of *H. tuberosus* tubers (21). Kocsis et al. (22) examining the response of inulin obtained from JA to frosts, found that its late varieties (e.g. Violet de Rennes, Rote Zonenkugel) obtained a similar amount (55-60% DM) as in the collection of early and medium early harvested tubers already after 29-33 weeks after planting. These authors have proved that changes in harvest time as well as changes in the frost period caused the conversion of inulin with a high polymer content to inulin with a low polymer content, as well as to sucrose. This knowledge of the different carbohydrate profiles in *Helianthus tuberosus* cultivars gives you the opportunity to choose the right cultivars and decide on the right time to harvest for optimal tuber processing for use as a prebiotic and functional food ingredient.

Yang et al. (23) ran a database search for the transcriptome of Jerusalem artichoke from the Qinghai-Tibet Plateau, resilient to unfavourable climate, with high-throughput sequencing in order to obtain important transcriptional and SSR loci information. This allowed characterization of the overall expression features of the JA transcriptome identifying the key genes involved in metabolism in this species. In turn, this offers a foundation for further research on the regulatory mechanisms of fructan metabolism in *Helianthus tuberosus*. The GO classification showed a division into three ontologies, with a total of 49 functional groups encompassing biological processes, cellular components, and molecular functions. Among them, the most heterogeneous functional groups were responsible for cellular processes, metabolic processes, and single-organism processes. 39,000 unigenes were annotated by KOG and divided into 25 categories according to their functions; the most common one being a general function. A total of over 13,800 unigenes (22%) were annotated, with the largest proportion corresponding to pathways related to carbohydrate metabolism. It was recorded that a total of 12 unigenes were involved in the synthesis and degradation of fructan. 12 unigene proteins were dispersed in the 5 major families of proteins involved in fructan synthesis and degradation. The synergistic effect of INV gene is necessary during fructose synthesis and degradation in *Helianthus tuberosus* tuber development. The sequencing data from the transcriptome of this species can provide a reliable data basis for the identification and assessment of the expression of the INV gene family members. A simple sequence repeat (SSR) loci search was performed on the transcriptome data of JA, identifying over 6,600 eligible SSR loci with a large proportion of dinucleotide and trinucleotide repeats (23, 24).

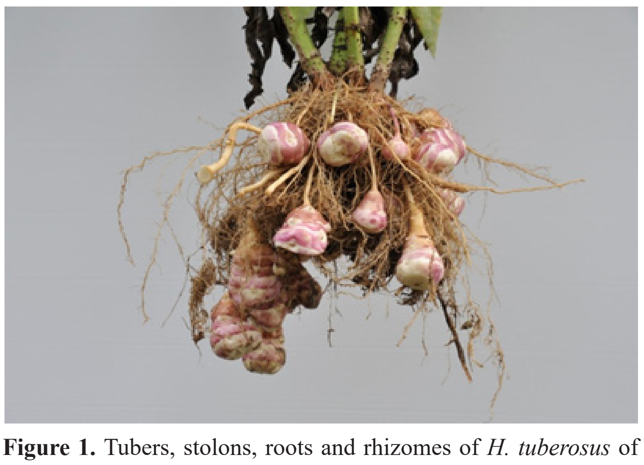

Figure 1. Tubers, stolons, roots and rhizomes of *H. tuberosus* of the Rubik variety. Source: B. Sawicka.

Chemical composition of tubers and aerial parts

The nutritional value of food products is determined by their chemical composition (Table 1). Dry matter (DM) amounts to 16.5–36.2% of *Helianthus tuberosus* tuber mass (7, 9, 25). According to other authors, DM ranges from 20.5–28.1% (25). *Helianthus tuberosus* tubers also contain carbohydrates of various structure, e.g. simple sugars, such as: glucose, fructose; double sugars: sucrose; and oligosaccharides: inulin, pseudo-inulin, galactooligosaccharides (GOS), fructo-oligosaccharides (FOS) and polysaccharides: mannans and cellulose, lignins and hemicelluloses (9, 26-30).

Moreover, tubers contain levorotatory carbohydrates, such as heliantin and sinantrin. The largest share of carbohydrates are fructans, or fructose oligomers (26, 31). They contain fructose particles linked into molecular groups by β linkages (2→1). They have various structures and chain lengths, from 3 to several hundred fructose units. At the end of the chain, a glucose molecule can be linked by an α linkage (1→2). The degree of polymerization (DP) ranges from 2 to several hundred (31-32). Fructans stored in *Helianthus tuberosus* tubers have a maximum of 50 α linkages (1→2). They include: inulin, oligofructose, fructo-oligosaccharides (FOS). Fructans have a reserve function (23). One of the most important carbohydrates is water-soluble inulin, with simple chains of fructofuranose linked by glycosidic linkages (33-35). Inulin is a name for heterogeneous collection of fructose polymers (fructans) with

Table 1. Nutritional value of 100 g fresh mass of *Helianthus tuberosus* tubers.

Specification	Quantity	Percentage of daily demand (% DV)
Water	117.02 g	N/D
Energy	110 Kcal	N/D
Energy	456 kJ	N/D
Protein	3.00 g	6.00%
Total fats (lipids)	0.02 g	0.06%
Ash	3.81 g	N/D
carbohydrates	26.16 g	20.12%
Total dietary fiber	2.4 g	6.32%
Total sugars	14.4 g	N/D
Mineral compounds		
Calcium, Ca	21.00 mg	2.10%
Iron, Fe	5.10 mg	63.75%
Magnesium, Mg	26.00 mg	6.19%
Phosphorus, P.	117.00 mg	16.71%
Potassium, K.	644.00 mg	13.70%
Sodium, Na	6.00 mg	0.40%
Zinc, namely	0.18 mg	1.64%
Copper, Cu	0.21 mg	23.33%
Manganese, Mn	0.09 mg	3.91%
Selenium, Se	1.00 µg	1.82%
Water soluble vitamins		
Witamina B1 (Tiamina)	0.30 mg	25.00%
Witamina B2 (Riboflawina)	0.09 mg	6.92%
Witamina B3 (Niacina)	1.95 mg	12.19%
Witamina B5 (kwas pantotenowy)	0.596 mg	11.92%
Witamina B6 (Pyridoksyna)	0.116 mg	8.92%
Witamina B9 (Folate)	20.00 µg	5.00%
Kwas foliowy	0.00 µg	N/D
Kwas foliowy. Żywność	20.00 µg	N/D
Kwas foliowy. DEF	20.00 µg	N/D
Cholina	45.00 mg	8.18%
Witaminββαa C (kwas askorbinowy)	6.0 mg	6.67%
Fat soluble vitamins		
Vitamin A, RAE	2.0 µg	0.29%
Vitamin A, IU	30.0 IU	N/D
β-Carotene	18.0 µg	N/D
Vitamin E (α-tocopherol)	0.28 mg	1.87%
Vitamin K (phylloquinone	0.20 µg	0.17%
Lipids		
Monounsaturated fatty acids. together	0.006 g	N/D
18: 1 oleic acid (octadecenoic acid)	0.006 g	N/D
Polyunsaturated fatty acids. together	0.002 g	N/D
Linoleic acid 18: 2 (octadecadienoic acid)	0.002 g	N/D

Source: Sawicka (7)

*Percent Daily Demand (% DV) is based on a diet of 2,000 calories. Daily values (DVS) may vary depending on your daily caloric needs. The values provided are recommended by the US Department of Agriculture. Calculations were based on an average age of 19 to 50 years and a body weight of 88 kg.

