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SEA BUCKTHORN PLANT AS A FUNCTIONAL FOOD INGREDIENT, WITH ANTIOXIDANT AND ANTI-INFLAMMATORY PROPERTIES

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ABSTRACT

Plants with valuable health properties, rich in a spectrum of compounds with various biological activities, have long been a focus of interest of researchers and the food industry. Undoubtedly, it is a great challenge for science to compose an innovative product with functional food status, managing to combine as many advantages of a particular plant preparation as possible to obtain a product that satisfies the requirements of a specific group of consumers. This article provides a brief overview of current information on the status of sea buckthorn plant (*Hippophae rhamnoides* L.) as a food ingredient, as well as its interesting biological activity. Sea buckthorn is a very valuable plant in terms of its content of various substances of high nutritional value, which recently makes the plant an area of growing scientific and industrial interest. This is due to its broad biological properties, extremely rich phytochemical composition and extensive pharmacological activity, especially antioxidant and anti-inflammatory activity. The above-mentioned advantages of sea buckthorn and its preparations make it a good candidate for a food ingredient that can be used in functional food products produced with the support of modern food industry technologies.

Keywords: sea buckthorn plant, antioxidant, anti-inflammatory, biological activity, functional food, seed oil

INTRODUCTION

A well-chosen and balanced diet rich in fruit and vegetables is one of the factors that contribute to maintaining good health. Information from various scientific fields shows that regular consumption of fruit and vegetables, physical activity and good eating habits are associated with a reduced risk of various diseases, especially civilization diseases. In addition, the condition of the body is also influenced by mental well-being, especially stress reduction. In recent years, there has been an increase in public health awareness and numerous research reports confirm the health-promoting importance of functional foods. It is already possible to design a food product by enriching it or selecting chosen ingredients with the desired activity. The future of the food industry belongs to innovative functional foods, which, through appropriate modification, will become an important part of the diet. Microencapsulation technology which allows for the effective protection of active substances (Zhang et al., 2023), a novel composite food preservative for fresh-cut lettuce using flavonoids from sea buckthorn leaves (Feng et al., 2023), fermented juice (Liu et al., 2023) or novel symbiotic beverages based on sea buckthorn syrup or powder with inulin, and soy milk (Maftei et al., 2023) become a good example of such innovative technology or final products.

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Hippophae rhamnoides L. is part of *Elaeagnaceae* family, which is rich in numerous biologically active constituents, such as vitamins, flavonoids, terpenoids, organic acids, unsaturated fatty acids, as well as macro- and microelements, which have beneficial effects on the functioning of the body. Preparations from sea buckthorn (*H. rhamnoides* L.) can be an excellent source of valuable bioactive components (Żuchowski, 2023).

Due to the very numerous group of chemical compounds found in sea buckthorn and virtually no research on the synergism of action of these compounds, it is difficult to determine which determine its specific properties and which are most crucial for the development of functional or fortified food products. A lot of new compounds, mainly phenolics, were isolated from this plant (Żuchowski, 2023). Moreover, it contains flavonoids, alkaloids, triterpenoid saponins, ellagitannins, lignans, naphthols, naphthoquinones, anthraquinonoids, triterpenoids, phytosterols, volatile compounds as well as carotenoids. The fatty acids, organic acids, amino acids, vitamins and minerals are also present in *H. rhamnoides* L. preparations (Sławińska et al., 2023b; Wang et al., 2022; Wang et al., 2023; Żuchowski, 2023). Moreover, it is a valuable plant with many biological and pharmacological properties described over the last 2 years by many authors: antioxidant (Nowak et al., 2022; Wang et al., 2022), antimicrobial (Nowak et al., 2022; Wang et al., 2022), treating metabolic syndrome (Geng et al., 2022; Chen et al., 2023), anticancer (Visan et al., 2023), anti-osteoporosis (Park et al., 2022), antihyperlipidemic (Kopčeková et al., 2023), anti-inflammatory (Laskowska et al., 2022; Zhou et al., 2023), antifatigue effect (An et al., 2023), dermatological (Skowrońska and Bazylko, 2023), neuroprotective (Lan et al., 2023), hepatoprotective (Ma et al., 2023).

This paper describes the status of sea buckthorn as a food or food ingredient, including its potential as a functional food. The paper also presents the selected activity of preparations of this plant, valuable from the point of view of food design.

PLANT CHARACTERISTICS

There are many cultivars of sea buckthorn (*Hippophae rhamnoides* L.). According to the scientific literature, about 150 varieties of this plant have been identified (Piłat et al., 2015). They differ from each other in location, appearance, and nutritional value of the fruit. Examples of cultivars include: Avgustinka, Altaichka, Altaichskaya, Ananasnaya, Atsula, Ayaganga, Ayula, Bajan Gol, Baikal, Baikal ruby, Batutinskaya, Bogatyrskaya, Botaniczeskaya (aromatnaja; liubitelickaya; luczistaya), Dar-Kazakovu, Desert maslicznyj; Diujmovochkaya, Donchanka; Dubovchanka, Dyet, Elisaveta, Gibrid Perchika, Gomelskaya, Gus-Hructalinaya, Inja, Kapriz, Karamelika, Lilla kalug, Lisichka, Marija, Marinka, Maslichnaya, Mockvichka, Moriachka, VIL P-2, VIL P-3, VIL P-4, VIL-5, VIL-8 Vitaminnaya (B29), Vostochnaya, Zalatistaya Sibiri, Zarevo, Zarya Dabat, Zhivko, Zoltaja rannaya (Piłat et al., 2015). Sea buckthorn fruits of different varieties vary in color from yellow to dark orange, the size of the fruits themselves, from spherical to oval berries, and the content of sugars, vitamin C and oil phase (Piłat et al., 2012; Sharma and Singh, 2017).

It is a rather tall, thorny shrub or tree, with lanceolate leaves, producing yellow, spherical, juicy fruits. It is naturally grows in cold and dry regions around the world (Vilas-Franquesa et al., 2020). Sea buckthorn grows wild, and is also cultivated on an almost industrial scale, especially in Russia and China, as well as Germany, Finland and Estonia. It is also distributed throughout Mongolia, the United Kingdom, France, Denmark, the Netherlands, Poland, Sweden, and Norway (Ren et al., 2020). It also grows on cold desert areas of North America and India. Growing sea buckthorn in the garden is relatively simple. The plant prefers sandy, dry, light, well-drained and slightly acidic soil. It does much worse on moist, compacted or clay soil. It also likes sunny positions. It is resistant to drought and high salinity in the soil (Vilas-Franquesa et al., 2020; Ren et al., 2020; Kubczak et al., 2022). The plant raw material is sea-buckthorn fruit (*Fructus Hippophae*) and sea-buckthorn oil (*Oleum Hippophae*).

CHEMICAL COMPOSITION

It is a highly valuable plant in terms of the content of varied substances of high nutritional value (Wang et al., 2022; Kubczak et al., 2022). Parts of the plant such as seeds, fruits and leaves contain polyunsaturated fatty acids, organic acids, amino acids, flavonoids, catechins, proanthocyanidins, carotenoids, vitamins C, E, P, A, B group, phytosterols and tocopherols as well as mineral elements (potassium, phosphorus, calcium, magnesium, iron, zinc, manganese, copper, cadmium) (Liu et al., 2021; Ren et al., 2020; Sławińska et al., 2023a; Wang et al., 2022). Table 1 shows selected biologically active ingredients.