a length of 10–12 molecules. They contain both oligomers and polymers, best characterised with the degree of polymerization (DP). It contains β-D-fructofuranose molecules linked by β-2,1-glycosidic linkages. The chain also includes a α-D-glucopyranose or β-D-fructofuranose molecule (32, 36, 37). Inulin content in *Helianthus tuberosus* ranges from 14–25% of fresh tuber mass (36, 38-40). Inulin is a fructan and a valuable prebiotic reducing the development of pathogenic bacteria in the intestines and facilitating the functioning of bifidobacteria capable of enzymatic hydrolysis of the β-1,2-glycosidic linkage (16, 36). Inulin molecules are varied, like starch, and can contain more or less fructose. In the process of partial hydrolysis of inulin with the use of enolase, oligofructose is obtained. The degree of polymerization of the oligofructose chain is from 2 to 10 (41). Unlike starch and cellulose, which are glucose polymers, inulin can be used as: source of nutrition, fructose, FOS (fructo-oligosaccharides), ethanol, prebiotics, sweeteners and hydroxymethylfurfural − a source of synthesis of many valuable drugs, pigments and other compounds (12, 30, 34, 36). Inulin has a mild sweet taste and a very low glycemic index, so products containing inulin can be consumed by diabetics and dieters. Inulin in human body is hydrolysed to fructose, which can be safely used by diabetics thanks to a different metabolic pathway as compared to glucose, utilised only in the presence of insulin. It belongs to food ingredients referred to as prebiotics (31, 34, 42-44). Thanks to β-glycosidic linkages, it is resilient to hydrolysis by digestive enzymes in the small intestine, because human body does not have the enzymes to decompose such linkages. Therefore, inulin transfers in an unaltered form to the large intestine, where it becomes a substrate for the desired gut flora – bifidobacteria (5, 31, 37, 44-45). Almost the entire inulin is fermented by the colonic microflora (*Bifidobacterium* sp. and *Lactobacillus* sp.). The products of fermentation are short-chain fatty acids (acetic, propionic, butyric), lactic acid and gases (carbon dioxide, hydrogen, methane). Short-chain fatty acids reduce the development of harmful bacteria, e.g. *Salmonella* and *E. coli*. Therefore, this polysaccharide is categorised as a soluble fraction of dietary fibre. A prebiotic effect is observed after an intake of 10 g of inulin per day, with an average daily inulin intake in Europe estimated at 3–11 g, and in the US 1–4 g (31, 36). The degree of polymerization of inulin as well as the presence of branching are very important, because they greatly enhance its functionality. Plant inulin DP is generally low (max. <200) and changes depending on cultivars, weather conditions and the physiological and chronological age of the plant. The degree of polymerization of inulin obtained from *Helianthus tuberosus* tubers can be equal to inulin extracted from chicory roots or even higher (16, 36). A lot of research was conducted on refined prebiotics, such as inulin or fructo-oligosaccharides (FOS) as nutraceuticals, but there is very little information on the prebiotic potential of products rich in inulin and FOS, such as *Helianthus tuberosus* L. Samal et al. (12) conducted a research in order to assess the prebiotic activity of *Helianthus tuberosus* tubers on rats. Their results confirmed that JA has a positive influence on immunity, blood metabolites, intestinal morphometry and gut fermentation in rats.

Another soluble fraction of fibre are fructo-oligosaccharides (FOS), inulin derivatives. The amount of FOS and the degree of polymerization in inulin depend on the stage of plant growth (46). FOS are stored in shoots, until they are rapidly transferred to tubers in late autumn (27, 46). So, the harvesting time is optimised based on yield size and the content of sugars in tubers as well as easily fermentable sugars in the stem (26). Fructo-oligosaccharides with DP 3–10 can be divided into short-chain with DP DP 3–5, and long-chain with DP 6–10. Short-chain FOS include include 1-kestose (DP 3), nystose (DP 4) and fructosyl-nystose (DP 5) (29, 31). It was found that *Helianthus tuberosus* tubers contained 1-kestose and nysnose. Fructans are synthesised by combined activity of at least two different fructosyltransferases. At the initial stage, sucrose is converted to 1-kestose with the participation of 1-fructosyltransferase, called sucrose-1-fructosyltransferase (1-SST). The chain of 1-kestose is further elongated in the presence of fructans: fructan 1-fructosyltransferase, called 1-FFT, leading to an increase in the length of oligofructose chains from DP3 to DP15 (31, 37). 1-FFT demonstrated a relation to fructans with a low degree of depolarisation (31). Florkiewicz et al. (26) tested the content of fructans with results between 41.4–50.5 g $\cdot$100 g^{-1} of DM, depending on the harvesting time of tubers. In tubers from the autumn harvest, the content of fructans was 50.3 g $\cdot$ 100 g^{-1} of DM, whereas in tubers from the spring harvest – on average 42.9 g $\cdot$ 100 g^{-1} of DM. The degree of polymerization changed during the overwintering of tubers underground. A significant part of the macromolecular fraction, with a degree of polymerization DP>10, is transformed into a micromolecular fraction with a degree of polymerization DP=3–5 (37). While tubers are overwintered in soil, additional development of medium-chain fructans and sucrose takes place, necessary for the regulation of the osmotic pressure in cells (28). A high content of fructans in *Helianthus tuberosus* tubers is usually accompanied by a low concentration of simple sugars. Unripe tubers usually contain small amounts of fructose and glucose and only traces of sucrose, whereas ripe tubers contain much more – from 8.0 to 14.8% of DM. Overwintered tubers differ in terms of glucose concentration by 30% as compared to tubers harvested in autumn (26, 27, 30).

Fibre content in *Helianthus tuberosus* tubers ranges from 11.4–20.8 g 100 g^{-1} of DM (1, 28). The main components of fibre are: cellulose, hemicellulose, pectin, and lignins accompanying cellulose, yet built not of monosaccharides but of phenylpropan alcohol (47). Hemicellulose makes up only 0.7% of tuber DM (36). Jerusalem artichoke (JA) is rich in fibre and pectins (3.5 g$\cdot$100 g^{-1} of DM), and contains more of them than roots of other known species (7). According to Florkiewicz et al. (26), the average content of dietary fibre in *Helianthus tuberosus* tubers is 16.4 g$\cdot$100 g^{-1} of tuber DM. The substances contained in dietary fibre have multiple positive effects on human body: they increase intestinal peristalsis, decrease the absorption of cholesterol and some toxic substances in the digestive system (the so-called slagging), delay carbohydrate hydrolysis, and thus lower the blood glucose level (30). Apart from a high content of soluble fibre, *Helianthus tuberosus* tubers also contain significant amount of insoluble fibre. The content of raw fibre in fresh tuber mass amounts from 0.9 to 1.9%, that is 2.7–13% of DM (4, 7).

However, JA is noteworthy not only for the content of fructans; recent research shows that it also contains a high amount of protein, including essential amino acids (2, 3, 8, 10, 49). The majority (70%) of nitrogenous compounds contained in *Helianthus tuberosus* tubers are easily soluble (5, 10, 26). *Helianthus tuberosus* tubers contain from 2 to 3% of protein in fresh mass. In Poland, protein content in *Helianthus tuberosus* tubers ranges from 5.5–12.5 g 100 g^{-1} of DM, on average 7.6 g $\cdot$ 100 g^{-1} of DM (1, 10, 26), of which 57% represents protein nitrogen (3, 10, 50). Lyophilisate obtained by Cieślik et al. (2) is characterised by a higher protein content (6.36%) as compared to chicory (which is the main source of fructans produced on an industrial scale) or potato. Moreover, JA protein has a high biological value. Fresh tuber mass contains between 0.8–1.4 g$\cdot$100 g^{-1} of protein (1, 2). Usually, cultivars whose tubers have red skin contain more protein than white-skin cultivars (7). Protein plays a very important role in the metabolism of all living organisms. It is a component of membranes and acts as biologically active compounds (enzymes and hormones). It is also a crucial part of protoplasm and enzymes, takes part in cellular metabolism, participates in the accumulation and dissimilation of organic matter. If case a higher amount of protein was consumed than the Recommended Dietary Allowance (RDA), it was often considered harmful for kidneys and bone mineralisation. However, lately these assumptions were replaced by a new understanding of the role of dietary protein for health purposes (3, 8, 23). In their research, Danilčenko et al. (10) demonstrated that directly after harvest and during storage, the dominating exogenous amino acid is arginine and endogenous – asparagine, glutamine and alanine, whereas tyrosine and methionine showed the lowest levels. Tyrosine is undesirable in tubers due to its negative influence on the co-

Table 2. Assessment of Jerusalem artichoke sunflower protein value based on chicken egg protein standard * compared to Indian plants.

Aminoacids	Squaw-root (*Conopholis americana*)	Jerusalem artichoke	Indian bread-root (Inca bread)
Sulfur amino acids (methionine and cystine)	81**	58**	36**
Aromatic amino acids	87***	83***	94
isoleucine	92	89	77***
leucine	96	94	>100
Valin	>100	>100	92
others	>100	>100	>100
Protein evaluation	81	58	36

Own study based on: Mikos-Bielak et al. (51); Don (52), * value of each of the essential amino acids compared to chicken egg protein, adopted as 100 according to the FAO expert group, (53); ** first limited (limiting) amino acid; *** second limited (limiting) amino acid.

lour of raw tubers. Tests covered the relations between the amount of some amino acids in tubers during storage. A strong positive relation was recorded between threonine and tyrosine, glycine, phenylalanine and leucine, as well as between valine and glycine, phenylalanine, leucine and isoleucine; and between: leucine and glycine, tyrosine, as well as between phenylalanine and isoleucine (10, 49).

The assessment of *Helianthus tuberosus* protein value, as compared to Indian tuber crops is presented in Table 2. It compares the content of exogenous amino acids in JA, based on chicken egg protein model, with other valuable Indian plants. *Helianthus tuberosus* protein is mainly characterised by a high percentage of sulphur amino acids and aromatic amino acids (10, 48, 51). The nutritional value of protein can be determined by using the EAA (essential amino acid) index or identifying the CS coefficient (the limiting amino acid coefficient) (51).

The value of *Helianthus tuberosus* tubers as a raw material in food and pharmaceutical processing depends on their mineral composition. Its tubers are characterised by a high content of alkaline-forming mineral components, mainly potassium (3, 54). Sawicka and Kalembasa (3) recorded the following quantities of elements in *Helianthus tuberosus* tuber DM: 1,850 mg nitrogen, 3,210 mg potassium, 280 mg phosphorus, 1,120 mg magnesium, 89 mg calcium, 5.8 mg sodium, 1.6 mg iron, 0.3 mg copper, 5.7 mg zinc, 0.9 mg manganese, 0.001 mg cobalt, 0.018 mg nickel, 0.9 mg aluminium, 0.005 mg cadmium and 0.004 $mg \cdot 100\ g^{-1}$ lead. According to Bergmann's dietary guidelines (55), this means that *Helianthus tuberosus* tubers contain enough phosphorus and magnesium, lack in calcium and potassium, and contain an excessive amount of sodium. A thorough review of the mineral composition of tubers was provided by Jarienė et al. (20) and Catană et al. (16). The antagonism between obtaining particular elements from *Helianthus tuberosus* tubers by humans and animals causes that not only their chemical composition but also the interdependencies between the elements matter. From the nutritional perspective, the calcium to magnesium ratio is the most important. Excessive concentration of potassium in tubers is not able to make up for calcium deficiency or the optimal content of magnesium (55-56). Upon an assessment of relative proportions of minerals in tubers, Sawicka and Kalembasa (3) and Sawicka (7) were concluded that the: K:Ca, K:(Ca+Mg), Ca:Mg and K:Mg ratios deviated significantly from the approved optimum, whereas the relative proportions of K:(Ca+Mg), K:Ca, K:Mg exceeded it; Ca:Mg was be-

Table 3. Content of mineral compounds in *Helianthus tuberosus* plants ($mg\ kg^{-1}$).

Elements	Content of microelements		Average content in the plant
	in green mass	in tubers	
Co	0.3	0.3	0.2
Be	0.005	0.006	not marked
Zn	7.0	8.5	3.0
Cu	4.0	2.0	2.0
Mn	45.0	15.0	10.0
Mo	0.15	0.2	0.2
Li	0.8	0.6	0.1
Ni	2.25	1.75	0.5
Pb	0.08	0.03	0.5
B	12.5	10.0	1.0
Cr	0.3	1.2	5.0
V	0.8	1.4	1.0
Ba	40.0	30.0	not marked
Sr	40.0	48.0	0.01
Cd	-	0.01	0.01
Sc	0.14	0.10	not marked
Ag	0.008	0.003	0.01
Ti	15.0	15.0	1.0

Own study based on: Sawicka and Kalembasa (3), Suturin and Kochnev (57).

low the optimal ratio of ingredients; the only optimal ratio was Ca:P. (Table 3)

H. tuberosus tubers contain a lot of vitamins. The most significant ones include: vitamin C and β-carotene, as well as vitamins B, such as thiamine, riboflavin, niacin, biotin. The greatest concentration of vitamin C was found in tubers, but the amount varied depending on genetic properties, physiological age of tubers as well as the humidity and temperature conditions during the vegetation period (7). According to Žaldarienė et al. (27), the content of ascorbic acid in *H. tuberosus* tubers ranged from 7.6–10.8 mg in 100 g of fresh mass. The content of provitamin A was at a level of 37 IU (IU – international unit 1 IU of retinol (vit. A) = 0.3 mcg RAE) in fresh tuber mass (16, 58).

Lipids are found both in tubers and in aerial parts of JA (27). Total lipids, free lipids and bound lipids on average amount to 0.73–0.76 $g \cdot 100\ g^{-1}$ of fresh tuber mass, and according to USDA (58) – 0.01 $g \cdot 100\ g^{-1}$ of fresh tuber mass. Isolated from leaves and stems of JA, they are dark-green, and from tubers – light brown, as total lipids, free lipids and bound lipids (59-60). Chlorophyll in leaves contains more lipids than chlorophyll in stems (59). The colour of fats isolated from tubers contains carotenoid pigments at a level of 34.7 mg 100 g of fresh mass (60). Saturated acids dominate in *Helianthus tuberosus* tubers, whereas unsaturated – in leaves (39, 59). Isolated bound lipids were found in the form of neutral lipids, glycolipids and phospholipids. The neutral lipids level ranges from 58.3 in stems to 49.6 in tubers, the highest concentration of glycolipids was recorded in tubers (43.1%), and the lowest in stems (35.2%), whereas phospholipids are predominant in leaves – 11% (16, 59-61). The isolated neutral lipids included: paraffinic and olefinic hydrocarbons, isoprenoid hydrocarbon squalene, tocopherols, free fatty acids, carotenoids, isoprenoid alcohols, triterpenols, sterols, fatty acid esters with phytosterols and triterpenols, triacylglycerides, 4-monomethyl sterols and chlorophyll. Squalene is a component of human skin surface lipids with antibacterial and antifungal properties. It is a metabolic precursor of cholesterol and other sterols. GL examples include: mono- and digalactosyldiacylglycerols, steroidal glycoalkaloids and free fatty acid esters, whereas PL in the tubers include: phosphatidylcholines, phosphatidylinositols, phosphatides and phosphatidylethanolamines (59-60). Talipova (59) showed that fats from leaves, stems and tubers comprise 7 fatty acids, whereas Chernenko et al. (60) isolated 10 fatty acids in tubers. *H. tuberosus* organs mostly contain unsaturated fatty acids with 16:0 linkages, whereas leaves and tubers also contain acids with 18:2 linkages. The greatest concentration of acids with 18:3 linkages was found in stems, and the smallest – in tubers (58-59). Li et al. (61) proved the physico-chemical and lipid oxidative properties of emulsion gels containing JA inulin. Purified inulin extract (1%) improved the homogeneity of the emulsion gel (without syneresis) and developed droplets with smaller particle sizes (on average 40 μm) compared to the control object (on average 60 μm). Crude inulin extract (0.08-0.33 mg ml^{-1}) delayed oxidation of linoleic acid due to the higher total phenol content.

In recent years, phenolic compounds have become increasingly popular due to their strong antioxidant properties (26, 62-64). Phenolic compounds are natural antioxidants. They are phenolic acids (derivatives of hydroxybenzoic and hydroxycinnamic acids, such as: chlorogenic acid, 1,5-dicaffeoylquinic acid, 3,4-dicaffeoylquinic acid, 3,5-dicaffeoylquinic acid, neochlorogenic acid, cryptochlorogenic, caffeoyl-glucoside acid, p-coumaroylquinic acid, feruoylquinic acid, caffeic acid, 4,5-dicaffeoylquinic acid) and flavonoids. Michalska-Ciechanowska et al. (5) demonstrated that chlorogenic acid is the dominating polyphenolic compound in tubers and leaves of JA. They estimated the content of chlorogenic acid at 66.4% in 'Violette de Rennes' and at 77% in the 'Waldspindel' and 'Topstar' cultivars, regardless of fertilisation, so this is mainly a cultivar-related feature. These compounds have the following functions: scavenging free radicals, increasing dismutation of free radicals to much less reactive compounds, chelation of pro-oxidant metals, reducing or boosting the activity of a number of enzymes. Jerusalem artichoke tubers contain high amounts of phenolic compounds, ranging from 1,477 to 1,802 mg kg^{-1} DM (5). Mattila and Hellström (65) assessed the content of polyphenols in tubers at 2,210 $mg \cdot kg^{-1}$DM. Showkat et al. (66) measured the level of main phenolic acids in tuber, leaf, flower and stem extracts. Total phenolic content (TPC) was the highest in leaves (4.5–5.7 mg gallic acid equivalents g^{-1} dry substance), followed by flowers (2.1–2.9), tubers (0.9–1.4), and the lowest in stem extracts (0.1–0.2 mg gallic acid equivalents g^{-1} dry substance). Out of the identified phenolic acids determined by quantitative HPLC-UV analysis, chlorogenic and dicaffeoylquinic acids accounted for 72–82% of corrected TPC in leaf and tuber extracts. Further developments in extraction processing of crop residues may open ways for improving the utilization of JA in valuable products. Hwang et al. (67) assessed the protective effect of a 50% ethanol extract of JA flowers (HAF) against UVB-induced photodamage using normal human dermal fibroblasts. HAF extract significantly blocked UVB-induced ROS and MMP (MMP-1 and MMP-3) production and procollagen type I reduction. The photoageing inhibitory actions were related to promotion of Nrf2 nuclear translocation, upregulation of TGF-β1 level, and downregulation of AP-1 and MAPK phosphorylation. Importantly, HAF effectively inhibited UVB-induced VEGF and inflammatory cytokines such as IL-6, COX-2, iNOS, and TNF-α secretion, which might be involved in the regulation of the NFAT signaling pathway. This indicates that HAF is a very useful botanical source protecting against UVB-mediated skin photodamage.