Table 1. Examples of identified compounds in sea buckthorn

Groups of active components	Part of plant	Compounds
1	2	3
Minerals	fruit mg/kg DW	P 491 mg/kg DW
		K 1674 mg/kg DW
		Ca 1290 mg/kg DW
		Mg 990 mg/kg DW
		Fe 291 mg/kg DW
		Zn 29.77 mg/kg DW
		Mn 108.37 mg/kg DW
		Cu 17.87 mg/kg DW
		Cd 0.021 mg/kg DW
		Cl 2.18 mg/kg DW
Amino acids	berry juice mg/100 g	Alanine 21.2 mg/100 g
		Arginine 11.3 mg/100 g
		Aspartic acid 426.6 mg/100 g
		Cysteine 3.3 mg/100 g
		Glutamic acid 19.4 mg/100 g
		Glycine 16.7 mg/100 g
		Histidine 13.7 mg/100 g
		Isoleucine 17.4 mg/100 g
		Leucine 1.94 mg/100 g
		Lysine 27.2 mg/100 g
		Methionine 2.3 mg/100 g
		Phenylalanine 20.0mg/100 g
		Proline 45.2 mg/100 g
		Serine 28.1 mg/100 g
		Threonine 36.8 mg/100 g
		Tyrosine 13.4 mg/100 g
		Valine 21.8 mg/100 g
Polyphenols	mg per kg of dry matter of berries	Total phenolic acids 1135.6 ±51.8 to 1868.8 ±120.7 depending on the species
		2,5-Dihydroxybenzoic 0.3 ±0.0 to 20.7 ±2.5 depending on the species
		3,4-Dihydroxycinnamic 5.9 ±0.6 to 27.3 ±1.9 depending on the species

Table 1 – cont.

1	2	3
		Caffeic acid 6.3 ±0.9 to 15.8 ±2.1 depending on the species
		Cinnamic acid 0.8 ±0.1 to 803.9 ±70.0 depending on the species
		Ferulic acid 5.1 ±0.6 to 17.8 ±3.0 depending on the species
		Gallic acid 146.3 ±19.0 to 1008.0 ±120.0 depending on the species
		Hydroxycaffeic 9.1 ±1.0 to 58.5 ±7.0 depending on the species
		m-Coumaric acid 18.1 ±2.0 to 86.4 ±4.8 depending on the species
		o-Coumaric acid 4.3 ±0.6 to 12.5 ±1.8 depending on the species
		p-Coumaric acid 90.3 ±10.0 to 290.8 ±30.9 depending on the species
		p-Hydroxyphenyl-lactic 2.3 ±0.2 to 70.0 ±0.8 depending on the species
		Protocatechuic acid 7.9 ±0.9 to 21.3 ±2.8 depending on the species
		Pyrocatechuic acid 3.3 ±0.4 to 5.2 ±0.5 depending on the species
		Quinic acid 2.3 ±0.1 to 5.8 ±0.6 depending on the species
		Salicylic acid 899.5 ±100.0 to 1524.1 ±120.0 depending on the species
		Syringic acid 2.5 ±0.1 to depending on the species
		Vanillic acid 1.4 ±0.1 to 8.4 ±0.5 depending on the species
		Veratric acid 0.3 ±0.0- 20.0 ±2.6 depending on the species
	berries mg/kg DW	Flavonoids Kaempferol 102 mg/kg DW Quercetin 40–375 mg/kg DW
		Isorhamnetin 103–964 mg/kg DW
		Q-3-O-rutinoside/Rutin 233–288 mg/kg DW
		Q-3-O-glucoside 402 mg/kg DW
		Q-3-O-sorphroside-7-O-rhamnoside 227–272 mg/kg DW
		I-3-O-rutinoside 210–840 mg/kg DW
		I-3-O-glucoside 260 mg/kg DW
		K-3-O-sophroside-7-rhamnoside 341 mg/kg DW
		I-3-O-sophroside-7-O-rhamnoside308–753 mg/kg DW

Table 1 – cont.

1	2	3
		I-3-O-glucoside-7-O-rhamnoside1340 mg/kg DW
		I-3-O-neohesperidoside546–1847 mg/kg DW
Carotenoids	berries, mg/100 g DW	Lutein 0.1–1.1 mg/100 g DW depending on the species
		Zeaxanthin 0.1–2.5 mg/100 g DW depending on the species
		Neoxanthine 0.5–0.6 mg/100 g DW depending on the species
		β-Cryptoxanthin 1.3–1.6 mg/100 g DW depending on the species
		β-Caroten 0.1–0.9 mg/100 g DW depending on the species
		Cis β-Carotene 0.5–0.6 mg/100 g DW depending on the species
	fruit	Lycopene 0.13 to 0.20 mg/g DW
	berries	Xanthophylls 37.76 ±4.77 to 80.73 ±10.22 mg/g DW depending on the species
Fatty acids	berries g/kg total fatty acid content	wild/cultivar Myristic (C14:0) 2.60 ±0.00/2.00 ±0.00
		Pentadecanoic (C15:0) 0.93 ±0.00/2.23 ±0.31
		Palmitic (C16:0) 227.2 ±0.65/223.1 ±2.39
		Docosapentaensyre (C22:5n-3) 2.53 ±0.13/2.60 ±0.20
		Margaric (C17:0) 0.86 ±0.16/0.56 ±0.00
		Stearic (C18:0) 13.25 ±0.33/17.86 ±0.44
		Arachidic (C20:0) 2.81 ±0.00/3.72 ±0.71
		Henicosanoic (C21:0) 0.73 ±0.10/1.54 ±0.51
		Docosatetraenoic (C22:4 n-6) 3.90 ±0.11/4.41 ±0.31a
		Behenic (C22:0) 1.09 ±0.13/ 2.28 ±0.24
		α-Linolenic (C18:3 n-3) 100.3 ±0.23/109.8 ±0.30
		Lignoceric (C24:0) 0.60 ±0.00/0.93 ±0.00
		γ-Linolenic (C18:3 n-6) 0.30 ±0.16/0.60 ±0.25
		Myristoleic (C14:1) 0.31 ±0.00/1.53 ±0.22
		Linoleic (C18:2 n-6) 127.0 ±2.22/163.5 ±0.16
		Pentadecenoate (C15:1) 0.00 ±0.00 /0.60 ±0.40
		Nervonic (C24:1 n-9) 1.51 ±0.10/ 1.00 ±0.22
		Palmitoleic (C16:1 n-7) 185.0 ±1.37/134.6 ±0.50
		Hexadecenoic (C16:1 n-9) 0.91 ±0.11/0.80 ±0.00
		Margaroleic (C17:1) 0.44 ±0.00/ 0.71 ±0.36
		Oleic (C18:1 n-9) 255.5 ±0.30/264.1 ±0.80
		cis-Vaccenic (C18:1 n-7) 65.61 ±0.30/ 56.52 ±1.10

Table 1 – cont.