Petkova et al. (68) showed that flour obtained from the 'Scorospelcu' cultivar tubers and a wild population of *Helianthus tuberosus* was the most valuable source of polyphenols (including caffeoylquinic acid, neochlorogenic acid, chlorogenic acid and cryptochlorogenic acid, 4 isomeric di-caffeoylquinic acids, caffeoylquinic derivatives) and soluble dietary fibre. In the JA cultivars under study, 11 polyphenolic compounds were identified (5). The content of polyphenolic compounds ranged from 1.5 to 1.8 g kg^{-1} DM of tuber samples. Chlorogenic acid was the predominant phenolic acid in all cultivars, and it accounted for around 66.4% of the identified polyphenolic compounds in cultivar 'Violette de Rennes and for around 77% of polyphenolic compounds in cultivar

'Waldspindel' and 'Topstar'. Four isomers of dicaffeoylquinic acid were also identified in the evaluated tubers, and 1,5-dicaffeoylquinic acid was the predominant isomer. Chlorogenic acid, 3,5-, 3,4-, 1,5-caffeoylquinic acids, and neochlorogenic acid had the strongest influence on antioxidant potential measured by the ABTS on-line profiling method. Nevertheless, the polyphenolic compounds are stress metabolites, and their content in the plants can be modified by fertilisation; so, this aspect should be considered in order to provide a thorough recommendation for a single polyphenolic component (5, 25, 63-64). This proves a potential possibility of using these raw materials in human and animal nutrition and in preparation of healthy food products.

Jerusalem artichoke (JA) also has strong antioxidant potential. Michalska-Ciechanowska et al. (5) recorded that antioxidant capacity in 3 cultivars of *H. tuberosus* ranged from 0.87 to 3.28 μmol Trolox kg^{-1} DM in the ABTS radical scavenging activity assay. Chlorogenic acid exerted the strongest effect on the antioxidant potential of JAs, followed by caffeoylquinic acid and neochlorogenic acid. No significant correlations were found between the concentrations of individual polyphenolic compounds in *Helianthus tuberosus* tubers and the antioxidant capacity of the extracts determined spectrophotometrically in the ABTS radical scavenging assay. Catană et al. (16) proved that powder obtained from tubers contained 18.51–44.03 mgGAE g^{-1} of polyphenols and had strong antioxidant potential, useful in diets preventing diseases caused by free radical

Helianthus tuberosus also contains numerous phytochemical compounds, including coumarin, unsaturated fatty acids (69), polyamine derivatives and sesquiterpenes (63, 42, 70-71). Plant extracts rich in antioxidants can be used as active ingredients of many preparations, mainly due to their antioxidant, regenerative and anti-ageing properties.

Pharmacological raw material

Due to its rich chemical composition, JA is a raw material in the production of many pharmaceutical products (7, 5, 72). The polysaccharide, inulin, can be fully hydrolysed to its monomers, fructose, which is widely used as a sweetener instead of sucrose or glucose and in functional dietary, pharmaceutical and drink products. A significant difference between fructose and other monosaccharides is its glycemic index (GI), which was introduced as a means to categorise carbohydrates depending on their ability to raise blood glucose level and was implemented in the selection of foods for diabetics. It was assumed that glucose GI equals 100, sucrose GI – 65, whereas fructose GI – only 23 (30, 72). A much lower GI of fructose makes it the most beneficial sweetener for patients suffering from diabetes or obesity (5). 100 kg of tubers can yield 9–10 kg of fructose (1, 23, 73). Difficult crystallisation of fructose and high losses in calcium fructosan precipitation led to the development of fructose syrup as the final raw material allowing for better utilisation of tuber sugars. The syrup is widely used in the confectionery industry as a substitute for sucrose and glucose, as well as in liqueur production (30). An addition of fructose syrup to preserves, sweets, jams, alcohols and non-alcoholic beverages prolongs their shelf-life. It also prevents saccharification of preserves and delays bread staling (74). In the confectionery industry, tuber flesh can be used as praline filling. *Helianthus tuberosus* tubers have the valuable ability of retaining 98% of aromas and flavours and can be candied, closely resembling the taste of real fruit (12).

Inulin and fructose are ready products to be used by body cells, so they can be used in diabetes treatment and prevention. β-inulin between fructose monomers can be digested by human intestine enzymes, so it can be used in functional food and the treatment of type 2 diabetes, obesity and to lower blood sugar level (23). In the case of oral administration, inulin passes through the mouth, stomach and small intestine and is metabolised until the big intestine, where it is fermented by the gut flora. In this way, the use of inulin has no influence on the blood sugar level or insulin release stimulation (23, 75). In addition, inulin is considered a soluble form of dietary fibre and is categorised as a prebiotic. Inulin facilitates intestine functions by increasing the stool amount and frequency, in particular in constipated patients. These effects reduce colon putrefaction (76). As a prebiotic, inulin also stimulates the growth of existing positive bacteria strains in the colon, increasing the absorption of important minerals, such as calcium and magnesium, as well as the synthesis of vitamins B (23, 36, 77). Inulin and non-absorbable oligosaccharides can stimulate the growth and activity of a limited amount of desired bacteria in the large intestine, and in this way improve human health. Moreover, it was proven that inulin has a positive influence on reducing glucose homoeostasis in blood, the lipid level, the bioavailability of minerals and the immunity modulation effects, as well as improves the texture, rheological and nutritional properties of food, which make it functional food (23, 30, 16, 78). According to Yang et al. (23) the use of *Helianthus tuberosus* tubers results not only in normalizing the blood sugar level, but can also have a positive influence in the case of diabetic retinopathy. Inulin with pectin and fibre bind large amounts of redundant and harmful compounds, such as: heavy metals, radionuclides, cholesterol, fatty acids, toxic compounds. The compounds enter the system with food and are produced within the intestine. Metabolism disorders in the system can result in intestinal dyspepsia, poisoning, allergies, or even impaired liver's detoxification system. Inulin stimulates peristalsis, leading to excretion of waste or even harmful substances and regulation of human physiological functions by normalizing bowel movement in chronic constipation. It improves the energy efficiency of cells (any cellular burden quickly leads to depletion of energy reserve; it can result in shifting the pH value, oxygen deficiency, cell death); the cell is provided with an energy substrate in the form of quickly and easily absorbable simple sugar – fructose. Inulin also prevents urinary tract infections. Part of the undigested fructose in the digestive system is eliminated through glomeruli membrane to the bladder, where pathogenic bacteria attach to it. Jerusalem artichoke (JA) also has hepatoprotective and immunostimulant properties, which are more and more often considered necessary in preventing cancer (30, 16). Fructose and fructose syrup are made from *Helianthus tuberosus* tubers (78).

Helianthus tuberosus requires increasing and better integrated biotechnical processing. In recent years, the medical and nutritional aspects of this species have been undergoing intensive research in many countries all over the world. This species has multiple functions:

− anti-cancer and antimutagenic properties (30, 66, 79, 80);
− auxiliary in cardiovascular diseases (e.g. cardiac dysrhythmia), chronic infectious diseases, chronic fatigue syndrome) (15, 48);
− auxiliary in immune system disorders (5, 12, 23, 48, 77).
− detoxification of the system (e.g. Alcohol, heavy metals, radionuclides) (5, 16);
− facilitating slimming processes (helps reduce body weight) (7);
− immunostimulation (15, 16, 23, 48);
− improving metabolism (in lipid metabolism disorders) and preventing acne (30, 39, 81);
− lowering high cholesterol level (normalizes lipid metabolism disorders (33);
− lowering high glucose level (helps in type 2 diabetes) (15, 16, 80).
− lowering the uric acid level (68);
− positive effects on reducing diabetic retinopathy (30);
− promoting regular bowel movement (prevents constipation) (67);
− protecting the cardiovascular system, mainly by decreasing the cholesterol level in plasma and preventing arteriosclerosis (79, 80);
− protecting the gastric mucosa (71);
− relief in gut flora disorders (15, 23, 78);

Helianthus tuberosus also has therapeutic effects in patients with hyperuricemia. Jerusalem artichoke products are useful in preventing arteriosclerosis and arterial hypertension, coronary heart disease and tachycardia, gout, kidney stones, bladder infection, tuberculosis, leukemia, anemia, pancreatitis. Regular consumption of such products not only lowers the blood sugar level, but also improves sight and lowers the uric acid level in the system (15, 48). There is also evidence that the species has anti-cancer properties due to its antioxidant, anti-inflammatory and immunostimulant characteristics (5, 15, 16, 23, 48, 77, 80).

Healing baths including decoctions and infusions of pellets and flour obtained from JA leaves and stem mass have a tonic influence on normal sleep and increase appetite (7, 83). Some inulin derivatives can be used as blood substitutes to stimulate iron absorption. Inulin-based medicines can be used in surgery as drug carriers. There are also some interesting records on how inulin binds radioactive strontium (48, 83).

Helianthus tuberosus tubers can be effectively used in the diet of children with kidney membranopathy or constipation, as antioxidant and immunostimulating natural plant products; in reducing the frequency of respiratory diseases, to prevent premature ageing and cancer in people living in areas with heavy metal pollution (48, 84).