1	2	3
		Eicosenoic (C20:1 n-9) 2.50 ±0.11/2.73 ±0.22
		Erucic (C22:1 n-9) 1.06 ±0.10/ 1.07 ±0.20
Phytosterols	mg/100 ml lipid fraction berries	Squalene 885.71 ±29.16 to 1872.42 ±106.12 depending on the species
		Kampesterol 44.37 ±2.14 to 201.32 ±12.67 depending on the species
		Stigmasterol 24.08 ±0.06 to 68.22 ±2.03 depending on the species
		b-Sitosterol 2036.14 ±59.47 to 6145.58 ±41.11 depending on the species
		Sitostanol 96.50 ±0.94 to 254.67 ±13.63 depending on the species
		Δ^5-Avenasterol 114.93 ±1.27 to 377.56 ±5.46 depending on the species
		a-Amyrin 112.86 ±2.68 to 314.52 ±2.82 depending on the species
		Cycloartenol 293.49 ±3.12 to 474.38 ±1.18 depending on the species
		Δ^7-Avenasterol 80.80 ±0.08 to 194.97 ±1.01 depending on the species
		28-Methylobtusifoliol 70.88 ±1.40 to 251.85 ±4.48 depending on the species

Sea buckthorn leaves are characterized by a wide variety of nutrients and biologically active components, especially polyphenols. The leaves contain a lot of vitamins, folic acid, carotenoids (26.3 mg/100 g), and micro- and macronutrients (Ca, Mg, and K), anthocyanidins, flavonols, (–) epicatechins, (+) gallocatechins, (–) epigallocatechin gallic acid and chlorophyll (98.8 mg/100 g) as well as catechins, esterified sterols, triterpenes and isoprenols. *H. rhamnoides* L. leaves also contain proteins (20.7%), and amino acids (0.73% lysine, 0.13% methionine and cystine). Guan et al (2005) has found that fresh sea buckthorn leaves are rich in carotenoids (26.3 mg/100 g) and chlorophyll (98.8 mg/100 g), mineral salts, catechins, esterified sterols, triterpenes and isoprenols (Guan et al., 2005).

Sea buckthorn fruit contains fiber, protein-rich histidine, valine, threonine, leucine and lysine, as well as sugar, and the minerals: potassium, copper and phosphorus (El-Sohaimy et al., 2022).

H. rhamnoides L. juice was found to contain phenols, flavonoids and carotenoids, as well as a high content of vitamin C (322.33 mg/g). In the research by Lipowski et al., 2009, the quality of juices obtained from the fruits of different varieties of sea buckthorn: Prozracznaya', 'Botanicheskaya-Lubitelskaya', 'Luczistaya' and 'Botanicheskaya' was checked. The 'Botanicheskaya-Lubitelskaya' variety was proved to have the highest content of total sugar (3.71%) and ascorbic acid (82.3 mg/100 ml). In the Prozracznaya variety the highest carotenoid content (9.97 mg/100 ml) was identified (Lipowski et al., 2009).

Sea buckthorn oil is rich in tocopherols. According to data obtained by Zadernowski et al., 2003, the total tocopherol content of whole berry oil ranged from 101.4–128.3 mg/100 g. α-tocopherol is the predominant tocopherol of sea buckthorn berries, with only γ-tocopherol present in trace amounts. In the work of Zadernowski et al., 2003, the tocopherol content of the oil has been defined, for α-tocopherol at the level of 62.5–67.9% and for δ-tocopherols as 32.1–37.5%. It should be noted that the researchers recorded significant amounts of γ-tocopherol in unripe green berries,

Table 2. Selected activity of biologically active compounds from sea buckthorn

Vitamins	Tocopherols	Potential for strong antioxidant activity, protects against lipid peroxidation of cell membranes, anti-carcinogenic and antimutagenic properties
	Carotenoids	Potential for antioxidant activity
	Vitamin K	Takes part in blood clotting and calcium binding in bones and other tissues
	Vitamin C	Antioxidant; accelerates collagen synthesis
	Vitamin B complex	It participates in the metabolism of amino acids and nucleic acids and is involved in the synthesis of neurotransmitters
Phytosterols		Show antiulcer, antiatherogenic, and anticancer effects Consumption of plant phytosterols lowers blood cholesterol levels- health claim EFSA
Polyphenolic compounds		anticancer, antioxidant, anti-inflammatory, antiatheroscleroti, antiplatelet
Poly unsaturated fatty acids (PUFA) ALA		Immunomodulatory and neuroprotective, Alpha-linolenic acid exhibits antioxidant, neuroprotective effects and alleviates inflammation
Organic acids		Lower the risk of heart attack and stroke; show antiulcer effects; antiarthritic
Coumarins and triterpenes		Control of appetite, anticancer agents
Zinc		Antimicrobial activity
Organic acids		Antiulcer effects; promote wound healing; antiarthritic

the concentration of which decreased to trace amounts as the sea buckthorn fruit ripened (Zadernowski et al., 2003). In a similar study, the amount of tocopherol has been determined in oil obtained from seeds and from fruit pulp. The content of α-tocopherol in the seed oil was calculated at 223.4 mg/100 g, while in the oil obtained from the pulp at 143.7 mg/100 g. β-tocopherol content was determined to be 12.1 mg/100 g for seed oil and 21.1 mg/100 g for pulp oil. Δ-tocopherol level was determined to be 8 mg/100 g in the seed oil and 6.5 mg/100 mg in the oil obtained from the pulp. The largest difference was observed in ɤ-tocopherol content (seed oil – 177.4 mg/100 g and pulp oil – 11.1 mg/100 g) (Rehman et al., 2018). Interestingly, inversely to tocopherols, the amount of carotenoids in the seed oil was lower (22.2 mg/100 g) than their amount in the pulp oil (527.8 mg/100 g) (Rehman et al. 2018). In a study conducted by Górnaś et al., 2016, the tocopherol content of both commercially available nectar (0.25 to 26.33 mg/l) and juices (12.63 to 75.90 mg/l) of sea buckthorn was determined. The profile of tocopherol homolog in sea buckthorn beverages was as follows: α-tocopherol (85%), β-tocopherol (6.2%), γ-tocopherol (2.8%), δ-tocopherol (0.6%), and tocotrienols; α-tocotrienol (1.8%), β-tocotrienol (0.3%), γ-tocotrienol (2.4%) and δ-tocotrienol (1.0%) (Górnaś et al., 2016).

Moreover, one of interesting flavonoids present in the leaves, flowers and fruits of *H. rhamnoides* L. is isorhamnetin, which has a broad spectrum of pharmacological activities, including cardiovascular protection, anti-inflammatory, anticancer, antioxidant, antimicrobial, and antiviral effects (Gong et al., 2020). Table 2 lists chemical compounds that exhibit antioxidant activity and protect cellular structures.

BRIEF DESCRIPTION OF SEA BUCKTHORN FOOD PRODUCTS CONSUMED

The use of sea buckthorn as an ingredient in food products is increasingly appreciated. The interest in this plant can be attributed to the fact that it contains many valuable nutrients, beneficial for the proper functioning of the body. Despite the high nutritional potential and many health benefits offered by its fruit, their consumption in many countries is not common because they are not particularly tasty and have sour taste and unpleasant odor (Schubertová et al., 2021). These basic nutrients determine the sensory, nutritional and processing advantages of sea buckthorn fruits. The most valuable raw material extracted from sea buckthorn is its orange fruits. From the seeds of the plant, oil is pressed. Pulp edible oil is remarkedly rich in tocopherols, phytosterols and carotenoids (Jiang et al., 2020). Definitely less commonly used are the leaves. However, the leaves are used to obtain an infusion-tea (Ma et al., 2019). Additionally, aqueous extracts from the leaves are valuable due to their antioxidant, cytoprotective and anti-inflammatory and antibacterial properties (Upadhyay et al., 2010).

FOOD PRODUCTS OBTAINED FROM THE FRUITS

The fruits can be eaten without any processing. In practice, however are subjected frozen, dried or freeze-dried. This method preserves maximum nutritional properties. Sea buckthorn is increasingly used in the food industry in bakery, confectionery, in dairy products (yogurts). It is used to make jams, jelly, drinks, teas and other food products (Wang et al., 2022). The most common preserve made from sea buckthorn is, of course, juice, but also syrup, jam, and even wine.

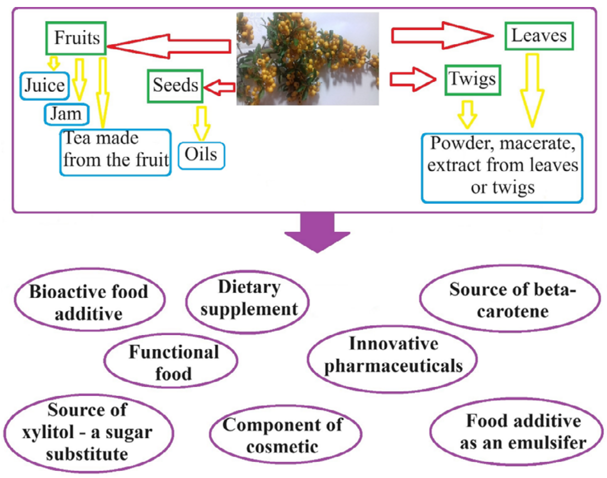

Fig. 1. Diagram showing different products obtained from sea buckthorn

The fruit consists of skin, pulp and stone. During the pressing process, the watery part of the fruit (juice) can be separated from the seed, peel and some residual pulp by means of screw filtration (Cenkowski et al., 2006). The juice can be further clarified by centrifugation and three different products are obtained: the clarified juice (main layer), the oily part of the pulp (supernatant), and the residual pulp, which consists of the seed and peel. Diagram showing types of different products from sea buckthorn is presented as Figure 1.

SEA BUCKTHORN OIL

Sea buckthorn oil is obtained from the seeds of this plant (Cenkowski et al., 2006). The percentage yield of seed oil extraction is about 12%. There are mainly three fatty acid groups in oil: monounsaturated omega-7 and omega-9 fatty acids (palmitoleic acid, vaccenic acid and oleic acid), polyunsaturated omega-3 and omega-6 fatty acids (linoleic acid and linolenic acid), and saturated fatty acids (stearic acid and palmitic acid) (Cenkowski et al., 2006; Yang et al., 2001;Yang et al., 2002).

Palmitoleic acid (PA) (16:1) is a monounsaturated omega-7 fatty acid, which is very rare in plants. Therefore, it occurs rarely in the human diet. The soft parts of sea buckthorn berries contain this unique fatty acid (Yang et al., 2002). According to a study performed by Yang and Kallio 2002 (Yang et al., 2002), the oil obtained from sea buckthorn flesh and skin contains about 43% PA (Yang et al., 2001), with less than 0.5% PA in seeds (Kallio et al., 2002a). It should be noted that fluctuations in the level of fatty acids depend on the origin, subspecies, harvest time, and place of cultivation. Sea buckthorn from Central Asia and the Baltic region contained more PA than plants from the Caucasus. Another study noted also differences in fatty acid levels between subsp. sinensis and subsp. rhamnoides (Yang et al., 2001).

Oleic acid (18:1) is an omega-9 monounsaturated fatty acid with 18 carbons and a double bond located at carbon number 9. The seeds and soft parts of sea buckthorn fruit are rich in oleic acid. It should be noted that oleic acid is quite resistant to oxidation. Sea buckthorn is, along with olive oil, an important source of this acid in the human diet. α-linolenic acid, ALA (18:3) belongs to the omega-3 unsaturated fatty acids consisting of 18 carbons and three cis double bonds. ALA belongs to the essential fatty acids (EFAs) and is an isomer of γ-linolenic acid GLA. A rich source of ALA is the oil extracted from sea buckthorn seeds (20–35%) (Yang et al., 2001). ALA levels can fluctuate between subspecies and, for example, there is more ALA in the seeds of subsp. rhamnoides than in subsp. sinnensis. ALA and GLA play important roles in the human body, they are physiological components of cell membranes and mitochondrial membranes, and play a role in the mechanism of cellular transport and the transmission of neuronal signals (Zielińska and Nowak, 2014).

LA, linoleic acid (18:2) is an omega-6 polyunsaturated fatty acid with two double bonds

at the 9th and 12th carbons and belongs to the EFA. LA is the main fatty acid in seed oil – up to 42% – being also present in berry oil and pulp in lower concentrations (6 to 33%). In sea buckthorn oil, the ratio of omega-3:omega-6 is 1:1 (Suryakumar and Gupta, 2011). This oil, like ALA, is needed for normal growth and development in children (EFSA, 2008).

γ-linolenic acid GLA (18:3) belongs to the omega-6 group. Oil rich in GLA consumed in the diet has a positive effect on inflammatory skin diseases and eczema, rheumatoid arthritis, premenstrual syndrome and prevents heart disease, counteracts allergies, relieves inflammation and slows down the aging process (Knowles and Watkinson, 2014; Zielińska and Nowak, 2017).

Sea buckthorn oil has a wide range of applications in the field of human health. The presence of EFAs and oleic acid, as well as the unique composition of the omega-7 fatty acid group, make products containing this oil fall into the category of functional foods. Nowadays, the environmentally friendly processing of sea buckthorn fruits into different types of oil, from the pulp, seeds and peel, is increasingly important.

STATUS OF SEA BUCKTHORN AS A FOOD, FOOD INGREDIENT OR FUNCTIONAL FOOD

According to the EU Novel Food Catalogue, the use of the fruits, leaves and flowers of *H. rhamnoides* is not considered as novel food supplements. The seeds and seed oil is considered as not novel in food supplements only. This means that they were present on the market as a food or food ingredient and were consumed to a significant degree before May 15, 1997, when the first regulation on novel food came into force. Thereby, its access to the market is not subject to the Novel Food Regulation (EU) 2015/2283. Moreover, the fruits of sea buckhtorn (*Hippophae rhamnoides* L.) are placed on the THIE Inventory List of Herbals Considered as Food (EHIA, 2022).