Tuber juice can be used in the treatment of hemorrhoids, conjunctivitis, blepharitis and dermatitis as well as psoriasis, ulcers and burns (84, 85). The juice also improves blood flow to all parts of the gastrointestinal and pancreatic mucosa, and thus plays an important role in the treatment of chronic disorders, such as: stomach, intestinal, colon, pancreas inflammation, etc. It is also possible to use JA in the diet in case of phenylketonuria due to lack of phenylalanine or tyrosine in the protein amino acids in this plant (10, 23, 48, 51).

Helianthus tuberosus leaves are traditionally used in folk medicine to cure bone fractures, skin wounds, swelling. A lot of valuable medicinal bioactive ingredients were isolated from aerial parts of JA, demonstrating antifungal, antioxidant and anti-cancer properties (23, 86). Pan et al. (87) isolated 9 bioactive compounds from the entire *Helianthus tuberosus* plant, including vanillin. Their bioactivity was assessed with the use of the MCF-7 human breast cancer cell and soybean isoflavonoid as biological activators. 2 of those compounds were identified as cytotoxic agents, with one capable of stimulating defense metabolites and 4 capable of blocking the soybean isoflavonoid. The extraction of bioactive ingredients from JA leaves by Ma et al. (86) led to significant progress. 6 phenolic free radicals from *Helianthus tuberosus* leaves make it a good source of natural antioxidants (23, 80, 86-88). Recently, several sesquiterpene lactones were also isolated as cytotoxic agents against cancer cells, which corroborated the results presented by Pan et al. (87).

Consumption of *Helianthus tuberosus* tubers regulates blood pressure and the functioning of the digestive system, protects the liver and kidneys, facilitates the absorption of iron, calcium and magnesium and helps remove alcohol from blood. It has cleansing properties, helps eliminate heavy metals and organic toxins. It improves the immune system, so it can be helpful in all kinds of infections. Besides, it relieves stress and improves concentration (23, 38, 89). The tubers and preparations containing swellable substances are recommended in overweight and obesity. This is due to various forms of fibre, mainly cellulose derived from the tubers. Based on them, such preparations were produced as: Topinulin, Topinambur-Sirup and Topinambur-Pulver (50, 90). Fibres protect the large intestine from dangerous lifestyle diseases. They are a breeding ground for the gut flora responsible for correct digestion in the intestine. It is also important in an antibiotic therapy, which damages the good flora. A diet enriched with inulin and inulin preparations stimulates the growth of acidifying bacteria and eliminates putrefying bacteria causing diarrhoea and large bowel inflammation, and thus prevents polyps and ulcers that can lead to cancer. Inulin can also enhance the immune system, decrease insulin resistance in diabetes and lower the cholesterol level. It is perfect in the diet of diabetics and patients after chemotherapy. It helps normalize the blood sugar level, and together with pectin's and fibre, it facilitates cleansing processes by binding harmful compounds and accelerating their elimination by stimulating peristalsis. Thus, it helps in constipations. *Helianthus tuberosus* tubers also act as immunostimulant agents, protect the liver and prevent urinary tract infections (23, 91).

Helianthus tuberosus extracts have antibacterial and antifungal properties, and heliangin, which is the source of sesquiterpene lactones isolated from leaves, demonstrates significant *in vitro* activity against Ehrlich ascites carcinoma cells (23). Leaves and flowers are used in the treatment of such diseases as: arthritis, osteoarthritis, bursitis, osteochondrosis, nerve root inflammation, gout; they stabilize the muscular system after injuries and help in the treatment of peripheral artery disease (92). Research by Nizioł-Łukaszewskiej et al. (71) showed that leaf extract demonstrates a higher content of phenols and flavonoids than tuber extract (5.1 and 7.1 times higher, respectively). An opposite tendency was observed after a proliferation assay based on a neutral red assay. It was recorded that tuber extract with a concentration from 25 to 500 μg · ml^{-1} has a positive influence on fibroblast growth. Leaf extract showed proliferation activity only in case of the lowest concentrations (25–100 μg ml^{-1}). Similar trends were observed for HaCaT cells. Leaves and tuber extracts had a significant influence on ROS development in HaCaT cells. Nizioł-Łukaszewska et al. (71) also proved that tuber and leaf extracts may increase the expression of the ROS SOD-1 inactivating enzyme gene in the fibroblast cell line. In the case of keratinocytes, the opposite effect was observed. The study suggests that *Helianthus tuberosus* leaves and tuber extracts affect the cell proliferation and can alter the expression of genes related to oxidative stress (71, 86).

Due to a low level of polyamines and the presence of inulin, it is possible to use *Helianthus tuberosus* tubers in the diet of persons with special needs and patients with diabetes or after chemotherapy (7, 82). In turn, Yildiz et al. (33) suggest that inulin extracted from *Helianthus tuberosus* tubers can play a huge role in modulating intestinal properties, blood metabolites and liver enzymes. Crude extract of *Helianthus tuberosus* callus also has strong hemagglutinations properties (71, 93).

Healing properties of jerusalem artichoke

Aerial parts properties

Aerial parts of this species, containing a variety of polysaccharides, proteins, organic acids, vitamins and other compounds, are a perfect herbal raw material (36, 42, 94). Leaves can also be treated as a great source of essential oils important from the pharmaceutical perspective. They are also a source of natural --bisabolene. A total of 17 volatile compounds were identified in its leaves. The essential oil content ranged from 0.00019 to 0.03486 g·100 g^{-1} in leaves and 0.00011 to 0.00205 g·100 g^{-1} in tubers of *H. tuberosus*. The major component found in leaves and tubers was β-bisabolene with 70.7% and 63.1% of oil mass, respectively. It was identified that *H. tuberosus* leaves and tubers contain: 3 oxygenated monoterpenes, 1 diterpenes hydrocarbons, 1 triterpene, 6 sesquiterpenes hydrocarbons, 2 oxygenated sesquiterpenes, 3 aldehyde 1-isoprenoids. Among the identified compounds only β-bisabolene has previously been reported as a constituent of JA (23, 42). For thousands of years, *Helianthus tuberosus* leaves have been traditionally used in Chinese folk medicine to cure bone fractures, skin wounds, swelling. Healing baths including decoctions and infusions of pellets and flour obtained from JA leaves and stems have a tonic influence on normal sleep and increase appetite (7, 15, 42).

From the aerial parts of JA, a number of bioactive compounds were isolated, demonstrating antifungal, antioxidant and anti-cancer properties, as well as other medicinal characteristics (42, 95). Pan et al. (87) isolated 9 bioactive compounds from the entire *H. tuberosus* plant, including vanillin. Their bioactivity was then assessed with the use of the MCF-7 human breast cancer cell and soybean isoflavonoid as biological activators. 2 of those compounds were identified as cytotoxic agents, with one capable of stimulating defense metabolites and 4 of them capable of blocking the soybean isoflavonoid.

In the Republic of Adygea, Russia, top-class JA flowers are used to make tea drinks with an addition of various herbs. *H. tuberosus* has a number of unique features beneficial for our health. For example, JA flower drinks can cleanse the body and restore the immune system, improve blood vessels, provide an energy boost and have medicinal properties: regular consumption of flower tea prevents diabetes and kidney disorders (19).

H. tuberosus extracts have antibacterial and antifungal properties, and heliangin, which is the source of sesquiterpene lactones isolated from leaves, demonstrates significant *in vitro* activity against Ehrlich ascites carcinoma cells (19, 42). Leaves and flowers are used in the treatment of such diseases as: arthritis, osteoarthritis, bursitis, osteochondrosis, nerve root inflammation, gout; stabilizes the muscular system after injuries and helps in the peripheral artery disease (87). Constant attempts to extract bioactive ingredients from JA leaves and stems (96) resulted in significant scientific progress. With 6 free radical scavenging phenolic leaf extracts, *H. tuberosus* is a good source of natural antioxidants (42, 80, 88, 96). Recently, it was also possible to isolate a number of sesquiterpene lactones demonstrating cytotoxicity against some lines of cancer cells (16, 30, 42, 95).