The status of sea buckthorn as a food or food ingredient, functional food or food supplement is being widely discussed. Functional food is broadly regarded as generally consumed foodstuffs that may provide added health benefits. Functional food is food of natural origin that, through certain modifications, have an exceptionally good effect on the health and functioning of the body. It can reduce the risk of certain diseases and improve overall well-being. Functional products can come from special crops, but usually bioactive ingredients are added to standard products. Sea buckthorn has the potential as a rich source of bioactive compounds for the production of functional food products. As mentioned earlier, phenolic compounds, flavonoids, vitamins, carotenoids, unsaturated fatty acids, present in different plant parts such as fruits, leaves, seeds, when added to various food products, can increase their nutritional value with additional valuable health-promoting properties (Wang et al., 2022). This makes *H. rhamnoides* L. an ideal candidate for a functional food ingredient - for an additive to bakery products, confectionery, dairy products, jams, juices. In many Asian countries, the powder from the aqueous extract of *H. rhamnoides* berries are consumed as a functional food (Baek et al., 2020). Sea buckthorn is very popular especially in China. It is used there mainly in juices, oils, drinks (non-alcoholic and alcoholic), various cosmetic products and also as an ingredient in medicines (Liu et al., 2021; Urbaniak et al., 2009).

The health-promoting properties of sea buckthorn fruit are due to the fact that it contains a large number of compounds with antioxidant properties, with particular emphasis on vitamin C, which is stable in preparations from this plant (Urbaniak et al., 2009). It is necessary to take advantage of the stability of vitamin C in sea buckthorn and to work on technological processes to obtain products with high vitamin C content. This is of great importance because many products have difficulty maintaining adequate levels of vitamin C after processing. Tiitinen et al., 2006 reported values from 128 to 1300 mg/100 ml of berry juice. Teleszko et al. 2015 reported 80.58 mg of vitamin C/100 g of fresh berries. The vitamin C content was determined to be 600 mg in 100 g of fruit (Ulanowska et al., 2018). According to the Scientific Opinion on Dietary Reference Values for vitamin C published by EFSA in 2013, in men, an Average Requirement (AR) of 90 mg/day of vitamin C and a Population Reference Intake (PRI) of 110 mg/day are proposed. As no value for metabolic losses is available in women, the AR for women is extrapolated from the AR for men on the basis of differences in reference body weight, and an AR of 80 mg/day and a PRI of 95 mg/day was proposed (EFSA, 2013). From these data, it appears that sea buckthorn preparations are able to more than cover the daily requirement of an adult for vitamin C. It can successfully be an ingredient in vitamin products, as an excellent, rich, stable source of natural vitamin C.

There have already been scientific reports on the activity of the juice from sea buckthorn in promoting the development of different beneficial gut bacteria. Its prebiotic properties are responsible for this action. The berry juice was found to promote the growth of lactic acid bacteria and bifidobacteria (Attri et al., 2018). Taking the above into consideration, sea buckthorn-based yogurt or cheeses could be a good direction for the development of food based on this plant. However, further research is needed on technological processes to simultaneously preserve health-promoting values and improve the organoleptic properties of the final product.

Sea buckthorn fruit or its preparations can be used as ingredients in novel fermented and probiotic foods as fermented non-probiotic beverages (for example juice) or fermented non-dairy products. Buckthorn juice is a suitable substrate for malolactic fermentation which enhanced antioxidant activity or improved sensory attributes. Enzymatic decarboxylation of L--malic acid into L-lactic acid as result of lactic acid bacteria metabolism lead to the reduction of malic acid content, decreasing the perception of astringency of sea buckthorn juice (Schubertová et al., 2021). In the novel work of Liu and team (Liu et al., 2023), fermentation was used to change the flavor profile of sea buckthorn. It is well known that sea buckthorn fruits are highly acidic, which can be unfavorably perceived by consumers of food products. Thus, in this experience, response surface methodology was used to determine the best process for producing fermented sea buckthorn juice with the use of probiotics. It was observed that, after the fermentation process, the biological activity of enzymes and total flavonoid content of sea buckthorn juice increased. The authors of the study suggest that the fermentation of sea buckthorn juice affects its biological properties, such as antimicrobial and antioxidant activity. It is not yet clear how substances with antioxidant properties and the mechanism involved in antioxidant activity change during fermentation. These issues require further research in this direction (Liu et al., 2023).

The available literature also contains information on extracts from the twigs of *H. rhramnoides,* which are also a valuable source of biologically active compounds. Berries, seeds, leaves and twigs are valuable, rich sources of antioxidant agents. The work by Kubczak et al., 2022 shows that also leaf and twig extracts of *H. rhamnoides* L. should be useful as a non-toxic source of different bioactive compounds which can be successfully used in various industries: food, pharmaceutical and others (Kubczak et. al., 2022).

Powdered sea buckthorn (*H. rhamnoides* L.) leaves are underutilized industrially. Methods of processing and obtaining an intermediate product that can be used in various industries is a key point. The work of Raudone et al. 2021 analyzed the composition of convection-dried and freeze-dried powders of *H. rhamnoides* leaves obtained from ten cultivars. They turned out to be raw materials rich in phytochemicals. Moreover, the freeze-drying ensures the retainment of antioxidative active compounds. That is why, leaf powders with defined phytochemical composition can be a good candidate for the production of innovative pharmaceuticals or functional food (Raudone et al., 2021).

Polyols, such as xylitol, sorbitol, erythritol and mannitol, occur naturally in some vegetables and fruits. Some authors report that the natural content of xylitol in food products, such as sea buckthorn, was about 213 mg. Xylitol content has been detected at this level in 100 g of dry matter (Ciekańska and Lesiów, 2020). Xylitol extracted from sea buckthorn can be an excellent low-calorie sugar substitute, especially for people with diabetes, as well as those on a diet. It is recommended for diabetics, as it is metabolized without the involvement of insulin. At the same time, it can be a source of energy in formulas intended for parenteral nutrition. Xylitol is also a prebiotic, which supports the development of beneficial bacterial flora for the human body (Ciekańska and Lesiów, 2020).

Carotenes are food additives (E 160), in the category of food colorings authorized under the Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives (Regulation EC, 2008). Food additives are substances that are not normally consumed as food itself but are added to food intentionally for a technological purpose described in this Regulation, such as the preservation of food (Regulation EC, 2008). Sea buckthorn, especially sea buckthorn fruit, belongs to the materials rich in carotenoids. The riper the berries are, the content of carotenoids is higher, and ranges from 7.94–28.16 mg/100 g of fruit (Ulanowska et al., 2018). These colors are resistant to freezing, which makes them attractive to the food industry. Sea buckthorn is a rich source of β-carotene, which is the main dietary source of vitamin A in humans. β-carotene obtained from different parts of *H. rhamnoides* can be a natural food additive added to various types of food after the development of an appropriate technological process (Ulanowska et al., 2018; Regulation EC, 2008).

As reported in recent world literature, the current trend in dietary supplements and functional foods is based on lipophilic bioactive compounds (polyunsaturated fatty acids, tocopherols, carotenoids) (Tereshchuk et al., 2022). In the novel work of Tereshchuk and the team, an emulsified biologically active food additive containing sea buckthorn products (pulp, juice, and oil) which was stabilized with soy phospholipids has been designed. Moreover, it turned out that emulsions containing 1.5% soy phospholipid mixture had the best oxidative stability. The resulting direct oil-in-water fine emulsion contains polyunsaturated fatty acids, tocopherols and phospholipids (Tereshchuk et al., 2022). This is a valuable advantage that allows the use of such emulsions for the production of dietary supplements in various forms (liquid, capsules) and future functional foods. Further research is needed to develop effective technology for the production of food products containing plant-based lipophilic ingredients (Tereshchuk et al., 2022).

Another example is the creation of wheat beer enriched with sea buckthorn (*H. rhamnoides* L.) fruit juice. Sensory evaluation showed that wheat beers with 5% v/v sea buckthorn juice were characterized by a balanced flavor and aroma. Physicochemical analyses showed that compared to control samples, wheat beers enriched with 5% v/v or 10% v/v defatted sea buckthorn juice were characterized by high total acidity with average values of 5.3 and 6.88, respectively (with the use of 0.1 M NaOH/100 ml), energy values lower by an average of 4.04% and 8.35%, polyphenol content of 274.1 mg GAE/L and 249.7 mg GAE/L, respectively, and higher antioxidant activity (measured by DPPH, FRAP and ABTS tests). The results show that wheat beer samples enriched with sea buckthorn juice had an average ascorbic acid content of 2.5 and 4.5 mg/100 ml (in samples with 5% v/v and 10% v/v addition, respectively) and contained flavone glycosides, such as kaempferol-3-O-glucuronide-7-O-hexoside. Based on the current findings, it can be concluded that wheat beer enriched with sea buckthorn juice may become a new trend in the brewing industry (Belcar and Gorzelany, 2022).

In health-promoting, functional foods, in the form of sea buckthorn extracts can be successfully used. Aqueous extracts prepared from different parts of plant, shown antioxidant, cytoprotective, and antibacterial activity (Upadhyay et al., 2010). Despite their high health-promoting potential, they are not sufficiently appreciated in the food industry.

Although there are many works glorifying the use of sea buckthorn in the food industry, there is still not enough scientific research on modern technological processes and its use in the production of innovative foods. The use of the plant, especially the leaves and extracts of sea buckthorn is still rare (Vilas-Franquesa et al., 2020). There is a constant need to develop the new ways of processing sea buckthorn fruits, leaves and twigs, which could make these products more attractive to potential food consumers. Its valuable biological properties are not fully exploited.

SELECTED BIOLOGICAL ACTIVITY

There are still not enough studies on the biological activity of sea buckthorn preparations (Sławińska et al., 2023b; Zhang et al., 2018). These components are useful in miscellaneous industrial applications due to the antioxidant, anti-inflammatory, antibacterial, antiviral, antitumor, cardiovascular system protection and neuroprotective properties (Asofiei et al., 2019) as well as anti-atherosclerotic or hepatoprotective effects (Liu et al., 2021). In the present study, the focus was on the anti-inflammatory and antioxidant activity of sea buckthorn preparations, which can be helpful for the formulation of food products with health-promoting properties.

ANTIOXIDANT ACTIVITY

Many *in vitro* and *in vivo* studies on the antioxidant potential of sea buckthorn preparations have been conducted. It has been observed that the phenolic fraction from sea buckthorn fruit scavenges hydrogen peroxide (H_2O_2), inhibits protein carbonylation and H_2O_2/Fe-stimulated plasma lipid oxidation. Plasma proteins treated with H_2O_2 or H_2O_2/Fe underwent weak carbonylation under the influence of phenols contained in sea buckthorn fruit. Olas et al. 2016 (Olas et al., 2016) noted that phenolic fractions from sea buckthorn at a concentration of 50 g/ml inhibited plasma lipid oxidation by as much as 60% (Olas et al., 2016). In *in vitro* studies, it has been observed, that sea buckthorn fruit extracts reduced lipid damage induced by atorvastatin administered for the treatment of hyperlipidemia (Mohamed et al., 2020). Sea buckthorn leaf extract alleviates intracellular oxidative stress in a dose-dependent manner and caused increased PC-12 neuronal cell viability and membrane integrity (Cho et al., 2017). In another work conducted by Papuc et al., 2008 ethanol extracts obtained from dried and ground sea buckthorn fruits showed greater antioxidant capacity than BHT and BHA in the DPPH assay (Papuc et al., 2008).

Serban et al. 2019 reviewed major databases such as Web of Science, Scopus, PubMed, and noted that many studies demonstrate the action of sea buckthorn in reducing inflammatory parameters and oxidative stress (Serban et al., 2019). For example, sea buckthorn seed oil has a protective effect on the skin by inhibiting ultraviolet (UV) radiation-induced redox imbalance. In the study of Gęgotek et al., 2018, an approximately 25% decrease in the production of reactive oxygen species under the effect of sea buckthorn oil on fibroblasts has been observed (Gęgotek et al., 2018).

The DPPH radical scavenging action of *H. rhamnoides* leaf extracts was also studied. It was noted that the radical scavenging activity was dose-dependent and the leaf extract had a statistically significant effect on reducing H_2O_2/Fe-induced carbonylation of plasma proteins, and protected human fibroblasts from H_2O_2-induced oxidative stress (Kubczak et al., 2022). Yuca et al. 2022 determined the radical scavenging activity of DPPH and ABTS for 70% methanol, ethyl acetate, n-butanol, n-hexane, dichloromethane as well as water extract from *H. rhamnoides* leaves. The results were as follows: DPPH IC_{50} value for 70% methanol was 48.83 µg/ml, for dichloromethane was 146.52 µg/ml, for ethyl acetate was 27.67 µg/ml, for n-butanol was 48.15 µg/ml and for water extract was 68.64 µg/ml. For comparison, the authors also determined values for Trolox at 16.86 µg/ml and α-tocopherol at 41.07 µg/ml (Kallio et al., 2002b; Yuca et al., 2022). Analogously, the authors also assessed the IC_{50} value of ABTS. The values obtained were at the level of: 6.61µg/ml for 70% methanol, 24.44 µg/ml for dichloromethane, 1.89 µg/ml for ethyl acetate, 7.25 µg/ml for n-butanol and 9.29 µg/ml for water extract. IC_{50} value (µg/ml) of ABTS for Trolox at 7.65 µg/ml and for α-tocopherol 21.34 µg/ml was also determined (Yuca et al., 2022). Additionally, in the n-butanol extract a following phenolic compounds were identified: isoquercitrin, isorhamnetin-3-O-β-d-glucopyranoside,isorhamnetin-3-O-β-d-glucopyranosyl-7-O-α-l-rhamnopyranoside, isorhamnetin-7-O-α-l-rhamnopyranoside, narcissin, one triterpene glycoside arjunglucoside I, ellagitannin casuarinin. Arjunglucoside I was isolated for the first time from the n-butanol extract of sea buckthorn (Yuca et al., 2022).