Tuber medicinal properties

The underground parts of JA have multiple applications in human nutrition. Among them is the pharmacological application (5-7, 15). In case of overweight and obesity, it is recommended to consume the tubers or preparations containing swellable substances, causing a feeling of satiation and decreasing the amount of consumed food. The interest in *H. tuberosus* tubers is mainly a result of the content of inulin and fructooligosaccharides characterized by prebiotic properties, and natural fructose, minerals, essential amino acids, vitamins and flavonoids (17, 36). Research on microbes, cell lines and experimental animals showed activation of cell transcription factors NFκ-B and lower level of blood glucose in experimental rats, whose diet included an addition of JA powder (41, 60). The consumption of products containing powdered JA tubers has a positive influence on lipid metabolism (39, 60). Research conducted by Lattanzio et al. (97) showed that the species develops several active compounds that together generate additive or synergistic pharmacological effects. These include mono-and dicaffeoylquinic acids and flavonoids. *Helianthus tuberosus* is believed to have strong prebiotic properties, because it lowers the glucose level in plasma and intestine pH, resulting on higher bioavailability of calcium. It also has a positive influence on the plasma lipid profile, acts as an immunomodulator, affecting the digestive system's lymphatic tissue (98). Due to its characteristics, it can be used in the diet of obese and type 2 diabetes mellitus patients, and recently, it was discovered that JA tuber secretion works as a cytotoxic agent contra breast cancer cell (12, 15). Research conducted by Kronberga et al. (17) showed that an addition of JA powder and syrup to cakes and jellies does not stimulate the development of microorganisms after consumption, therefore, it increases their nutritional value and lowers the food energy. In sausage production, replacing 5% of meat with 5% of JA powder, improves the fat–protein ratio, increasing the water content maintenance by approx. 3%, the mass of finished product by approx. 5%, and the content of minerals and amino acids (17, 99, 104, 105).

Inulin and its derivatives (fructo-oligosaccharides) in human diet facilitate the growth of positive probiotic bacteria in the organism: *Bifidobacterium*, *Lactobacillus*, reducing the development of pathogens, such as: *Clostridium*, *Fusobacterium*, or gram-positive streptococci (106). Jerusalem artichoke (JA) is recommended for diabetics due to the fact that fructose is tolerated better by patients with diabetes (17). Yang et al. (23), Kronberga et al. (17) discovered that streptozotocin (STZ) is a free-radical activator, which can selectively destroy pancreatic islets and lead to glucose metabolism disorders. It also results in HK deficiency, where glucose cannot be phosphorylated, and thus, glucose penetrates through cell membrane, causing high blood sugar level and symptoms of diabetes.

Inulin used orally affects the lipid fraction in the blood, in such a way that it reduces the concentration of low-lipoprotein LDL (low density lipoproteins) and triglycerides in humans and animals (7). In Davidson et al. (107) inulin consumed in a dose of approx. 18 g day^{-1} in a low-fat diet for six weeks significantly reduced the concentration of LDL cholesterol in men and women by about 7 and 12%, respectively (107). It has been observed, that diets given to rats containing an aqueous extract from chicory or 5% inulin food supplement by 4 weeks causes a significant increase in fraction concentration HDL (high density lipoproteins) and lowering the LDL fraction (108). Reduction of cholesterol absorption in the small intestine was confirmed in rats (by 30% in the jejunum and 41% in the ileum). Pure inulin used at the same concentration reduces significantly cholesterol absorption in both sections of the small intestine, by approx. 40 and 50%, respectively, relative to the control group. It is associated primarily with increasing the viscosity of the intestinal contents. This indicates that products containing Jerusalem artichoke extract, pure inulin can have a positive effect both in healthy people and with cardiovascular diseases (109). Zaky (89) showed that in diabetic rats fed for 5 weeks with food containing 5, 10 and 15% dry extract from Jerusalem artichoke, a lowering was observed total cholesterol as well as blood triglycerides and LDL and VLDL (very low-density lipoproteins) cholesterol in all groups. However, no significant group was found HDL changes (89). Fructans, including inulin, exert effect of lowering cholesterol in the blood through ability to bind fatty acids in the intestine.

Inulin and fructose are ready products to be used by body cells, so they can be used in diabetes treatment and prevention. α-inulin (2,1) between fructose monomers can be digested by human intestine enzymes, so it can be used in functional food and the treatment of type 2 diabetes, obesity and high blood sugar level (17). In the case of oral administration, inulin passes through the mouth, stomach and small intestine and is not metabolized until the big intestine, where it is fermented by the gut flora. In this way, the use of inulin has no influence on the blood sugar level or insulin release stimulation (17, 39). In addition, inulin is considered a soluble form of dietary fibre and is categorized as a prebiotic. Therefore, this polysaccharide is considered a soluble fraction of dietary fibre. The prebiotic effect of inulin is observed in case of consuming 10 g per day. An average daily intake of inulin is estimated between 3–11 g in Europe, and between 1–4 g in the United States (50, 58). Inulin facilitates intestine functions by increasing the stool amount and frequency, in particular in constipated patients. These effects reduce colon putrefaction. As a prebiotic, inulin also stimulates the growth of existing positive bacteria strains in the colon, increasing the absorption of important minerals, such as calcium and magnesium, as well as the synthesis of vitamins B (17, 50). Inulin and non-absorbable oligosaccharides can stimulate the growth and activity of one or a limited amount of desired bacteria in the large intestine, and in this way improve human health. Moreover, it was proven that inulin has a positive influence on reducing glucose homoeostasis in blood, the lipid level, the bioavailability of minerals and the immunity modulation effects, as well as improving the texture, rheological and nutritional properties of food, which make it functional food (8, 16, 78). The use of *H. tuberosus* tubers results not only in normalizing the blood sugar level, but can also have a positive influence in the case of diabetic retinopathy. Inulin together with pectin and fibre bind large amounts of redundant and harmful compounds, such as: heavy metals, radionuclides, cholesterol, fatty acids, toxic compounds. The compounds enter the system with food and are produced within the intestine. Metabolism disorders in the system can result in intestinal dyspepsia, poisoning, allergies, or even impairment of liver's detoxification system, as a more indirect consequence. Inulin stimulates peristalsis, leading to excretion of waste or even harmful substances and regulation of human physiological functions by normalizing bowel movement in chronic constipation. It improves the energy efficiency of cells (any cellular burden quickly leads to depletion of energy reserve; it can result in shifting the pH value, oxygen deficiency, cell death); the cell is provided with an energy substrate in the form of quickly and easily absorbable simple sugar – fructose. Inulin also prevents urinary tract infections. Part of the undigested fructose in the digestive system is eliminated through glomeruli membrane to the bladder, where pathogenic bacteria attach to it. JA also has hepatoprotective and immunostimulant properties, which are more and more often considered necessary in preventing cancer (17, 19, 39).

Helianthus tuberosus also has therapeutic effects in patients with hyperuricemia. Products of JA are useful in preventing arteriosclerosis and arterial hypertension, coronary heart disease and tachycardia, gout, kidney stones, bladder infection, tuberculosis, leukemia, anemia, pancreatitis. Regular consumption of such products not only lowers the blood sugar level, but also improves sight and lowers the uric acid level in the system (50). There is evidence that the species has also anti-cancer properties due to its antioxidant, anti-inflammatory and immunostimulant characteristics (17, 75, 102).

Some inulin derivatives can be used as blood substitutes to stimulate iron absorption. Inulin-based formulas can be used in surgery as drug carriers. There are also some interesting records on how inulin binds radioactive strontium (39, 60).

H. tuberosus tubers can be effectively used in the diet of children with kidney membranopathy or constipation, as antioxidant and immunostimulant natural plant products; in reducing the frequency of respiratory diseases, to prevent premature ageing and cancer in people living in areas with anthropogenic contamination with heavy metals (84).

Jerusalem artichoke (JA) and its derivatives can be used in a diet of people with phenylketonuria (blue diaper syndrome), diabetes or obesity, because they lower the "bad cholesterol" level in the system. Eating *H. tuberosus* tubers helps regulate the blood sugar. Regular consumption of the plant in the case of type 1 diabetes plays an important role in lowering the blood sugar level and the production of insulin in pancreatic cells, which is facilitated by Si, Zn, Mn, K (94). Research conducted by Zaky (89) on rats showed that a diet containing *H. tuberosus* tubers does not lower the level of glucose, triglycerides, total cholesterol or LDL cholesterol in rats with hyperglycemia. However, it improves the condition of the liver and kidneys due to the use of those additives.

Consumption of *H. tuberosus* tubers regulates blood pressure and the functioning of the digestive system, protects the liver and kidneys, facilitates the absorption of iron, calcium and magnesium and helps remove alcohol from blood. It has cleansing properties, helps eliminate heavy metals and organic toxins. It improves the immune system, so it can be helpful in all kinds of infections. Besides, it relieves stress and improves concentration (17, 35, 38). The tubers and preparations containing swellable substances are recommended in overweight and obesity. This is the result of various forms of fibre, mainly cellulose and inulin derived from the tubers. Based on them, such preparations were produced as: Topinulin, Topinambur-Sirup and Topinambur-Pulver (82). Inulin fibres protect the large intestine from dangerous lifestyle diseases. They are a breeding ground for the gut flora responsible for correct digestion in the intestine. It is also important in an antibiotic therapy, which damages the good flora. A diet enriched with inulin stimulates the growth of acidifying bacteria and eliminate putrefying bacteria causing diarrhoea and large bowel inflammation, and thus prevents polyps and ulcers that can lead to cancer. Inulin can also enhance the immune system, decrease insulin resistance in diabetes and lower the cholesterol level. It is perfect in the diet of diabetics and patients after chemotherapy. It helps normalize the blood sugar level, and together with pectin's and fibre, it facilitates cleansing processes by binding harmful compounds and accelerating their elimination by stimulating peristalsis. Thus, it helps in constipations. Besides, the tubers also act as immunostimulant agents, protect the liver and prevent urinary tract infections (17, 90). In 1991, Jerusalem artichoke (JA) was registered for the first time as a homoeopathic remedy (82).

Due to a low level of polyamines and the presence of inulin, it is possible to use *H. tuberosus* tubers in diet of persons with special needs and patients with diabetes or after chemotherapy (32). Yildiz et al. (33), Žaldarienė et al. (27) suggest that inulin extracted from *H. tuberosus* tubers can play a huge role in modulating intestinal properties, blood metabolites and liver enzymes. Crude extract of *H. tuberosus* callus has also strong hemagglutinations properties. Meals containing *H. tuberosus* tubers can be used in the treatment of obesity or cardiovascular diseases (20, 27). Jerusalem artichoke (JA) is a good source of natural antioxidants. It has been reported that a number of sesquiterpene lactones isolated from JA can act as a cytotoxic agent contra two lines of breast cancer cells, and that proteins isolated from tubers have anti-cancer properties (47, 80, 88). Damage on *H. tuberosus* tubers can secrete bioactive metabolites of various structural classes, with good resilience to some lines of human cancer cells, in particular human breast cancer cells MDA-MB-52 (17). With the content of valuable minerals and nutrients, *H. tuberosus* tubers can be a useful raw material for the pharmaceutical industry (6, 20).

Helianthus tuberosus preparations

Various forms of fibre, mainly cellulose and inulin, obtained from *H. tuberosus* tubers, are used in the production of preparations such as: Topinulin, Topinambur-Sirup and Topinambur-Pulver (36, 88, 89, 16, 100). The majority of EU states, the United States and Japan have registered products containing inulin as food products suitable for unlimited consumption (9, 20). Preparations containing *H. tuberosus* available on the European market are the following:

− 'Botanaflor' − helpful in intestinal diseases;
− 'Fabacin' – a dietary supplement facilitating weight loss;
− 'Chromium Polynicotinate; − supplements the diet with ingredients that facilitate weight loss;
− 'Tiens Digest Natural' – used in arteriosclerosis, painful uterine bleeding, diabetes, body detoxification and other diseases;
− 'Topinulin' − used in the prevention and treatment of diabetes, prevention of cardiovascular diseases, increased physical and mental load (chronic fatigue syndrome), protection of the normal gut flora, boosting the immune system.
− 'Topinulin Diabetes'
− 'Topinulin Active' with chromium and iodine − supplements the diet with ingredients that facilitate weight loss (7, 50, 86, 90, 101, 102, 103).
− 'Joy Day-Topinambur' – a concentrate facilitating probiotic functions (35, 110).

The process of obtaining technical inulin is similar to the process of producing sugar from sugar beet, so the majority of industrial installations, major Fructan producers, such as: Orafti Group (Belgium, 70% of world production), Brenntag Nederland BV (Netherlands), Chemofarma Chemikalien (Austria); Shandong East Chemical Industry (China), Vijay Chemical Corporation (India), Synergy Vaccines Inc. (USA), Beta Pure Foods (Canada), Predilife (Mexico), Dr. Paul Lohmann (Germany) and others (35).

Inulin can also be a symbiotic in combination with the right bacteria strain, e.g. *Bacillus subtillis*. The substance regulates intestinal peristalsis and stimulates the intestinal immune system (71, 82). It is also an important component of a diet, so inulin products are used in various diet types and appetite reducers. Reduces appetite was observed after administration of 100–250 mg inulin propionate between meals. In case of some pharmaceutical compositions, a synergistic effect of anti-cancer drug ingredients containing inulin was observed (72).

Inulin is an ancillary substance in the production of ointments, e.g. herpes or wound healing ointments. The natural combination of magnesium and potassium in *Helianthus tuberosus* tubers can be used as a safe biopharmaceutical to cure cardiovascular diseases, prevent heart attacks and strokes (111). It was also noted that the combination increases the absorption and stabilizes calcium and magnesium levels in the organism, and contributes to bone mineralization. Increased calcium absorption is also important in the prevention and treatment of osteoporosis and magnesium deficiencies resulting from stress and drinking large amounts of coffee. The influence of supplementing this prebiotic on mineral metabolism and healthy bones is crucial, in particular during the menopause and postmenopausal stage in women (35, 111). The results of future research can determine the factors connected to potential health benefits of probiotics, supported by food products/additives, which answer the needs of consumers' healthy bones. Research conducted by Legette et al. (47) showed that inulin has a significant influence on calcium metabolism, which is connected to changes in intestines and caecum wall, which means that is takes part in the production of short-chain higher fatty acids. Under the influence of inulin, intestinal fibre demonstrate better magnesium absorption and retention in the early and late metabolic balance (112). The influence was more visible in the case of magnesium than calcium. Another result is also decreased blood viscosity due to lower concentration of fibrinogen (23, 91). The concentration of selenium plays an important role in heart attack. In this case, JA is also significant, because it promotes the absorption of essential trace elements in food (47, 87, 11).

In addition, qualitative and quantitative analysis of essential oils in JA leaves and tubers revealed 17 chemical components. The main ingredient in the leaves and tubers was - β-bisabolen, in a proper ratio of 70.7% and 63.1%. However, the profile of essential oils from JA shows significant differences in both leaves and tubers between species. In addition, Jerusalem artichoke leaves are a promising source of natural β-bisabolen (110).

Functional role in food

Functional food means food that benefits human health beyond the very function of food, e.g. preventing cardiovascular disease, allergies, or intestinal problems. Probiotics are living microorganisms with health benefits for humans. They mainly include lactic acid bacteria (LAB): *Lactobacillus* and *Bifidobacterium*, although the probiotic potential of other bacteria and yeast has not been ruled out. The benefits of probiotics include modulation of the immune system, anti-inflammatory properties, improved intestine functioning, pathogen reduction and treatment of such diseases as travelers' diarrhoea. Some health issues, such as inflammatory bowel disease, diabetes, liver diseases, neurological, respiratory and cardiovascular diseases and some cancers, such as colorectal cancer, are connected to lack of probiotic balance. Probiotics are mainly isolated from human flora, faces, breast milk and fermented products. Fermented fruit and vegetables are also listed as sources of probiotics. They are rich in functional antioxidants, providing synergistic health benefits for humans (92, 112, 113). One of the methods to stimulate probiotic bacteria growth in intestines is to supplement the diet with prebiotics, which are a source of energy and carbon. The benefits of using probiotics and prebiotics are observed in the prevention and treatment of a number of diseases, e.g. of the digestive system. Probiotics are mainly added to milk products: yoghurt, yoghurt-based drinks, kefir, buttermilk, acidophilus milk, as well as cheese. More and more often, it can also be found in fruit, vegetable, meat and cereal products. Yogurt is considered one of the most popular food products consumed all over the world, especially in the probiotic and symbiotic version. Sunflower flour is used as a new, prebiotic source for the development of functional yogurt (103). In recent years, intensive works have been conducted to develop technologies of new food products containing probiotic bacteria and prebiotics. These ingredients are added to confectionery products, bread, juices. A significant growth of consumer awareness of the functionality of such products contributes to the development of this food industry branch. The latest progress in the development of modern probiotics focuses around the dysbiosis of the gut microbiota. So far, gastrointestinal symptoms have been alleviated with modern probiotics. Presently, most of the commonly used probiotic strains belong to the *Lactobacillus, Clostridium, Bifidobacterium* and *Streptococcus* genera. Recent developments in culturomics by the implementation of newer technologies in combination with the use of gnotobiotic animal models are the basis for innovative host-specific probiotic therapies (35, 114). However, there is no strict execution of the law protecting end users from pseudo-probiotic products. While modern probiotics bring great hope for the future, more rigorous regulations are required in order to develop real probiotic products and characterize new probiotics with the use of state-of-the-art research and technologies.

Fructo-oligosaccharides and inulin are considered prebiotics that stimulate the growth of physiological colonic microflora. Prebiotics are food ingredients not digested by endogenous enzymes, stimulating the growth of good probiotic colonic microflora (16, 101, 113, 115). The best-known prebiotics, both chemically and clinically, are fructo-oligosaccharides and inulin (5, 46, 115). Inulin is present in frequently consumed fruit and vegetables, which contain from 0.3 to 22% of inulin (44, 102). It is found in tubers and roots of plants from the *Asteraceae* family (JA, chicory, asparagus, artichoke, common dandelion), and the *Liliaceae* family (e.g. onion, garlic, leek, etc.). A lower concentration is also found in wheat, barley and triticale (9, 116).