Other authors studied the antioxidant properties of ethanolic, n-hexane and ethyl acetate fractions of sea buckthorn seed extracts (Arimboor et al., 2012). The authors determined IC_{50} DPPH (µg/ml) values of 6.7 µg/ml for the ethanolic extract, 18.9 µg/ml for the n-hexane fraction and 4.9 µg/ml for the ethyl acetate fraction. ABTS [TEAC] values obtained were as follows: for ethanol extract 5.8 nM, for n-hexane fraction 0.1 nM and 8 nM for ethyl acetate fraction. IC_{50} values for hydroxyl radical scavenging were also estimated at the level of 58 µg/ml for ethanol extract and 39 µg/ml for the ethyl acetate fraction. O_2-radical scavenging by the ethanol extract gave an IC_{50} value for 69 µg/ml, the n-hexane fraction of the seed extract reached 854 µg/ml and the ethyl acetate fraction 80 µg/ml. Xanthine oxidase inhibition IC_{50} of the ethanolic seed extract was 122 µg/ml and for ethyl acetate fraction was 78 µg/ml. The ethanolic sea buckthorn seed extract chelated iron ions at 12%, the ethyl acetate fraction at 17%. The reducing power of Fe^{3+} of the ethanolic extract was at the level of 9 nM, the n-hexane fraction of the seed extract at the level of 5 nM and the ethyl acetate fraction at 20 nM. In the tested extracts, the authors identified such compounds as quercetin-3-O--rutinoside, isorhamnetin-3-O-rutinoside and isorhamnetin-3-O-sophroside-7-O-rhamnoside,isorhamnetin--3-O-glucoside,3-O-sophroside-7-O-rhamnosides, 3-O-glucoside-7-O-rhamnosides, quercetin, kaempherol and isorhamnetin. The authors noted that the polar fraction of extracts obtained from sea buckthorn seeds is rich in flavonoids such as quercetin glycosides, kaempferol and isorhamnetin. These compounds are responsible for the bioactivity of sea buckthorn seed oil. Due to its antioxidant potential, it can be a component of pharmaceutical and nutraceutical preparations. The authors emphasized that the antioxidant potential and composition of different fractions of sea buckthorn seed extracts depend on their maturity, variety, geoclimatic conditions, processing and post-harvest storage (Arimboor et al., 2012).

Plasma samples treated with H_2O_2/Fe were studied, with increased concentrations of TBARS (a marker of lipid peroxidation) and carbonyl groups in plasma proteins (a marker of protein oxidation). It was noted that in the presence of isorhamnetin and its derivatives – compounds contained in sea buckthorn fruit extract reduced lipid peroxidation in plasma induced by H_2O_2/Fe. All phenolic compounds contained in sea buckthorn fruit effectively reduced lipid peroxidation in plasma. Moreover, the effect of compounds contained in sea buckthorn fruit extracts on platelet aggregation was tested. It was noted that all compounds examined (at a concentration of – 10 µg/ml) did not change ADP- or collagen-stimulated platelet aggregation and isoramnetin inhibited the process induced by thrombin (Skalski et al., 2019). The research conducted clearly indicates that isorhamnetin and their derivatives exhibit antioxidant, antiplatelet and anticoagulant properties as well as the compounds in sea buckthorn can be used as potential components in the prevention and treatment of cardiovascular disease (Skalski et al., 2019). Additionally, Fang et al., 2013 examined scavenging of free radicals of the nitric oxide by sea buckthorn fruit extract, ascorbic acid, 2-(4-carboxyphenyl)-4,5-dihydro--4,4,5,5-14tetramethyl-1H-imidazolyl-1-oxy-3-oxide and myricetin. The results obtained were as follows: EC_{50} for sea buckthorn fruit extract was 15 µg/ml, for ascorbic acid 1.2 µg/ml, for 2-(4-carboxyphenyl)-4,5--dihydro-4,4,5,5-14tetramethyl-1H-imidazolyl-1-oxy--3-oxide at 6.8 µg/ml and for myricetin 9 µg/ml. Studies have shown that in the myricetin molecule the presence of three adjacent hydroxyl groups in the ring may be the most important feature determining the activity of flavonols in scavenging NO radicals. However, the authors emphasize that myricetin glycoside is found in *H. rhamnoides* fruit in trace amounts of 0.1%, so it is the presence of ascorbionic acid that is the main contributor to NO-scavenging activity (Fang et al., 2013). The El-Sohaim et al. 2022 study noted that the antioxidant potential (DPPH and ABTS) of sea buckthorn juice was higher than that of ascorbic acid. In addition, the fermentation process of sea buckthorn juice with *Lactobacillus plantarum* RM1 increased the content of functional phenols and flavonoids, as well as antioxidant activity. In sea buckthorn juice fermented with *L. plantarum*, the contents of phenols, flavonoids and vitamin C were 304.16 ±1.31, 131.2 ±1.68 and 327.4 ±1.70 mg/g, respectively. In contrast, the trace content of sulfated polysaccharides was 0.42 ±0.042 mg/g (El-Sohaim et al., 2022). Table 3 summarizes an overview of information on the antioxidant activity of sea buckthorn.

According to the literature, phenolic compounds are responsible for the antioxidant properties of sea buckthorn fruits, leaves, and seeds. Many phenolic acids (gallic acid, salicylic acid, p-coumaric acid, and quinic acid, as well as hydroxybenzoic and hydroxycinnamic acid derivatives) or flavonoids (isoramnetin, rutin, quercetin, kaempferol, (+) catechin) have been identified in sea buckthorn. Sea buckthorn is also a rich source of ascorbic acid, which is stabilized by phenolic compounds. Sea buckthorn oil is also a rich source of hydrophobic antioxidants such as tocopherols, and carotenoids. Flavonoids and phenolic acids, scavenge reactive oxygen species. Many studies prove that sea buckthorn fruits when administered in the diet in the form of food, supplements, or alcoholic extracts, have antioxidant effects, protecting cells from oxidative damage and the subsequent appearance of

Table 3. Selected antioxidant activity of *H. rhamnoides*

Part of plant/ preparation	Type of study	Metod	Conclusion
Fruits – phenolic fraction	*in vitro*	TBARS test and superoxide anion production in human platelets	antioxidant activity and antiplatelet potential
Fruit extract	*in vivo*	sea buckthorn, grape extract, atorvastatin examination of biochemical parameters	hypolipidemic and protective effect on the liver
Leaf extract	*in vitro*	ABTS, DPPH tests and cytotoxicity test on cell line PC-12	antioxidant and attenuate oxidative stress
Fruit extract	*in vitro*	DPPH tests	antioxidant
Seed oil	*in vitro*	human keratinocytes and fibroblasts examination	skin photo-protection
Extracts of leaves and twigs	*in vitro*	DPPH tests, hemolysis and cytotoxicity on human fibroblast (BJ) cells	antioxidant
Leaves	*in vitro*	DPPH, ABTS tests	antioxidant
Seeds	*in vitro*	DPPH, APTS tests	antioxidant
Fruit extract	*in vitro*	TBARS tests	antioxidant, anti-platelet and anticoagulant
Fruit extract	*in vitro*	nitric oxide scavenging	antioxidant
Juice	*in vitro*	DPPH, ABTS tests	anti-hypertension, anticancer properties

changes leading to the development of diseases. In addition, they inhibit lipid peroxidation, protecting cell membranes from damage by reactive oxygen species. Based on the research, it can be concluded that sea buckthorn can be used as a natural source of antioxidants that helps prevent and treat diseases associated with oxidative stress.