With its combination of unique physico-chemical and medicinal characteristics, JA is a valuable, promising dietary product and a raw material for functional food

(16, 88, 100). Among the recommended biologically active substances in dietary products and supplements for adults, the use of JA as a source of polyfructoses (inulin, etc.) is noteworthy (19, 113). Fructose contained in tubers has a lower energy with the same sweetness, and is thus less harmful for diabetics. It is possible to obtain 9–10 kg of fructose from 100 kg of tubers, hence JA is considered functional food (6). The Functional Food Science in Europe (FUFOSE) defines functional food in the following way: "Food can be considered functional, if it has been proven to beneficially affect one or more target functions in the body beyond adequate nutritional effects in a way that is relevant to either an improved state of health and well-being and reduction of risk of disease. Functional food is similar in appearance to a conventional food, but has a positive effect on the body in amounts that would be normally consumed in a diet. It is not a pill, a capsule or any form of dietary supplement, but a constituent of a normal diet" (117). The production of functional food, including probiotics, is now very popular in the society (6, 8, 118).

Despite modern antibiotic therapy, there is an increase in the number of infections and mortality rate from organisms that are often resistant to many drugs. This raises the question of whether restoration of a healthy microbiome via probiotics or symbiotics (probiotic and prebiotic combinations) to intervene on ubiquitous ICU dysbiosis would be an optimal intervention in critical illness to prevent infection and to improve recovery. Growing data for probiotic and symbiotic therapy reveals a need for definitive clinical trials of these therapies, as recently performed in healthy neonates (61). Davison and Wischmeyer (107) believe that probiotics and symbiotics can decrease complications at ICU and in other populations.

Fructo-oligosaccharides and inulin are D-fructose polymers linked with beta-(2-1)-glycosidic linkages. Fermentation of those compounds results in short-chain fatty acids, mainly acetic, butyric and propionic, which lower colon pH, thus affecting the intestinal peristalsis (113, 119). Consumption of fructo-oligosaccharides and inulin increases faecal weight, reducing or preventing constipation (9, 102, 116). Adding oligosaccharides into a diet can increase the bioavailability of minerals. It was proven that a prebiotic preparation has a positive influence on the absorption of zinc, calcium, magnesium, copper and iron from the digestive system. Increased absorption of those elements is related to their higher solubility in a lower-pH environment (23, 115). Prebiotics can also positively influence the skeletal system, because their presence improves calcium absorption from the digestive system (8). Inulin prevents diabetes by reducing the increase of insulin and glucose level in blood. This slows down gastric emptying, digestion and absorption (8, 45). Food energy of those compounds is only 1–1.5 kcal g^{-1} (1, 102). Inulin and oligofructose also help lower the cholesterol level in blood serum, and in this way decrease the risk of cardiovascular diseases. In addition, they support the immune system and have anti-carcinogenic properties reducing the risk of colorectal cancer (16, 45, 92). Cieślik and Gębusia (120) showed that oligosaccharides are not fermented in the mouth, so they are not a breeding ground for plaque bacteria, which are responsible for tooth decay. The amount of oligofructose and inulin that has a positive impact on human's ranges from 3 to 6 g per day (121). A daily intake of 4 g or more fructo-oligosaccharides can result in an increase in the amount of *Bifidobcterium* in the human digestive system (46, 102, 119, 122). According to Kolida et al. (123) in order to achieve a positive effect on the gut flora, a dose of 5–8 g inulin is required. Elaheh et al. (114) also studied and compared *in vitro* prebiotic effects of JA poly-fructans on the survivability and activity of *Bifidobacterium bifidum* and *Escherichia coli* with high performance-inulin (a high molecular weight fraction of chicory-derived inulin). They concluded that JA fructooligosaccharides can provide greater stability of probiotics and propionic acid production, so it can be considered as a potential source of high yielding oligosaccharide for commercial prebiotic production to develop food industry and improve human health (124).

However, Dybkowska and Zalewska (119) point to the fact that a high intake of fructo-oligosaccharides: 49 g per day in women and 44 g per day in men, can increase digestive conditions and cause diarrhoea. The food products market should face consumers' needs and high demand for food quality, in particular health security. It is observed that consumers are becoming increasingly interested in food that has a beneficial influence on the body. This leads to a higher demand for products containing e.g. probiotics and prebiotics, which have a positive effect on human health (122, 124). Food products enriched with such ingredients are mainly dairy products. Prebiotics are also more and more often used in the fat and oil, bread, and meat industries. The offer of probiotic and prebiotic products on the food market is quickly rising due to medical research revealing their positive influence on human health (122).

The use of biocontrol for plant pathogens and microbes causing product spoilage is a promising alternative to chemical means of pathogen control transferred to food and microorganisms causing spoilage. Finally, there is an urgent need to establish international standards in order to regulate probiotics and prebiotics as well as a health claim on the label to ensure product effectiveness and safety (116). FAO (53) recommend that basic information about products should be stated, such as: type, species, strain kind, minimum viable cell count of each probiotic strain at the end of the shelf-life, storage conditions and traceability information, such as contact data (125). Although regulation standards on prebiotics are not established at an international level, there are no periodic safety controls or quality controls. Probiotic products are not subject to strict regulation, but they were presented some elements of quality assessment from Europe, Asia, South Africa, the United States and Australia with erroneous interpretation of type, species and strain level and wrong labelling. According to Chen et al. (127), it very often happens that the viable cell count per product dose is significantly lower than declared on the label. Other main concerns include contamination and lower functional properties of probiotics, caused by processing, handling and food matrices (116, 125).

Davidson and Wischmeyer (107) believe that future research should focus mainly on administering probiotics and symbiotics with known mechanistic benefits in order to improve patients' therapy results. Optimally, future research on probiotics and symbiotics should be conducted with the use of microbiome signatures in order to characterize the real ICU dysbiosis and perhaps even customize perfect probiotic and symbiotic therapies. A large potential and tangible benefits of consuming prebiotic and probiotic products encourage research centers to carry out further intensive works on the possibility to enrich food products and introduce them to the market (113, 116, 118-119, 122, 128,129).

Conclusion

Helianthus tuberosus is a multifunctional plant with high usability, including the use of its medicinal and health properties and functions. A wide scope of application of products obtained from Jerusalem artichoke (mainly inulin and fructo-oligosaccharides) make it a possible source of renewable chemical raw materials. Presently, a lot of research centers focus on developing technologies for isolating and processing JA-based raw materials. Increasing demand for the so-called functional food results in regularly increasing interest in inulin and other chemical substances obtained from JA. The subject of JA-based chemical raw materials seems vital and is becoming more and more popular. *Helianthus tuberosus* tubers are among the most important raw materials for industrial production of fructose and inulin. This raw material has a positive influence on human health and well-being, as a functional (healthy) food additive, medicinal plant, laxative, aphrodisiac, choleretic, diuretic, spermatogenetic agent, stomach tonic. The consumption of *H. tuberosus* tubers not only helps stabilize blood sugar level, but also lowers the "bad cholesterol" level, regulates blood pressure and the functioning of the digestive system, protects the liver and kidneys, facilitates the absorption of iron, calcium and magnesium, and the elimination of blood alcohol. It has cleansing properties, helps eliminate various poisons, carcinogenic heavy metals and organic toxins. Probiotics have proven highly beneficial for human health. The way their consumption can reduce the use of antibiotics in treatment of such disorders and diarrhoea, decreasing the risk of antibiotic resistance and other health issues related to microbiota imbalance. It improves the immune system, so it can be helpful in all kinds of infections. Besides, it relieves stress, boosts energy and improves concentration. It also has a positive influence on gastrointestinal functions by stimulating the reproduction of beneficial bacteria. Inulin and fructo-oligosaccharides, as JA reserve substances, belong to prebiotics, which stimulate the growth of beneficial gut bacteria. They regulate the digestive system function, increase the absorption of minerals and play an important role in preventing various disorders. Technological properties of inulin and fructo-oligosaccharides make them suitable for the production of low-fat and low-carb products. JA is also capable of reducing lipid disorders and insulin resistance, but the underlying mechanisms are not well known yet. In practice, JA requires increasing and better integrated biotechnical processing. Over dozens of years, the medical and nutritional aspects of this species have been undergoing intensive research in many countries all over the world. The results of future research can determine the factors connected to potential health benefits of probiotics, which can support food products/additives and answer consumers' health and food needs. It also has preventive and medicinal properties, in particular in patients with diabetes, cardiovascular diseases, nervous system diseases and human cancer. Attempts are made to isolate and identify a larger number of medicinal compounds. Presently, this species has a broad perspective due to its medicinal, dietary, economic and ecological importance.

Contribution of the authors

B.S. – she planned artickel and wrote a preliminary draft of the manuscript; D.S. – she was collected literature and wrote a section; P.P. – he was collected literature and wrote a section, I.A. – he took part in planning article and reviewed the manuscript; J.S-R –he was took part in writing and reviewed the manuscript, B. K-M. – she reviewed the manuscript and was a correspondent author.

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Conflicts of interest

The authors declare no conflict of interest.

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