ANTI-INFLAMMATORY ACTIVITY

In the study of Jiang et al., 2020, the anti-inflammatory potential for sea-buckthorn pulp oil measured as reduction in cellular inflammatory cytokine production during refining process was examined. The experiments carried out have shown that in Human intestinal epithelial (Caco-2) cells crude extract inhibited LPS--induced cytokine production in a dose-dependent manner. Moreover, the refining process significantly enhances the oil's anti-inflammatory effect (Jiang et al., 2020).

Yuan et al., 2016 investigated anti-inflammatory activity of *H. rhamnoides* L. Protein isolated from sea buckthorn seeds (100–200 mg/kg/day) administered per os lowered the levels of IL-6, TNF- and NF-B pro-inflammatory factors in streptozocin-induced diabetic mice. Authors suggest that sea buckthorn seeds protein has a significant anti-inflammatory activity (Yuan et al., 2016).

The paper by Shi et al. 2017 describe the beneficial effects of sea buckthorn pulp and seed oils derived from *H. rhamnoides* L. against the radiation-induced acute intestinal injury in mice. Sea buckthorn oil pretreatment increased the post-radiation survival rate, reduced the damage of the small intestine villi, reduced the number of cells in apoptosis and inflammation by downregulation of the mRNA level of inflammatory factors (tumor necrosis factor-α, interleukin (IL)-1β, IL-6 and IL-8) (Shi et al., 2017).

Anti-inflammatory activity of three triterpenes (oleanolic acid, maslinic acid, asiatic acid) was examined in a study by Han et al., 2021. It was shown that these three compounds inhibited the production of pro-inflammatory factors by LPS-induced RAW264.7 cells. Triterpenoid acids significantly affected the release of LPS-induced pro-inflammatory mediators, such as nitric oxide (NO), inducible nitric oxide synthase (iNOS), and interleukin (IL-6). Thus, oleanolic acid, maslinic acid and asiatic acid possess significant anti-inflammatory activity [93]. In a similar study, Baek et al. 2020 analyzed the impact of the 1,5-dimethyl citrate from *H. rhamnoides* L. on lipopolysaccharide induced inflammatory response in RAW 264.7 mouse macrophages. It was found that 1,5-dimethyl citrate demonstrated a significant role in preventing LPS-induced NO production and markedly inhibited the expression of IKK/, I-B, NF-B p65, iNOS, and COX-2 as well as activity of IL-6 and TNF-α factors. This compound exhibits the anti-inflammatory effect (Baek et al., 2020).

Isorhamnetin is one of the most important flavonoid compounds found in the leaves, flowers and fruits of *H. rhamnoides* L. This particular compound is characterized by a wide range of pharmacological activities, including anti-inflammatory activity. It is most likely that the anti-inflammatory activity of this compound translates into the anti-inflammatory activity of sea buckthorn. Several papers describing the anti-inflammatory activity of isorhamnetin are cited below. The mechanism of its action is related to regulating the production of inflammatory mediators, cytokines and ROS. Mechanism of isorhamnetin action is closely related with inhibition of NF-κB pathway (Gong et al., 2020). However, at the moment there are not many works that describe the anti-inflammatory activity of this compound. The work of Chauhan et al. 2019 studied the potential of isorhamnetin to prevent gram-negative sepsis. The results of the study indicated that isorhamnetin has the possibility to reduce proinflammatory cytokine levels in the serum and lung tissue of *Escherichia coli* infected mice. Isorhamnetin also reduces the levels of aspartate aminotransferase, alanine amino transferase and blood urea nitrogen, which causes that this compound can improve kidney and liver function (Chauhan et al., 2019). Moreover, the paper of Kim et al., 2019 demonstrated that isorhamnetin alleviates lipopolysaccharide-induced inflammatory responses in BV2 microglia. The results obtained in the study showed that isorhamnetin significantly suppressed the LPSinduced secretion of proinflammatory mediators, including nitric oxide and prostaglandin E2. In addition, isorhamnetin reduced the release of TNF-α and IL-1β by blocking their expression in LPS stimulated microglial cells. Further studies are required to clarify the mechanism of action of this compound related to anti-inflammatory activity (Kim et al., 2019). It was also found that isorhamnetin inhibits human gallbladder cancer cell proliferation and metastasis via PI3K/AKT signaling pathway inactivation (Zhai et al., 2021). This action could provide a novel potential treatment strategy for different inflammatory processes. It has also been confirmed that isorhamnetin alleviates airway inflammation by regulating the Nrf2/Keap1 pathway in a mouse model of chronic obstructive pulmonary disease. Isorhamnetin exhibited anti-inflammatory effects by activating the nuclear factor erythroid 2-related factor (Nrf2) pathway to increase the expression of different protective factors (Xu et al., 2022). In another paper, the anti-inflammatory and anti-psoriatic efficacies of oil from the fruit pulp of *H. rhamnoides* was examined. Psoriasis is associated with the release of pro-inflammatory mediators resulting in development of edema and distress. Results obtained in this work clearly show that sea buckthorn oil can act as an anti-inflammatory and anti-psoriatic factor (Balkrishna et al., 2019).

CONCLUSIONS

In developed countries, the public's consumption of highly processed foods is a major problem. An alternative to such nutrition can be the consumption of products enriched with plant components having health-promoting and nutritional properties in the form of dietary supplements or functional foods. In the present study, it is considered that nutrient-rich sea buckthorn preparations such as jams, juices, marmalades or tinctures, as well as seed-based teas, leaf infusions and fruit teas can be a great option for this type of food. This is due to the valuable biological properties of this plant. Information on antioxidant, anti-inflammatory, antibacterial, antiviral, antitumor, cardiovascular system protection and neuroprotective properties as well as anti-atherosclerotic, hepatoprotective activity of sea buckthorn preparations was encountered in the literature. Examples confirming the anti-inflammatory and antioxidant activity of sea buckthorn preparations described in this work provide a stable basis for designing single- or multi-ingredient plant food products with health-promoting properties.

The scientific literature summarized in this paper shows that sea buckthorn is used in the food industry. It is used in bakery, fruits are used in the production of cakes, jams, preserves, jellies, beverages, juices, syrups, teas and other food products such as wine, for example. In addition, the food industry uses sea buckthorn oil extracted from the seeds of the plant, valuable for their health-promoting properties. Moreover, sea-buckthorn fruit or its preparations can be used as ingredients in new fermented and probiotic food products, such as non-probiotic fermented drinks (e.g. juices) or fermented dairy products. In the brewing industry, various types of beer can be enriched with sea buckthorn juice.

Although there are many scientific reports on how sea buckthorn can be used in the food industry, there is still not enough scientific research on modern technological processes and innovative formulations for the use in the production of innovative foods based on preparations from this valuable plant.

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